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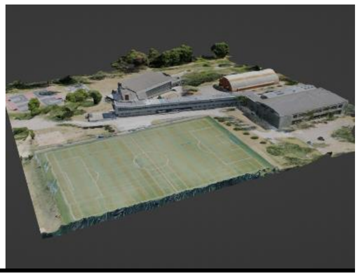

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LEVEL OF DETAIL CATEGORIZATION FOR THE APPLICATION IN URBAN DESIGN

POZIOM SZCZEGÓŁOWOŚCI KATEGORYZACJI MODELI CYFROWYCH DLA ZASTOSOWANIA W PROJEKTOWANIU URBANISTYCZNYM

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ABSTRACT

Urban planning and urban design involve complex processes that require detailed information about the visual information of a place at various scales. Different graphic tools, such as game engines, are evolving to use urban representation fields. The concept of "level of detail" (LOD) has been used to categorize the level of detail in AEC applications such as BIM and GML for urban representation models. However, there is a need to distinguish between different LOD concepts commonly used in various fields, as these terms have different interpretations and implications. This article presents a novel approach to re-categorizing the level of detail concept in AEC applications, led by the traditional use of LOD and in parallel with urban planning scales. From an urbanist perspective, a four-stage LOD classification framework has been studied: LOD 1000 for urban and neighbourhood scales, LOD 2000 for the plaza and square scales, LOD 3000 for architectural and street scales, and LOD 4000 for protected and private areas.

Key words: urban representations, Level of Detail (LoD), Level of Development (LOD), Urban design, urban planning, Optimization, visual information, AEC.

1. INTRODUCTION

Urban design and planning play crucial roles in shaping the physical environment of cities and creating livable spaces for their residents. Planners rely on accurate and detailed information about various aspects of the built environment to effectively plan and design urban areas. The "level of detail" (LOD) provides a framework for categorizing the level of detail required in urban design and planning applications. This article proposes a Level of Detail (LOD) categorization framework tailored explicitly for urban design and planning applications. This framework is based on extensive research and considers the different scales and objectives within the urban context. Our approach addresses the confusion and similarities between LoD (Level of development) and LOD (Level of detail), providing a clear and consistent categorization system for urban design and planning professionals.

The proposed LOD categorization framework consists of four primary stages: LOD 1000, LOD 2000, LOD 3000, and LOD 4000. Each step corresponds to a specific scale within the urban environment. LOD 1000 is designed for urban and neighbourhood scales, providing an overview of the entire metropolitan area. LOD 2000 focuses on the plaza and square scales, offering more detailed information about public spaces. Finally, LOD 3000 is intended for architectural and street scales, providing highly detailed information about buildings and streets. LOD 4000 is final, providing a comprehensive look at special and preserved areas. Therefore, it is essential to establish consistency and purpose within each LOD level. Each level should serve a distinct purpose and contain specific information while optimizing for computational systems and user understanding. Furthermore, the features of each LOD level should cumulatively affect the subsequent level, akin to the scales found in urban and architectural plans.

While existing LOD categorizations, such as Level of Development and CityGML Level of Details, may only partially incorporate the quantitative features of 3D models due to their software-based nature, our proposed categorization framework includes these features in depth. Additionally, this study aims to align the LOD concept with various urban design principles and objectives. Collaborating with each LOD level's identified urban design principles and goals can provide valuable guidance to urban planners and designers. This alignment will enhance the usability of the LOD categorization framework and facilitate its application in future studies in urban design and planning.

2. THEORETICAL FRAMEWORK

With the developed graphical hardware and software, remote 3D scanning and laser scanning technologies are increasingly used in the AEC industry and Computer-aided design (CAD) (Fassi et al., 2013; Javaid et al., 2021; Wu et al., 2021). At the same time, the demand and interest of city municipalities, local and National governments, and commercial organizations for scanned urban 3D models due to various applications are increasing daily. This is mainly because of the significant improvements in the 3D field made in the last decade (Albrecht & Moser, n.d.; Gröger & Plümer, 2012; Nouvel et al., n.d.).

Contrary to conventional GIS-based systems, they still use another framework for model creation. In computer graphics, where it originated, the LOD concept is used to derive efficient visualizations from highly detailed data. However, in GIS applications, the model creation process is different. Representations of an object are collected and stored independently from the semantics. The final representation can be created in different ways. For example, data about a building can be obtained by constructing it using CAD software, making ground measurements, or evaluating aerial photographs. Thus, in GIS applications, the main problem is not to derive less-detailed 3D representations from more detailed ones but to create several representations by consistently using and managing their attributes (Hughes et al., 2013). Concepts such as digital twin strengthen the connection between game engines and urbanism applications and lead the industry towards this field due to the increase in graphics processing capacities and opening the way for integrating infrastructures such as GIS (Somanath et al., 2023). Therefore, re-categorization using the current LOD in AEC industry LOD languages for realistic 3D urban representations was necessary, led by their input 3D models characteristics and features, such as poly-counts, displayed areas within monitors, and visible distortion points.

A discrete study has been made, aiming at the 3D remote sense model characteristics and implementing LOD optimization workflows utilizing different scaled urban representation models. Three different LOD levels have been found in a case study. However, it only covers the technical aspect of the models to be displayed with standard computers generally used by urban planners. These levels are designed to contain several million polyfaces in every scene, be optimized at every observation distance, and still be usable for the observer. The related work investigated the link between observation distance, detail amount, and useful detail quality for the observer. Hypothetical LOD optimization zones were determined by comparing the models' usability levels and surface numbers.

Fig. 1. Diagram Presenting Different Level of Detail Depending On Distance. Source: by authors

Architecture, engineering, urban planning, and urban design involve complex processes that require detailed knowledge of the visual information of the urban space at various scales. Though the methodology to introduce visual inputs in the design process could be better and more adequate, the visual qualities of the built environment are essential (Lozano, 1974). Urban designers' working processes have been compared to a mysterious and unbreakable "black box," where the input (the need for detailed plans, the available resources, the detailed data), the output (the schemes regularly reported in periodicals), and the working processes are all but unexplored and undocumented.' The complexity of urban design, which can include multiple agencies over a lengthy period, is rarely made public, in contrast to how frequently architects detail the progress of their projects (Jarvis, 1980; McLoughlin, 1973). Digitalizing these processes offered new possibilities with cameras and computers in those industries and still does with advanced graphic computing technology (Schwarzer, 2017; Zimmerman, 2014). In particular, 3D scanning and visualization technologies have significantly impacted architecture and urban planning/urban design (Xiao et al., 2018). These technologies enable precise and detailed visualization and simulation of spatial data. Three-dimensional city modelling has become an important issue worldwide for geomatics researchers because geomatics techniques play a key role in creating virtual 3D city models. The Main Geomatics techniques are Photogrammetry, LIDAR, Radargrammetry, Geographical Information System, and Global Positioning System. However, because of the spread of usage and accessibility, photogrammetry techniques play a major role in creating virtually realistic 3-D city models. (Singh et al., 2013, 2014) However, creating a truly photorealistic city model requires much work and time due to its high precision and undefined level of detail (LOD) (Rau & Cheng, 2013).

In this context, the theoretical framework of this study focuses on the usage of the concept of LOD in various applications in the AEC industry. In order to better preserve the importance of the LOD concept, its uses, and approaches in the AEC industries, the introduction section will proceed with an overview of the LOD and LoD (Level of Development) concepts and their application in various fields, as well as discussions over the benefits and challenges of using LOD in the urban planning field. Despite its importance, the word LOD has yet to be sufficiently specified or defined in 3D city modelling, according to (Goodall et al., 2012) and many others. In 3D city models, there are widely used standards for LOD that have been uncertain, such as CityGML level of details. The reason for the lack of study and the widely accepted approach of the LOD concept for urbanist models in drawn literature might be the need for various applications in this field. Therefore, the LOD concepts and their definitions have only applied to these applications. Also, they were designed to be useful for the established technology of their systems, data, and elements.

In creating 3D city models, the Level of Detail (LOD) concept lacks a universally agreed-upon definition due to variations in its interpretation among different approaches. Furthermore, a consistent methodology for LOD has yet to be widely established. The need for clarity surrounding LOD is remarkable, considering its prevalence in GIS, 3D city modeling literature, and the substantial number of publications addressing LOD in computer graphics. Given these circumstances, addressing the need for a comprehensive understanding and clarification of LOD in the context of 3D city modeling is necessary (Biljecki et al., 2013). However, in the last decade, the situation in this field has started to change thanks to decreasing requirements, increasing interest, and various developments, platforms, and applications for creating 3D city models. However, there still needs to be more research within the scope of the needs of city planners and designers, who are important target users of the platforms. The LOD that was utilized in the analysis or what would be the minimum needed LOD for users or apps is rarely discussed in the current publications that have been created in this sector (Zhu vd., 2009; Döllner vd., 2007).

The main difficulty in managing LOD is that the relationships between representations at different levels can be very complex in obtaining coherent views (Köninger & Bartel, 1998). To establish LOD categorization, multiple aspects must be considered, such as the questions in 2013 by Biljecki et al., "What drives the levels of detail? What is the difference between the level of detail and the scale? How to sort multiple LODs, and is there a way to quantify them? Moreover, should there be constraints and strict specifications for each LOD?" (Biljecki et al., 2013). In addition, considering the LOD concept in its broader form, questions such as whether LOD categorizations should remain application-specific and what scales existing LOD categorizations cover in architecture, urban planning, and design can be asked. "Models are, by definition, simplifications of the real thing, and in that sense, they do not aim to replicate the original system in the same detail as that system. In short, key features of the original system are thrown away, and usually, the model abstracts that the scientist considers key to the features of the real system that are under scrutiny" (Batty, 2018). In this context, the concept of LOD refers to an optimization scheme constructed depending on the purpose of use and how a model is observed. This idea has been widely used, mainly in game engines and AEC systems such as CityGML and BIM applications, but differently.

Planning Support Systems is a general notion describing software which supports urban planning (Batty, 2012). Moreover, games are one of the most powerful planning support tools. With hardware support, they provide excellent opportunities to produce 3D visuals in real time. In a scenario, they make it possible to manipulate objects. The most advanced area of computer graphics is found in video games; the interactivity of these tools determines the range of possible instructional applications (Hanzl, 2007; Hanzl & Wrona, 2004). Many simulation games are made by using game engines, focusing on urban environments and urban planning at different levels, such as SimCity, and CitySkylines, for teaching the Urban Planning discipline from students' perspectives, development analysis, implementing AI machine learning algorithms (Duncan et al., n.d.; Khan & Zhao, 2021). LOD levels are also widely used in these games to display large urban spaces in an interactive way in game engines. There is LOD usage for visualization, computational, and organizational purposes. Different applications in the AEC industry mainly use each. Similar to the usage of urban scales, 3D city models are characterized by their level of detail (LOD), a measure that indicates their grade and scale (Biljecki et al., 2014; Coltekin & Reichenbacher, 2011). In this way, LOD was a great tool for categorizing and generalizing the 3D city aspects and regenerating them without holding vast amounts of 3D data.

Compared to LOD in computer graphics, which is applied especially for optimizing visualization, LOD in 3D city modelling is more associated with modelling concerning many requirements for the application. The object's distance from the viewer is one of many factors considered when choosing the level of detail in computer graphics. Technicians in 3D city modelling often refer to the common LOD of all objects, no matter where they are located or how they are visualized in a scene. The current approach to LOD for AEC models involves classifying the models based on their qualitative features to accurately recreate the models in each LOD. Computer graphics approaches often need to be implemented, like mesh simplification and the specification of the number of polygons in the scene per LOD. The LOD concept in 3D city modelling currently refers to a larger but entirely distinct workflow than in computer graphics. However, computer graphics—not included in 3D city modelling LOD languages—are eventually used to display the models (Biljecki et al., 2013). Given the advancements in generating highly realistic models, the convergence of these two workflows and their expanded definitions and applications will likely occur in the foreseeable future. However, before this convergence, it is imperative to differentiate between the various levels of detail (LOD) concepts frequently employed in these domains, as these terms encompass distinct contents, interpretations, and significance.

Model Content	LoD 100	LoD 200	LoD 300	LoD 400	LoD 500
3D Model-based Coordination	Site level coordination	Major large object coordination	General object-level coordination	Design certainty coordination	N/A
4D Scheduling	Total project construction duration. Phasing of major elements	Time-scaled, ordered appearance of major activities	Time-scaled, ordered appearance of detailed assemblies	Fabrication and assembly detail including construction means and methods (cranes, man-lifts, shoring, etc.)	N/A
Cost Estimation	Conceptual cost allowance Example $/sf of floor area, $/hospital bed, $/parking stall, etc. assumptions on future content	Estimated cost based on measurement of the generic element (i.e. generic interior wall)	Estimated cost based on measurement of specific assembly (i.e. specific wall type)	Committed purchase price of specific assembly at buyout	Record cost
Program Compliance	Gross departmental areas	Specific room requirements	FF&ampE, casework, utility connections	-	-
Sustainable Materials	LEED strategies	Approximate quantities of materials by LEED categories	Precise quantities of materials with percentages of recycled and/or locally purchased materials	Specific manufacturer selections	Purchase documentation
Analysis/Simulation	Strategy and performance criteria based on volumes and areas	Conceptual design based on geometry and assumed system types	Approximate simulation based on specific building assemblies and engineered systems	Precise simulation based on the specific manufacturer and detailed system components	Commissioning and recording of measured performance

Fig. 2. The Capability of a BIM Model According to LOD Level. Source: by authors based on Victor, 2022

2.1. Level of development in BIM

Throughout the full lifespan of the facility under assessment, the Building Information Modeling (BIM) technique employs digital information. It is built on a thorough digital representation of each geometric and spatial component, encapsulating their properties and interdependencies. (Borrmann et al., 2018). The categorization of these representations for different applications and specializations is done with a categorization scheme called Level of Development. Although, at that time, it was new in this AEC industry, the Level of Detail concept is a topic discussed in computer graphics (Luebke et al., 2002). The American Institute of Architects (AIA) adopted the LoD. It improved it to become the Level of Development (LOD), which refers to the accuracy and completeness of the building element information (Abualdenien & Borrmann, 2022a; Summary: *E203TM–2013, Building Information Modeling and Digital Data Exhibit – AIA Contract Documents, n.d*.).

	LoD 100	LoD 200	LoD 300	LoD 350	LoD 400	LoD 500
United BIM Definition	Pre-design stage, the model consists of 2D symbols and the masses to signify an element's existence	The elements are partially defined by outlining their approximate quantity, size, shape, and location	The elements are defined with exact dimensions and their relative positions bolstering precision	Describes the information about an element precisely and outlines an element's relation and connection with other components	Level outlines the basic information about the construction of various elements	The model begins representing the real-life functions of elements in a real building. Here are all the levels of development with their definitions in detail
BIM FORUM Interpretation	LOD 100 elements are not geometric representations. Examples are information attached to other model elements or symbols showing the existence of a component but not its shape, size, or precise location. Any information derived from LOD 100 elements must be considered approximate.	At this LOD elements are generic placeholders. They may be recognizable as the components they represent, or they may be volumes for space reservation. Any information derived from LOD 200 elements must be considered approximate.	The quantity, size, shape, location, and orientation of the element as designed can be measured directly from the model without referring to non-modeled information such as notes or dimension call-outs. The project origin is defined and the element is located accurately with respect to the project origin.	Parts necessary for coordination of the element with nearby or attached elements are modeled. These parts will include such items as supports and connections. The quantity, size, shape, location, and orientation of the element as designed can be measured directly from the model without referring to non-modeled information such as notes or dimension call-outs.	An LOD 400 element is modeled at sufficient detail and accuracy for fabrication of the represented component. The quantity, size, shape, location, and orientation of the element as designed can be measured directly from the model without referring to non-modeled information such as notes or dimension call-outs.	Since LOD 500 relates to field verification and is not an indication of progression to a higher level of model element geometry or non-graphic information, this Specification does not define or illustrate it.

Fig. 3. Fundamental LoD Definitions based on Revit Modeling Services | United-BIM Company in USA, n.d. and BIMForum (2020c) 2020 Level of Development Specification Guide, 2020

Significant distinctions exist, even if LoD is occasionally read as "level of detail" rather than "level of development." The level of development indicates how much the geometry of an object and its associated information have been taken into account or how much the project groups can rely on the data while utilizing the model. In reality, the level of detail is the element's input, while the level of development is the element's legitimate output. At various phases of the design and construction process, professionals in the AEC industry can assess the content and consistency of building information models (BIMs) using the Level of Development (LoD) Standard as a reference (*BIMForum (2020c) 2020 Level of Development Specification Guide, 2020).* For more than a decade, several efforts have been launched in the BIM space to reach an agreement on the types of data that should be included throughout the construction of architectural elements throughout a project (Abualdenien & Borrmann, 2022b). In 2008, according to United BIM, AIA (American Institute of Architects) originally presented LoD as five distinct phases of development to characterize BIM models. However, Vico Software, a software developer for construction analysis, might be credited with being the first user of LoD. Vico Software implements a "LOD-like system" to connect model data to estimated costs. At different phases of the design process, the company made every digital model's characteristics and attributes accessible to everyone. Afterwards, LoD describes the stages of development for various systems in BIM, functioning as a standard for the industry. Architects, engineers, and other professionals may communicate clearly with one another using LoD requirements (Victor, 2022). Standardizing the LoD categorization applied in architectural projects is important to ensure the consistency of the projects of different BIM applications and teams. Among the multiple variations to ensure this standardization, the different definitions made by platforms such as United BIM and BIMFORUM can be found in the table below.

2.2. Level of detall in CityGML

Kolbe explains CityGML; GML means Geography Markup Language. It is a unified information model for storing and transmitting 3D city models. A virtual city 3D environment linked with spatial data infrastructures based on ISO/OGC standards is often represented by CityGML. Digital landscape models, transportation elements, vegetation, city furnishings, water bodies, and sites are all included in CityGML, which employs multi-scale models to allow for adaptable visualizations at different levels of LOD (levels of detail) (Kolbe et al., 2005; Yao et al., 2018). CityGML offers an extension method that enables models within certain domains to be enhanced with novel features and properties, in addition to unifying information and visualization. Urban planning, urban design, landscape planning, architectural design, tourism and leisure, 3D cadastres, environmental simulations, mobile telecommunications, disaster management, homeland security, vehicle and pedestrian navigation, and training simulators are specifically targeted application areas (Saran et al., 2018; Singh et al., 2013).

The Level of Detail (LOD) concept, first introduced by Clark in 1976 as a hierarchical geometric model for visible surface algorithms for computer graphics, is one of the key features of CityGML (Clark, 1976; Löwner et al., 2016). In addition to having a wide range of applications, it is a crucial phrase for describing the complexity of representation in GIS and 3D city modelling. With small modifications in definition, the LOD idea has been taken from computer graphics and improved upon in GIS (Halik & Kent, 2021; Wong & Ellul, 2016). Different LODs are often represented primarily for effective visualization. Besides effectiveness, maintaining LOD is also necessary due to the minimal volume of data (Köninger & Bartel, 1998).

The LOD is considered a 3D model's product description and is distinct from ideas about data quality like accuracy or spatial correctness. Therefore, it is feasible to design an accurate LOD1 block model and a LOD3 model with lower data quality (Biljecki et al., 2015). CityGML supports different levels of detail (LOD). LODs have to adjust for diverse collection methods with different application needs. The same item may be represented in many LODs simultaneously in a CityGML dataset, allowing for analysis and representation of the same object concerning various levels of precision. Separate objects from the same LOD will frequently be generalized to be embodied in a group of objects in a lower LOD; nonetheless, in CityGML, each object can have a distinct model for each LOD (Gröger vd., 2006). Consideration to the consistency among these many representations, which frequently operate hierarchically. They offer guidelines for choosing a group of spatial objects from various LODs that may be examined and viewed together. The constraints ensure every genuine item in the scene or utilization is precisely represented once (Joachim et al., 2013).

Based on the international CityGML standard established by the Open Geospatial Consortium (OGC), an increasing number of cities and even entire nations across the world have been developing semantic 3D city models of their physical environments over the past ten years (Yao et al., 2018). The most widely used standard on LOD has been published in CityGML 2.0, a significant update to the prior version 1.0 of this international standard established in 2012. CityGML 2.0 brings significant enhancements and new capabilities to the CityGML structure model. One of the innovations was adding the LOD0 "regional-landscape" level to the initial classification, which was justified by the fact that footprint and roof edge polygons may now represent LOD0 buildings. As a result, it is simple to include 2D data from the past and roof reconstructions from aerial and satellite photos into 3D city models. Vertical, three-dimensional surfaces are the only representational options. Each component of the city, including the buildings, bridges, land use, topography, transit, tunnels, landscape, and water body models, has been classified uniquely (Gröger et al., 2012). Each has different types of information, including semantic models with different details, increasing by the observation distance, using the same idea as LOD in computer graphics.

	LOD 0	LOD 1	LOD 2	LOD 3	LOD 4
Model Scale Description	Regional,landscape	City, region	Districts and Neighboorhoods	Architectural models, landmarks	Architectural models, interiors
Classes of Accuracy	Lowest	Low	Middle	High	Very high
Absolut 3D Point Accuracy(position/height)	Lower than LOD1	5/5 m	2/2 m	0.5/0.5 m	0.2/0.2 m
Generalisation	Maximal generalization (classification of land use)	Object blocks as generalized features; > 6*6m/3m	Objects as generalized features; > 4*4m/2m	Object as real features; > 2*2m/1m	Constructive elements and openings are represented
Building Installations	No installation	Basic volume	Basic form	Representative exterior effects	Real object form
Roof Form/Structure	No	Flat	Roof type and orientation	Real object form	Real object formA
Roof Overhanging Parts	No	No	No	Representative parts	Yes
City Furniture	No	Important objects	Prototypes	Real object form	Real object form
Solitary/Vegetation Objects	No	Important objects	Prototypes, higher 6m	Prototypes, higher 2m	Prototypes, real object form
Plant Cover	No	>50*50m	>5*5m	<LOD2	<LOD2

Fig. 4. OGC standarizations. Source: by authors

Different accuracy rates and minimal object dimensions are additional characteristics of LODs. The accuracy criteria outlined in this standard are controversial and must be treated as debate points. There are also standardizations in this field other than OGC. One of them is the standardization made by Albert (Albert et al., 2003). The whole 3D point coordinates' standard deviation serves as a measure of accuracy. A later release of CityGML will introduce relative 3D point accuracy—often significantly higher than absolute accuracy—. In LOD1, points' location and height precision must be 5 meters or fewer, and all objects with a footprint of at least 6 meters by 6 meters must be considered. LOD2 must have a location and height accuracy of at least 2m. All items with a footprint of at least 4m 4m must be considered in this LOD (Gröger et al., 2008).

Moreover, the 2020 Open Geospatial Consortium CityGML 3.0 standards The conceptual model distinguishes four levels of detail (LOD 0-3) that increase the complexity level concerning the item's geometry. Because all feature types can now include outdoor and indoor features in LODs 0-3, LOD4 was removed. This means that the inside components of a structure, such as rooms, doors, hallways, and staircases, might be physically represented in LOD1 and the exterior shell of the building in LOD2. Building layouts, which are LOD0 representations of building interiors, may now be represented using CityGML (Konde et al., 2018; Kutzner et al., 2020).

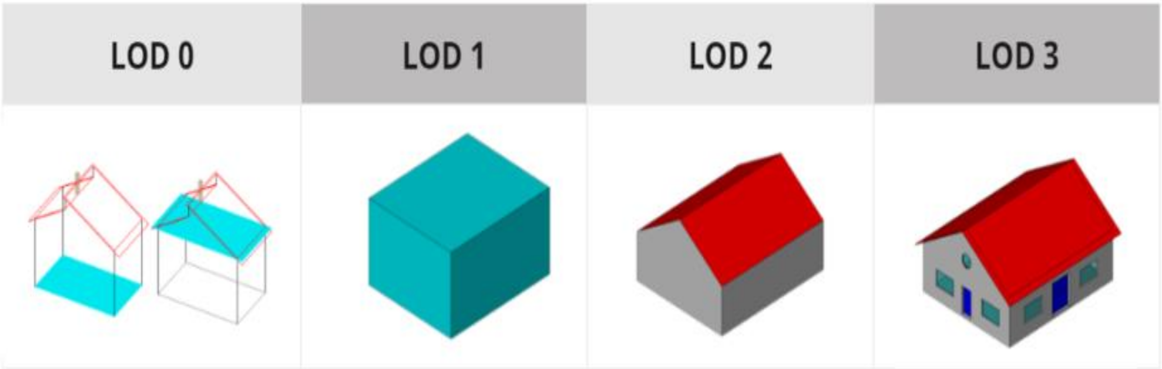

Fig. 5. OGC CityGML 3.0 standards LOD levels (LOD). Source: by authors

As the model is built on ideas established by the ISO and the OpenGIS Consortium, it is a first step towards uniform, interconnected 3D city models. In order to better understand how to model appearances and physical properties (materials and textures), more research has to be done. Combining ideas from computer-aided architectural design (CAAD) will be a further concern for upcoming development (Billen, n.d.).

3. MATERİALS AND METOD

3.1. The digitalization process

The digitalization of 3D urban representation models must be optimized for the system's requirements. The digitalization process has to be decided where and how they will be optimized due to their large data and output model sizes. The diagram below shows the digitalization process. With the photogrammetry method, 3D representation models can be created using various software after collecting the necessary data. The data could contain higher or lower details according to the desired scale and observation distance. In that case, data may need to be reproduced or optimized. The optimization should be considered with two options. After determining the system that will be used, the required geometrical accuracy for the models to be displayed, and choosing the appropriate level of detail, optimization can be made by narrowing the visual data according to the selected LOD and region or scanning all the visual data by using settings of the appropriate LOD level. Appropriate LOD categorization is crucial for creating the 3D models to be used in the most optimized way.

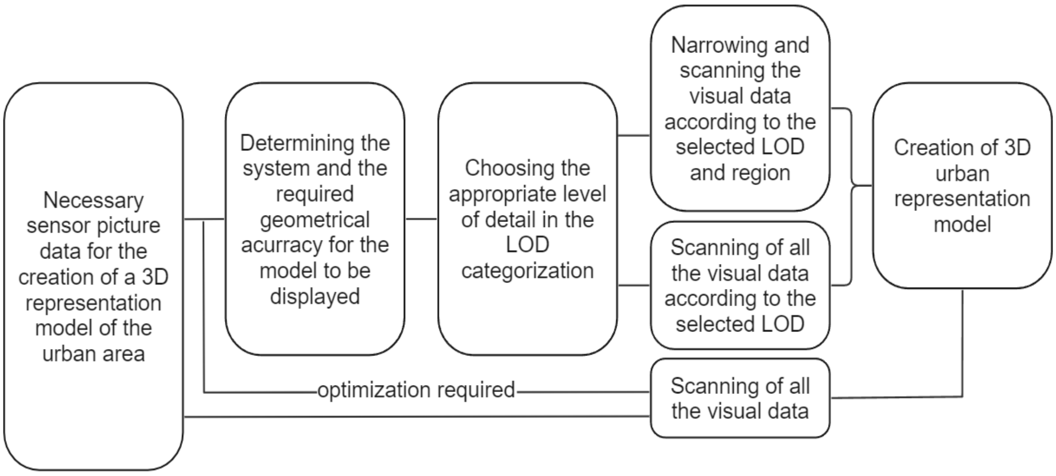

Fig. 6. Digitalization process. Source: by authors

3.2. Data collection

The data used in this study is based on different-sized urban and architectural 3D models and mesh optimization. Computer Graphics LOD workflow was implemented on the various scaled 3D models created by 3D scanning technology. According to the case study results, four different optimization zones have been found by evaluating statistical features according to the chosen 3D models. The results were collected based on Open-Source 3D scan models and shared online by creators with similar workflows. According to the study, the optimization zones and their definitions are shown in the following diagram. The table's observation distances and distortion points were examined, and it was found that the LOD_1000 level represented city and neighbourhood scales and displayed between 1500 and 500 meters; the LOD_2000 level represented public space and square scale and displayed between 500 and 100 meters; and the LOD_3000 level represented architectural and street scales; and 100-20 meters range, followed by LOD_4000 level; which, according on the models and applications are chosen, is shown between 20 and 0 meters and illustrates private and protected areas.

	Definition	Face Amount (min-max)
LOD_1000	Contains city and neighborhood scale models to be used between 1500-500 meters observation distances	400.000-3.000.000
LOD_2000	Contains square scale models to be used between 500-100 meters observation distances	400.000-1.500.000
LOD_2050	Contains square scale models to be used between 500_100 meters observation distances and may contain more surface numbers than its upper category LOD_2000	1.500.000-3.000.000
LOD_3000	Contains architectural and street scale models for use at observation distances of 100-50 meters	400.000-1.500.000
LOD_3050	Can be used as a subcategory of LOD_3000 level to be used between 50-20 meters observation distances and contains architectural-street scale models	1.500.000-3.000.000
LOD_4000	Contains preserved sites and special area models for use at observation distances below 20 meters	According to max system requirments

Fig. 7. Face amounts and Definitions of Proposed LOD categorization for Urbanism. Source: by authors

3.3. Research design

This study will use a mixed approach designed to be the following work. In the first phase, after the literature review, this study will analyze the different LOD levels' characteristics and set their parameters' domains. In the second phase, a LOD categorization chart will be developed using the current LOD-based categorizations driven by BIM and CityGML applications. The graphic shows the research design below for investigating the LOD framework to the most detailed 3D representation tool using semantic 3D models. According to the diagram above, the inputs of the study are described as a Literature review of digitalization of site methods, LOD-related urban studies, and LOD on CityGML and BIM applications in the first phase of the study. The current settings of domains of parameters for LOD categorization have been described by analyzing possible LOD scenarios on urban and architectural scales. In the second phase, by considering the data derived by the concerned study, the concepts of digitalization and CityGML applications LOD formats will be crossed over for building a framework for LOD scenarios according to individual purposes as the main output of the study. The part between the two phases has been investigated in the connected study "LOD workflow for 3D models to next generation urban designing tools", focusing on the system optimization settings and 3D urban representation models digitalization process.

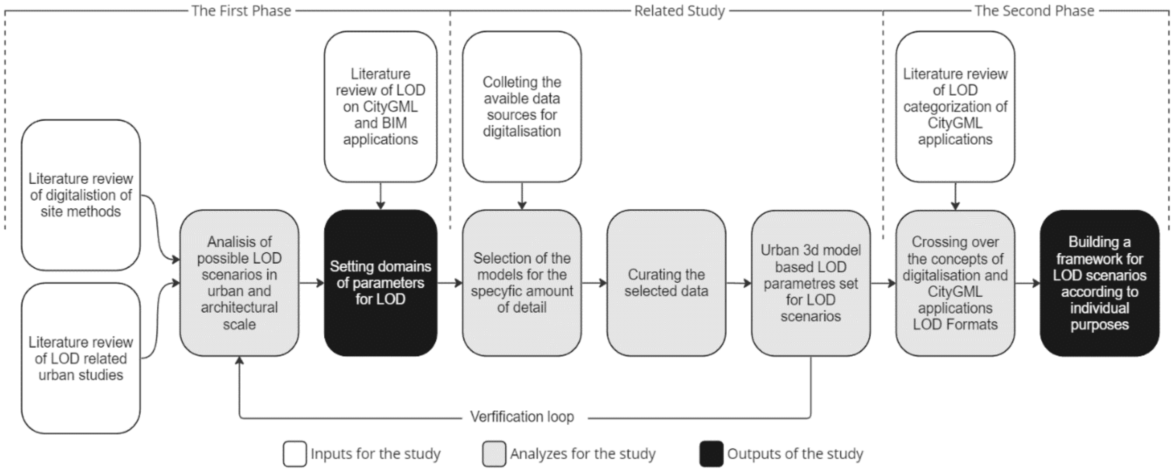

Fig. 8. Research Method. Source: by authors

4. RESULTS

4.1. The basic concepts on lod settings

Based on the referred research, the LOD categorization will be derived over three basic stages. LOD 1000 for urban and neighbourhood scales, LOD 2000 for plaza and square scales, and LOD 3000 for architectural and street scales. These LOD categories will be further developed and diversified to specify each level's information and objectives. Each LOD level must have its special usage and purpose to separate the information they contain and the software infrastructure they use to be optimized for the computing systems and understandable for the users. The features of the LOD levels must be cumulatively affecting each other. They affect the next level bindingly, similar to the scales of urban and architectural plans.

Even though many other predetermined systems recruitment-based LOD categorizations provide progressive and consistent categorization, some known as Level of Development and CityGML Level of Details, those categorizations often do not involve the 3D model's quantitative features nor observation distances because of their software basis. In the categorization that has been formed in this study, the 3D model quantities have been added and distributed on the most regarded level of detail for the best visual quality, practicability, and optimization. The study will also explore how the LOD concept can be aligned with different urban design principles and objectives to make it more usable for urban planners and designers. The identified urban design principles and objectives will collaborate with each LOD level to guide future studies in this field.

4.2. Lod categorization based on urban plannıng scales

4.2.1. Urban / Neighborhood scale (LOD_1000)

It can be described as the utmost level of LOD categorization, focused on capturing the city's most overall and representative layout, with detailed information over major infrastructure elements such as transportation networks, water and power systems, and social structure elements such as green spaces and social facilities. It can also include other non-physical city-scaled data such as boundaries, demography, and the planning decisions related to its scale to ensure the information should be precise enough to provide a general idea of the city's structure and topology.

4.2.2. Plaza and Square scale (LOD_2000 - LOD_2050)

Level 2000 is divided into two sub-level because of the accuracy requirements. The division has been needed because of the various demands, 3D model outputs, and site characteristics on this LOD level. However, because of the general purpose of these two levels, they share the objectives of LOD 2000. Overall geographical accuracy is important because of the properties and the private and public differences. Those levels should include information on the neighbourhoods within the city, including their boundaries, land use, zoning regulations, and social facilities such as schools, hospitals, and parks. It can also include other nonphysical and statistical information, such as domains of the social facilities, building block data provided by GIS applications, and historical and distinctive information about public spaces. For more accuracy, LOD_2050 can be chosen. This sublevel can provide more detailed information on the physical characteristics of individual city blocks, such as their detailed 3d models containing information about their size, shape, orientation, and the relationships between the buildings and open spaces. It can also include information on the streets, sidewalks, and other urban elements related to the block. The objective of this level is to support the development of urban design strategies that promote walkability, accessibility, and social interaction.

4.2.3. Architectural and Street scale (LOD_3000 - LOD_3050)

The level 3000l is divided into two sub-levels because of the accuracy requirements. The division has been needed because of the various demands, 3D model outputs, and site characteristics on this LOD level. However, because of the general purpose of these two levels, they are sharing the objectives of LOD 3000. This level should Provide a highly detailed view of buildings and streets, including their materials, textures, and architectural style, that can transfer the visual data of the city site to be input in the urban designing process. It can establish a digital spatial infrastructure to transfer spatial information. It can provide a better understanding of the characteristics of the actual space, physical infrastructure, assets of the place such as urban furniture and facilities, view elements, physical and psychological borders, human scale with appropriate camera settings, and many other income for urban designing. For more accuracy, the LOD_3050 sub-level can be chosen. It can be a building or street sub-level of LOD 3000, including BIM information at an appropriate LOD level for the project, such as LOD 200 or LOD 300.

4.2.4. Special/Protected/Conservation Areas (LOD_4000)

As an extra level included in the categorization, it has been deemed appropriate to copy and store the special areas, such as protected areas in or outside the city, to preserve them digitally. Since the development of alternative areas, such as digital tourism and the production of indestructible copies of protected areas, has become a local government understanding, it is not unlikely that such 3D assets will be included in a holistic system. This level should focus on the best visualization and presentation of such models individually, with accuracy of detail based on windows partitions, decorative elements, and different materials, distinguishing the age of architectural tissue.

4.3. The objectives of lod levels

4.3.1. Urban / Neighborhood scale (LOD_1000)

The data at this level should be suitable for high-level planning and decision-making. Detailed and trustworthy data must be available for high-level planning and decision-making processes to function effectively. The information required to analyse and evaluate various growth scenarios and their possible effects on the neighbourhood or city is available at this level. Detailed and large views of the district or city, including larger transportation networks and distribution of green spaces, can help increase visual expression and legibility. Much information, such as the distribution of green areas, the types of public services, and the levels of these areas, can be processed at this level, making it easier for the observer to analyze the visual data and read the urban concept. Allowing analysis of different development scenarios and their impact on the neighbourhood is an essential objective for GIS software and, if constructed, to create a wide-ranging three-dimensional city model to effectively analyze various 3D development scenarios and how they impact the entire city and its neighbourhoods. Models at this level should take advantage of the various 3D analytical capabilities of GIS software. Each unit model's 3D infrastructure or required parts must be maintained. Providing data for transportation planning and management and displaying basic land use and zoning information is another essential for the three-dimensional city representation tool for urban planners to observe the basic urban hierarchy and urban planning. In this way, the establishment of the relationship between transportation systems and different urban regions can be facilitated for the observer, and the digitalization of verbal data can be made through 3D representation in order to utilize up-to-date analyzes when necessary.

Moreover, making the distinction between transportation systems, roads, bike and pedestrian networks, and public transit is also important at this level for understanding the backbones and adequacy of the transportation system. LOD_1000 models must include 3D models or 2D maps on 3D topology. The 3D models must be specifically created or optimized to be observed from 1500 to 500 meters of distance using 400.000 to 3.000.000 faces according to the desired accuracy or processing capacity. Street networks, topography, special land uses, and other infrastructure data that are georeferenced and compatible with Geographic Information Systems (GIS) software must be associated with their 3D representations in order to facilitate them. The necessary digital infrastructure should be constructed.

4.3.2. Plaza and Square scale (LOD_2000):

The first objective of this level is to display the general building types and urban patterns for visualization purposes. Because the urban details, which are important for the scale of urban design, begin to become evident at this scale. The visual representation of the urban design factor, such as the permeability of buildings, Space occupancy, and human scale, can be observed over this level. In addition to this, visualization of the basic distinction between public and private spaces is also important to make it more understandable for the observer. A detailed understanding is crucial, which is formed by merging the city's built environment and non-geometric information, Including more detailed information about the city's districts, such as the location of social facilities and their domains, to allow designers to develop spatial planning strategies and design interventions. All the novel information must be added to the related 3D models to create a good information system for designers and citizens. Problem area detection with feedback for the participant city management also begins at this level.

LOD_2000 models must include detailed 3D models created by using UAV sensing methods to be observed from 500 to 100 meters of distance. Three-dimensional models to observe at this level should be specifically created or optimized. The quality must be between 400.000 and 1.500.000 faces. Street networks, topography, and other infrastructure data that are georeferenced and compatible with Geographic Information Systems (GIS) software must be associated with their 3D representations in order to facilitate them. Survey data from city government and public organizations must be associated with 3D representations, and the necessary digital infrastructure for participant planning should be constructed.

4.3.3. Plaza and Square scale (LOD_2050)

In addition to LOD_2000, it provides a detailed and accurate 3D observation opportunity and instructive information about the urban plan and built environment. To achieve this, in addition to 3D urban models, street assets can include 3D assets for large street elements such as lighting, signage, and vegetation.

LOD_2050 models must include detailed 3D models created by using UAV sensing methods to be observed from 500 to 100 meters of distance. Three-dimensional models to observe at this level should be specifically created or optimized. The quality must be between 1.500.000 and 3.000.000 faces. In addition to Street networks, topography, and other infrastructure data that are georeferenced and compatible with Geographic Information Systems (GIS) software, LOD_2050 models must include a lower level of detailed secondary model to use in simulations and collusions. The secondary models can be GIS models produced using CityGML LOD1 or LOD2 levels, accurate enough for the digital simulations and containing special 3D assets for the required simulations. To contain simple but consistent models so that physics simulations can be created.

4.3.4. Architectural and Street scale (LOD_3000)

In addition to allowing analysis of different development scenarios and their impact on the neighbourhood setting, more detailed information about the plot and parcellation has become important at this level to be used by citizens, architects, and urban Planners and designers. Also, the difference between public and private spaces must be distinctive for the user. One of the main purposes of this level is to create highly detailed views of buildings and their surrounding site, including their architectural elements, materials, and textures which is useful for urban designers and architects. Also, 3D urban furniture, traffic, and vegetation that do not have consistent forms could be replaced by using optimized and realistic 3D digital assets. Using digital representations is a tool for analyzing the impact of building design on the surrounding urban texture to manage building construction and maintenance. On the other hand, by allowing new designs to be tested in the 3D environment, they should be evaluated together with their environment, thus contributing to the development of sustainable design.

LOD_3000 models must include detailed 3D models created by using both UAV sensing methods and street-level imagery to be observed from 100 to 20 meters of distance. Three-dimensional models to observe at this level should be specifically created or optimized. The quality must be between 400.000 and 1.500.000 faces. LOD_3000 models include detailed 3D models with geometrical details on building elements such as windows, doors, roofs, and facades. In addition to building face details, LOD_3000 models must include a lower level of detailed secondary model for simulations and collusions. The secondary models can be GIS models produced using CityGML LOD1 or LOD2 levels, accurate enough for the digital simulations and containing special 3D assets for the required simulations. To contain simple but consistent models so that physics simulations can be created. Survey data from city government and public organizations must be associated with 3D representations, and the necessary digital infrastructure for participant planning should be constructed.

4.3.5. Architectural and Street scale (LOD_3050):

In addition to LOD_3000, we are allowing for the real-time Data captured from remote sensors from surveys and collaboration with design tools and basic BIM LoD 300 and 200 models on the background of the models for enabling disaster management simulations. Also, non-physical attributes of urban assets can be associated with their representations, such as sound isolation and durability, to use in various other simulations. LOD_3050 models must include detailed 3D models created by using both UAV sensing methods and street-level imagery to be observed from 100 to 20 meters of distance. Three-dimensional models to observe at this level should be specifically created or optimized. The quality must be between 1.500.000 and 3.000.000 faces. LOD_3050 models include detailed 3D building models that include facade level geometrical details on building elements such as windows, doors, roofs, and facades; they also must include BIM LoD 300 and 200 models must be associative; information on the site's topography, drainage, and landscaping must be added. At this level of detail, they contain simple but consistent models so that physics simulations can be created to use in disaster management simulations.

	LOD_1000	LOD_2000	LOD_2050	LOD_3000	LOD_3050	LOD_4000
Model Scale Description	Urban/Neighborhood scale	Plaza and Square Scale	Plaza and Square Scale	Architectural and Street Scale	Architectural and Street Scale	Special Scales
Urban Scale Description	Regional and Master Plans	Master plan	Master plan and Urban design	Urban Design and Architectural Plan	Urban Design and Architectural Plan	Urban Design-Architectural Plan-Lanscape Plan
Classes of Accuracy (1- low/ 10-high)	1	3	5	7	9	10
Digital Observation Distance	1500-500m	500-100m	500-100m	100-20m	100-20m	<20m
3D Model Face Amount per frame	400.000-3.000.000 face	400.000-1.500.000 face	1.500.000-3.000.000 face	400.000-1.500.000 face	1.500.000-3.000.000 face	max
3D Model Accuricy	visualization and information purposes	visualization and information purposes	Simulation and Analysis Purposes	visualization and information purposes	Simulation and Analysis Purposes	visualization and information purposes
Scanning Type	sattelite and plane imagery	plane or uav imagery	plane or uav imagery	uav imagery	uav/Street level imagery	Street level imagery
Generalization	-	-	CityGML LOD1, LOD2	CityGML LOD1,LOD2	BIM LOD200, LOD300	-

Fig. 9. LOD Categorization Table. Source: by authors

4.3.6. (LOD 4000): Special Areas (as Builded)

This level specifically focuses on special areas, such as protected or archaeological sites, which require the highest level of detail, geometrical accuracy, and important elements in the urban built environment. LOD_4000 aims to provide designers and planners with an accurate representation of a city asset, such as heritage buildings and historical places. Allowing highly detailed and specialized 3D models to operate can transfer the characteristics of urban sites to be better-preserved copies of them for future observers and help store the cultural assets of the place. LOD_4000 models must include the most detailed 3D models created using UAV sensing methods and street-level imagery to be observed lower than 20 meters of distance. Three-dimensional models to observe at this level should be specifically created or optimized. The quality must be aligned with the optimization limits of the systems in usage.

4.4. Categorization table

The findings obtained from all the evaluations are brought together in the table below, and the gradually changing general contents of the LOD categorization, whose definitions were made before, are included. LOD categorization is presented in 6 stages, 4 of which are basic, according to the table; It has been designed to be associated with urban theories and CityGLM and BIM systems; with high visual realism and various simulations that can be used in digital tools such as game engines. More accurately, LOD_1000 and 2000 focus on providing high visual realism and powerful user interfaces, LOD_2050, 3000, and 3050 levels are additionally focusing on supporting urban simulations, and LOD_4000 is based on the purposes of archiving accurate digital copies of urban heritages and culturally important areas.

5. DISCUSSION

This study's categorization of the Level of Detail (LOD) in urban design and planning builds upon existing literature while introducing novel elements. The framework proposed in this research considers the different scales within the urban context, aligning with the notion that urban design and planning require varying levels of detail at different scales. By categorizing LOD into four stages (LOD 1000, LOD 2000, LOD 3000, and LOD4000), this framework provides a clear and practical structure for urban design professionals. Comparing our findings to the existing literature on LOD categorizations, such as Level of Development(LoD) and CityGML Level of Details, we recognize the limitations of these frameworks in incorporating quantitative features of 3D models. By including the 3D model quantities and urban design criteria in our proposed categorization, we enhance the visual quality, practicability, and optimization of the urban representation models to use in 3D model-based urban representation systems. This addition aligns with the growing importance of advanced visualization techniques and the need to represent the built environment accurately.

Additionally, the proposed framework is based on another study primarily focusing on the visual aspects and quantitative features of 3D models within various urban scales. Future research could further delve deeper into incorporating other critical dimensions, such as semantic information, contextual relationships, and data interoperability, to enhance the LOD categorization's usability and comprehensiveness. Another aspect to consider is the need for standardization and interoperability across different software platforms and tools used in urban design and planning. While the proposed framework aims to optimize the categorization for computational systems, more work is required to ensure seamless integration and compatibility among various software infrastructures. Especially considering the broad concept of urban digital twins, recent developments between gaming engines and GIS applications are gaining significant importance.

Moreover, aligning the LOD concept with urban design principles opens wide avenues for further explorations. Future research could investigate how each LOD level can be more linked to urban design principles and objectives. This could lead to developing guidelines and best practices for utilizing the LOD categorization in real-world urban design projects. Furthermore, applying the proposed LOD categorization framework should be tested and validated through case studies and practical implementations. Such studies can provide valuable insights into the framework's strengths, weaknesses, and potential improvements, as well as its impact on decision-making processes and the overall quality of urban design and planning outcomes.

Nevertheless, While this study presents a comprehensive framework for categorizing LOD in urban design and planning, specific aspects of the study should be acknowledged. The proposed categorization is based on extensive research but is still subjective because of the materials and the computer system used. The 3D quantitative within each LOD level must be adapted to the system used. On the other hand, This study can be quickly outdated by further developing the graphic card capabilities and alternative 3D computer visualization methods such as NeRF technology. Even so, the LOD-based approach will maintain its importance due to its applicability in many different stages and its relation to the hierarchical order in urban planning.

6. CONCLUSION

In conclusion, this study introduces a categorization framework for the Level of Detail (LOD) in urban design and planning. The framework addresses the confusion between LoD and Level of Development (LOD). It provides a clear and consistent approach to categorizing the level of detail at different scales within the urban context. The proposed framework consists of four stages: LOD 1000 for urban and neighbourhood scales, LOD 2000 for the plaza and square scales, LOD 3000 for architectural and street scales, and LOD 4000 for special and preserved areas. Each level serves a specific purpose and contains relevant information for its respective scale, enabling urban design and planning professionals to work systematically. By incorporating quantitative features of 3D models, the framework enhances visual quality, practicability, and optimization in urban design and planning applications. This inclusion acknowledges the significance of advanced visualization techniques and the need to represent the built environment accurately.

Furthermore, aligning the LOD concept with urban design principles guides decision-making processes. The framework can link specific urban design principles and objectives with each LOD level, facilitating effective planning and design. While the study presents a comprehensive categorization framework, there are limitations. Subjectivity in the categorization process and the need for empirical validation are areas for future research. Additionally, incorporating semantic information and data interoperability dimensions could enhance the framework's comprehensiveness.

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