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Visualization of Existing Rights and Restrictions of 3D Buildings towards an Integrated Land Administration of Indonesian Urban Areas

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Abstract

Rapid urbanization in Indonesian cities has intensified the demand for an advanced land administration system capable of managing complex three-dimensional (3D) spatial arrangements above, on, and below the Earth's surface. However, current land administration practices remain constrained by fragmented datasets across cadastral, spatial planning, and building permit authorities, resulting in limited interoperability and institutional inefficiencies. Concurrent advances in infrastructure engineering further accelerate the utilization of multi-level urban spaces, emphasizing the urgency for a modernized and integrated framework. This study proposes an integrated 3D Land Administration (3D LA) framework that embeds Rights, Restrictions, and Responsibilities (RRR) within transparent volumetric technic. The framework employs Level of Detail (LOD) 1 to represent legal objects and LOD3 for physical structures, improving the precision and interpretability of 3D spatial representations. Existing spatial plans, building regulations, and land certification constraints are predominantly expressed through textual descriptions and two-dimensional (2D) records, which are insufficient for interpreting vertical overlaps and assessing permit compliance in dense urban environments. By converting legal boundaries into 3D visualizations using LOD1, the proposed framework reduces interpretive ambiguity and strengthens decision support. Case studies from Surabaya and Malang were conducted, in which 2D architectural drawings were transformed into detailed 3D models and enriched with legal constraints derived from detailed spatial plans (RDTR) and property rights documents. The results indicate that conventional 2D systems in-adequately represent overlapping land uses, particularly in high-rise and subterranean developments. The proposed volumetric visualization approach enhances the understanding of property boundaries, height restrictions, and legal entitlements, supporting informed decision-making and stakeholder engagement. Overall, this research demonstrates the potential of 3D LA to better align legal frameworks with urban spatial realities, contributing to more effective and sustainable urban governance in Indonesia.

Keywords

3D Land Administration (3D LA), Rights, Restrictions and Responsibilities (RRR), 3D Visualization, Spatial Planning, Land Right

1. Introduction

The rapid development of modern cities has created new challenges in land management, particularly concerning the utilization of space above and below the ground surface. Governments worldwide have recognized the need to regulate the management of multi-level urban objects and have introduced legal frameworks to govern the registration of use rights for both above-ground and underground spaces. A recent example is the Indonesian government's introduction of Government Regulation No. 18 and 13 of 2021 [1] [2] and Ministerial Decree No. 16/2021 [3], which regulate the registration of spatial units that extend beyond the conventional two-dimensional (2D) parcel boundaries. In alignment with these regulatory frameworks, the domain of spatial planning serves as a prerequisite, mandating that the validity of these three-dimensional registrations is contingent solely on their conformity with the zoning and building intensity standards stipulated in the prevailing Detailed Spatial Plans (RDTR-Rencana Detail Tata Ruang) [4] [5].

Despite these advancements, practical implementation remains a challenge. The increasing density of urban environments has led to overlapping public and private rights, resulting in significant complexity in urban land management. High-rise buildings, shopping malls, underground parking facilities, mass rapid transit infrastructure, and pedestrian bridges represent typical examples of urban objects that utilize three-dimensional (3D) space [6] [7]. Managing these complex spatial arrangements requires precise and accurate representations of property boundaries commonly referred to as 3D parcels to ensure clarity in ownership, use rights, restrictions, and responsibilities [8].

Traditional 2D LA systems are inadequate for capturing the vertical complexity of urban objects. They could not effectively represent overlapping or multi-layered land use, which can result in ambiguity, conflicts, and inefficiencies in urban governance [6] [9]. Consequently, scholars and practitioners have increasingly focused on the development of 3D LA systems. These systems aim to enhance the management of urban spaces by enabling the visualization, registration, and monitoring of land rights, restrictions, and responsibilities in three dimensions [10]-[16].

The shift from 2D to 3D LA is not merely a technical improvement; it represents a paradigm shift in how property, rights, and urban development are conceptualized and governed [6] [17]. While several countries have successfully implemented 3D LA in various contexts, Indonesia is still in the early stages of this transition. Current practices remain fragmented, with land rights and spatial planning restrictions still managed separately, and cadastral data largely represented in 2D. This fragmentation poses significant challenges for local governments, particularly in relation to permit issuance, spatial monitoring, and integrated city planning.

Against this background, this study seeks to explore the integration of land rights and restrictions through 3D visualization techniques, with a specific focus on case studies in Surabaya and Malang, Indonesia. Existing spatial plans, building regulations, and land certification constraints are predominantly expressed through textual descriptions and two-dimensional (2D) records, which are insufficient for interpreting vertical overlaps and assessing permit compliance in dense urban environments. This study proposes volumetric visualization of property boundaries, height restrictions, and legal entitlements. By converting legal boundaries into 3D visualizations using LOD1, the proposed framework reduces interpretive ambiguity and strengthens decision support. By converting available 2D architectural drawings into 3D digital models and incorporating legal restrictions from spatial planning documents, this research demonstrates how 3D LA can be utilized to support better urban governance and sustainable city development. This paper is organized as follows. Section 2 presents a comprehensive review of relevant literature on 3D LA, with a particular focus on the representation of Rights, Restrictions, and Responsibilities (RRR), the limitations of conventional 2D systems, and international experiences in implementing 3D cadastral and visualization approaches. Section 3 explains the research materials and methods, including the selected case study areas, data sources, and the procedures for converting two-dimensional data into integrated three-dimensional physical and legal models. Section 4 reports the results of the study, highlighting the development and visualization of 3D physical and legal objects and their integration within a 3D LA framework. Section 5 discusses the implications of the findings, addressing technical challenges, visualization effectiveness, and the role of 3D integration in supporting spatial planning and urban governance. Finally, Section 6 concludes the paper by summarizing the key contributions of the research and outlining its significance for the future development of sustainable urban land administration in Indonesia.

2. Literature Review

Research on land administration has long recognized that traditional two-dimensional (2D) cadastral systems are inadequate for representing both land rights and spatial planning constraints in increasingly complex urban environments. These systems, which represent land parcels using *x* and *y* coordinates, cannot adequately capture the vertical dimension of land, even though urban development increasingly involves multi-level structures such as tunnels, underground facilities, and high-rise complexes [18] [19]. This inadequacy, representing the increasing complexity of 3D land uses, has given rise to the concept of the three-dimensional (3D) cadastre and, more broadly, 3D LA. Unlike the 2D cadastre, which focuses narrowly on parcel boundaries, 3D LA encompasses the management of rights, restrictions, responsibilities (RRR), as well as land values, and land-use planning, extending even to marine spaces, aligning with the broader scope defined in ISO 19152 [6] [20].

Recent developments in land administration emphasize the need for 3D cadastral models capable of representing formal, informal, and customary Rights, Restrictions, and Responsibilities (RRRs) in volumetric space. Such models improve legal certainty, support transparent governance, and reduce spatial conflicts [21] [22]. In this case, the concept of 3D objects and 3D fields becomes very important. A 3D object refers to a property unit legally defined in vertical and horizontal dimensions, while a 3D parcel is understood as the spatial unit to which RRR are attached [8] [23]. Clearly defined rights help establish ownership and usage rights, while restrictions imposed by regulatory frameworks protect the public interest and prevent land conflicts. Responsibilities further ensure that landholders act in accordance with environmental and social obligations [24]-[26].

Visualization is another crucial component in the operationalization of 3D LA. While physical objects such as buildings, land surfaces, basements, and tunnels can be depicted directly, legal objects those defined by property law and zoning regulations require more sophisticated approaches to representation [10] [27]-[29]. Techniques such as transparent visualization, volumetric modeling, and interactive 3D interfaces enhance the ability of both experts and laypeople to understand spatial complexities and legal boundaries [14] [28] [30] [31]. Recent studies further show that digital visualization supports public participation in planning processes, facilitates access to cadastral information, and strengthens urban governance [31]-[33].

In recent studies, the use of different Levels of Detail (LoD) has been recognized as a pragmatic strategy to distinguish between legal and physical representations in 3D LA systems. For legal objects, simplified geometric representations such as LoD1 are often considered sufficient, as the primary objective is to communicate legal boundaries, spatial extents, and regulatory constraints rather than architectural detail. LoD1 models enable clear visualization of volumetric rights and restrictions, reduce interpretive ambiguity, and lower data complexity, making them suitable for representing abstract legal entities such as property boundaries and zoning envelopes [8] [10] [27].

In contrast, physical objects such as buildings and infrastructure frequently require higher levels of geometric detail to accurately reflect their real-world form and internal structure. LoD3 representations, which include detailed exterior elements and interior spaces, have been widely applied to capture the complexity of built environments and to support spatial analysis, validation, and user interpretation [8] [12] [27] [28]. The differentiation between LoD1 for legal objects and LoD3 for physical objects has been highlighted as an effective approach to balance computational efficiency and semantic clarity in integrated 3D LA and spatial planning workflows.

International experiences provide important lessons in this transition from 2D to 3D LA. In Victoria, Australia, authorities have developed integrated frameworks that combine 3D spatial models with legal cadastres, improving the management of urban development [34]-[37]. The integration of digital building permit procedures with 3D city modeling and 3D LA presents substantial potential to enhance the efficiency of permitting and infrastructure management [38]. Conventional permit systems, dependent on 2D documents and manual reviews, are limited in addressing the complexities of urban development. Linking these processes through 3D spatial data enables automation, transparency, and improved coordination across agencies. While research indicates significant progress worldwide, practical implementations remain scarce, highlighting the need for further adoption and development to unlock these benefits fully. Sweden has made notable progress in adapting its legal, organizational, and technological frameworks to support 3D property formation and visualization. Although full legal reform is still ongoing, the country has acknowledged the need to investigate and potentially revise existing legislation to enable the integration of 3D models into cadastral decisions [39]. As [8] emphasize, "current legislation has to be investigated and interpreted in detail to be able to add or transform into using 3D models as part of cadastral decisions in Sweden," highlighting the importance of aligning legal, technological, and policy dimensions in land administration. Complementing these efforts, national initiatives such as the Smart Built Environment demonstrate Sweden's commitment to harmonizing organizational practices, digital tools, and policy development in support of a comprehensive 3D cadastre system [40]. Canada has actively explored innovative visualization techniques to enhance the understanding of legal 3D cadastral objects, particularly among non-specialist stakeholders. Early work by [41] emphasized the need for intuitive visualization tools such as 3D PDFs, CAD models, and augmented reality to support broader accessibility and comprehension of 3D parcels, including by planners, notaries, and the general public. Building on this, [42] conducted empirical usability testing on the use of transparency as a visual variable, demonstrating that varying levels of transparency significantly improved users' ability especially law students unfamiliar with 3D tools to distinguish between physical and legal boundaries in condominium units. Further, [27] highlighted that Canadian research has focused on user-centered design, targeting professionals such as notaries, surveyors, and building managers, and confirmed that 3D visualization facilitates understanding of ownership boundaries and spatial relationships in complex urban environments. Collectively, these studies underscore Canada's leadership in developing 3D cadastral visualization methods that are both technically robust and accessible to non-expert users. Together, these international cases highlight the benefits of 3D LA, particularly in terms of transparency, public engagement, and integrated planning.

In Indonesia, the implementation of 3D LA is still at an early stage. Land rights and spatial planning regulations are still managed independently, with current land administration and spatial planning practices relying predominantly on textual descriptions and two-dimensional (2D) representations. As a result, vertical constraints such as zoning regulations, building height limits, and subsurface use restrictions are rarely visualized spatially. Recent studies confirm that several countries have experienced the same which are insufficient to capture the vertical complexity of modern land use and property rights [6]. Current cadastral and land use planning systems still rely heavily on 2D spatial representations, which are insufficient for managing the complexities of modern urban environments. Moreover, land rights, planning restrictions, and related spatial data are often fragmented across institutions, hindering integration and efficient data exchange. This fragmentation poses challenges for local governments in aligning land ownership with planning regulations, resulting in poor coordination in licensing, monitoring, and enforcement of urban development policies [9] [43]. Despite the technical, legal, and institutional challenges associated with implementing 3D LA systems, recent studies highlight significant opportunities for innovation and reform. The integration of 3D visualization technologies with Rights, Restrictions, and Responsibilities (RRR) within a unified framework has been shown to enhance the transparency, efficiency, and spatial accuracy of land administration processes. As demonstrated in prototypes [10] and [13], such integration supports more informed decision-making and facilitates sustainable urban governance. In the Indonesian context, pilot studies conducted in cities such as Surabaya and Malang provide a valuable testing ground for these approaches. These localized implementations, aligned with global developments reported by [17], may serve as a foundation for broader national adoption of 3D LA practices.

Three-dimensional (3D) land administration in Indonesia represents a vertical spatial management approach that encompasses air space, surface land, and subsurface areas as separate yet interconnected legal entities. This concept aligns with the mandate of Law No. 5 of 1960 on Basic Agrarian Principles, which affirms state control over land, water, and airspace for the greatest prosperity of the people [44], and is reinforced by Government Regulation No. 18 of 2021 [1], which regulates management rights and land rights, including spaces above and below the surface [1]. Within this framework, airspace can be utilized for vertical development, such as towers or high-rise buildings, while surface land serves fundamental functions such as housing, agriculture, or industry. Subsurface areas are regulated separately for specific purposes, such as underground parking or utility facilities, provided they comply with Spatial Utilization Activity Conformity (KKPR—Kesesuaian Kegiatan Pemanfaatan Ruang) and do not interfere with strategic natural resources. The visualization in Figure 1 illustrates the integration of these three spaces within a single administrative system, enabling optimal land use while ensuring legal certainty over spatial control and utilization in accordance with social function and sustainability principles as stipulated in the UUPA [44] and PP 18/2021 [1].

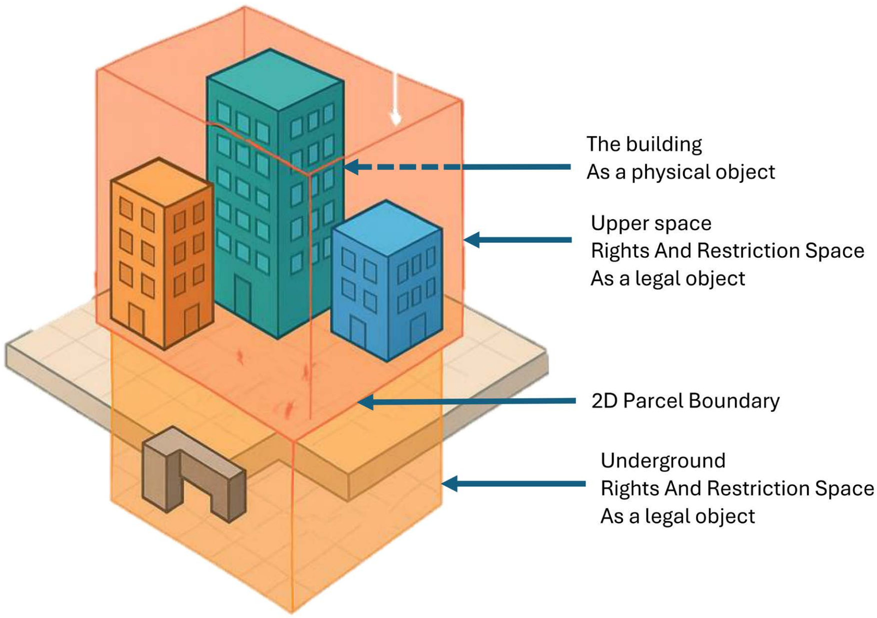


Figure 1. Visualization physical and legal object in 3D land administration.

Despite significant advances in 3D LA research, most existing studies still treat land rights and spatial planning regulations as separate or loosely connected components. While 3D visualization techniques have been widely explored to represent legal and physical objects, the explicit integration of land rights with spatial planning constraints such as zoning regulations, height limitations, and subsurface restrictions remains limited, particularly in practical urban governance contexts. In Indonesia, this separation is further exacerbated by institutional fragmentation and the dominance of textual and two-dimensional planning documents. Addressing this gap, the present study focuses on integrating land rights and spatial planning regulations within a unified 3D visualization framework, demonstrating its application through urban case studies in Surabaya and Malang.

3. Materials and Methods

3.1. Materials

The research objects considered in this study were three buildings, as follows: 1) Buring Flats, Citra Garden Boulevard Street No. 1, Malang City; 2) Balai Pemuda Building, Gubernur Suryo Street No.15, Surabaya, East Java; and 3) Siola Building, Tunjungan Street No.1, Genteng, Genteng District, Surabaya (Figure 2).

(a) Buring Flats (image from personal collection)

(b) Balai Pemuda Building (Unair, 2023a)

(c) Siola Building (Unair, 2023b)

Figure 2. Research objects.

The selection of Buring Flats, Balai Pemuda, and Gedung Siola was based on a maximum variation sampling strategy designed to rigorously test the proposed framework across various typologies of legal and physical complexity. Buring Flats was chosen to represent an object located in a Residential Zone, which is a high-density vertical housing structure, serving as a critical test laboratory for modeling "Sarusun" rights (strata rights) and the division of private units that are geometrically uniform in shape and size and are jointly owned in accordance with the latest regulations. On the other hand, Balai Pemuda, located in the Socio-Cultural Zone, offers a unique spatial unit scenario, requiring a clear representation of spatial utilization restrictions that are geometrically irregular in shape and size, both above and below ground. Finally, the Siola Building illustrates the challenge of adaptive space utilization in strategic government assets, testing the framework's ability to represent high-rise buildings in the Office Zone that are geometrically irregular in shape and size. Collectively, these cases validate the system's flexibility in handling the diverse RRR (Rights, Restrictions, and Responsibilities) configurations inherent in Indonesia's urban environment.

3.2. Methods

To implement an effective 3D LA (LA) system in Indonesia, a structured and comprehensive methodological approach is required. This methodology involves several key steps, from making a 3D Model to the integration between right and restriction aspects in 3D LA.

The first step is conducting an in-depth analysis to identify the challenges faced by stakeholders in land management. Key stakeholders include local governments, urban planners, landowners, and the public impacted by land-use policies. The focus will be on managing vertical and horizontal land rights, as well as the complexities of managing high-rise buildings and underground spaces. The expected outcome of this phase is the identification of specific needs for a 3D model that more accurately represents both physical and legal dimensions of land use, thereby addressing current limitations in land administration and improving urban planning and land management.

In the next phase, data collected from various sources will be used to create detailed and accurate 3D models. This includes both physical objects (e.g., buildings, land parcels) and legal objects (e.g., rights and restrictions). The 3D modeling and data conversion processes were performed using the Revit student version software, specifically using floor, wall, and door features. The data collection will consist of building drawings and spatial planning documents from local government agencies, which provide detailed information about zoning regulations, building height restrictions, and the layout of existing structures. Using software, the 2D building plans (e.g., floor plans, elevation drawings, section drawings) will be converted into detailed 3D models that include structural elements such as walls, windows, doors, and other architectural features. A local coordinate system was adopted for the 3D modeling process, as the models have not yet been visualized according to the field coordinates. Legal boundaries and restrictions will be modeled as 3D volumetric objects, with transparent surfaces used to represent the legal spaces within buildings and surrounding areas. The final expected outcome of this phase is the creation of integrated 3D models that accurately represent both physical structures and legal boundaries.

After the 3D models are developed, the next step is visualization and data integration. The 3D models will be displayed to explore between physical boundaries and legal rights. Color-based rendering and transparency techniques will be applied to differentiate between legal spaces and land-use functions, making the complex relationships between property rights and restrictions clearer. Data integration will involve spatial planning documents and cadastral data. The expected outcome of this phase is an integrated 3D visualization that allows viewing both physical and legal boundaries, enhancing urban planning and land management.

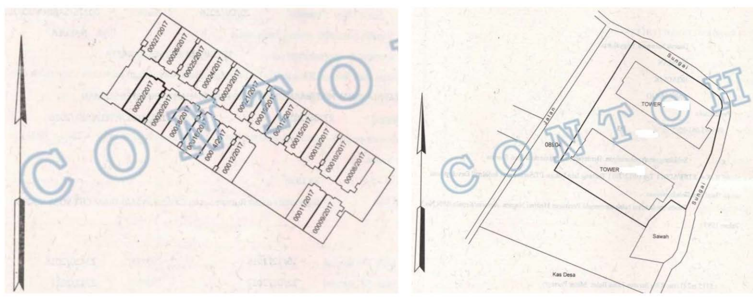
Following the implementation and visualization, the next step is the evaluation. This phase aims to ensure that the 3D models are accurate, effective, and usable by stakeholders. The models will be validated by comparing them against real-world conditions using methods such as direct surveys. The expected outcome of this phase is the delivery of a validated 3D model that provides comprehensive insights into land use, ownership, and restrictions.

Finally, this methodology introduces new approaches to visualization and data integration. Techniques such as volumetric transparency and color-based visualization will improve the understanding of complex spatial data by stakeholders. These technologies offer innovative solutions to visualize property rights, restrictions, and responsibilities more intuitively.

In other words, the implementation of a 3D LA system in Indonesia represents a significant advancement in depicting land rights, restrictions, and responsibilities. By moving beyond the limitations of traditional 2D systems, this methodology incorporates the vertical dimension, which is particularly important for high-rise buildings and underground infrastructure. Adopting this approach will enhance urban planning and land management, ultimately leading to more transparent and efficient land administration practices.

4. Results

In the context of land management in Indonesia, particularly in urban areas experiencing pressure from vertical development and underground space utilization, stakeholders face a range of complex challenges. Local governments, as key actors in land administration both in terms of granting rights to space and spatial planning, are confronted with fragmented land data distributed across multiple agencies, as well as regulatory limitations that fail to accommodate three-dimensional (3D) spatial aspects, especially regarding rights to vertical and subterranean spaces. Currently, legal documentation of spatial rights is limited to commercial strata title units, and the drawings in certificate documents remain in two-dimensional (2D) formats (see **Figure 3**).



(a) 2D Building Floorplans (b) 2D Building Drawings

Figure 3. 2D drawings in certificate documents for strata tittle.

The same thing happens in spatial planning images, which only divide spatial utilization zoning in 2D, while vertical spatial utilization restrictions are still written in text as explanations. For example, in Surabaya, detailed spatial planning can be accessed at https://petaperuntukan.dprkpp.web.id/ (see **Figure 4**).

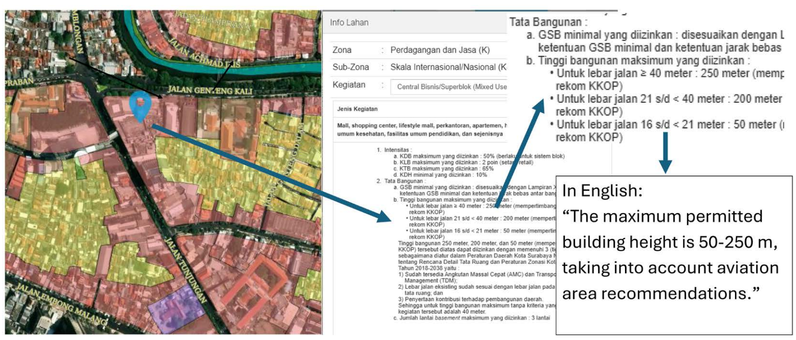


Figure 4. The 2D representation of vertical land use restrictions is based on the detailed spatial plan and its explanation.

The needs analysis revealed several critical challenges in land management within Indonesia's urban areas, particularly in relation to high-rise and underground developments. Local governments highlighted the limitations of the current two-dimensional (2D) systems in managing both vertical and horizontal land rights. These systems often fail to represent the complexities of landownership in multi-layered urban environments, where rights and responsibilities extend above and below the ground. Overlapping ownership, unclear zoning boundaries, and fragmented regulatory documents were identified as significant obstacles to effective land use management.

Moreover, 2D representations hinder stakeholders' understanding and transparency, often resulting in disputes and inefficient decision-making processes. Stakeholders struggled to navigate the complexities of land rights and restrictions when they were solely represented in two dimensions. This lack of clarity created confusion, particularly for property owners and urban planners dealing with multi-story buildings or underground facilities, where the legal and physical boundaries are intricately intertwined.

Given these challenges, the need for a 3D LA system became evident. Such a system would integrate legal objects such as rights, restrictions, and responsibilities with physical objects, including buildings and land parcels, within a single framework. A 3D model would allow for the visualization of both vertical and horizontal boundaries, incorporate zoning and regulatory data, and provide a standardized platform for the integration of data from multiple institutions. This would enhance clarity, facilitate informed decision-making, and improve urban planning. The findings of the analysis confirm that a 3D LA system is essential for accurately representing complex land use in urban Indonesia, promoting a better understanding of land rights and obligations, and improving the efficiency of land administration.

This study further explores the integration of land rights and restrictions through 3D visualization techniques, focusing on case studies in Surabaya and Malang, Indonesia. By converting available 2D architectural drawings into 3D digital models and incorporating legal restrictions from spatial planning documents, this study demonstrates how 3D LA can support better urban governance and sustainable city development. The integration of legal and physical objects in 3D enables more effective urban space management, fostering a clearer understanding of the impacts of development.

The absence of accurate 3D spatial models has made it difficult for urban planners to simulate and predict the impacts of vertical development on both the environment and infrastructure. Zoning regulations often lack clarity regarding vertical space utilization boundaries, which can lead to disputes between property owners, especially in high-rise buildings and underground facilities. This ambiguity also undermines public understanding of how development affects their living environment, as spatial information is not presented in an intuitive and comprehensible 3D format.

These findings underscore the urgent need to develop 3D models that can simultaneously represent the physical and legal dimensions of land ownership and use. Accurate 3D representations would not only enhance land administration efficiency but also strengthen legal certainty, improve urban planning processes, and promote public participation in sustainable urban space management. These models will support spatial decision-making by integrating data from multiple sources, enabling more informed and transparent planning and development decisions for Indonesia's growing urban areas.

4.1. 3D Physical Object

Technological developments and the increasing complexity of land use in urban areas have driven the evolution of LA systems from 2D to 3D. RRR is an essential component of 3D LA that includes ownership rights, usage rights, restrictions on land utilization, and responsibilities of landowners or users in 3D space [45]. The representation of RRR in 3D requires the integration of technical and legal aspects by defining a land parcel in a 3D model as a spatial unit associated with one or more unique rights, responsibilities, or restrictions [33] [46]. The implementation of RRR in 3D LA systems faces several challenges related to the complexity of representation for overlapping structures in urban environments [45], integration of data from various institutions with different formats, reference frames, and projection systems, and the dynamic nature of rights boundaries and the utilization of space. The development of 3D models successfully integrated both physical and legal objects, providing a comprehensive spatial representation of urban land use in the study areas. Physical objects were reconstructed into detailed 3D models from 2D architectural drawings, such as floor plans, elevation views, and sections. These models captured structural elements, such as walls, doors, windows, staircases, and other architectural features, reflecting the complexity of existing buildings.

The 3D physical object models produced in this research are classified as LoD3 (level of detail three) in the OGC Standard for structures [47] [48], as they depict the geometry of both the inside and exterior, encompassing windows, doors, and other architectural features. However, they are classified as LoD 200 (level of development 200) in the BIM (Building Information Modeling) Standard [49], as they are based on data engineering design, which is likely to differ from the actual conditions in the field (see **Figure 5**).

Figure 5. 3D physical object models.

There were several aspects that differed between the architectural drawing data and the field conditions. Figure 6 shows that there is a door in the existing building, although there is no door in the 3D model. Some room plans have complex architectural features, such as curved walls, vaulted ceilings, irregular shapes, and intricate details. Translating them into a 3D model can be time-consuming and may require special modeling techniques. Figure 7 shows an example of a complicated architectural feature that has little resemblance to an existing building. Another element with complicated geometric features (irregular shapes) is shown in Figure 8; the door and stairs are dissimilar between the model and the existing building. The 2D floor plan data does not provide complete height information, resulting in inaccurate 3D object modelling (see Figure 9). In addition, the existing building does not show the civil structure as in the data because it is covered by the ceiling.

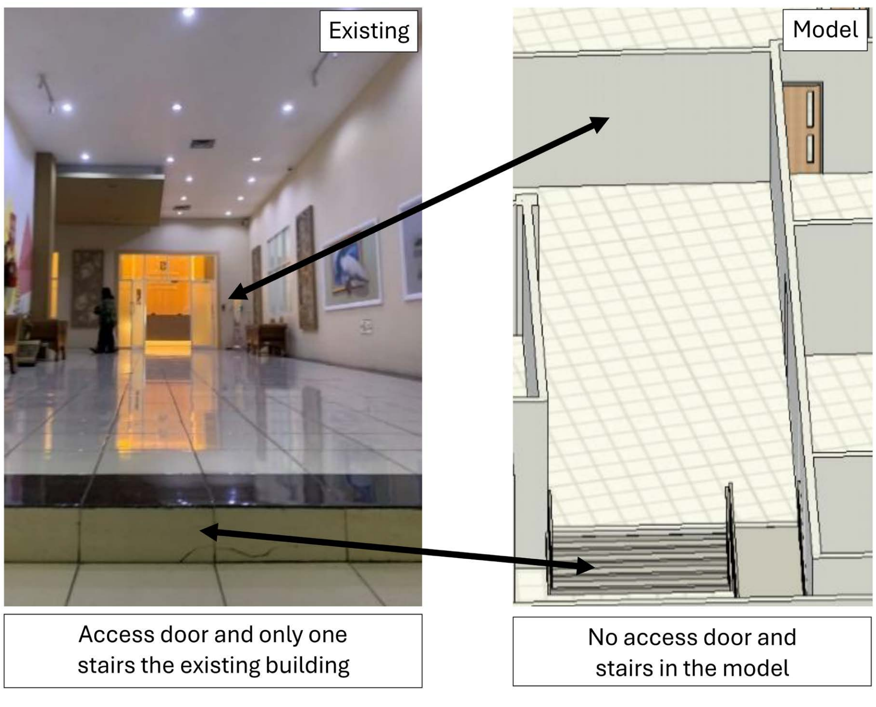


Figure 6. Example of a drawing plan that does not represent the existing building elements.

Figure 7. Example showing the non-conformity of architectural features.

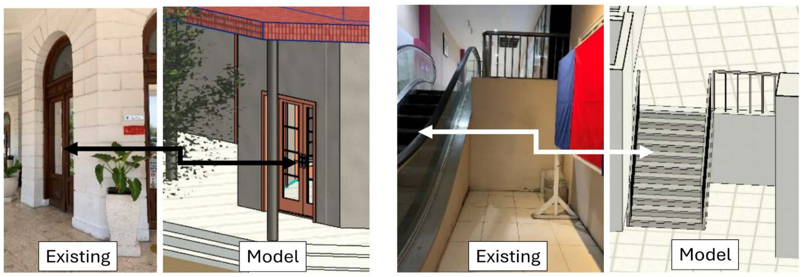


Figure 8. Examples showing the non-conformity of building elements.

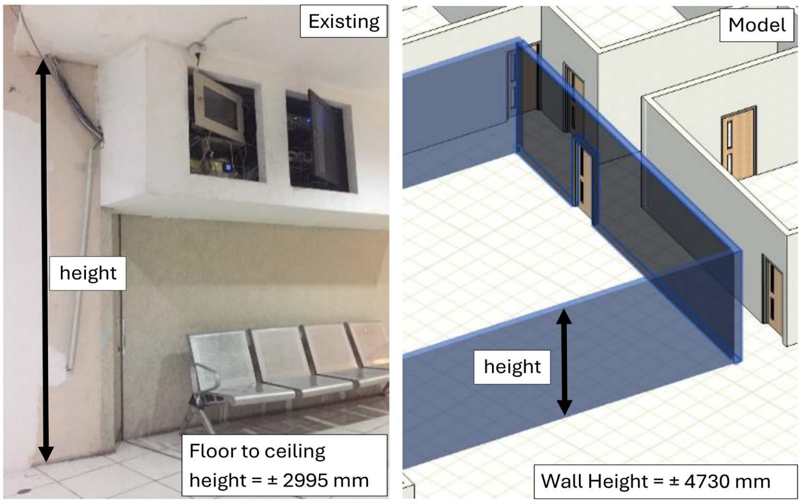


Figure 9. Examples showing the differences between existing buildings and the 3D model.

The process of converting 2D plans to 3D models often relies on human interpretation, which can introduce subjectivity and potential errors. Different modelers may interpret the same 2D data differently [50] [51]. For building objects where it is difficult to interpret the 2D plan drawings, taking photographs of existing building elements in the field can help to provide a clearer picture, which eases the modeling process. Although there are differences, as mentioned above, this approach could still be used in this study. The most important aspect is that a 3D physical object model can represent and have sufficient similarity with an existing building.

4.2. 3D Legal Object Models

The state grants land rights to local governments, which are known as management rights. These rights refer to the authority the state grants to an entity in terms of allowing them to control certain aspects and can only be granted to certain parties related to the government and indigenous peoples. The parcel boundaries represent horizontal rights, while the height restrictions represent vertical rights. The horizontal and vertical rights form the basis for the creation of a 3D model representing the rights and restrictions of the legal object.

The boundaries of the Buring Flats parcel were obtained from https://bhumi.atrbpn.go.id/shortlink?id=ks2ej12, whereas those for the Siola and

Balai Pemuda buildings were obtained from a land parcel map derived from the Regional Financial and Asset Management Agency, Surabaya City Government. The vertical space boundaries refer to the detailed spatial plan (RDTR) documents produced by Malang City and Surabaya City authorities. The Surabaya RDTR can also be found at https://petaperuntukan.cktr.web.id/. The Malang City Government refers to Malang City Regional Regulation Number 6 of 2022 concerning the Malang City Regional Spatial Plan 2022-2042 and Malang City Regional Regulation Number 1 of 2012 concerning the building. Each zone of space utilization has different limits on the permitted building height. Thus, the space utilization boundaries are represented vertically, using a volumetric imaginary plane with transparent colors.

The Buring Flats are in the residential zone, and the building has a maximum permitted height of 55.50 m. The Siola Building is in the Trade and Services zone (International/National Scale sub-zone in UP VI Tunjungan), and has a maximum permitted height of 200 m. The Balai Pemuda Building is in the Public Service Facilities zone and the Socio-Cultural sub-zone in UP VI Tunjungan, and is limited to a height of 25 m. The use of space below the ground surface is controlled by government regulations, which limits it to a depth of 30 m from the ground surface if it is not in the spatial plan regulation [1].

Figure 10 shows a 3D representation of the rights and spatial boundaries for a plot of land as described in the previous paragraph. The boundaries of the legal object are the imaginary planes above and below the ground surface, which restrict the right to space. Integration of the land parcel boundary, zoning, and permitted building heights is an important aspect of land rights and spatial planning in the LA system. These 3D representations cannot be visualized in the 2D system and there is still a separation between land rights and spatial planning as space utilization boundaries concept.

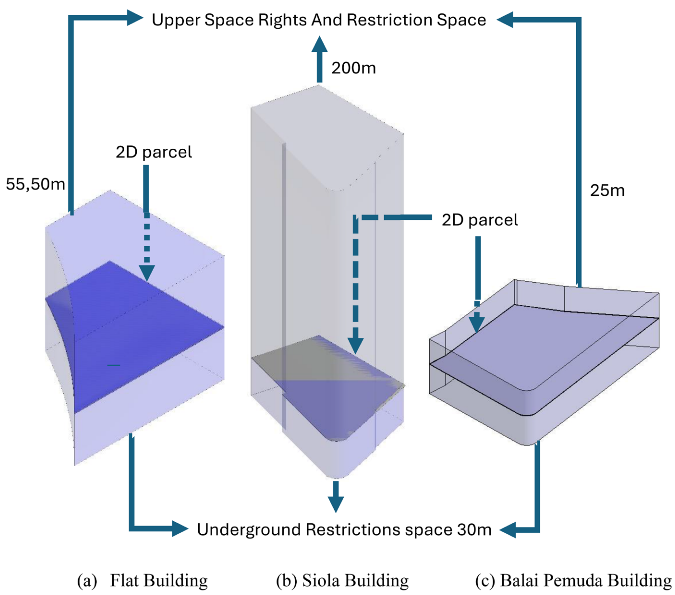
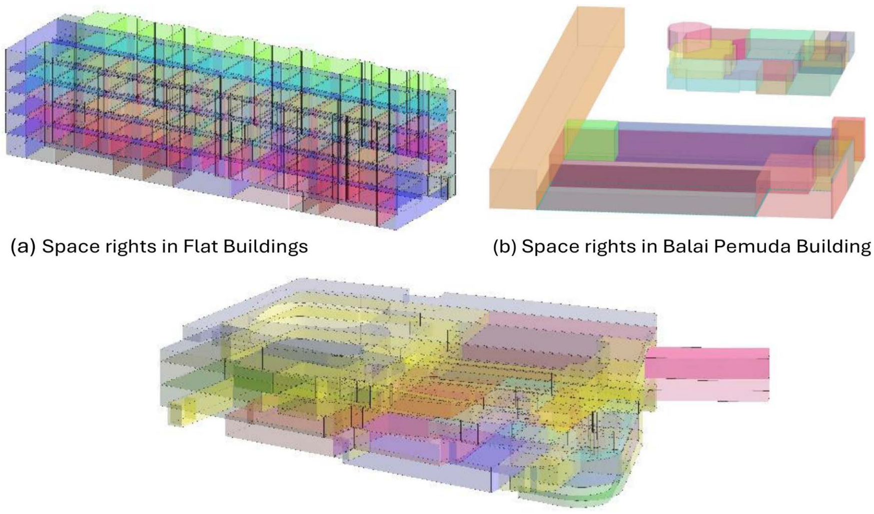


Figure 10. Legal objects based on boundary parcels and height rules.

In 3D LA, the physical boundary of a building's wall serves as the spatial limit of a legal object an abstract entity representing rights, restrictions, and responsibilities (RRRs) within the built environment. These legal objects are visualized as transparent volumetric forms, with color schemes used to differentiate room functions. For instance, the Siola Building comprises multiple functions, including government offices, museums, and community service centers, resulting in irregularly shaped legal objects (see **Figure 11(c)**). Similarly, the Balai Pemuda Building exhibits a complex spatial configuration due to its diverse uses, such as an art development venue, exhibition hall, tourist information center, library, and meeting room (see **Figure 11(b)**). In contrast, the legal objects within a flats building are relatively uniform in shape and size (see **Figure 11(a)**).



(a) Space rights in Flat Buildings

(b) Space rights in Balai Pemuda Building

(c) Space rights in Siola Building

Figure 11. Legal objects based on the physical objects of the buildings.

The spatial utilization in flats is characterized by consistent geometry, area, and volume, with rooms defined by permanent walls and fixed functions. A room is considered static when its boundaries are permanently constructed and designated solely for residential use. Conversely, buildings like Siola and Balai Pemuda exhibit dynamic spatial divisions, where non-permanent partitions allow flexible reconfiguration based on user needs. This dynamic nature introduces geometric irregularity and functional variability, complicating the modeling process.

Representing such complex scenarios in 3D LA using color-coded volumetric transparency techniques poses significant challenges. These techniques aim to distinguish between various types of space utilization, including those with invisible or conceptual boundaries. Moreover, they serve to visualize the extent of legal objects that stakeholders may use to implement RRRs. For these models to be effective, the 3D representations must be both recognizable and interpretable. Visual attributes such as color, hue, and contrast are essential for conveying quantitative and qualitative differences between spatial features, enabling users to identify and understand the legal and functional characteristics of each space.

5. Discussion

While this study is primarily exploratory, the validity and effectiveness of the proposed framework were evaluated using three key performance indicators to assess its improvement over conventional 2D systems. First, Compliance Detection Capability was measured by the model's capacity to visualize spatial conflicts—such as setback encroachments (GSB-Garis Sempadan Bangunan) or floor area ratio excesses (KDB-Koefisien Dasar Bangunan)—by overlaying physical models with regulatory volumes. Second, Interpretative Ambiguity Reduction was assessed based on the framework's effectiveness in translating textual regulations into distinct 3D spatial boundaries, thereby minimizing the interpretative discrepancies inherent in 2D documentation. Finally, Data Integration Integrity evaluated the success of semantically linking legal attributes (RRR) with physical geometry, ensuring that every 3D object conveys valid information to support administrative decision-making.

5.1. Data Conversion

The transition from traditional 2D cadastral systems to 3D digital models in 3D LA presents a range of challenges, particularly in the representation of physical objects. The conversion process is far from straightforward, especially when dealing with architectural elements and building ornaments that exhibit complex and irregular shapes (see **Figure 7** and **Figure 8**). As building designs increasingly reflect architectural artistry, the limitations of digital representation become more apparent.

Converting 2D data into 3D models requires specialized software that is not only time-consuming but also demands specific training and technical skills. This process goes beyond simply extruding flat shapes; it requires a deep understanding and the ability to interpret 2D information within a three-dimensional context (see **Figure 12**). The complexity of the building itself also influences the accuracy of the resulting 3D model. For example, a five-story structure with non-uniform spatial divisions is significantly more difficult to interpret than a smaller, more regular building (see **Figure 6**).

The level of detail in a 3D model is highly dependent on the quality and completeness of the 2D building plan drawings used as source data. In other words, the more detailed the 2D floor plans and cross-sections, the more accurate and refined the resulting 3D model will be. To address these challenges, a simplification approach can be applied to architectural forms. For instance, a complex dome shape may be replaced with a geometrically similar but simpler form, without compromising the user's understanding of the object's function and meaning (see **Figure 7**).

The transformation from two-dimensional archives to three-dimensional models is essential for visualizing the complexity of rights and spatial restrictions (RRR), but reliance on manual reconstruction limits scalability at the city level. Implementing Scan-to-BIM technology offers a strategic approach to accelerate

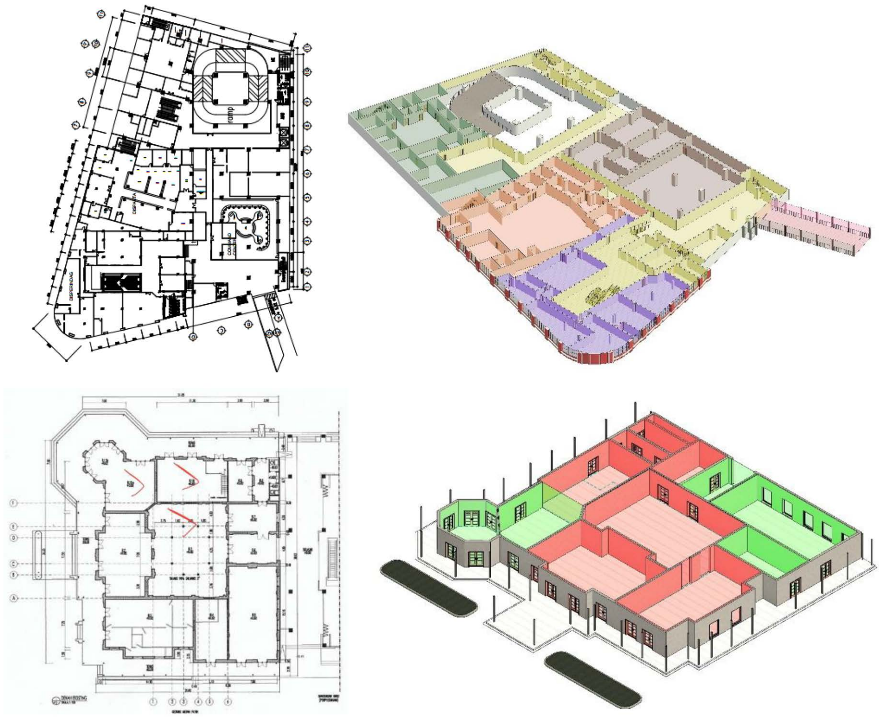


Figure 12. Converting models from 2D to 3D.

the acquisition of existing building geometry data. Laser scanning and photogrammetry within the Scan-to-BIM process generate three-dimensional models with greater precision and efficiency compared to manual conversion from outdated and infrequently updated two-dimensional images [52]-[54]. Moving forward, integrating Scan-to-BIM for existing assets and requiring the submission of original model-based data (IFC/BIM) for new building permits will be critical for reducing interoperability barriers and supporting the long-term sustainability of the 3D Land Administration system.

One critical finding during the 3D conversion process was a significant discrepancy between the archived image data and the actual physical conditions, a challenge exacerbated by incomplete stored data. This study identified that strictly relying on incomplete data poses a high risk of misinterpretation. For mitigation, the framework adopted a "Level of Certainty" approach to categorize model reliability. Specifically, in cases of Geometric Uncertainty—where as-built drawings are unavailable, particularly in stored data—3D geometry is obtained by extracting commonalities or general building structure standards. While these estimates are sufficient for macro zoning analysis, the system explicitly flags these models as fundamentally providing an adequate representation for strata title registration. Similarly, Legal Uncertainty arises when emphasizing that the transition to 3D Land Administration in Indonesia is not merely a task of geometric conversion, but requires robust mechanisms to manage the uncertainty of technical guidelines for regulatory implementation and the alignment of authorized institutions to prevent boundary disputes and ensure the integrity of administrative decision-making.

5.2. Enhancing Spatial Data Visualization in 3D Land Administration Systems

The visualization of spatial data in 3D LA Systems (LASs) has become a critical component in contemporary urban planning and land management. As urban environments grow increasingly complex, traditional two-dimensional (2D) representations of land and property rights are no longer sufficient to capture the intricacies of multi-layered spatial arrangements [52]. To address this limitation, several scholars have emphasized the importance of color as a key visual variable in representing rights, restrictions, and responsibilities (RRRs) in three dimensions [40] [53]. Color enhances the interpretability of 3D objects by improving visual clarity and facilitating user understanding [31] [40].

A combination of solid object rendering and transparent surface visualization has proven effective in delineating boundaries within 3D models. Solid rendering provides clear and unambiguous boundary representation, while transparency allows users to view internal construction details and surrounding spatial elements without obstruction. Furthermore, boundary visualization can be harmonized with architectural features such as windows, doors, columns, and other structural components to ensure that legal boundaries remain visible and contextually integrated.

The representation of boundaries in 3D LASs may vary depending on the required level of precision and the architectural complexity of the building. Legal considerations, including ownership rights and height restrictions, must be incorporated when converting 2D cadastral data into 3D digital models. In conventional LASs, spatial rights and planning regulations are typically visualized in 2D, with vertical dimensions described textually. In contrast, 3D LASs enables the depiction of legal objects and their associated RRRs through volumetric models, often using cross-sectional or isometric views to represent spatial relationships (see **Figure 12** and **Figure 13**).

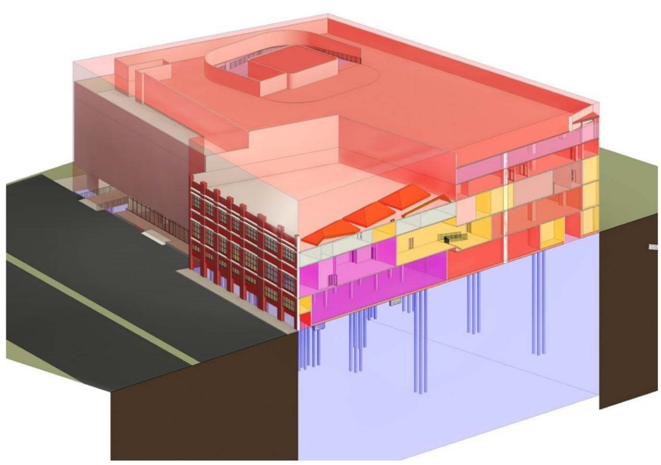


Figure 13. Visualization in cross-section or isometric mode.

This approach offers a more intuitive and comprehensive visualization of overlapping property rights, particularly in high-density urban areas. By integrating vertical and volumetric dimensions, 3D visualization enhances transparency in land administration processes, allowing stakeholders including government agencies, developers, and the public to better understand and engage with property-related information.

5.3. Integrating RRR in 3D Land Administration: Toward Comprehensive Spatial Representation

In the context of 3D LA, the concept of Rights, Restrictions, and Responsibilities (RRR) is fundamental for defining and managing the complex relationships between people and land within a three-dimensional spatial framework [54]. Traditional 2D-based systems are increasingly inadequate for representing the intricate and overlapping nature of RRRs in modern urban environments, particularly in the context of high-rise buildings, underground infrastructure, and airspace utilization [55]. Integrating RRR as spatial data within a 3D LA perspective enables a holistic view of property rights, values, spatial arrangements, and development potential [56]. In this section, we provide a clear representation of how legal objects and physical objects are integrated within the 3D LA (LA) model, demonstrating the relationship between these objects. The results presented here highlight how legal boundaries and restrictions interact with the physical aspects of land and building structures, especially in the context of high-rise developments and underground spaces in Indonesia.

The core methodology of this study involves the integration of legal objects representing rights, restrictions, and responsibilities (RRRs) with physical objects representing actual buildings and land parcels within a three-dimensional (3D) spatial environment. This integration facilitates a more intuitive and precise representation of land use, property rights, and spatial regulations, which are essential for effective urban land management. The 3D models developed in this research illustrate the spatial relationships and interdependencies between legal and physical entities, emphasizing their relevance to the Indonesian urban context. By incorporating perspectives from both land administration and urban planning, the study provides a comprehensive visualization of the RRRs associated with each property unit (see **Figures 14-16**). This integration is achieved through the use of 3D object-based data models, which can capture the complexity and interconnectedness of spatial data in three dimensions. Such models enable the representation of overlapping rights and spatial constraints in a manner that is both analytically robust and visually accessible [57].

Physical objects, such as buildings, land parcels, and infrastructure, are represented by 3D geometries that provide a detailed and accurate depiction of the spatial dimensions of these structures. For example, buildings are modeled with their footprint, height, and depth, accurately depicting the floor layout, structural elements (walls, windows, doors), and even intricate architectural features (e.g., curved walls or vaulted ceilings) (see **Figures 5-8** and **Figure 12**). This modeling

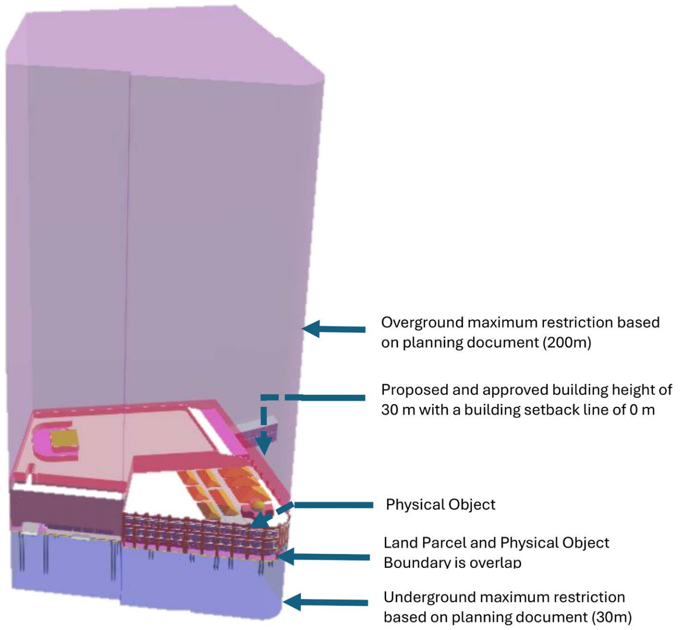


Figure 14. Integration of physical and legal objects in the Siola building.

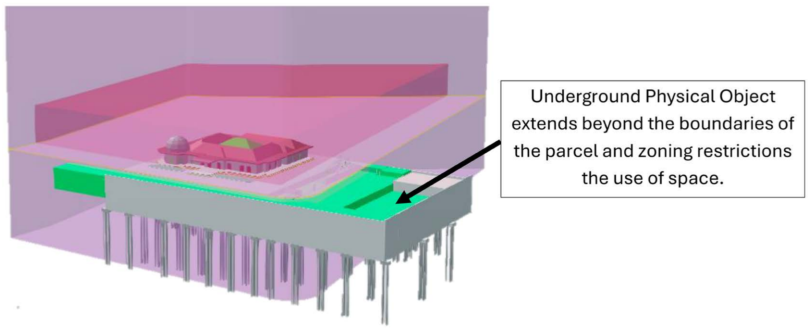


Figure 15. Integration of physical and legal objects in the Balai pemuda building.

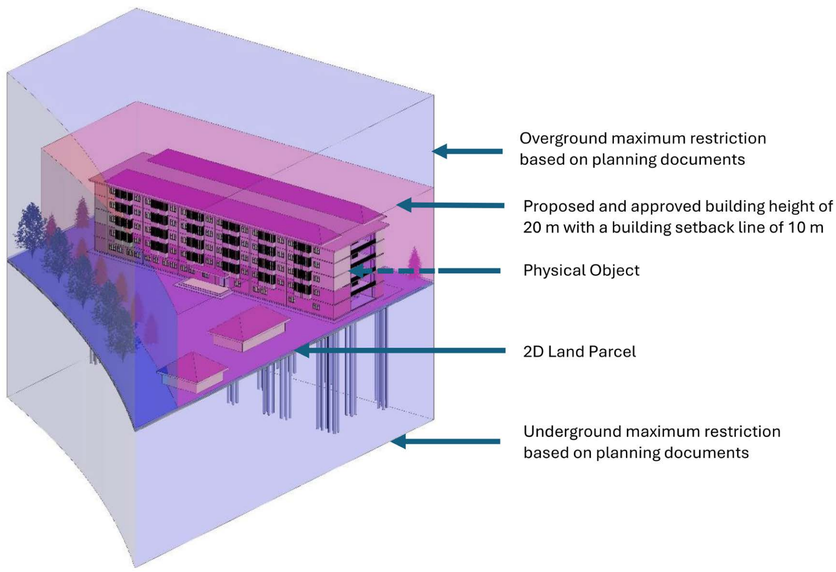


Figure 16. Integration of rights and city planning aspects for a land parcel in flat building.

process incorporates floor plans, elevation drawings, and section drawings to reflect both horizontal and vertical spatial relationships. For high-rise buildings, the model also includes multi-story representations that extend both above and below ground.

Legal objects, on the other hand, represent the boundaries and restrictions associated with properties, such as ownership rights, zoning regulations, height restrictions, and spatial planning restrictions. These legal boundaries are visualized as volumetric objects that extend vertically, both above and below ground (see **Figure 11**). For instance, legal boundaries may include the maximum allowable height for a building, or the extent of underground usage, as regulated by zoning laws and local spatial plans (see **Figure 10** and **Figure 11**). These legal objects are modeled with transparent volumetric shapes that visually distinguish them from physical structures, allowing users to clearly interpret the intersection between legal rights and physical properties (see **Figure 12** and **Figure 13**).

A Land Administration System (LAS) capable of integrating physical and legal objects representing ownership rights and boundaries benefits significantly from 3D technologies that can spatially visualize these relationships (see **Figure 12** and **Figure 13**). These technologies open new possibilities for managing and understanding complex 3D spatial relationships [52]. **Figures 14-16** illustrate a 3D model of a single land parcel, demonstrating how property use can extend both vertically and horizontally, encompassing height and depth. This approach provides a more comprehensive understanding of property rights and restrictions, visualized as spatial boundaries, which is invaluable for urban planning and land policy formulation [53].

The primary goal of integrating legal and physical objects in the 3D model is to show how legal rights and physical structures interact, especially in multi-layered developments such as high-rise buildings and underground facilities. The integration allows stakeholders to visualize how legal restrictions, such as building height limitations or underground space regulations, affect the physical construction of buildings.

In the case of high-rise buildings, the 3D model clearly shows the relationship between vertical legal rights (height restrictions) and physical buildings (see **Figure 14**). For example, the Siola Building in Surabaya, which is located in a commercial zone, has a height restriction of 200 meters according to local zoning regulations. This height limit is modeled as a transparent volumetric boundary that intersects with the building's physical structure. The 3D model makes it immediately apparent if the building exceeds this legal boundary, visually indicating conflicts between physical development and legal restrictions.

Similarly, legal objects governing underground space are integrated into the 3D model. For example, the Balai Pemuda Building in Surabaya has underground spaces that are subject to regulations that limit their depth to 30 meters, unless otherwise permitted by specific spatial plans (see **Figure 15**). This restriction is modeled as a volumetric legal boundary below the ground level, which interacts with the physical underground infrastructure (such as parking garages or utility systems). The model provides a clear visual of how the underground space is utilized and regulated, showing the spatial extent of both physical and legal objects in this vertical direction. **Figure 15** clearly shows that there is an underground section of the building that extends beyond the land's boundaries. This indicates that this section is also exempt from zoning regulations on the use of underground space, as the section above it is a sidewalk, which is public land.

The zoning regulations and space utilization restrictions, as defined by local authorities in Malang and Surabaya, are represented as legal objects in the model. For instance, residential buildings may have different legal restrictions compared to commercial or public service buildings. The integration of these legal objects with physical buildings allows users to visualize the zoning boundaries, and the model shows how these zones interact with the building structure (see **Figure 16**). In the case of the Buring Flats in Malang, the building's legal object is defined within the residential zone, with restrictions on its height (55.5 meters). This legal object interacts with the physical object of the building, showing where the building's height falls within the allowed zone.

The implementation of 3D RRRs often necessitates updates to existing legal and policy frameworks [6]. While this presents certain challenges, it also offers opportunities to modernize and enhance land administration practices. As demonstrated in **Figures 14-16**, advanced techniques for visualizing 3D RRRs can support more informed decision-making and improve public understanding of complex spatial arrangements [58].

In the context of vertical land use and multi-layered developments in urban Indonesia, the relationship between legal and physical objects becomes even more complex. The integration of these objects in a 3D model allows for a comprehensive understanding of how land rights and building codes shape the use of space. A critical feature of the 3D model is the visualization of vertical land rights, which are essential for managing high-rise developments and underground spaces. The legal objects, such as height restrictions and underground usage boundaries, are represented as volumetric zones that intersect with physical buildings. These visualizations clearly show how the legal restrictions apply at different levels of the building, illustrating the spatial limits of each floor or section. The model also addresses horizontal land use in terms of zoning and property boundaries. Legal objects in the form of zoning regulations and spatial plans dictate how the land can be used in both the horizontal and vertical dimensions. In areas where multiple buildings share space (such as in shopping malls or complexes with multiple floors), the 3D model demonstrates how these spaces are allocated and regulated according to legal frameworks.

In the Indonesian planning system, three key regulatory parameters Koefisien Dasar Bangunan (KDB), Koefisien Lantai Bangunan (KLB), and Garis Sempadan Bangunan (GSB) play a central role in shaping urban form and land use: KDB defines the maximum percentage of land area that buildings may cover. In a 3D model, this is visualized as the footprint of the building relative to the parcel boundary, enabling planners to assess compliance with land coverage limits. KLB regulates the total floor area allowed relative to the land parcel size. The 3D model represents this as stacked building volumes, enabling clear visualization of allowable building mass and density. GSB establishes setback distances from parcel boundaries, roads, or other public spaces. In the 3D environment, GSB is depicted as buffer zones around buildings, ensuring that spatial planning rules regarding building placement are respected.

Given Indonesia's complex regulatory landscape characterized by overlapping zoning laws, building codes, and spatial plans the integration of legal and physical objects within a 3D spatial model is not only beneficial but essential for addressing contemporary urban development challenges. The 3D model provides a clear and accessible representation of how spatial planning regulations influence land use, particularly in high-density and multifunctional urban environments.

By incorporating key regulatory parameters such as Koefisien Dasar Bangunan (KDB), Koefisien Lantai Bangunan (KLB), and Garis Sempadan Bangunan (GSB) into the model, the system establishes a robust framework for evaluating development proposals against existing legal constraints. This integration enhances transparency, supports regulatory compliance, and facilitates effective coordination among stakeholders including urban planners, developers, and government authorities.

Ultimately, the 3D integration of legal and physical objects contributes to a more informed, equitable, and efficient land administration system. It enables stakeholders to visualize and understand the spatial implications of legal frameworks, thereby promoting better decision-making and fostering sustainable urban development in Indonesia.

Overall, the integration of Rights, Restrictions, and Responsibilities (RRR) elements into a 3D environment constitutes a fundamental advancement toward holistic spatial legal certainty, directly supporting the mandate of Government Regulation No. 18 of 2021, which extends land registration to cover vertical spaces and strata titles. Nevertheless, it is crucial to underscore that the validity of such 3D rights registration is not autonomous; it is strictly contingent upon adherence to the technical building standards outlined in Government Regulation No. 16 of 2021 and the spatial planning provisions of Government Regulation No. 21 of 2021. Considering that current spatial planning instruments, such as Detailed Spatial Plans (RDTR), remain largely confined to static 2D formats, the proposed 3D framework functions as a critical technical validation bridge. By volumetrically visualizing the spatial planning "legal envelope", this approach ensures that registered ownership rights are fully synchronized with prevailing zoning restrictions and building intensities, effectively minimizing interpretative ambiguities between legal documents and actual physical conditions.

6. Conclusions

This study demonstrates that three-dimensional (3D) visualization of physical and legal boundaries provides a clearer and more realistic representation of overlapping land use compared to conventional two-dimensional (2D) systems. By integrating land rights, spatial planning regulations, and building constraints within a unified 3D LA framework, the proposed approach improves the interpretation of Rights, Restrictions, and Responsibilities (RRR), particularly in the context of high-rise buildings and underground infrastructure.

The findings confirm that conventional 2D LA and spatial planning systems are insufficient to represent vertical and volumetric urban complexity. In contrast, 3D integration enables land rights and spatial planning limitations such as zoning, height restrictions, and subsurface constraints to be visualized simultaneously, supporting clearer regulatory compliance assessment and more informed spatial decision-making.

This study contributes by demonstrating how the integration of legal boundaries and spatial planning constraints into volumetric 3D models can reduce interpretive ambiguity, strengthen legal certainty, and enhance coordination between land administration and urban planning processes. However, challenges remain related to data availability, data quality, and the complexity of transforming existing 2D plans into consistent 3D representations. Future research should focus on standardizing data workflows, advancing 2D-to-3D automation, and improving institutional interoperability to support the scalable implementation of integrated 3D LA and spatial planning systems in Indonesia.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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