# Exploring Spatial Interaction and Visualization Paradigms for 3D Cadastral Visualization

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## Abstract

Effective visualization of spatial data, especially in the realm of 3D cadastral visualization, relies on the utilization of optimal interaction techniques and user interfaces for navigating complex datasets and understanding property delineations. This paper synthesizes findings from diverse studies investigating the efficacy of interaction modalities and user interfaces in 3D visualization across various domains. Drawing parallels to the broader field of 3D visualization, particularly in interaction tasks and user interface paradigms, this paper examines the potential for advancing 3D cadastral visualization systems. The study identifies fundamental interaction tasks crucial for effective 3D cadastral visualization, including object manipulation, widget manipulation, and data selection and annotation. It evaluates a range of user interfaces, from traditional input methods to emerging technologies such as gesture-based interfaces and virtual reality (VR) headsets, highlighting their respective strengths and limitations.
Embracing insights from comparative analyses of immersive and non-immersive scenarios, this paper reveals significant insights into the effectiveness of immersive environments, such as virtual reality and augmented reality, in enhancing user experience and task performance for 3D cadastral visualization. Additionally, it aims to address key challenges associated with visualizing 3D cadastral data in immersive environments by proposing a comprehensive framework for evaluating the effectiveness and utility of immersive visualization for 3D cadastral purposes.

## 1. Introduction

The evolution of information visualization is propelled by advancements in interaction technologies, transcending conventional desktop paradigms. Emerging modalities including virtual reality, augmented reality, and immersive displays afford users more intuitive data perception and interaction, leveraging real-world interactions to enhance understanding. Within this domain, visualization and visual analysis play pivotal roles in unravelling the complexities of spatial data, which often exhibits multivariate characteristics.

Cadastral visualization, a subset of geovisualization, revolves around the representation of ownership boundaries and related descriptive data on 2D maps or legal documents. As emphasized by (Williamson et al., 2010), visualization stands as a fundamental component within cadastral systems, providing instantaneous clarification of boundaries and conveying information about various property units.
The advent of 3D cadastral visualization signifies a noticeable advancement in spatial representation, offering enhanced depth perception and the ability to navigate complex ownership scenarios. Researchers, including (Shojaei et al., 2015) and (Pouliot et al., 2018), highlight the importance of addressing challenges related to visualizing legal boundaries, ensuring system usability, and fulfilling both visualization and cadastral requirements. Challenges include facilitating user interaction, maintaining Level of Detail (LoD) completeness, and addressing cadastral features such as the representation of transparency.

Generating an accurate 3D visualization of cadastral data poses numerous challenges, including common issues encountered in 3D visualization such as occlusion, distortion, and challenges in accurately perceiving the position, size, and shape of objects (Cemellini et al., 2018).

The shift towards interactive 3D visualization systems might help addressing these limitations. The integration of effective interaction techniques stands as a promising avenue for surmounting these obstacles, underscoring the indispensable role of interaction in 3D visualization. In fact, the majority of developed 3D cadastral visualization prototypes utilize desktop interfaces for display and interaction. Users typically engage with 3D cadastral systems through a screen and a mouse. However, research on augmented and virtual reality (AR/VR) within the Architecture, Engineering, and Construction (AEC) domains has yielded a range of case studies focused on 3D visualization and interaction. These studies have shown numerous findings indicating overall advantages of novel interactions paradigms. (Weerasinghe et al., 2023)

This paper aims to explore the literature and studies in related domains, how different dissemination interfaces might influence the cadastral user's experience and the performance of interaction tasks. Firstly, we provide an overview of existing approaches and paradigms for interaction within 3D visualization, based on available literature (section 2 and section 3). Secondly, we discuss the potential of tangible and immersive environments in enhancing interactive 3D cadastral visualization (section 4). Finally; we give conclusion and future insights (section 5).

## 2. 3D Interactive Visualization

Interaction lies at the heart of effective exploration and comprehension of complex 3D visualizations. As datasets grow in size and complexity, traditional input methods like mouse

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and keyboard interactions may prove insufficient in providing users with the necessary depth of engagement and control. Interactive 3D environments are defined as computer representations of real world or imaginary spaces through which users can navigate and in which they can interact with objects in real time‖ (Jankowski and Hachet, 2014). Unlike typical 3D interaction, the visualization of 3D datasets is more about interpretation than creation. Making sense of 3D datasets entails manipulating the data or viewpoint, selecting specific regions of interest in 3D, and utilizing visualization widgets to comprehend the dataset's structure or properties (Feiyu et al., 2022).

Interaction with 3D cadastral visualization environments is required due to the increased density of cadastral information and the need of extensive exploration required by many cadastral tasks. The complexity of 3D cadastral visualization stems from the diverse array of geometric objects presents in the scene. In addition to physical structures, 3D cadastre encompasses legal objects and areas outlined in official urban planning documents. (Aien, 2013). Interactive exploration for 3D cadastral visualization must include functionalities like, rotation, placement of cuttings planes, as well as selection and identification of property units. Visualization and manipulation of 3D spatial complex objects may necessitate increased degrees of freedom (DoF). Interaction is indispensable for enabling users to pinpoint 3D objects, select, zoom in or navigate through the data.

In this session, the following sections will present an overview of the interaction tasks needed for 3D visualization, and the spatial interfaces used to interact with 3D content.

## 2.1 Interaction Tasks

We start by addressing the interaction tasks required for spatial 3D data visualization, which also apply for 3D cadastral visualization. The study by Hand (1997) identifies three universal interaction tasks in interactive 3D environments: Navigation, involving travel and wayfinding; Selection and Manipulation, encompassing object choice and specification of position, orientation, and scale; and System Control, involving communication between the user and system. These tasks are generics, in the way that they can be applied to any 3D user interface. (Jankowski & Hachet, 2014) provide an in-depth analysis of recent advancements in interaction techniques tailored for 3D environments. Through a comprehensive examination of novel approaches and technologies, the study explores improvements in user interaction within virtual spaces, focusing on navigation, manipulation, selection, and system control tasks, by synthesizing findings from various domains such as virtual reality, computer-aided design, gaming, and data visualization.

Several classifications of visualization tasks for interactive 3D environments have been suggested. Here, we categorize them according to the three classifications outlined by (Lonni et al., 2021).

**2.1.1 Object manipulation Tasks:** These are important features for interactive visualization applications which allow users to viewing objects from different angles, heights, and distances (Shojaei et al., 2013), locating and navigating to specific points within visualization. Navigating interactive 3D environments poses unique challenges due to the expansive representation of space beyond a single viewpoint. Users must traverse the environment to access different perspectives, a process encompassing various techniques such as wayfinding, locomotion, navigation, and camera/viewpoint control. The development of effective navigation methods for these environments is inherently complex. Viewpoint control, with its six degrees of freedom, presents a significant challenge, compounded by the limitations of 2D devices that require multiple state changes for comprehensive translation and rotation. Moreover, the diverse nature of tasks requiring viewpoint control, ranging from exploration of large-scale 3D environments to detailed object inspection, further complicates navigation. Additionally, wayfinding in large virtual worlds is hindered by technological constraints like limited field of view and the absence of orientation information, impacting users' mental models of the environment. A usability test questionnaire conducted by (Cemellini et al., 2018) on the 3D cadastral dissemination prototype, which involved users performing various cadastral tasks, including navigation tasks, revealed challenges in maintaining orientation within the viewer after shifting the cursor from its initial position. Addressing these challenges necessitates navigation techniques that not only meet general interface requirements but also mitigate user disorientation, ensuring ease of use and efficient exploration. (Jankowski and Hachet, 2014)

While basic rotations and translations allow for external viewing of 3D data, internal viewing may be challenging, particularly in the case of 3D cadastral visualization where dense data and diverse geometries often lead to occlusion (Pouliot et al., 2018). Interactions and object manipulation should tackle this issue. Cutting planes editors and cross section views are often used for this purpose (Lonni et al., 2021). (Pouliot et al., 2017) integrated 3D displacement with cross-section to provide an internal view of the building, as illustrated in Figure 1.

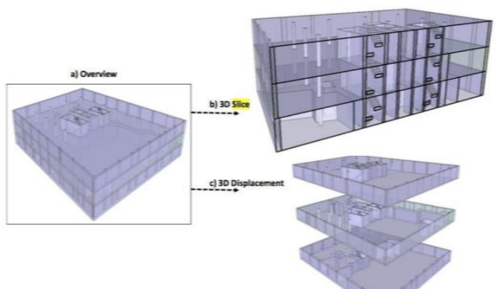


Figure 1. Combination of 3D displacement and cross section view. (Pouliot et al., 2018)

Navigation tools for 3D cadastral visualization were identified by (Shojaei et al., 2013) and include the following components: Pan, Compass, Tilt, revolve around a location, revolve from a location, zoom in/out, scrolling forward or backward, zoom (in, out, to location, to previous view, to next view, to max extent), etc.

**2.1.2 Manipulating Visualization widgets:** Spatial 3D data analysis often requires more than simple observation; interacting with widgets is necessary for in-depth exploration and interrogation of the data. Visualization widgets are digital components or elements that users can interact with to visualize and explore data in a graphical interface. They are typically designed to present data in a user-friendly and intuitive manner, allowing users to dynamically adjust parameters, filter data, and explore different perspectives of the information being displayed. Examples of visualization widgets include sliders, dropdown menus, checkboxes, buttons, and interactive charts or graphs (Lonni et al., 2017).

(Andrianesi and Dimopoulou, 2020) integrated a variety of widgets into an integrated BIM-GIS platform designed for representing and visualizing 3D cadastral data. These widgets, sourced from the ArcGIS API for JavaScript, provide features including accessing 3D web scenes, measuring distances and areas, generating slices to uncover concealed entities within buildings, and highlighting spatial attributes.
Visualization widgets have the potential to significantly improve the usability, functionality, and effectiveness of 3D cadastral visualization. Interactive widgets empower users to manipulate, query, and explore cadastral data seamlessly. By offering interactive controls such as sliders, buttons, and input fields, users can dynamically adjust visualization parameters, measure distances and areas; navigate through datasets, and gain deeper insights into spatial relationships. In addition, widgets provide valuable guidance and assistance to users, facilitating their navigation through complex datasets and understanding of visualization functionalities. Tooltips help buttons, and tutorials embedded within widgets offer contextual information, guiding users through the visualization process and enhancing their overall experience.

**2.1.3 3D Data selection and annotation:** Selection is a process of identifying an object, a set of objects or parts of objects that are targets for subsequent action (Steed, 2006). The process of selection serves as the primary means to delve into deeper layers of information within 3D spatial data, enabling the annotation of these datasets to incorporate insights or queries. The selection process manifests in diverse forms contingent upon the characteristics of the dataset. Particularly with dense datasets, navigating this task poses a significant challenge. However, dense data with small or ill-defined features present significant challenges for selection tasks. Moreover, annotation complements selection by allowing users to record insights and findings within the spatial context of the data, fostering knowledge sharing and collaboration. Integrating annotation into 3D visualization systems requires defining proper interfaces and automated positioning.

## 2.2 User Interfaces for 3D Interaction and Visualization

As display technologies evolve rapidly, interactive visualizations have become increasingly important for enhancing content exploration across various domains, including cadastral visualization. Desktop monitors, multi-touch displays on mobile tablets, and virtual reality headsets have emerged as common tools for interacting with visualizations. However, the impact of device type on the presentation, interaction, and learning outcomes of interactive cadastral visualizations remains uncertain.
In fact, the majority of developed 3D cadastral visualization prototypes utilize desktop interfaces for display and interaction. Users typically engage with 3D cadastral systems through a screen and a mouse, largely because of the widespread availability and affordability of these tools.

However, these options fail to provide easy access to the complete 6 Degrees of Freedom (DoFs) needed for interacting with 3D content, which includes 3 rotations and 3 translations, and thus prove to be less effective for tasks involving 3D visualization (Pouliot et al., 2018). Perceiving 3D content in a tangible and interactive environment surpasses the experience offered by a desktop environment, which only features a flat screen without stereoscopic imagery.

The landscape of display and interactive technologies has undergone significant transformations, marking a departure from the era dominated by large desktop PCs to the prevalent use of compact, touch-based mobile devices and immersive virtual reality (VR). The proliferation of smartphones, tablets, and laptops equipped with touch screens has revolutionized user interactions with visual objects, offering a more intuitive and direct means of engagement. Several studies have investigated touch as one of the most interaction styles, for example, (Sadana and Stasko, 2014). Mobile devices, including smartphones, tablets, and laptops, enjoy widespread usage. Fitted with compact, touch-based screens, these devices enable users to engage directly with virtual objects (Chen et al., 2020). Furthermore, technologies such as virtual and augmented reality, tangible interfaces, and immersive displays offer more intuitive approaches for individuals to perceive and interact with data, harnessing their inherent abilities for real-world perception and interaction (Bach et al., 2017).
VR technology, epitomized by HMDs (Head Mounted Devices) has introduced users to immersive virtual environments, where they can navigate and interact with virtual spaces. While traditional desktop virtual reality allow users to see the virtual world from outside, HMDs offer a more personalized and immersive experience inside the virtual reality (Bian et al., 2020).
Tangible user interfaces also, have been shown to offer greater effectiveness in interacting with 3D content when compared to touch interactions on tablets or mouse-based interactions. (Besançon et al., 2017)
Currently, there exists a variety of methods for interacting within 3D environments, which can be classified, for the purpose of this research, as mouse-driven, touch-based, midair-based, and tangible user interfaces, among others.

**2.2.1 3D Interactions based on Mouse and Keyboard (Mouse-based interface):** Mouse based interfaces are designed for 3D data exploration and interaction on conventional desktop computers. Users are seated at a desk, using a standard keyboard and mouse, with interaction primarily relying on the left mouse button. The display shows a perspective projection of the visualization, which can be rotated by dragging the mouse (Bach et al., 2017).

The majority of prototypes for cadastral visualization are primarily built upon desktop visualization interfaces. The interaction techniques involve mapping actions executed by the user on the input device to the 3D output displayed on the screen. Traditional desktop visualization methods have their limitations, as they often rely on rendering images on 2D screens without incorporating stereo depth cues or maintaining viewpoint correlation. Interaction with desktop displays typically requires arm movements, although users have the flexibility to either stand or sit in close proximity to the interaction space (Cordeil et al., 2017). Moreover, the conventional use of indirect mouse input means that only one


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action, such as rotation or translation, can be performed at any given time, a single DoF control. To enhance user interaction with virtual environments, alternative methods such as widgets have been developed. These widgets offer users the ability to interact with unconstrained perspective projections of 3D virtual environments, allowing for explicit selection of specific transformations and axes for desired objects (Mendes et al., 2018).

Some studies evaluated the use of Multi-DoF mouse for interaction with 3D visualization environments. These devices often incorporate additional input controls, such as buttons, dials, or pressure-sensitive surfaces, to facilitate rotation, translation, and scaling of objects along multiple axes simultaneously, but their benefits may not always be quantifiable, and they may be best suited for particular applications or user groups.

Commercial solutions like Unity3D, SketchUp and 3D Studio Max employ virtual handles and handle boxes for object manipulation and offer orthogonal views to simplify 2D manipulations along different axes.

**2.2.2 Touch Based Interaction for exploration:** Touch-based interaction has emerged as a significant approach for enhancing user engagement and control in 3D visualization environments. With the rise of mobile devices equipped with touch screens, tactile input has become increasingly prevalent and offers several advantages over traditional input methods. A tactile-based visualization platform utilizes tablet or mobile devices as the primary interface for 3D visualizations. Users interact with the visualizations through touch gestures, utilizing the tablet's touchscreen capabilities.

Operating on a 2D surface, each touch point provides up to two degrees of freedom (DoF) through translation, but effective navigation in 3D visualization demands six or more DOF to precisely determine position and orientation (Xiyao et al., 2019). To enable the required input degrees while avoiding occlusion (‘multi-touch’, more fingers or widgets on a small screen), (Xiyao et al., 2019) utilizes phone-based pressure sensing with a binary mapping to separate interaction DoF (having 6 DoF and separating rotations from translation). This approach allows users to seamlessly switch between different manipulations, such as performing rotations initially and then transitioning to translations with a simple pressure input.

Another approach is the 3D Rotation-Scale-Translation (RST) technique, which allows users to rotate, scale, and translate objects in a 3D space using tactile input. This method uses one finger for rotation, two fingers for scaling, and gestures like pinching for translation, providing users with a familiar and efficient means of manipulating objects.

(Lonni et al., 2021) distinguishes between two primary categories of devices for tactile interaction: touch-enabled tabletops or wall displays, which are fixed and conducive to collaborative work, and mobile devices with multi-touch interfaces, which offer portability but have limited space for interaction.

Touch-based interfaces enable users to interact with virtual content by directly using their fingertips, facilitating more intuitive and natural interactions. This leverages familiar physical manipulation metaphors and may potentially decrease the learning curves associated with different techniques (Mendes et al., 2018).

**2.2.3 Mid-air interaction-based interface:** Mid-air interaction, leveraging spatial input within a physical 3D environment, offers the potential to manipulate 3D objects through more intuitive input mappings. This interaction modality is facilitated by tracked handheld or wearable devices, as well as by external sensors that monitor users' hand movements, such as cameras or depth cameras (Mendes et al., 2018). It involves utilizing human postures and movements to interact with a computer system (Panayiotis et al., 2019). This approach harnesses human postures and gestures to interact with computer systems, representing a distinctive form of Human-Computer Interaction (HCI) (Panayiotis et al., 2019). Key characteristics of mid-air interaction include touchless interaction with remote displays or devices, real-time sensor tracking of the user's body using non-intrusive sensors or reflectors, vision-based tracking without requiring additional accessories, and recognition of body movements, postures, and gestures, with a particular focus on the user's hands, which can signify specific intentions and objectives in manipulating content or devices (Panayiotis et al., 2019).

Several researchers have utilized a 3D visualization prototype to explore various mid-air interaction techniques for tasks such as targeting (point and select), as demonstrated by (Bossavit et al., 2014), zooming (Mewes et al., 2016), and defining cutting plane (Fleury et al., 2012).

## 2.3 3D Interaction in Immersive Environment

Immersion, through virtual reality, is able to bridge the divide between perception and interaction spaces (Bach et al., 2017). Virtual reality, a concept coined by Steuer in 1992, refers to a distinct human experience marked by a strong sensation of presence. Presence, often articulated as the impression of physically existing within a perceived environment, originates from the processing of external stimuli received through our senses. This complex "awareness phenomenon" enables individuals to immerse themselves within virtual environments, experiencing a sense of being inside a fictitious space, such as a building in architectural contexts.

The key distinction between non-immersive and immersive virtual reality lies in the level of presence or immersion. Immersive environments aim to enhance presence through stereoscopic visualization and other resources, facilitating high levels of engagement by providing multiple sensory interfaces. Projection-based immersive systems enable users to navigate virtual worlds with head movements, walking navigation, and manipulation of virtual objects using hand gestures (Daniel et al., 2017). Despite the high costs associated with immersive systems, the development of low-cost immersive environments has democratized access to immersive technologies (Coburn et al., 2018). These systems leverage readily available low-end equipment and require less advanced computational skills, making them accessible to a broader audience.

(Wolfgang et al., 2016) explored the critical aspect of data locality in immersive data visualization, particularly focusing on spatial interaction with mobile devices for 3D visualization. Two primary approaches are explored: "Fixed in Space" and "Fixed on Device". The former allows users to physically navigate through the visualization, directly controlling the virtual camera's position and orientation with their mobile device. While enhancing engagement and tangibility, this approach may pose physical demands (Figure 2).

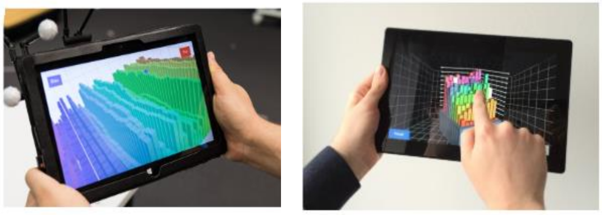

Figure 2. Bar chart, (Left figure) Fixed in Space with spatial interaction, (Right figure) Fixed on the mobile Device. (Wolfgang et al., 2016)

Conversely, the "Fixed on Device" approach anchors the data to the mobile device itself, enabling more personal and constrained use cases primarily through device gestures. To optimize user experience, the study proposes a combination strategy that leverages the strengths of approaches, facilitating seamless exploration and detailed analysis while mitigating their respective limitations.

Designing the interaction within an immersive virtual reality (VR) environment presents unique challenges, as they have a direct impact on task performance and also shape the level of immersion and presence that users experience, while these factors are pivotal benefits of utilizing VR technology (Andres et al., 2019). (Bai et al., 2020) assert that interactions include aural cues (i.e., speech and para-linguistics), visual cues (i.e., gaze and gesture) and environmental information (i.e., object manipulation, writing and drawing). While (Andres et al., 2019) provided an overview of interaction styles in immersive virtual environments focusing on tasks identified by (Bowman and Hodges, 1997), including viewpoint motion control and selection/manipulation techniques. Various metaphors, such as physical movement and virtual pointing, are discussed for navigation and selection tasks. While physical movement is intuitive but challenging to implement due to spatial constraints, combinations of steering and target-based techniques are often utilized. Selection methods like virtual pointing offer advantages in reaching targets beyond physical reach, with ray-casting and gaze selection considered natural options. Research indicates that head movements-based selection may offer optimal performance, while Laser Pointer Selection (LPS) tends to be more intuitive and quicker to learn.

## 3. The effect of User Interface on Interactive Visualization

Several studies have been dedicated to the comparative analysis of interaction techniques across various 3D visualization devices. Most of these research efforts explore interaction techniques in 3D visualization in a general manner, without linking them to any specific domain.

(Besançon et al., 2017) evaluated the performance and usability of mouse-based, touch-based and tangible interaction for manipulating objects in a 3D Virtual environment. The comparative analysis conducted in this study offers valuable insights into the efficacy of interaction modalities for 3D manipulation tasks, particularly within the context of visual exploration of 3D data. The study considered aspects like: efficiency, learnability, effectiveness, workload, fatigue, experience.

Contrary to common assumptions, all three modalities prove equally adept at precise 3D positioning tasks. Tangible interaction emerges as the fastest, followed by tactile and then mouse, although learning effects were observed.

(Feiyu et al., 2022) investigates the influence of different display platforms—desktop displays, tablet multi-touch displays, and virtual reality head-mounted displays (VR HMDs)—on interactive learning experiences. While participants demonstrated heightened engagement and immersion in VR environments, challenges such as visual fatigue and motion sickness were noted, potentially limiting prolonged usage. Desktop and tablet displays provided stable interaction experiences, although multitouch interactions on tablets were hindered by finger/hand occlusion. Despite differences in engagement, all three platforms yielded similar learning outcomes, suggesting their effectiveness in facilitating spatial knowledge acquisition.

(Vuibert et al., 2015) compares the performance of mid-air interaction methods to a mechanically constrained desktop device in a docking task, revealing intriguing insights into user preferences and device capabilities. While the desktop device demonstrates superior accuracy in position and orientation, tangible mid-air interactions offer faster completion times. Notably, despite its accuracy, the desktop device exhibits longer completion and clutching times, potentially due to physical constraints. The findings suggest that while the desktop device excels in precision, mid-air interactions, particularly using fingers, offer competitive performance with added mobility benefits, making them suitable for various applications, especially in mobile environments.

(Bach et al., 2017) aimed to evaluate the effectiveness of interactive exploration in 3D visualizations across different environments: immersive tangible augmented reality (AR), tablet-based AR, and traditional desktop setups. The findings revealed that direct interaction with 3D holographic visualizations via tangible markers significantly enhances both time efficiency and accuracy, particularly in tasks necessitating intricate manipulation. Notably, immersive tangible augmented reality (AR) emerged as the most effective environment, surpassing traditional desktop setups, despite participants limited prior experience with the HoloLens device. Tablet-based AR exhibited inferior performance, primarily attributed to spatial mismatch issues between perception and interaction spaces. The training interventions demonstrated potential for improving performance within immersive AR environments, underscoring the role of familiarity and practice. The proximity between perception and interaction spaces was identified as a crucial determinant of task success, with tangible AR benefiting from closer alignment. Additionally, participants' engagement was notably heightened in immersive environments, where active body movement was observed during navigation tasks. (Andres et al., 2019) explored the effectiveness of different interaction styles in enhancing Geographical Information Systems (GIS) through Virtual Reality (VR) technologies. Two main interaction strategies, body-based and device-based, were compared in terms of usability and performance in controlling VR map interfaces. The experiment assessed factors such as selection time, error rate, usability, and user experience. Results indicate that device-based interaction significantly outperformed body-based interaction in terms of selection time. However, body-based interaction resulted in fewer errors.

Additionally, users perceived device-based interaction as more usable and comfortable, although it was deemed more physically demanding. Participants' comments highlighted the comfort and haptic feedback provided by device-based interaction, while expressing confusion with body-based interaction.

## 4. Perspectives for 3D Cadastral Visualization

Having discussed various aspects of interaction techniques and user interfaces in the context of 3D visualization, it is evident that these findings lay a solid foundation for further exploration in the realm of 3D cadastral visualization. Incorporating insights from the broader field of 3D visualization, particularly regarding interaction techniques and user interfaces, can provide valuable guidance for developing effective 3D cadastral visualization systems.
In the upcoming sections, we will present the use of interaction tasks and 3D visualization user interfaces for 3D cadastral visualization.

### 4.1 Interaction tasks for 3D Cadastral Visualization

Interaction tasks in 3D cadastral visualization are fundamental for effective exploration, analysis, and interpretation of spatial data pertaining to land parcels, property boundaries, and cadastral information.
Our study identified three main groups of interaction tasks necessary for 3D cadastral visualization: object manipulation, manipulation of visualization widgets, and selection and annotation of data.

Building upon the interaction tasks outlined for spatial 3D data visualization, it becomes evident that many of these tasks are applicable in the context of 3D cadastral visualization. One critical interaction task in 3D cadastral visualization is navigating through complex spatial datasets. Similar to spatial 3D data visualization, users in cadastral mapping contexts often need to traverse through expansive representations of urban landscapes and property boundaries to access different perspectives and gain insights different property ownership components. However, the unique characteristics of cadastral data, such as dense urban environments and diverse geometries, pose specific challenges to navigation. Techniques such as pan, tilt, zoom, and rotation are essential for enabling users to explore 3D cadastral datasets seamlessly. Moreover, tools like cutting planes editors and cross-section views can help mitigate issues of occlusion and enhance internal viewing of cadastral data. Manipulating visualization widgets is another crucial interaction task in 3D cadastral visualization. These widgets serve as digital components or elements that allow users to interact with and explore cadastral data in a graphical interface. Integrating a variety of widgets into 3D cadastral visualization platforms enables users to dynamically adjust parameters, filter data, measure distances and areas, and explore different perspectives of the information being displayed.

Furthermore, the process of selection and annotation plays a crucial role in 3D cadastral visualization. Selection enables users to identify specific land parcels, property boundaries, or spatial features for further analysis or annotation. With dense cadastral datasets, navigating the selection process can be challenging, requiring intuitive interfaces and automated positioning to facilitate the identification of objects of interest. Annotation complements selection by allowing users to record insights and findings within the spatial context of the data, fostering knowledge sharing and collaboration among stakeholders involved in urban planning and land administration.

In summary, interaction tasks in 3D cadastral visualization encompass a range of activities essential for exploring, analyzing, and interpreting spatial data relevant to land management and urban planning. By addressing these tasks through intuitive interaction mechanisms, we can create effective 3D cadastral visualization systems that empower users to make informed decisions and facilitate effective communication in land administration contexts.

### 4.2 User Interfaces for 3D Cadastral visualization

Effective spatial interaction mechanisms are crucial for facilitating intuitive exploration, analysis, and interpretation of 3D cadastral data. In examining user interfaces for 3D visualization, we have assessed various types commonly employed. Each interface type presents distinct advantages and drawbacks concerning efficiency, usability, and immersion.

Traditional input methods such as mouse and keyboard interactions have long been the primary means of interacting with 3D cadastral systems. While these methods offer familiarity and precision, they may not be well-suited for complex 3D cadastral situations where users may need more degrees of freedom to navigate spatial datasets seamlessly. Touch interfaces offer intuitive and direct engagement, although they can be constrained by screen size and finger occlusion issues.

Emerging technologies offer promising alternatives for spatial interaction in 3D cadastral visualization. Gesture-based interfaces enable users to manipulate and interact with 3D objects using natural hand gestures, mimicking real-world interactions. This approach enhances user engagement and immersion by removing the barrier between the digital and physical worlds. Tangible user interfaces (TUIs) provide physical objects or tools that users can manipulate to control and navigate 3D environments, but can be restricted by the availability and complexity of tangible devices.
Virtual reality (VR) headsets provide immersive experiences that enable users to explore and analyze 3D cadastral data in a virtual environment. By wearing VR headsets, users can navigate through spatial datasets as if they were physically present within them, enhancing spatial understanding and perception. VR environments also allow for collaborative exploration and decision-making, where multiple users can interact with the same dataset simultaneously, regardless of their physical location.

Previous research has compared the effectiveness of different types of interfaces for 3D visualization. These studies have shown that tangible and virtual reality interfaces often provide better performance and user experience compared to mouse-based and touch interfaces. The superiority of immersive environments, as demonstrated in tasks requiring intricate manipulation, suggests their potential for enhancing the user experience in navigating complex cadastral data. Additionally, insights from studies comparing display platforms, such as desktop displays, tablet multi-touch displays, and virtual reality headsets, highlight the importance of balancing engagement with usability and comfort.

Enhancing visualizations through the incorporation of effective spatial input methods has the potential to address challenges related to perception and interaction. In addition, incorporating Immersive interfaces, such as virtual reality (VR) and augmented reality (AR) have the potential to offer users a highly interactive and immersive experience by placing them within the 3D spatial context of spatial data. Unlike traditional desktop interfaces, immersive environments provide users with a sense of presence and spatial awareness, allowing for more natural exploration and interaction with the data.

In fact, Users will appreciate the ability to directly link the exact legal boundaries of their Rights, Restrictions, and Responsibilities (RRRs) with the tangible reality they experience and observe. The primary characteristic of 3D cadastral visualization lies in visualizing the invisible, as described by (Midtbø et al.,, 2021). Most cadastral boundaries are not physically presents and are existing as invisible lines or extents in space. Identifying these elements in the physical world poses considerable challenges. Traditionally, physical boundary demarcation has depended on physical boundary markers. However, these markers prove insufficient for various rights such as easements and covenants and may not be used in specific situations, especially concerning three-dimensional rights. As a result, determining the legal definition of a property unit becomes notably complex, even when physical markers like fences or walls are utilized to assert ownership. This issue is further compounded within 3D cadastral situations, where property boundaries frequently align with tangible structures such as walls or ceilings, as seen in defining private and common property in condominium ownership cases. Cadastral users gather evidence to align these legal boundaries with their physical reality.

When comparing virtual reality (VR) and augmented reality (AR) for 3D cadastral visualization, it's essential to note their distinct characteristics. AR is defined as “an enhanced version of reality created by the use of technology to add digital information on an image of something” (El Miedany, 2019). In contrast, VR “completely consists of computer-generated factors, which makes a user totally immersed in it” (Ma et al., 2007).

Virtual reality immerses users in fully virtual environments, offering immersive and detailed visualization experiences. VR enables users to explore cadastral properties from various perspectives and scales, facilitating in-depth analysis and simulation of spatial relationships. However, virtual reality requires specialized equipment such as VR headsets, which may limit its accessibility and practicality for everyday use.
Conversely, Augmented reality operates by loading models onto a mobile or tablet device and integrating them into the user's real environment (Figure 3 & Figure 4). This allows the model to seamlessly blend with the physical surroundings, enabling users to freely manipulate, view, rotate, scale, and obtain dimensions as required. Also, Augmented Reality enables outdoor applications such as navigation and on-site controls.


Figure 3: Augmented Reality view of rights and restrictions boundaries. (Grant et al., 2014)

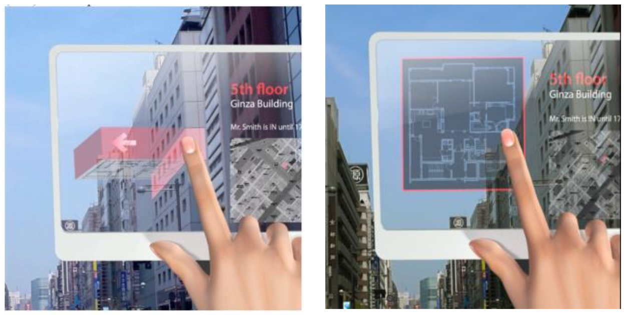


Figure 4: Conceptual design for an augmented reality application: dragging a building floor to see its floor map. (Funamizu, 2009)

Users can explore cadastral data in real-world contexts, manipulating and analyzing it within their surroundings using mobile or tablet devices.
The concept of augmented reality can be used to visualize different types of content related to cadastral properties, including Rights Restrictions and responsibilities, and offers the capability to seamlessly integrate new objects into existing environments and guide user within intricate structures. In contrast to virtual reality, augmented reality presents a closer approximation to reality by supplementing the real environment with desired objects or information rather than simulating the entire environment for example:

- Visualizing RRR associated with cadastral properties, such as easements, covenants, and zoning restrictions, aids in understanding property rights and limitations.
- Displaying textual data from cadastral surveys, including surveyor notes, measurements, and boundary descriptions;
- Presenting textual descriptions of cadastral boundaries and legal rights associated with properties helps users understand the legal framework governing land ownership and use.
- Clearly delineating the boundaries of cadastral parcels helps users understand property lines and boundaries.
- Displaying land use zoning information helps users understand the permitted uses and regulations for different areas within the cadastral map.
- Displaying textual information about cadastral properties, such as parcel numbers, land area, ownership details, and valuation data, provides essential context for property analysis and decision-making.
- Adding textual annotations and notes to specific features or areas within the 3D visualization allows users to highlight important information, make observations, and communicate insights with collaborators.

By incorporating textual information alongside visual elements in a 3D cadastral visualization, augmented reality provides a comprehensive understanding of cadastral properties and supports informed decision-making for land management.
Augmented reality boasts several advantages over virtual reality, including the ability for users to manipulate models without losing awareness of their surroundings. Additionally, the creation of augmented reality models is simpler compared to developing complete virtual environments. Furthermore, models used in augmented reality can be generated from CAD files

sourced from the 2D cadastre and visualized through compatible mobile or tablet applications.

Therefore, the efficacy of immersive environments, whether augmented or virtual reality, in enhancing user experience and task performance, along with the consideration of the challenges and benefits associated with each, suggests their potential applicability in the context of cadastral visualization.
However, visualizing 3D cadastral data in immersive environments such as virtual reality or augmented reality presents several challenges and requirements.

Firstly, 3D cadastral data is inherently complex, often involving multiple layers of spatial and legal information. Representing this data in a clear and understandable manner within the constraints of immersive environments, where users may have limited field of view or interaction capabilities, is challenging. Indeed, a 3D cadastral visualization system must encompass the extents of rights, restrictions, and responsibilities (RRRs) pertaining to land and real property. These RRRs will be identified, and relevant information about their boundaries described by surveys and registered on titles as graphical or textual descriptions will be incorporated into the cadastral system. These boundaries will be spatially represented in a form allowing for visualization in relation to one another within the cadastre.

Additionally, ensuring the precision of 3D Cadastral model placement and accuracy is critical, particularly in real-time AR applications. In fact, precise placement of cadastral boundaries within the 3D model is essential for maintaining the integrity of spatial relationships. Even minor inaccuracies in placement can lead to significant distortions, impacting the reliability of land parcel delineations and property boundaries (El Barhoumi et al., 2022). In urban environments where cadastral data often intersects with architectural structures and infrastructure, such inaccuracies can have far-reaching consequences for urban planning, development, and legal delineations.

Moreover, maintaining the currency of cadastral information introduces complexity, as updates and revisions necessitate continuous synchronization efforts. Addressing these challenges demands a multidisciplinary approach that combines advanced geospatial technologies with rigorous quality assurance protocols.

Furthermore, integrating 3D cadastral visualization with existing Geographic Information Systems (GIS), spatial datasets is essential for holistic comprehensive planning and land administration. Ensuring interoperability between different data formats, standards, and software platforms poses technical challenges.

The integration of immersive visualization into existing workflows poses a notable challenge, particularly in ensuring seamless interoperability with established tools and platforms, and existing Geographic Information Systems (GIS) and spatial datasets. Incorporating immersive technologies into professional workflows requires compatibility with various software ecosystems, including CAD software, GIS systems, and data analytics tools. Achieving this seamless integration necessitates careful consideration of data formats, communication protocols, and compatibility standards.

Lastly, protecting the privacy and security of cadastral data is paramount, especially when visualizing sensitive information such as property ownership details. Implementing access controls and encryption mechanisms to safeguard data privacy presents significant challenges.
In summary, while the potential benefits of immersive environments for 3D cadastral visualization are clear, their implementation presents significant challenges and requirements. From ensuring the accuracy of cadastral data representation to addressing technical hurdles in integration with existing systems, a comprehensive approach is necessary to realize their full potential. Additionally, various considerations must be taken into account while deploying immersive environments for 3D cadastral visualization.

One of the key considerations is that employing immersive environments for 3D cadastral visualization should ideally be underpinned by a hypothesis that promises added value.
Evaluating the added value in the context of 3D cadastral visualization can be achieved through two steps, each serving a distinct purpose in assessing the effectiveness and utility of immersive visualization for 3D cadastral visualization:

Evaluation of Interaction Task Effectiveness: This step involves isolating specific aspects of cadastral interaction tasks and comparing them across different media. The effectiveness must be evaluated in terms of its ability to support the tasks and workflows relevant to cadastral visualization. For instance, tasks such as parcel selection, boundary editing, and spatial analysis require different types of interactions, each with its own requirements in terms of precision, efficiency, and ease of use. Comparing user experiences between traditional screen visualization and virtual reality (VR) can provide tangible evidence of effectiveness.

Comparative Evaluation of Immersive and Non-Immersive Scenarios: This evaluation directly juxtaposes the advantages and disadvantages of an immersive visualization with its non-immersive counterpart.

Another important factor to consider is the accessibility and ease of use of the immersive environments for 3D cadastral visualization. For example, while advanced technologies like virtual reality headsets may offer compelling experiences, they may also require specialized hardware and training, limiting their adoption among users. Therefore, it is essential to strike a balance between functionality and usability when selecting an interaction method for 3D cadastral visualization.
By following these steps, the effectiveness and utility of immersive visualization for 3D cadastral purposes can be comprehensively assessed.

## 5. Conclusion

In conclusion, this paper has highlighted the significance of effective interaction techniques and user interfaces in 3D visualization. By exploring various modalities and immersive environments, we've underscored their potential to enhance user experience and task performance for 3D cadastral visualization. Moving forward, addressing challenges in precision, integration, and privacy, while evaluating the added value of immersive visualization, will drive further advancements in this field, ultimately enabling more efficient cadastral visualization systems.

Further research will involve practical evaluations of visualization environments, directly involving users in the process. Through these evaluations, researchers can closely observe how users interact with different types of interfaces and identify the strengths and limitations of each approach. These

evaluations will also gather valuable user feedback, aiding in guiding the future development of visualization environments.
Moreover, integrating user experience into the evaluation process will provide a better understanding of end-user needs and preferences, ultimately leading to more tailored and effective cadastral visualization solutions.

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