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Review

Digital Twin for Active Stakeholder Participation in Land-Use Planning

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Abstract: The active participation of stakeholders is a crucial requirement for effective land-use planning (LUP). Involving stakeholders in LUP is a way of redistributing the decision-making power and ensuring social justice in land-management interventions. However, owing to the growing intricacy of sociopolitical and economic relations and the increasing number of competing claims on land, the choice of dynamic land use has become more complex, and the need to find balances between social, economic, and environmental claims and interests has become less urgent. These facts reflect a paradigm shift from top-down, noninteractive, and one-directional policymaking approaches to a more negotiable, bottom-up, deliberative, and responsible one. Geospatial industries claim that digital twin technology is a potential facilitator that improves the degree of stakeholder participation and influences land-use planning. The validity of this claim is, however, unknown. By adopting the integrative literature review, this study identifies where in LUP is stakeholder participation much needed and currently problematic, as well as how digital twin could potentially improve. The review shows that digital twins provide virtual visualisation opportunities for the identification of land-use problems and the assessment of the impacts of the proposed land uses. These offer the opportunity to improve stakeholder influence and collaboration in LUP, especially in the agenda-setting phase, where land-use issues could be identified and placed on the LUP agenda. This relies on the ability and willingness of local planning institutions to adopt digital twins, and stakeholders' perception and willingness to use digital twins for various land-use goals. Despite the assertion that digital twins could improve the influence of stakeholders in LUP, the focus and the development of digital twins have not accomplished much for those features of the technology that could improve stakeholder influence in LUP. By adopting the principles of the social construction of technology, this study proposes a "technological fix" of digital twins to focus more on improving stakeholder influence on land-use planning.

Keywords: digital twin; stakeholder participation; land-use planning; active participation

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1. Introduction

One of the current planning discourses centres on improving stakeholder participation and influence on land-use planning (LUP) measures. The inclusion of stakeholders in LUP helps to enhance planning processes, ensures responsible land-use planning, and finds balances between development needs and social life [1–5]. The underlining idea is that the LUP decision-making process should include people who will be affected by the planning intervention or those who will obstruct the process if they are not included [1,6,7]. Stakeholders can also provide "valuable knowledge and perspectives of the realities of the problems affecting their region" [8] (p. 546). Therefore, the degree of participation, the level of influence, and the decision space of stakeholders are critical to achieving responsible land-use planning [9]. However, globally, there is still a lack of active stakeholder participation in land-use planning [1,4,7,10–12]. Land-use decisions are made mainly by local authorities, excluding various stakeholders who bear the outcome of such decisions [1–3,5,13]. The role of stakeholders in various government and private planning models is mainly to choose among a set of scenarios; participate in surveys with no opportunity to come up with other suggestions, data, models, or solutions; or interact with planning officials [1,4,10,11]. This form of participation is "passive", noninteractive, and one-directional, and there are no real negotiations or deliberations involved. As a result, stakeholders have limited influence on land-use-planning decisions. Conventional geospatial technologies, such as geographic information systems (GIS), remote sensing, and volunteered geographic information (VGI), have to some extent contributed to enhancing stakeholder participation in land-use planning. However, these technologies are employed mainly in comparative analysis, land-use change monitoring, and detection, not specifically to ensure active stakeholder participation [14]. Additionally, the current visualisation tools adopted by many local authorities are still in 2D [15], are static, and lack spatial analytical functionalities [11]. Stakeholders in this case have little influence on land-use decisions as these geospatial tools are not interactive enough to provide the support needed for land-use interventions.

A digital twin is a digital representation of a physical entity [16–18]. In geospatial applications, this could include a virtual representation of land parcels, buildings, roads, utilities, proposed development, or even an entire city [19–21]. Geospatial industries claim that the digital twin (DT) technology could potentially enhance the influence of stakeholders on land-use planning [19,21–23]. Despite this claim, not many studies have attempted to establish this relationship, and there is currently no comprehensive research that has analysed or that has shown where or how this could play out. In this study, we assess how DT technology could enhance stakeholder participation and stakeholder influence on the land-use-planning process. This is accomplished by first identifying which step within the LUP process stakeholder participation is most needed and is currently problematic and second determining how and where in the LUP processes DT could improve. This research fosters and encourages active participation from and equal representation for all stakeholders in land-use planning, which are paramount in planning measures. It also shows major bottlenecks in achieving responsible land-use planning, where the needs of stakeholders are taken into consideration and all stakeholders participate in making such decisions. The study therefore seeks to provide answers to the following questions:

1. Could new technologies, and in particular digital twins, fundamentally alter the degree of stakeholder participation in and stakeholder influence on one or more stages in a land-use-planning process and, if so, how, where, and under which conditions?
2. Which qualities and potentials of the DT technology, compared with those of conventional geospatial technologies, could enhance the decision space of stakeholders in land-use planning?

The next sections of the paper are structured in the following manner: Section 2 presents a nuanced understanding of the concept of "responsible" land-use planning and how the concept is relevant to the current discourse on active stakeholder participation in land-use planning. Section 3 highlights the research process, the sources of the materials, and the method adopted in this research. Section 4 presents the results, and the interpretation and discussion of the results are presented in Section 5. The general conclusions of the research are presented in Section 6.

2. Theoretical Backgrounds

2.1. "Responsible" Land-Use Planning

"Land-use planning" is defined by Metternicht [24] as the systematic assessment of land and water potential, alternatives for land use, and economic and social conditions in order to select and adopt the best land-use options. While all the other types of planning may be spatial in terms of their geographical distribution, land-use planning directly concerns the physical space [25]. Therefore, the LUP process should involve a thorough analysis of various dimensions: the social, economic, environmental, physical, and political dimensions [26] in an iterative or continuous process [6,25]. Here, all the stakeholders are actively involved in the decision-making process [11]. Land-use planning may be termed "responsible" land-use planning, under certain conditions. The word "responsible" has been extensively used in many land-related concepts. This includes "responsible" land governance [27]; "responsible" land consolidation [28]; "responsible" land administration [29]; and "responsible" governance of tenure [30]. De Vries and Chigbu [9] (p. 70) have identified 8R indicators, namely responsiveness, respect, reliability, resilient, robustness, reflexivity, retraceability, and recognition, to describe how an intervention could be considered responsible or not. In the land-use-planning domain, various studies have also adopted the word "responsible" to describe how, where, to what extent, or under which conditions land-use planning is responsible or not. The term "responsible land-use planning" has therefore been adopted to bring new meaning to the approach, methods, and processes of land-use planning. "Responsible land-use planning" can therefore be defined as land-use planning that ensures the best use of land; that is responsive to the needs of the stakeholders; that ensures accountable decision-making; and that guarantees that all stakeholders can identify and recognise themselves in the decisions [31]. For example, Johnson [32] described how responsible land-use planning could improve stormwater management and water quality by using a geographic information system. Responsible land-use planning, therefore, goes beyond the preparation and execution of land-use planning to also include elements of responsibilities and accountabilities [31]. In the same way, it should be aligned with societal demands, should respond to the needs of the people, should reinforce sustainable development initiatives, and should improve peoples' lives [29].

2.2. Social Construction of Technology

The social construction of technology (SCOT) is a theory that supports the idea that society shapes the design and direction of technology [33,34]. Advocates of SCOT argue that the scope, form, practice, and outcome of technological development are determined by humans and certain social arenas [35]. In this sense, technology is not viewed as an autonomous tool with a fixed outcome but rather as a social construct shaped by some social preconditions and what humans tend to achieve. SCOT counters the approaches of technological determinism which views technology as an autonomous tool with a fixed outcome and no real social component or context. SCOT has four major elements: relevant social groups, interpretative flexibility, closure or stabilisation, and a wider context [34]. According to Bijker et al. [36], relevant social groups are those (organised or unorganised) groups of individuals who are connected to or concerned with an artefact. This could include producers, advocates, users, or consumers [37]. Interpretative flexibility is concerned with how people think of or interpret artefacts as well as the flexibility of how artefacts are designed [36]. Closure or stabilisation is when the problem associated with a particular artefact is solved or when the relevant social groups reach an agreement on an interpretation of an artefact [36,38]. The wider context, according to Pinch and Bijker [34], is the sociocultural and political context within which technological development takes place.

3. Materials and Methods

The application of digital twins in land-use planning is new, and there has been little discussion on it in the literature. One reason is the novelty of the digital twin technology. To examine such new topics that connect two distinct disciplines, it is important to first establish a relationship between them, which will then bring new perspectives that will lead to an initial conceptualisation and theoretical framing. Therefore, methodologically, this research adopted the integrative review, which is considered the most appropriate approach in this circumstance [39–42]. The integrative review allows the researcher to use existing literature to develop new knowledge on a topic [40]. This type of review allows dynamic topics and allows for diverse research sampling, which can include empirical, methodological, and theoretical approaches, from diverse sources, leading to a holistic understanding of a particular phenomenon [42]. An integrative review can be used to address mature, new, or emerging topics [39,41,42]. While it fills the gaps and brings new understanding and a significant reconceptualisation to ongoing topics, it also leads to a preliminary conceptualisation of new and emerging topics [41]. An integrative review is considered much more appropriate in this context than a narrative review or systematic review [43]. The integrative review, however, has been criticised for its potential for bias and its lack of rigour [43]. This research overcomes the critiques by considering findings from diverse methodologies and looking at various perspectives of the study, as suggested by Whittemore and Knafl [43]. The synthesis of this research follows the guidelines provided by Cooper [44] in undertaking review research. Cooper identifies the stages of undertaking an integrative review as follows: problem framing, data sources or literature search, the evaluation of data, data analysis, and the interpretation and presentation of the results.

The introduction section of this research highlights the research problem under investigation. This further translates into the research questions that this study aims to answer. This research connects and brings new understandings to two backgrounds: land-use planning and digital twin technology. Therefore, most of the literature in this research focuses on these two backgrounds, while other materials are from other secondary fields of study that complement this research, making it a multidisciplinary study. The literature search was systematic and commenced with an internet search of documents in various scientific databases, such as Google Scholar, Web of Science, ResearchGate, JSTOR, Springer, Taylor and Francis, and Elsevier, as well as a search of the grey literature from governmental websites, organisations, and institutions. Some of the keywords and phrases used include participation, land-use planning, active stakeholder participation, and digital twins. These keywords or phrases were used alone or in combination with another, which generated several research documents that aided in performing the validity and reliability checks.

The evaluation stage of this research included a screening process, an eligibility stage, and an inclusion stage to select the final studies used in this research. As indicated in Figure 1, the initial search of various scientific databases and websites resulted in a total of 713 research documents. Following this, duplicate documents were removed, which brought the number down to 579. After this, the titles were screened, and this resulted in the elimination of documents that were unrelated to the current study. This brought the number of research documents down to 347. The next step involved an abstract screening of the remaining documents. Studies that were not relevant to this research were excluded, yielding 93 selected documents eligible for full-text review. In this context, “relevant” means that the study focused on land-use planning and in particular addressed the issue of stakeholder participation or that it focused on the digital twin and addressed the theoretical point of the technology, its conceptualisation, its architecture, its characteristics, and its potential in land-use planning. The inductive content analysis method was used in analysing the data from the reviewed documents [45]. This included the categorisation, grouping, and abstraction of the main ideas, leading to new narratives of the connection between land-use planning and digital twins in broader themes. The data were analysed to identify where in the land-use-planning process stakeholder participation and stakeholder influence are currently critical. It was also analysed to identify those features of the digital twin technology needed to improve stakeholder influence on land-use interventions. Using logic and conceptual reasoning and the researcher’s knowledge of the subject matter, we narrowed this down to specifically establish the relationship between stakeholder participation in land-use planning and the potential of the digital twin technology. The results of the findings were interpreted to confer meaning and clarity to the data. This was accomplished by discussing, comparing, and contrasting the data to find similarities in and differences between the findings and the broader literature on land-use planning [42,44]. Some data were also presented by using tables, figures, and relational models. Figure 1 summarises the literature search process.

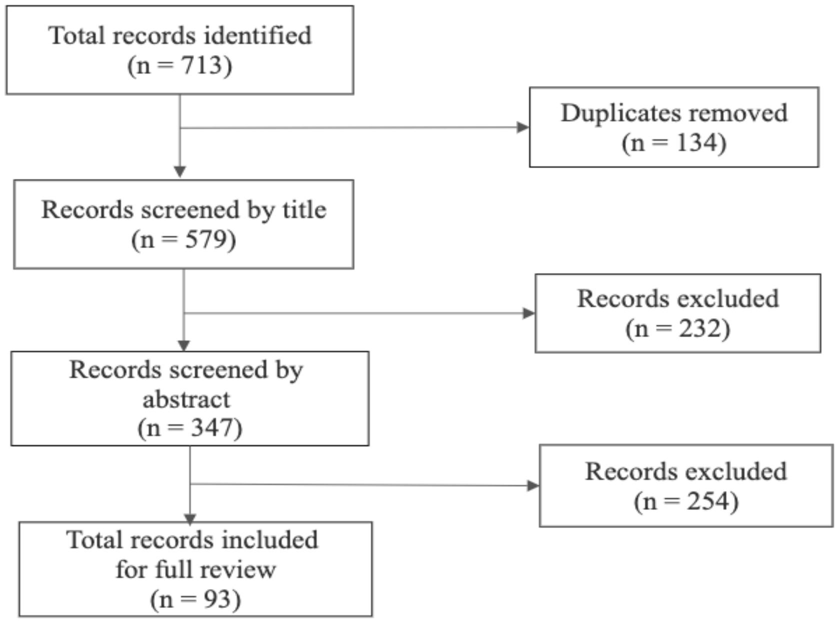

Figure 1. Literature-selection process.

4. Results

4.1. Digital Twin: Concepts, Characteristics, and Potentials

A digital twin (DT) is a digital surrogate, replica, or representation of a physical object, process, or system [17,46,47]. The underlying concept of the digital twin model is that all physical assets, people, devices, processes, places, and systems are dual: the physical nature and its virtual version [17]. The DT model can represent specific objects, such as buildings, land parcels, green areas, utilities, roads, rails, windmills, and bridges, or represent large and abstract entities, such as a city. A city-level digital twin means that the physical assets come from a group of assets in different categorisations. For example, a city digital twin would include buildings (e.g., residential, commercial, industrial), transportation systems (e.g., roads, rails), and utility lines (e.g., sewage, energy), among others. However, the inclusion or exclusion of a particular asset in a city-scale digital twin would depend on the objectives and scope of a given project. Digital twins have integrated simulation and service data that update and change as their physical counterparts change [46]. The connection between the physical asset and the digital version is established by using sensors to generate real-time data [47]. It is also facilitated through the Internet of Things (IoT) and the connectivity of advanced data analytics, which helps to predict current and future conditions for better and more-informed decisions [46]. This therefore saves time, costs, and resources because experiments can be performed on a virtual version without affecting or interfering with the physical assets [48]. Though the digital twin system is a recent initiative, the concept had already been envisioned much earlier [46]. It was first introduced as a concept for product life-cycle management, by Grieves in 2002.

The model is growing in both academia and industry [18] thanks to the advancement of IoT and artificial intelligence (AI) [49]. Although the digital twin has the capacity of being applied in almost every field of study, it has received much attention in manufacturing, healthcare, and smart city modelling [17]. For instance, the DT concept has been used for spacecraft monitoring by NASA, ocean-based production platforms by the oil industry, and smart city modelling, while the health sector has recommended it for improving patients' health [17].

The digital twin system is more than just the creation of prototypes or the display of virtual versions of physical assets. One important feature of the DT technology is its ability to exchange data with the physical twin in real time [48]. However, many articles have described the digital twin at various integration levels. That is, its integration and connection to a physical object could be performed in real time, near real time, offline, or as a virtual duplicate, depending on the context and its use case [50]. A digital twin could also be completely or partially modelled as a physical object, depending on the purpose or objective of what one intends to accomplish. Therefore, the DT concept can be said to be more of a fit-for-purpose concept rather than a one-size-fits-all concept. Table 1 depicts the various integration and fidelity levels that a digital twin concept can have. "Real time" means that there is a continual connection between the physical entity and the digital model, and any changes that occur to the physical entity automatically and simultaneously reflect on the digital component. "Near real time" means that there is a continual connection between the physical entity and the digital model, but any changes that occur on the physical entity take some time; it may take minutes, seconds, or microseconds before it reflects on the digital twin [50]. "Online" means that both the physical entity and the digital twin are connected; however, the reflections take place at a stipulated time. "Partially offline" means that the connection can be online and offline at different intervals. "Offline" or "virtual duplicate" means that there is no connection between the physical entity and the digital model; thus, the digital model is just a virtual form of or a model of the physical entity.

Table 1. Digital twin architectural perspectives and categorisations. Source: authors' construct, based on [50].

	Integration	**Fidelity**
Categorisation	Real time Near real time Online Offline (partial) Offline (virtual duplicate)	Complete Partial

Kritzinger et al. [51], however, classify the integration levels as follows: digital models, digital shadows, or digital twins. They classify an integration level as a digital model when there is no automatic data flow between the physical entity and the digital model; a digital shadow when there is automatic data flow but only in one direction; and a digital twin when there is an automatic data flow in two directions [51]. Digital twin technology requires the adoption of some technologies to make it possible and reach its potential. Each of these technologies has a unique role to play in the conceptualisation of digital twins. These are grouped into four main categories: the application domain, the middleware domain, the networking domain, and the object domain [18]. The application domain is for data capturing, preprocessing data, and creating high-fidelity models of physical objects and twin buildings [18]. The middleware domain has two subcategories: storage technology and data processing. This occurs basically through the integration of big-data and machine-learning technologies [48]. Big-data and machine-learning technologies also help in analysis, prediction, and optimisation. The third category is the networking domain, which performs the communication function. That is, wireless communication is needed for data communication between the digital twin architecture and the wireless transmission of the data across various IoT devices [48]. The object domain comprises the hardware platform and sensor technologies. While the hardware platform makes it possible to conduct DT analysis, the sensor technology facilitates the visualisation and collection of data for the provision of real-time information.

As indicated in Figure 2, a typical digital twin concept includes the physical entity, the digital model, and the connection between the physical entity and the digital model [52]. The entire digital twin system also has a connection to the outside world, where people could source information, visualise, and make analyses. The physical entities (twins) are connected with sensors and cameras, which generate and collect data. The digital twin receives the data from the physical twin, processes it, and sends the processed data back to the physical twin. The outside world can then visualise a real-time update on computer hardware and analyse it. The information obtained from the digital twin will then be used to improve the physical twin.

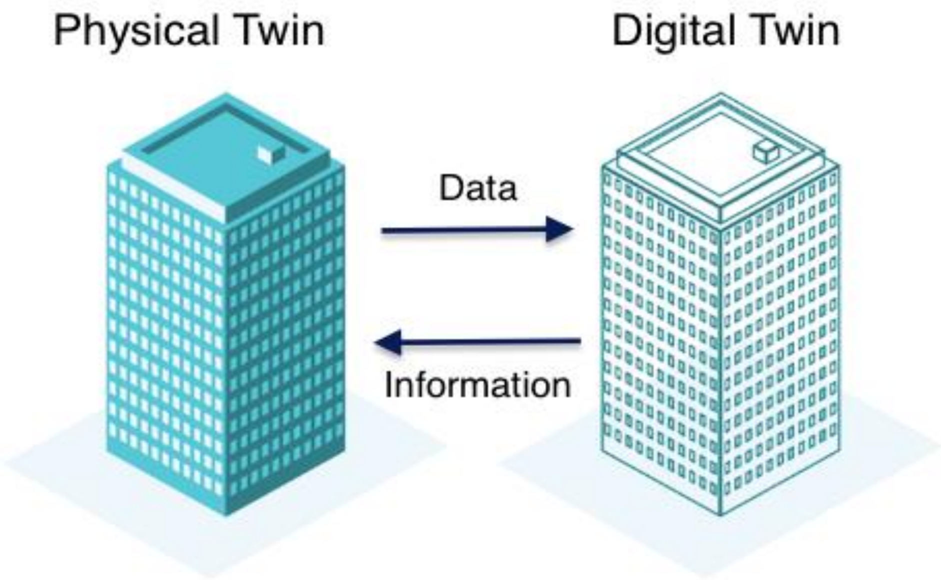

Figure 2. The connection between the physical twin and the digital twin. Source: adapted from [53].

It is important to recognise that many geospatial technologies have similar functions to those of a digital twin. These geospatial technologies can also capture, store, analyse, visualise, or manage data. For example, (open) LiDAR and drone technologies are for data acquisition; building information modelling (BIM) and geographic information systems (GIS) perform analytical and integration purposes; city geography markup language (CityGML) and immerse and virtual reality are for visualisation; and blockchain and NoSQL are for data management. Several of these technologies, including GIS, CityGML, and BIM, are also capable of producing 3D models. It is therefore important to differentiate digital twins from a conventional 3D model, BIM, and other geospatial technologies. A 3D model is a three-dimensional digital visualisation of a physical entity. BIM is a 3D model that provides compressive information about the physical entity; however, it requires manual data insertion for updates without any mutual connection to the physical entity [20]. A digital twin, on the other hand, is a 3D model of a physical entity with a mutual connection between the physical entity and the digital model and can perform in real time and in an interactive manner [20]. The characteristics indicated in Table 2 show the uniqueness of the digital twin technology.

Table 2. Characteristics of digital twins. Source: authors' construct.

Characteristics of Digital Twins	Description	Sources
Modelling and visualisation	Digital twins can capture, create, and model physical entities in 3D.	[18]
Real-time monitoring	DT can show the current status of the physical asset in real time or at a given time.	[49]
Connectivity and communication	There is a 2-way synchronising relationship between the digital model and the physical asset. It also ensures an accurate and timely flow of information through all IoT devices.	[17,48,54]
Integration capability	The digital twin system accepts the integration of other technologies.	[48]
Homogenisation	Digital twin makes the homogenisation of data possible. Digitised data from the physical asset can be computed, stored, or transmitted across various devices or agencies.	[54]
Interactive	Digital twins can respond to the user's input or action.	[55]
Analysis, prediction, and optimisation	With DT, future predictions are possible; hence, better and more-informed decisions can be made.	[18]

4.2. Land-Use Planning Phases and Stakeholder Participation

A stakeholder in land-use planning is anyone, a group or an institution with an interest, affected or anyone who will be affected by a land-use planning initiative. Stakeholders could include citizens, governmental and nongovernmental organisations, groups, companies, and institutions, among others. Stakeholders are the bearers of land-use decisions; therefore, it is prudent that they actively participate in the process. The identification of stakeholders should be one of the initial processes of land-use planning [4]. Various studies, including those by Kvam [56] and Wang and Aenis [57], recommend the adoption of stakeholder analysis as this will avoid leaving out some stakeholders and, at the same time, reveal whether to group or categorise stakeholders where necessary. The inclusion of stakeholders in the land-use planning process helps to better understand the circumstances and local dynamics that will positively shape the overall process. It also reveals the rights and responsibilities of the stakeholders and increases the chances that the project will be accepted by the stakeholders, while empowering and strengthening their trust in the land-use-planning process. In this study, we define "decision space" as the extent to which stakeholders will be able to contribute, provide feedback, and participate in the decision-making process for land uses. Like many organisational or institutional processes, the land-use-planning process includes the task of making, decisions and these decisions are crucial. Eisenfuhr [58] defined "decision-making" as "a process of making a choice from a number of alternatives to achieve the desired result". Therefore, to decide, there should be alternatives or options, there must a goal to achieve, and there must a process to choose among those options. All these elements are important to making decisions that will lead to maximisation and optimisation [59]. Therefore, decision makers should be able to figure out their alternatives, be aware of the various land-use outcomes, go through some steps or processes, choose the optimal land uses, and be able to implement them. However, local authorities alone cannot make such optimal decisions, because they might not know all the community information. The inclusion of stakeholders in the decision-making process provides the opportunity to highlight various possible alternatives related to the social, economic, and environmental dimensions. Land-use planning involves many interest groups with different perceptions and expectations of the outcome of the LUP process. Identifying what matters most and is less relevant in the land-use context is often debatable given that various stakeholders have different interests and perspectives. Planning officials and policymakers might also have different perspectives on what is relevant and what is not. For example, to the socialist, land-use planning should be able to enhance social conditions as well as the cultural dynamism of a group of people; to the economist, land-use planning should be able to generate the needed revenue or increase the economic output or land value of an area or region; to the environmentalist, land-use planning should be able to protect the biodiversity, ecosystem, flora, and fauna; and to the politician, land-use planning should be able to satisfy their political agenda. However, land-use planning should holistically assess every dimension and find a balance within these dimensions [6]. That is, land-use planning should be socially just, environmentally sustainable, economically sound, physically adaptable, and politically acceptable [6,26]. Therefore, identifying land-use problems and placing them on the agenda and in policy frameworks should be a collaborative effort from both planning officials and all other stakeholders [6].

The aim and principles of land-use planning are similar among many communities and countries; however, there are variations in the processes, methods, and approaches employed [11]. These variations are a result of differences in the institutional setup of LUP systems as well as the professional experiences gained with LUP in various environments [11]. There are also different phases of land-use planning. For instance, FAO [60] classifies land-use planning steps as follows: establish goals and terms of reference; organise the work; analyse the problems; identify opportunities for change; evaluate land suitability; appraise the alternatives; choose the best option; prepare the land-use plan; implement the plan; and monitor and revise the plan. The GIZ [6], using an iterative process, classifies land-use-planning phases as follows: definition of objective or approach;

analysis; plan formulation; approval; implementation; and monitoring. Lagopoulos [25], on the other hand, classifies LUP phases as follows: decision to intervene; survey of spatial system; policymaking; forecasting; model of spatial system; alternative spatial scenarios; evaluation and selection; and implementation. Each of these classifications demonstrates that land-use planning is not a linear process and that every phase has different types of requirements, methods, and participation processes. In the same way, the roles of stakeholders and the types of participation in the various phases of land-use planning differ. According to the GIZ classification, for example, each of the phases can be explained as follows. The problem or objective definition is the agenda-setting phase, which involves the identification and prioritisation of certain issues over others. Here, stakeholders identify pressing issues that need urgent attention and solutions. The analysis and plan-formulation stages involve the appraisal of various land-use options to select the optimal option [6]. Stakeholders contribute to these analyses by referring to not only physical conditions but also socioeconomic and cultural dimensions. The implementation and monitoring phases involve the execution of plans and the assessment of feedback on the effect of the project. Such feedback from stakeholders helps to re-evaluate land-use decisions.

4.3. Geospatial Data Twinning and Land-Use Planning

Digital twins are known for the creation of digital surrogates of physical entities [54]. In geospatial applications, this could include the creation of digital models of existing land parcels, buildings, and the various land uses or proposed developments, construction sites, and construction processes, a community, an area within a city, or even an entire city or country. Among other things, the digital twin model provides various functionalities for virtual visualisation, geospatial analysis, simulation, and prediction. That is, virtual experiments could be performed on the DT platform without interfering with the physical entity. Therefore, changes or adjustments could be made to the virtual prototypes without causing any harm to the physical entity. DT is capable of producing highly accurate and detailed 3D models for easy understanding and analysis [18]. Land-use planning, on the other side, also deals with geospatial data for analysis and decision-making [61]. A 3D geographic visualisation is a planning tool used for visual impact assessment and collaborative planning processes in both rural and urban land-use-planning initiatives [14,15,61]. Land-use-planning processes could differ depending on the process's aim, the area of concern, or the core question of the overall land-use-planning process. In the rural context, land-use planning involves the designation of various uses of land over agricultural or natural land [60]. In an urban context, land-use planning involves the assessment of land-use options, (re)designation, or change in urban land use to different uses [14]. This could include an urban regeneration process, a physical (re)organisation of the space, or urban development projects such as new market squares, bicycle lanes, roads, or tram and rail lines. Land use in the urban context is complex, and on many occasions, it involves the mixed use of land. A particular use of land also has external impacts on other uses as well as on other urban planning measures. Visually assessing such proposed use cases could highlight the impacts as well as the land-use conflicts that may arise. For example, the construction of a commercial high-rise building could be economically important; however, it could also be detrimental if it occludes other buildings from sky exposure, sunlight, or air movement (see Judge and Harrie [62]). In this scenario, it is important to assess the geographic position and the structure of the property in terms of its elevation, dimensions, extensions, and perspectives. Such planning measures involve not only the assessment of social, economic, and political dimensions of proposed developments but also physical conditions and their impact on other uses [62]. These urban management scenarios help to prevent land-use conflicts, promote sustainability, and lead to external factors such as traffic and disaster-prevention measures. Three-dimensional (3D) visualisation models of physical entities are therefore employed to improve understanding and bring about responsible decisions [63].

Land-use scenarios can be presented in two-dimensions (2D), in three-dimensions (3D), or even in a higher dimension. These dimensions have different levels of detail (LOD) and therefore different levels of contribution to analysis and decision-making. Because 3D has much more detail and it is more illustrative and comprehensible than 2D, analyses are more effective with 3D than with 2D [14,62]. This is because, terrain, building heights, and landscapes are mostly lost in 2D models [62,64]. Figure 3 shows five LODs and the level of contributions that each could offer.

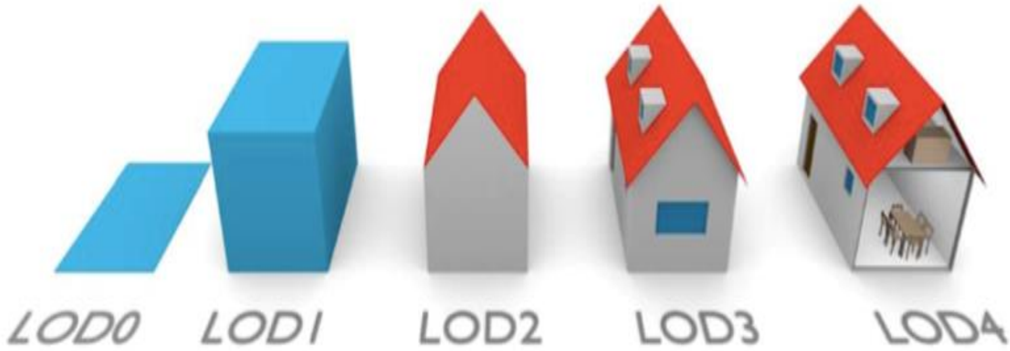

Figure 3. Levels of detail. Source: [65].

Many local authorities are gradually adapting to 3D visualisation models thanks to their added value to 2D data sets [66]. Additionally, more and more land-use dynamics require multidimensional and multispatial data sets [67]. Therefore, having a 3D model as a complement to the 2D is an effective way to conduct a comprehensive analysis. Though current geospatial technologies such as GIS, remote sensing, virtual reality (VR), augmented reality (AR), and volunteered geographic information (VGI) are used for various analytical functionalities and have 3D-modelling capabilities, the digital twin is said to be more comprehensive, be more interactive, and have various analytical functionalities that will improve the participation of stakeholders [19,68].

Digital twin technology has gained much popularity not only in academia but also among many governmental institutions, policymakers, and private organisations around the world. During the literature review, we came across some examples of where and how institutions have embraced and considered the application of digital twins in planning-related issues. As indicated in Table 3, we highlight the application areas of these examples. It can be observed that some of these digital twin adoptions are for urban development and planning interventions, some are to gather the city's spatial data or visualise urban infrastructure for planning purposes, and others are for bringing about participation and collaboration between planning authorities and stakeholders. Though the examples show that DT is considered in a way that ensures the sustainable and effective use of land, not many of these use cases aim specifically to improve the influence and collaboration of stakeholders. Additionally, few studies have demonstrated how DT could improve community participation in planning matters. For example, Shahat et al. [20] analysed a city-level digital twin; Abdeen and Sepasgozar [19] demonstrated how a smart city digital twin could improve community participation; and Dembski et al. [21] showed how communities could participate in spatial planning by using digital twin models. These studies show that DT could generally improve stakeholder participation, but not in a specific planning step.

Table 3. Examples of where and how digital twins are being considered. Source: authors' construct.

Where and How Digital Twins Are Being Considered	Source(s)
"A future-oriented and sustainable metropolis that actively and responsibly uses digitization for the benefit of urban society"	[69]
Openness, transparency, equality, and inclusion Autonomous digital twins for business and planning interventions	[70]
Virtual Singapore in 3D and a collaborative data platform Data access by various stakeholders Visualisation, enhanced planning, and decision-making	[22]
Potential for solar energy production Net-zero carbon emissions Sustainable and clean cities concept	[71]
Heritage restoration Improved operational and efficiency of infrastructure Urban resilience	[72]
Visual communication and collaboration Creation of urban planning scenarios Detailing and visualising building projects Collaboration between stakeholders	[73]
Urban-scale digital twin and integrating spatial data City data gathering Data for stakeholders Informed decisions	[23]

4.4. Current Challenges and Limitations of Digital Twins

Digital twins offer great opportunities to visualise, analyse, and predict future scenarios of physical entities. Despite its potential, several challenges limit its full utilisation. One of the main challenges, as noted by [20], is the mutual integration between the digital and physical counterparts. The communication of data from the physical entity to its virtual version is possible; however, the opposite communication of information from the virtual platform to the physical entity is currently challenging [20,51]. Additionally, a wholly mirrored city digital twin is still a challenge as the digitalisation of all physical entities is cumbersome and time-consuming, while nonphysical entities such as socioeconomic, political, and cultural patterns cannot be visualised [20]. There is growing literature on its conceptualisation; however, the technology is still in its infancy, with fewer practical applications [20]. The technology heavily relies on data to create digital models of physical entities; therefore, for large projects and city-scale initiatives, many data are required for the proper construction of digital twins [48]. These large data sets mean that large data-storage capacities are also needed. However, many studies have suggested the integration of big data as well as cloud storage initiatives into digital twins [11,20,48]. Meanwhile, the authors of [48] point out that data assembling, the extraction of duplicates, and the integration of big data into digital twins are currently challenging tasks and will be costly and time-consuming. Owing to the cost associated with the construction of DT, local planning offices with less revenue might face challenges in creating DT for their administrative staff and for residents. Currently, there are also various challenges relating to the design architecture of digital twins that are due to their complexities. As noted by Sharma et al. [48], DT requires interoperability with other components, such as real-time tools, big-data resources, and connection and visualisation tools. Assembling and linking these components can be laborious [48]. Additionally, given the design architecture of digital twins, it might be costly if the project validity period is not long enough or not able to achieve the intended purpose. One aspect of the design architecture of digital twins is how it could be linked to the outside world for use by citizens, local authorities, other governmental bodies, and all other stakeholders. Like many new technologies, DT is presumed to be difficult to understand and can be used only by a few elites in communities because of its complexities. The usage of digital twins involves internet connectivity; therefore, it is also presumed that many people in developing and transitioning countries who have limited internet access might encounter difficulties in using DT.

5. Discussion

The emergence of digital twins has brought different perspectives to how geospatial data are acquired and utilised in land-use planning. Adopting digital twins in land-use planning is, however, not straightforward, in that there are different variations and phases of LUP, where each phase has different requirements, processes, and approaches. This is shown in the examples of the LUP classifications that were carried out by FAO [60], GIZ [6], and Lagopoulos [25]. Similarly, the type of interaction, participation, and roles of stakeholders are different in each phase of LUP [6,11]. The type of interaction and roles of stakeholders in the agenda-setting, policy, or problem-framing phase is different, compared with those in land-use analysis, allocation, implementation, monitoring, or evaluation. For instance, stakeholders participate in the agenda-setting phase to decide which issues should be on the LUP agenda, while in the analysis phase, they evaluate various land-use options and choose the optimal land-use scenario. As noted by [6,11,35], the agenda-setting or problem-framing phase is equally critical, compared with other phases of LUP, as the overall objectives and issues that would be addressed in LUP are set at this stage. This phase also determines which issues go into the LUP agenda and which ones do not [35]. The level of participation and influence of stakeholders in this stage is therefore crucial [74]. However, practically, the level of interaction and participation of stakeholders in this phase is considerably low [1,7,12,14]. There is a wide array of conventional geospatial technologies that, to some extent, have contributed to improving stakeholder participation; however, these are used mostly in some specific steps in the land-use-planning process and not so much in agenda setting, problem framing, or the definition of objectives [14]. For example, GIS is used mostly in comparative analysis, land-use change monitoring, and land-use detection [75,76]; remote-sensing techniques are used mostly in change detection, risk assessment, monitoring, and urban expansion projects; light detection and ranging (LiDAR) are for data acquisition; and CityGML and BIM are for the visualisation of specific features, such as buildings [77]. These conventional geospatial tools can capture, measure, analyse, and support planning decisions; however, they are normally static, have limited spatial analytical functionalities, and are also not user-friendly [11,14], perhaps because they are not designed in a way that specifically supports participation and collaboration [67]. Notwithstanding, the static features provided by conventional geospatial technologies also play special roles in the analysis, monitoring, and evaluation phases of LUP [14,35,68,78]. As noted by Pettit et al. [14], improvements from collaboration in planning matters instead requires functional, user-friendly, dynamic, and interactive geospatial technology. Another feature that is lacking among conventional geospatial technologies is that changes in the physical entity do not cause it automatically update itself but rather require manual updates [14,21].

According to Hovik and Giannoumis [79], the adoption and use of geospatial technology depend on several factors for both the municipality and the citizens. Factors that determine a municipality's consideration to adopt a technology depend on the resources of that municipality and on the size, complexity, and dynamic nature of the municipality's social, economic, physical, and political conditions [79,80]. Additionally, some administrative cultures are more open to citizen participation than others are, and as such, they are more willing to adopt technologies to enhance the participation of their citizens in planning interventions and those citizens' influence on those interventions [79].

Improving stakeholder participation and influence in LUP processes are also contingent on whether the stakeholders are willing to use such technologies. Technology adoption theories have been used to assess individual willingness to use a particular technology. One such theory is the technology acceptance model (TAM). According to Davis et al. [81], TAM explains users' willingness to adopt and use a particular technology, which is based on two factors: perceived usefulness and perceived ease of use. Perceived usefulness is when there is a positive use–performance relationship, while perceived ease of use implies that the use of technology would require low effort [81]. The adoption and use of technology also depend on the social, environmental, and behavioural factors (individual beliefs and perceptions) at a specific point in time [79].

The advent of digital twins prompts the question whether they are merely another geospatial technology or whether they could significantly improve collaboration and the influence of stakeholders on planning matters. Wright and Davidson [55] show that several definitions and vague explanations of digital twins are leading to the loss of the actual definition and what DT entails. The variety of definitions of DT tends to mean that digital twins are just another 3D model [55]. However, according to Wright and Davidson [55], digital twins have three important parts: a digital model of an existing physical object, a physical object that keeps changing, and data evolving from the physical object that could be captured and that could dynamically update and adjust the virtual model. In that manner, digital twins are not useful if an object does not change over time, and the data associated with the change could not be captured [55]. Howard [49] also opines that such changes should be self-updating and update in real time, instead of using manual inputs and remaining outdated. They should also offer interactive and dynamic analytical features where stakeholders could perform complex analyses; select queries, filters, or data points; and visualise any changes that occur over time [22,82]. In that manner, data could be visualised and interacted with from different points, angles, and perspectives or in an immersive environment [82]. These features create the avenue for better virtual visualisation opportunities, which will improve the influence of and the collaboration between stakeholders in land-use planning, as compared to conventional geospatial tools, which help in the comparative analysis [19,52].

However, these specific features of DT have not received the needed attention among geospatial industries and in the literature. Additionally, as noted by Batty [83], another aspect that seems to be neglected in the DT concept is how people, social, and economic systems could be merged into the built environment to form a complete replica of the city. Batty [83] posits that a complete replica of a city that shows the interaction between people, the environment, social factors, and economic factors could never be achieved, because these social factors cannot be captured in the digital twin system. Additionally, various geospatial literature and government grey documents on DT have focused mainly on the physical modelling and simulation aspects of the technology and not so much on social, political, and cultural factors, which are equally relevant in land-use-planning interventions [77]. Notwithstanding, simulation and prediction are useful in specific use cases, such as noise, air, and flooding propagation analyses. Additionally, although the land-use-planning process requires that stakeholders take an active role and choose the optimal land use among several options in LUP [6,25], the current direction and development of digital twins has tended to limit these options and, at the same time, has neglected those features of the technology that are relevant in improving the influence of stakeholders on land-use planning [83,84].

6. Conclusions

This research assesses whether digital twins could fundamentally alter the degree of stakeholder participation and influence in one or more stages of a land-use-planning process; determine how, where, and under which conditions this could happen; and identify which qualities could enhance the decision space of stakeholders in land-use planning and identify the potential of the digital twin technology to be better than conventional geospatial technologies. The synthesis of the literature shows that digital twins provide virtual visualisation opportunities for the identification of land-use problems and the assessment of the impacts of the proposed land uses. These offer an opportunity to improve stakeholder influence on and their collaboration in LUP, especially in the agenda-setting, objective, or problem-framing phase of LUP, which is crucial but which currently has limited stakeholder participation and influence. This relies on local authorities' willingness and ability to adopt new technologies, such as digital twins, and stakeholders' perception and willingness to use digital twins for various land-use goals. Currently, the link between digital twins and land-use planning is attributed mainly to the physical assessment of land uses or the proposed use cases because DT is not able to capture social, economic, and political factors, which are also relevant in land-use interventions. The synthesis also demonstrates that conventional geospatial technologies have significantly and differently contributed in other phases of LUP, they have not contributed much in agenda setting or objection definition or in a way that fosters better stakeholder collaboration and influence. Digital twins, on the other hand, possess several qualities and features that are useful in specific use cases; their dynamic and interactive features are useful in improving the level of influence and decision space of stakeholders in LUP, particularly in the objective or problem-framing phase. The dynamic and interactive features of DT provide the opportunity to select queries and filters and to visualise geospatial data from different viewing points, angles, and perspectives and in certain levels of detail, thus presenting a comprehensive glimpse of potential scenarios. There is also a possibility of doing this in real time. These features provide a better understanding of realities, making stakeholders much more aware of the land-use issues within their community. This could serve as a basis for the analysis and identification of impacts and potential land-use conflicts.

Despite the publicity from geospatial industries that DT could influence the degree of stakeholder participation in LUP, the focus on DT is not so much on its dynamic and interactive features, which would improve the level of influence and the decision space of stakeholders. On the basis of the principles of the social construction of technology (SCOT), we propose a "technological fix" of digital twins, which is the process of adapting, modifying, or tweaking a technology for a particular use or purpose. SCOT sees technology as a social construct shaped by certain social arenas. The approach of SCOT means that technology possesses several functions and potentials; however, it can operate in a certain way only if it is shaped to do so. According to the principles of SCOT, a digital twin is co-constructed by certain social objectives. Therefore, to achieve active stakeholder participation in LUP, the emphasis of DT should be placed more on the influence of and collaboration between stakeholders while including the dynamic and interactive features of the technology needed in this circumstance.

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