Article: Assessing the performance and usability of urban digital twins

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Abstract

Cities around the world are rapidly adopting digital twin technology to address intricate urban planning issues, to foster more sustainable and efficient urban environments. However, despite this adoption and the recent increase of research on Urban digital twins (UDTs), few studies have been undertaken to examine how UDTs are performing in practice. The current body of literature focuses largely on the technological aspects of UDTs, leaving a research gap. Awareness is needed on what is happening in urban planning practice to help drive focus and prioritize the development of UDTs. Therefore, this paper develops a conceptual framework to assess the performance and usability of UDTs in urban planning. The framework is applied to examine the case studies of Amsterdam, Utrecht and the Province of Utrecht in the Netherlands. Data was obtained through online information and a series of in-depth interviews with key stakeholders. The results show that despite the advancement of this technology, UDTs are having a limited influence on urban planning. The case analysis provides a clear insight into the limitations and challenges. Practical and future research recommendations are given.

Keywords

Urban Digital Twins, Digital Planning, Planning Support Systems, Usability, Netherlands

1. Introduction

Globally, cities are grappling with numerous challenges such as rapid urbanization, fluctuating resource availability, housing shortages and unaffordability, climate change, and social inequality. Planning authorities undoubtedly face the task of addressing many of these complex environmental and economic issues while also managing stakeholder interests and increasing citizen engagement (Lin et al., 2024). Utilizing digital technology in the planning process can help effectively tackle these persistent problems. Many countries have introduced digital planning policies and practices to try and address the complex challenges cities are facing. By 2017, studies had shown that many European cities offer digital planning services such as, access to plan data on geoportals (Hersperger et al., 2022). Countries such as Finland, United Kingdom, Australia, and Singapore have implemented digital planning initiatives. Several European countries have made significant progress in building digital land registries and automating land use planning in local governments. Since early 2024, the Netherlands implemented the new environmental and spatial planning act (Omgevingswet) with the goal of streamlining spatial regulations and emphasizing the use of digital technology for public engagement and planning (Lin et al., 2024). Previous pilot programs in the Netherlands have utilized digital technologies to facilitate collaborative and participatory planning processes (Ministry of Infrastructure and Environment, 2017).

In recent years, there has been an increasing focus on utilizing digital technology in urban planning (Sabri & Witte, 2023). These tools were collectively referred to as planning support systems (PSSs) (Batty, 2007). Generally, PSS are computerized tools that help planners carry out their professional activities more efficiently. They are technologies that enhance the value of planners' work processes (Geertman & Stillwell, 2020). However, Russo et al. (2015) have highlighted usability issues and a lack of effort in user interface design for PSS. One emerging type of PSS is DTs. Grieves and Vickers (2019), explain that the concept of DT revolves around the ability to create, evaluate, produce, and utilize the virtual representation of various systems. In the context of urban planning, DTs are intended to be virtual representations of a country or city. Many governing bodies have started to adopt the use of this to enable real time monitoring, analysis and optimization to facilitate the decision-making process (Eça De Matos, 2023). One example can be seen in the city of Zurich, where a DT was implemented to enhance planning and decision making by using its DT to visualize and make more complex challenges easier to comprehend and understand

(Schrotter & Hürzeler, 2020). Although there is a growing body of literature on UDTs, it largely focuses on technological aspects and topics such as implementation issues. Awareness is needed on what is happening in urban planning practice to help drive focus and prioritize the development of UDTs. Therefore, this research develops a conceptual framework for assessing the performance and usability of UDTs in urban planning practice. The framework includes elements to assess the performance and usability of urban digital twins. The data is mainly collected through in-depth interviews The results show that despite the advancement of this technology, UDTs are having a limited influence on urban planning. The case analysis provides a clear insight into the limitations and challenges. Hence, this paper aims to accomplish three objectives. The first is to develop an assessment framework. Second, is to apply this framework to the case studies selected. Finally, analyse these cases and discuss the findings. The paper is structured as follows. Section two conducts a literature review on digital planning, PSS and UDTs. Section three describes the research methods used. Section four discusses the main case studies and framework analysis. Section five provides the discussion section which compares the two cases and makes recommendations. The paper concludes in section six.

2. Literature Review

The section reviews studies on digital planning, planning support science, and urban digital twins. A conceptual framework is developed to assess the usability and performance of UDT in urban planning practice (figure 2).

2.1 Digital Planning

Technological advancements, along with the global, political, social, and economic drive toward developing smart city concepts and applications has led to an increase in attention on the application of digital technologies in urban planning and management (Sabri, 2021). The digital tools available, assist planners in gaining a deeper understanding of spatial phenomena, enhancing communication among stakeholders, and facilitating decision-making processes (Christmann & Schinagl, 2023). Batty & Yang (2022a) highlight that urban planners play a key role in endorsing the use of more advanced technologies in practice. They highlight the potential of digital planning to improve the quality of life in cities by making them more sustainable, despite the diverse conceptualization of digital planning in existing studies. Lin et al. (2024) have defined digital planning as;

"The application of digital technologies and data-driven approaches to enhance efficiency, effectiveness, and inclusivity in planning processes at different scales and various contexts to improve social, economic, and environmental outcomes for achieving a more sustainable urban future" (Lin et al., 2024).

The authors contend that the digitization of planning involves more than simply adopting new technology. Novel ways of planning, appropriate methodologies and adjusting communication strategies between the actors concerned will be critical. Planning practice requires input from academia in terms of conceptual definition and methodological techniques, while academics need a comprehensive understanding of the practical requirements in order to generate more efficient solutions (Lin et al., 2024). In their report, a digital future for planning, Batty and Yang (2022b), emphasize that the full potential of spatial planning can be realized in numerous ways by employing a digitally enabled approach. However, they also highlight that digital integration in planning is uneven and extremely disjointed due to the fact that there is a significant digital skill gap in universities and local planning authorities. In their article on the digitization of planning culture in Finland, Nummi et al. (2023) highlight that the principal goals of digitizing spatial planning are to enhance efficiency and transparency while fostering innovation. Innovative solutions are identified in the form of digital planning support system (PSS) tools.

However, the additional worth of this digitalization really relies on how well the functionalities of these tools can assist with addressing urban planning issues. Several scholars have expressed concerns with user focus in the context of digital technologies like PSS and DTs. For instance, Gil (2020) specifically highlights this concern. This originates from the lack of focus on the users themselves and what the technology is required for, highlighting that usability and usefulness are reoccurring themes of concern. Stakeholders and actors involved in the implementation phase of these tools is critical (Gil, 2020). The use of new digital tools associated with digital planning can also increase the risk of inequality and exclusion as their use can reform power dynamics between different actors and stakeholders. It is imperative to make concerted efforts to resolve these issues and guarantee that technology is implemented in a fair and inclusive manner (Lin, 2022; Lin et al., 2024). Therefore, the digitalization of planning may result in serious implementation and usability problems. Although digital planning has the potential to improve urban development and administration, it also poses several obstacles.

2.2 Planning Support Science

As previously stated, PSSs are viewed as computerized tools that add value to planners' daily tasks by supporting planning activities in a dedicated and transparent way (Couclelis, 2005; Geertman & Stillwell, 2020). Briton Harris first defined the term 'planning support systems' (PPS) in the late 1980s. Harris (1989) stressed the importance of a comprehensive planning support system that goes beyond the basic analysis of coincidence, contiguity, and proximity, which are the typical functions of ordinary Geographic Information Systems (GIS). PSS can be utilized for various activities at different phases of the planning process, such as issue analysis and regular monitoring of development indicators or development control. Currently, several local authorities have used online platforms to facilitate regular planning operations and the provision of fundamental services (Geertman & Stillwell, 2020) However, for a PSS to be effective for a specific task, several conditions and design criteria must be fulfilled. Emerging fields like smart cities and big data have significantly driven the adoption of PSSs in planning practices and enhanced their visibility.

Nevertheless, despite these emerging fields a greater awareness of PSS in industry is needed as there is still a PSS implementation gap and issues around usability (Geertman, 2017). For example, Jiang et al.,(2022a) shed light on the issues planners face with PSS. They claim that the potential of PSS in city planning is hindered by fundamental and structural factors like insufficient technical skills, user-friendliness, and lack of adaptability by practitioners. Some PSS developments do not cater to the real needs of users and planning tasks, leading to a disconnect between technology advancements and planning practices. Pelzer (2017) argues that if a PSS does not connect to the planning tasks at hand, it becomes completely ineffective. The application of new PSS technologies outpaces the ability of planners and societies to adapt to changes, impacting the effectiveness of PSS in supporting planning. Geertman and Stillwell (2020) have shown that a transformation has taken place which has seen planning support system progress to *PSScience*. They argue, this is largely due to the evolution from focusing purely on the tools provided by PSS to emphasizing the goals and support these systems offer. PSScience primarily focuses on the scientific question of how tools (instruments) respond to governance and application within the context of a particular environment (Lin et al., 2024). This paradigm shift is also marked by contemporary developments in the applications of PSS and their role in governance. This includes not only the use of PSS for information provision and communication processes but also how these systems shape and are shaped by governance structures, planning practices, and societal needs. Prior research has produced evaluation frameworks for many categories of PSS tools (Pelzer, 2017; Russo et al., 2015). Therefore, it is worthwhile to invest in the development of a comparable framework for UDTs.

2.3 Digital Twins for Urban Planning

UDTs are an emerging type of PSS. They have been identified by scholars and professionals as one of plannings emerging technologies, alongside Artificial Intelligence (AI), and the Internet of Things (IoT) (Sabri & Witte, 2023). The DT concept was first introduced publicly by Michael Grieves in 2002. Grieves (2019) explaining the concept of the DT, refers to the notion that information about a physical thing may be detached from the object itself and subsequently replicated or mirrored. UDTs first emerged in 2018, are a 3D city model with additional modules that can increase its functionality (Ferré-Bigorra et al., 2022). Currently, there is no agreed definition for UDTs. Definitions have been presented in academia, but several types of UDTs exist, dependent upon the lifecycle aspect of the system itself (Barricelli et al., 2019; M. Grieves & Vickers, 2017). In the context of urban planning, a physical 3D model of the city is most commonly employed as the basis for urban DTs due to its simplicity and efficiency in comparison to other modelled systems (Ferré-Bigorra et al., 2022). The 3D model is typically supplied with information from multiple datasets. These could come from public administration, geo-spatial data, remote sensing data and IoT data (Ferré-Bigorra et al., 2022; Lin et al., 2024).

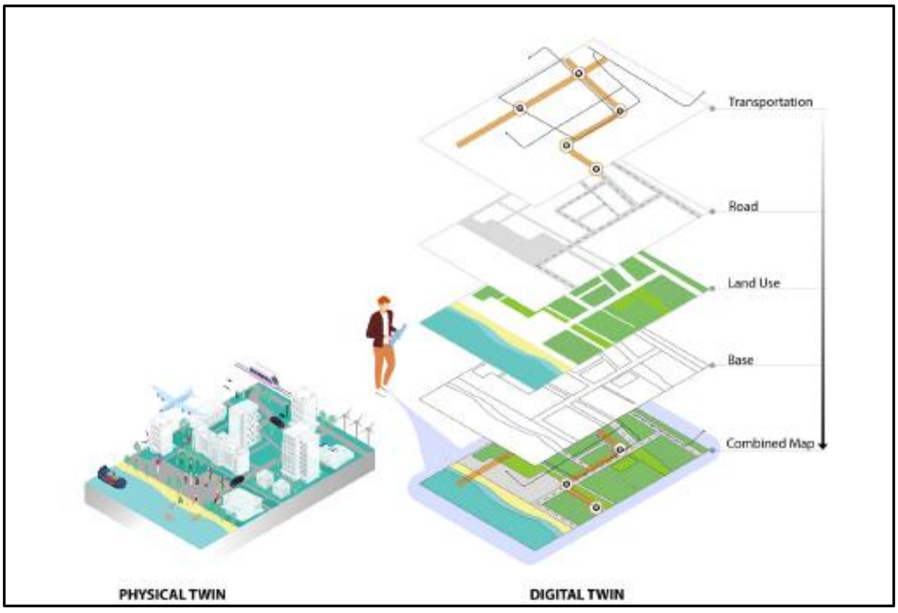

Figure 1: An overview of an UDTs main components (Haraguchi et al., 2024)

Cities are overwhelmed with a vast quantity of data that they are collecting, and the utilization of UDT technology can undoubtedly benefit from this. The potential to make data driven decisions can result in more efficient planning processes, subsequently generating just and robust cities (Eça De Matos, 2023). Batty (2018) highlights the significance of comprehending that DTs are not identical and that the concept of achieving an exact replica is unattainable. However, big data analytics, in conjunction with the development of artificial intelligence (AI) models and the Internet of Things (IoT), has enabled the advancement of DT technology (Barricelli et al., 2019). 3D virtual models of cities can provide information about a city, in turn, enabling strong communication and participation amongst citizens and key stakeholders. Ultimately, with the advancement of the technology surrounding UDTs, local authorities have the potential to simulate different scenarios. These scenarios can empower decision-makers to evaluate the potential impacts of different interventions and help tackle urban challenges, such as, infrastructure upgrades or traffic management (Eça De Matos, 2023; Gemeente Amsterdam, 2023). Batty (2018) states that an important key concept for UDTs, is that for the UDT to be beneficial to design and planning, it has to be run in a completely different context from the actual real-world system

While the integration of UDTs in the urban setting is seen as advantageous for the city, its inhabitants, and its officials, it is not without its disadvantages. Challenges exist that need to be considered and addressed both in research and in practice. Tello & Degeler (2021) argue that the fundamental difficulties lie in the potential hazards associated with ethical concerns, security, and privacy. Barricelli et al. (2019) emphasize, while utilizing IoT and cloud computing, it is imperative to prioritize the resilience of any UDT environment against cyber-attacks and viruses. Unauthorized access to private, confidential, or sensitive data might potentially harm all associated sources in the physical environment. Privacy and security of the data collected needs to be guaranteed prior to implementation and adoption. Artificial intelligence (AI) has also been integrated into UDT platforms. However, it does raise the question whether the results attained through the use of AI are ethical and fully comply with regulations, from a local to international level. Given that Europe’s General Data Protection Regulation (GDPR) is considered the toughest in the world, the implementation and design of a UDT will no doubt face challenged to be in compliance with these regulations (Tello & Degeler, 2021). Lei et al. (2023) have identified several technical and non-technical challenges to urban digital twins. These include, interoperability, data quality, financing and capacity building. Strong awareness of these challenges is essential. Despite, these obstacles there is no question that the use of UDTs is becoming increasingly valuable in urban planning.

2.3 Conceptual framework

A conceptual framework (figure 2) is developed to assess the performance and usability of UDTs in urban planning practice. In the Dutch context, the National Spatial Data Infrastructure (NSDI), Geonovum, have defined guiding digital twin principles in the physical environment to provide direction in the development and use of UDTs. Goal, trust, people, and effectiveness are key criteria derived from these principles used in this framework to assess the performance. Second, UDTs are considered an emerging form of PSS. Previous studies (see Lin & Benneker, 2022; Zhang et al., 2019) have assessed the usability of PSS, by adapting Nielsen's Human Computer Interaction (HCI) theory (Nielsen, 1994), as other studies (Jiang et al., 2022b) have also highlighted a lack of focus on users and usability. This framework combines both of these dimensions in order to provide an in-depth assessment and understanding of current developments within urban planning practice.

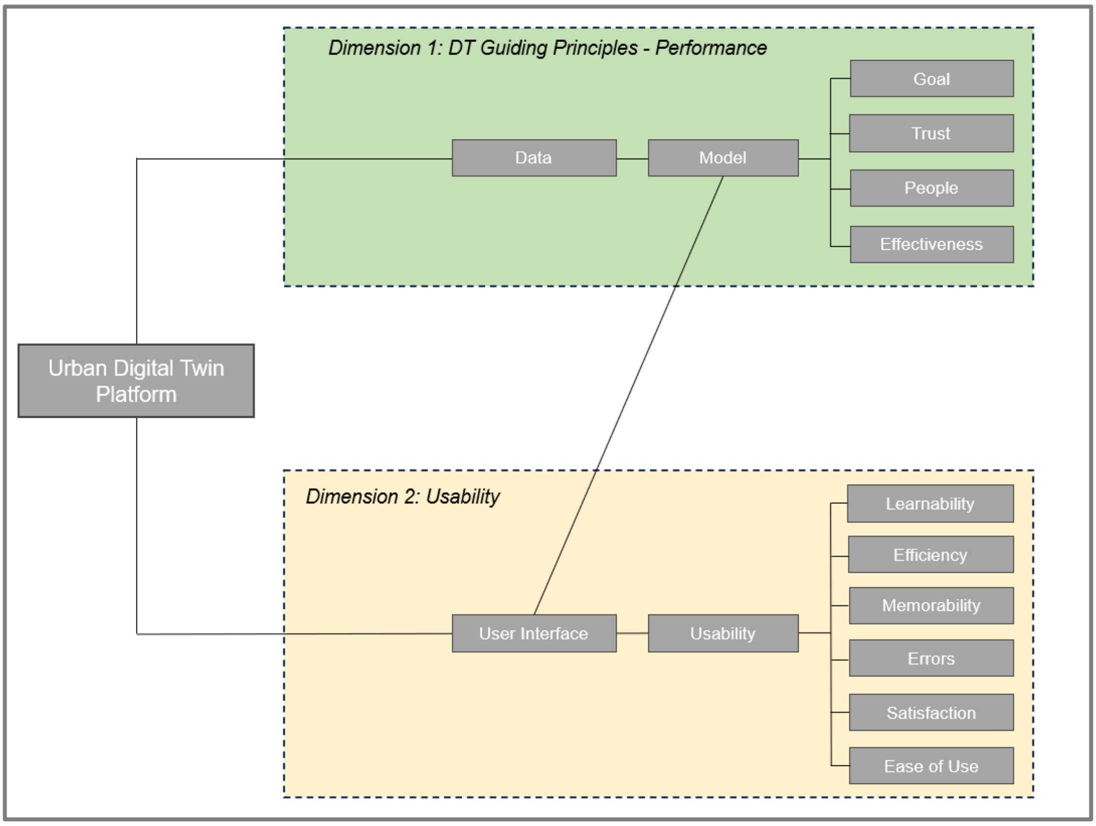

Figure 2: Conceptual Framework

The starting point of this framework begins with the platform, which in this case is the UDT. The framework is divided into two dimensions. The first dimension of the framework aims to assess the performance of the UDT through the lens of Geonovum's guiding principles. The second dimension outlined in the framework aims to assess the usability using criteria derived from Nielsen's HCI theory. The model and user interface are connected as the model could not be utilized effectively without the user interface.

Dimension 1: DT Guiding Principles – Performance

The research uses goal, trust, people, effectiveness as the main key criteria (these are translated from Dutch). From the starting point of the framework (which is the platform), the researcher has linked this with the data and model as these are key components of any UDT platform. The following key indicators which are explained in more detail below.

- **Goal:** Digital twins should improve objects, processes and systems in the physical living environment. Digital twins are never the goal, they are means to achieve the goal. Responsible digital twins serve the general well-being and create value for Dutch society. They work from a clear, simple and above all justified goal (Geonovum, n.d.).

- **Trust:** The UDT must be trustworthy for the public, municipality and stakeholders, in order to avoid a loss of value. An UDT and the ecosystem of UDTs must be robust and secure. This means that data and calculation models and the technical infrastructure on which UDTs run have high availability and are well secured (with possible access restrictions) against unwanted use (Geonovum, n.d.).

- **People:** This is linked with supervision and stakeholders. In relation to supervision responsibility for ethics should not lie with one person, staff department or committee. This takes responsibility away from others and from internal processes. By far the most important stakeholders are the people who share their personal data and anyone else who is influenced by the application of the data and the UDT. It is important to involve citizens and other primary stakeholders in the design phase of the UDT (Geonovum, n.d.) .

- **Effectiveness:** Clear ownership and assigned responsibilities enable effective data management and problem solving with UDTs and within the UDT ecosystem as a whole. Open standards for UDTs ensure trust through open and uniform semantics and exchange, prevent vendor lock-in, reduce costs and ensure that UDTs and the UDT ecosystem deliver optimal value (Geonovum, n.d.).

Dimension 2: Usability

The starting point of this dimension is linked to the user interface of the UDT. This then is linked to usability. As stated previously, Human Computer Interaction (HCI) theory was selected for this framework as this has previously been used in academic research to assess PSSs (see Lin & Benneker, 2022; Zhang et al., 2019). Human-computer interaction (HCI) is a multidisciplinary area of research that centres on examining, creating, executing, and assessing the ways in which humans interact with computer systems (Ritvo & Allison, 2017). In their research, Zhang et al. (2019) adapted Nielsen’s HCI theory in order to assess the usefulness of web-based PSSs in China. Nielsen’s (1994) categories of system usefulness are divided into both utility and usability. Utility refers to whether the system has the capability to execute the required tasks, while usability refers to how well users can operate the system's functionality to complete their tasks (Zhang et al., 2019). For this study, the researcher has focused solely on the usability as questions relating to the utility of the UDT platform will be addressed in dimension 1 of the framework. Nielsen (1994) states that usability encompasses all elements of a system that involve human interaction and that it is crucial to understand that usability is not a singular, one-dimensional characteristic of a user interface. Usability encompasses several elements and is traditionally linked to the following five attributes: learnability, efficiency, memorability, error, satisfaction, and ease of use. Therefore, these have been selected as the key indicators for this framework.

- **Learnability:** "Learnability" refers to how easy it is for a user to learn a system. This is seen as a key characteristic of usability as the first interaction most users have with a system is learning to use it (Nielsen, 1994).

- **Efficiency**: "Efficiency" refers to the fact that the system should be efficient to use. A high level of productivity should be obtained once the user has learned how to use the system. This is dependent on how experienced the user is and the complexity of the system (Nielsen, 1994).

- **Memorability:** "Memorability" refers to how easy the system is to remember, so that when users return, they don't have to relearn everything (Nielsen, 1994)

- **Error:** "Error" refers to the error rate a system has. Ideally this rate should be low in the hope that any errors made by users can easily be recovered. Commonly, an error is defined as an action that doesn't achieve the ideal objective. Therefore, system's error rate is measured by counting the number of these actions. (Nielsen, 1994).

- **Satisfaction:** "Satisfaction" refers to how pleasant the system is to use so that users are satisfied while using it.

- **Ease of Use:** "Ease of use" refers to whether users find the system sufficiently easy to use (Zhao & Coleman, 2007).

3. Research Methods

This research centers on the examination of three case studies within the Netherlands, which are the municipalities of Utrecht, Amsterdam and the province of Utrecht. These cases were selected as they are a strong example of UDT initiatives with key stakeholder involvement, with their main use case being city planning. These will be used for comparable analysis, to determine the performance and usability of UDTs in urban planning practice. A total number of 16 interviews were conducted between April and May, 2024. Each interview lasted between 30 min to 1 hour. The main approach used to gather the participants was by snowball sampling, which proved to be the most feasible strategy for recruiting respondents, i.e., the majority of respondents were referred by one of the key stakeholders. Interviews with urban planners focused with on the usability of the UDT. Interviews with key stakeholders, and developers focused on the performance of the UDT. A set of questions were designed to guide the interviews. Regarding the usability, questions related to the six criteria were asked. For example, Was the UDT platform easy to learn and, do you encounter errors when using the UDT platform? Regarding the performance questions related to the four criteria relating to Geonovum's DT principles. For example, is the UDT currently meeting the goals of the organisation and have you encountered any trust issues in relation to the UDT platform? Additional literature on UDTs was gathered to combine with the outcomes of the interviews for analysis. Once the data was collected it was transcribed in verbatim. The transcripts were then reviewed multiple times in order to gain familiarity with the content and context. Afterwards, a quantitative analysis was undertaken of the discourse, considering a set of several preselected codes based on the criteria in the framework.

4. Case Studies

To analyze the case studies this sample of industry professional have been interviewed.

Interviewees		
No.	Role	Type of Interview
Respondent 1	Programme Manager	In-person
Respondent 2	Product Owner	Online
Respondent 3	Programme Manager	In-person
Respondent 4	Researcher & Senior Advisor	Online
Respondent 5	Senior Urban Planner	In-Person
Respondent 6	Software Developer	Online
Respondent 7	Product Owner	Online
Respondent 8	Geo Data Analyst	Online
Respondent 9	Urban Designer	Online
Respondent 10	Urban Designer	In-person
Respondent 11	Urban Designer	Online
Respondent 12	Public Space Modeller	Online
Respondent 13	Public Space Modeller	Online
Respondent 14	Urban Planner	Online
Respondent 15	Urban Planner	Online
Respondent 16	Urban Planner	Online

Table 1: Overview of Interviewees.

4.1 Municipalities of Amsterdam and Utrecht

Background

In April 2019, the municipality of Amsterdam initiated its DT platform for the city, known as '3D Amsterdam. Initially, 3D Amsterdam operated with a small team. The primary objectives at the beginning of this project were to offer an engaging urban experience, improve communication and engagement through 3D visualization, and provide city-related information. Soon after 3D Amsterdam was established, the municipality of Utrecht formed a partnership with the municipality of Amsterdam. A replica of 3D Amsterdam was created, initiating collaboration between the two cities. It should be noted that during the interview process the researcher was informed that the development of 3D Amsterdam ceased one year ago and the focus is now on developing Netherlands 3D. Currently, the development team collaborating on Netherlands 3D are the Municipalities of Utrecht, Amsterdam, Rotterdam and the Provinces of Utrecht and Flevoland. These five parties are the main pioneers for UDT development in the Netherlands. The following section explains their UDT platforms in more detail.

The UDT Platforms of Amsterdam and Utrecht:

Both of 3D Amsterdam and 3D Utrecht platforms are publicly accessible via the web. Once either of these platforms are launched, the user will see an interface similar to what is shown below in figures 3 and 4 below. Users can simply start interacting with the 3D version of either city by using the functions on their mouse to pan, orbit, select and zoom. Around the main navigation area there are multiple options/tools visible.

Figure 3: Main page of 3D Amsterdam. See table below

User Interface: Reference for Figures 3 and 4.	
1	Navigation Bar (contains options for: standard selection, substrate transparency, download selected area, measure distance, create profile, take screenshot, share link to scene)
2	Feature Request (requests or comments can be made anonymously via the dialogue box provided).
3	Expandable palettes (search, layers, object properties, sun settings, interface settings)
4	Navigation Map (satellite view)
5	Additional Icons (right to left) View True North, toggle between orthographic and perspective & walk around/street view
6	Main Navigation Area

Table 2: User Interface

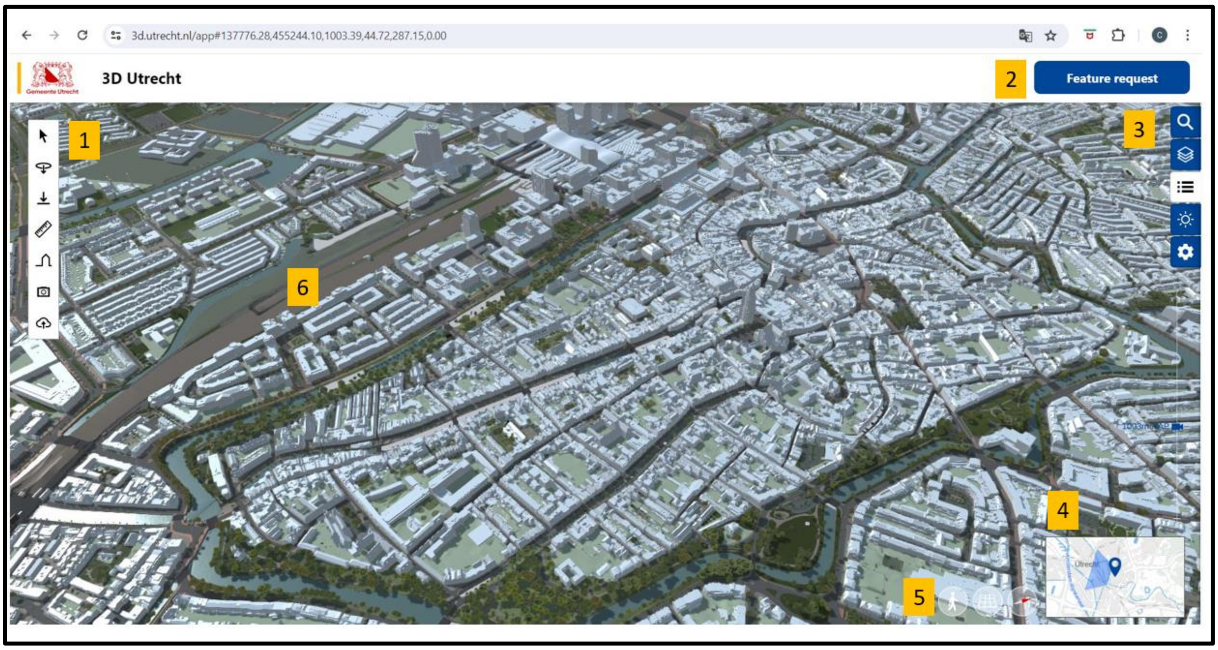

Figure 4: Main Page of 3D Utrecht. See table above

Both 3D Amsterdam and 3D Utrecht are populated by three main open datasets. The datasets being used are Basic registrations of addresses and buildings (3D BAG), Bomen

(Trees) and the Basic registration of large-scale topography (BGT). The 3DBAG is the national dataset of the buildings in the Netherlands. This dataset is developed by Technical University Delft and is the first open dataset featuring 3D building models, generated entirely automatically. It is a combination of both the BAG and the Current height file of the Netherlands (AHN). The AHN provides detailed height data. Next, the Bomen dataset, which is the registry of trees in the city. This is updated every three years and from this it is possible to check and monitor the status of each tree (i.e. have a collection of trees been removed, are trees in certain areas growing etc.). This data is captured using LiDAR measurements (a remote sensing method used to examine the surface of the Earth). Alongside this, the dataset BGT, captures information such as roads, cycle paths, waterways, and green space. The topographical surface is measured once a year by a private company that uses lidar scanning technology to create a point cloud survey. The linking between the UDT and the datasets automatically updates if any changes are made (i.e. if new buildings are added or a building is demolished). In addition to these three main datasets, there is also a dataset for the underground sewage pipes network (rioolnetwerk). Data from Kadaster, which includes critical information such as property boundaries, ownership information and land use is also integrated into both of these UDT platforms. This data is visualized in Unity. Unity is a cross-platform gaming engine that can create 3D and 2D visualisations. Both platforms contain an importer for API connections and web map services so users can add their own datasets. The code which is open source for both municipalities is stored on Github. From Github, the code can be managed and shared amongst different users. Additional features of the digital twin programme also include the key features shown below.

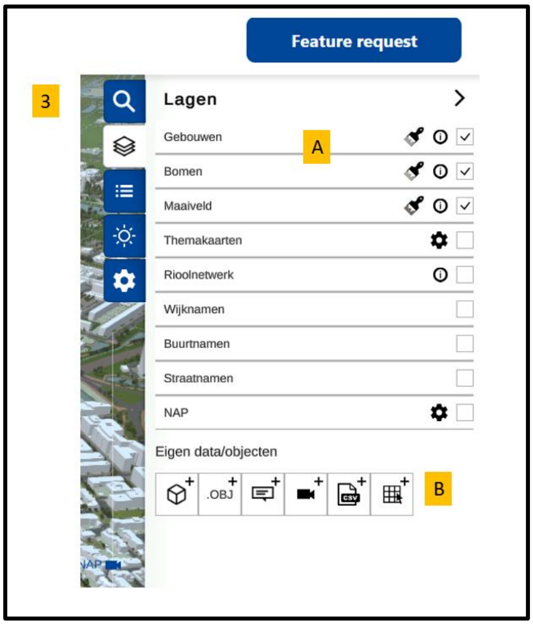

Figure 5: Key Features

3. Expandable palettes: Key features. Reference figure 5	
A	Layers listed in the UDT platform, include the three main datasets, themecards, sewage network, options to turn on and off contextual information (street and neighbourhood names), and NAP (national reference level for height on land is the Amsterdam Ordnance Datum)
B	Own data/objects – this provides users with the option to • Add a basic shape to the view • Import an OBJ file • Add annotation • Add camera location • Import CSV data files (coordinates, colour buildings, colour buildings with gradiant) • Tile Viewer (isolate specific area)

Table 3: Key Features Explained

The option to import custom data provides users with further versatility on the platform. As an illustration, an urban designer has the ability to submit a dataset that is necessary to showcase information that is required for a certain project.

Figure 6: Users have the option to zoom download a desired area of the city in .dxf or .dae format

Analytics within the UDT platforms

Each UDT platform also displays a series of standard theme cards in which the user can interact with some basic analytics (i.e. heat index and wind chill). These themes can be applied to the view displayed at the user's discretion. An example of this is shown below from 3D Utrecht. Proposals can be shared with other consultants/stakeholders but any manipulation to the view is specific to the user only and will be lost once the page is refreshed.

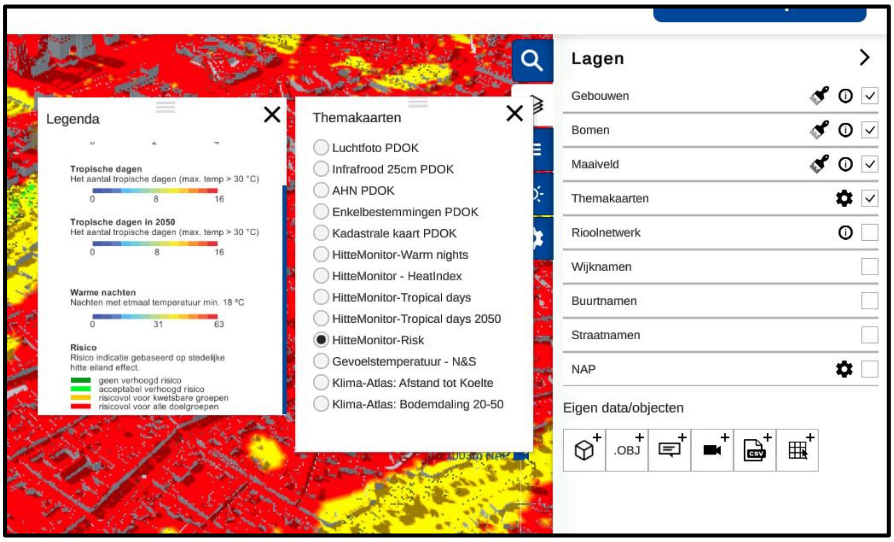

Figure 7: Extract from 3D Utecht showing option selected from the heat monitor risk. The legend on the right-hand side gives a risk indication based on urban heat island effect.

4.1.2 Case Analysis

Performance of the UDT

Throughout the interviews, questions were asked relating to the framework. Firstly, in response to dimension 1, when asked about the goals of the UDT, respondents indicated that the goals had not been met yet, primarily due to funding and data quality issues (interview, April 2024). In relation to funding, respondent 2 from Utrecht stated: ‘It was a struggle to find people who believed in the product (at the start), in order to get funding’ (interview, April 2024). In relation to the data, respondent 2 pointed out that, ‘the data is not perfect. It is open data, so there is always a risk’ (interview, April 2024). Data providers, such 3D BAG, are collaborating with the development team to address these issues. Furthermore, respondent 2 indicated that it is necessary for the Netherlands to have data validation on a national level. Respondent 7 from Amsterdam, had a mixed response when asked about the goal (interview, May 2024). Respondent 7 perceived it as a success to due to the high level of downloads on the platform. For example, many Architects and Urban Planners downloaded the 3D model of the city. In that sense, respondent 7 felt it was serving its purpose. However, respondent 7 did feel other goals set at the beginning of the UDT project were not achieved. Initially, he hoped it could have been used in participatory settings with citizens, for example. Respondent 7 indicated that this was not possible because the ‘mission and vision was not so clear’ (interview, May 2024). The development team wanted the platform to be available for multiple users but realistically this made ‘it difficult to come up with one tool and one aim as to why people should use it’ (interview, May 2024). This has led to a simplified aim for Netherlands 3D, which is the “visualization of data”. Furthermore, Respondent 2 stated that one of the goals of the development team is to include all the features that are in 3D Amsterdam, 3D Utrecht in Netherlands 3D by the end of this year.

Secondly, when asked questions in relation to trust, the majority of respondents reported that there are no privacy issues yet. This mainly because only open data is being used at the moment (Interview with respondent 1, April 2024). However, the development team are working on an identify access management (IAM) system. This may be needed, for example, if an urban planner from the municipality needs to work with private data using the UDT platform, for certain projects (Interview with respondent 2, April 2024). At the moment a link can be shared via the platform, but there are limited user privacy settings. Meaning the same link is accessible to everyone. Respondent 7 from Amsterdam, pointed out that his colleagues seem to trust the UDT at the moment but he has seen people lose interest in it once a certain functionality is missing (interview, May 2024). Thirdly, questions in relation to people were centred around the stakeholders and main users. Although, the 3D Amsterdam and 3D Utrecht are publicly available the UDTs are not used with citizens yet. Currently, the primary users are the city planning department at the municipalities. The UDT still needs to evolve as it is still an innovation and the transformation of this will take time. Respondent 1 explained that the technology is fast bit administration is slow and we are testing the programme internally first at smaller scale (interview, April 2024). Respondent 5 from Utrecht, pointed out that the actual users and the purpose of the UDT still needed to be determined. He added that as an urban planner, he finds it challenging to work with as there is a lot of triangulation from the point cloud scan (interview, May 2024). Lastly, questions related to the effectiveness of the UDT focused on planning processes were asked. The majority of respondents did not think the UDT was having any effect on planning processes yet. Respondent 5 stated, ‘it is more like a movement in the background’ (interview, May 2024). However, in contrast to this, three of the respondents felt the use of UDTs was having a positive effect on planning processes. Two of the respondents from Utrecht Municipality, believed it increased work speed and eliminated the need to use sketch-up (interviews, April 2024). A respondent from the municipality of Amsterdam was confident that the impact on planning would come with the development of Netherlands 3D (interview, May 2024).

Usability of the UDT

In response to dimension 2 of the framework, the interviewees were asked questions relating to the usability of UDT platform. These questions were posed to urban planners working at the municipalities of Amsterdam and Utrecht. Overall, only one respondent felt UDT would not be useful in urban planning but they mentioned they rarely interact with it. It was felt that the UDT could have more of an impact on urban planning but it is still missing some key functionalities. They also highlighted that as a result of this, the UDT does not align with their workflows. Giving the example that it is not easy to make changes, it is slow to use and the model has too much triangulation from the point cloud survey, (Interviews with respondents 9, 11 and 12, May 2024). On the other hand, a few of the respondents did think the UDT has great potential and it is useful for obtaining 3D contextual models (Interviews with respondents 14, 15 and 16, May 2024). The interviewees were also asked to respond to the following statements in relation to the UDT.

Statements:	Frequency of Use (per month)	Easy to Learn	Efficient to Use (productivity)	Easy to remember	Encounter Errors	Satisfying to use	Easy to use
Respondent 9	Sometimes	No	Disagree	Strongly Agree	Often	Neutral	Agree
Respondent 10	Never	Neutral	Disagree	Agree	Sometimes	Dissatisfied	Neutral
Respondent 11	Sometimes	Agree	Agree	Neutral	Often	Satisfied	Neutral
Respondent 12	Rarely	Agree	Agree	Neutral	Sometimes	Satisfied	Neutral
Respondent 13	Rarely	Neutral	Neutral	Agree	Sometimes	Satisfied	Neutral
Respondent 14	Rarely	Agree	Disagree	Agree	Sometimes	Dissatisfied	Agree
Respondent 15	Rarely	Strongly Agree	Agree	Agree	Rarely	Satisfied	Agree
Respondent 16	Sometimes	Agree	Disagree	Agree	Often	Neutral	Disagree

Table: Responses to usability statements given to Urban Planners

The case study shows that at this moment UDTs are being used at a low frequency which are perceived to be error prone. Therefore, ease of use is difficult to measure due to low adaptation. This can be related to the UDTs not being adaptable to urban planner’s typical day-to-day workflows and to the fact that key functionalities are missing.

4.2 Case Study B – Province of Utrecht

Background

The province of Utrecht have also been building their UDT platform called the GGO (Gezonde Gebiedsontwikkeling or healthy territory development) UDT for the last number of years. The province promotes their DT as a *'digital spatial planning support system'* and use this an instrument to provide a comprehensive understanding of intricate matters related to health and safety in digital 3D environments (Gezond Stedelijk Leven, 2023) . The GGO programme is centred around enhancing and safeguarding the well-being of the province by improving the physical living conditions. Essentially, the initiative assists Utrecht municipalities in implementing the concept of 'healthy & safe' in their policy and area development projects. The UDT is driven by a combination of visualization, signalling and calculations with a specific emphasis on different (policy) topics related to health and safety. For example, they see it as critical in looking at housing construction, climate adoption and both energy and mobility transition, In 2023, the province launched their digital GGO UDT Handbook Province of Utrecht which outlines this instrument in a very comprehensible manner (Provincie Utrecht, 2023b). The digital infrastructure for the GGO Template is provided by the software development company Tygron. The province built their customized GGO template based on Tygron. The datasets used are primarily the same as the data used in the UDT platforms of Amsterdam and Utrecht as these are open datasets (the BAG, AHN etc) (Tygron, 2023). Other datasets such as Risk Map and the NSL (National Cooperation Program on Air Quality) are also included. With the data and Tygron platform combined, the province has the capacity to run calculation models in order to simulate different scenarios. The visualization of these scenarios can be used to support decisions in relation to spatial policy, vision and planning. The system was developed by the Province of Utrecht in collaboration with the municipality of Amersfoort, Urban Sync and Tygron, as part of the DKH GSL innovation (Gezond Stedelijk Leven, 2023).

An overview of the GGO User Interface (Tygron)

Figure 8: An overview of the GGO Interface(Province Utrecht, 2023a).

GGO Tyron template: Five main components	
1	Functions (Functie) (a tab of four icons that have options in relation to building type, assign a function, energy supply, line elements (drawing tool, roads etc), demolition tool
2	Indicators (shows icons that represents a different theme/indicator. The figure below the icon shows the score for this theme)
3	Alerts (Alerts are shown as 3D pop-ups and will appear on screen when certain regulations or restrictions are exceeded. For example, where noise pollution may occur where a proposed construction site might be.
5	Overlays (choice of map layers that can be turned on and off. For example, open data map layers, such as the zoning plans may be turned on)
6	Bar chart (bar chart can show the overview of the scores per indicator/theme. For example, one theme could be air pollution. The values shown on the bar char range from 1-10. The calculations and their parameters are provided by the province and the Tygron engine calculates these scores. A score of least six under these indicators must be obtained for a plan to be approved.

4.2.1 Performance of the UDT

For this case analysis only dimension 1 was assessed as the province use their digital twin at a regional level with a number of expert users. When asked about the goals of the UDT, Respondent 3 said that the technology associated with the UDT working but it how does this integrate into your day-to-day processes. He explained they are facing organisational challenges, in that there needs to be a shift in mindset to use this technology. He also pointed out that the workflow is more of a circular rather than a linear process (i.e. moving away from using PDFs). Changes are dynamic and not static like they were before and people need to understand that the process has changed, (Interview with respondent 3, May 2024). Secondly, when asked questions in relation to trust, there seemed to be no issues in relation this according to the respondent. However, concerns were raised over the reliability of the data and the calculations used. Two examples were given relating to Floor Space Index calculations (FSI) and the 3-30-300 rule for greener cities where different organisations use different calculation methods and there is no standardization throughout the Netherlands. Thirdly, questions in relation to people were centred around the stakeholders and main users. At the moment the system is only used by expert users to run simulations (i.e. someone with the skills to carry out noise impact assessment). Finally, a key point that made in relation to the effectiveness was that using the UDT earlier in the planning process can improve project and policy outcomes. Both researcher and respondent 6 felt that there is a potential blind spot in the UDT industry narrative. When it comes to data and calculation power, respondent 6 emphasised that “three main technological drivers for dynamic UDTs are calculation power, wide availability of the data, and the exchangeability and interoperability of the data”. Respondent 4 highlighted that from a legal perspective, an UDT is needed which is archivable. For example, once a permit is issued, there needs to be a possibility that this moment is frozen and recorded in the algorithm registry.

The case study highlights the high performing capabilities of the technology and calculation power that can be integrated into UDTs. Emphasis should be placed on improving organizational change management and data calculation issues in order to optimize the capabilities of the UDT.

5. *Discussion*

Table 6: Comparative analysis of case studies

		Utrecht	**Amsterdam**	**Province of Utrecht**
	Criteria:			
Performance	Goal	Funding and issues with open data. Administration slow to change	Funding and data issues. City Model has high number of downloads. Initial goals/aims too broad.	Technology is working but administration slow to change.
	Trust	None yet	None yet	Data calculation issues
	People	City/Urban Planners	City/Urban Planners	Expert Users
	Effectiveness	No real effect on planning yet	No real effect on planning yet	No impact on planning yet, but can be very beneficial if used earlier in the planning process
Usability	Learnability	Mixed response see table 4	Mixed response see table 4	N/A
	Efficiency	Mixed response see table 4	Mixed response see table 4	N/A
	Memorability	Mixed response see table 4	Mixed response see table 4	N/A
	Errors	Mixed response see table 4	Mixed response see table 4	N/A
	Satisfaction	Mixed response see table 4	Mixed response see table 4	N/A
	Ease of Use	Mixed response see table 4	Mixed response see table 4	N/A

5.1 Case Comparison

This research develops a framework to assess the performance and usability of UDTs in urban planning practice. The framework is applied to analyse the case studies. Where applicable, a comparative analysis is conducted to understand the different use cases. The findings are highlighted in table 6. According to the findings of this research, similarities, differences and limitations were found amongst the case studies. One similarity is that both the province and the municipalities have yet to accomplish the main goals of their UDTs. However, these two cases are challenging to compare as these UDTs have different use cases. The difference in use cases is something that needs to be understood industry wide. Overall, the researcher discovered a significant amount of uncertainty and sometimes confusion regarding the UDT narrative throughout the research process. Therefore, it is crucial that there is a better industry-wide understanding. Perhaps by establishing the purpose of its usage from the beginning, an agreed industry wide maturity model or a more consistent narrative may prove beneficial.

Considering trust, there are no major obstacles around privacy and security. With the main reason that the data is open. However, as highlighted there is a risk that stakeholders could lose trust based on the lack of functionality of the platforms as well as data calculation issues. Open data, although easily available, has inherent risks in terms of quality and dependability. It is clear that emphasis needs to be placed on the significance of implementing uniform data standards. This is crucial in order to prevent errors in calculations, guarantee precise results and investment from future stakeholders. This could be strengthened by standardizing UDTs and data calculations. Tello et al (2021) highlight that there is a lack of standards in circulation for UDT.

In relation to the people (stakeholders), the two cases have different end users. This may extend to citizens with the development of Netherlands 3D. One strength, that the researcher observed was how each development team are collaborating with one another. The teams are working in a scrum environment (an agile project management framework). From the researcher's perspective there is a highly skilled selection of dedicated people working on these platforms who are continuously working on all aspects of the UDT programs to make improvements. The five parties mentioned earlier, have a shared vision and want all 342 municipalities to be able to 'plug-in' to 3D Netherlands. For this to become a successful reality it is paramount that the Dutch government provide financial support.

Interviewees did highlight that obtaining finance has been a major obstacle in the advancement of DT platforms

Finally in relation to the effectiveness, UDTs have yet to make a significant impact on planning processes. One additional key finding, that became apparent during the interviews is the growing concern of legal validation as UDTs evolve. Peters et al. (2022) urge that the legal framework needs to be modified to incorporate the use of UDTs into planning procedures, guaranteeing the archivability of data and the reliable recording and accessibility of permits and other legal documents. The capacity to archive is crucial for preserving the accuracy and traceability of planning choices and for meeting regulatory obligations.

5.2 Usability and Practical Recommendations

From a usability perspective, only the case of study of Amsterdam and Utrecht was assessed as the province use their UDT at a regional level with a number of expert users. However, this case study uncovered that there are usability issues that need to resolved for UDT platforms to be fully utilized by urban planners. Some urban planners found the platforms useful for basic modelling tasks but others said it did not align with their workflow and was too cumbersome to use. Other issues around interoperability were raised and examples were in relation to the import/export function needing to be streamlined. The issue of interoperability is a considerable barrier. The main challenge is in transferring data across different systems, which requires the use of standardised conversion techniques. (Haraguchi et al., 2024). Possible solutions to improve these issues would be to arrange regular focus groups amongst urban planners to UDTs can be developed to align closer with their workflows. Interoperability issues can be addressed by obtaining additional resources (via funding) to increase the resources on the development team.

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6. Conclusion

This paper assessed the performance and usability of UDTs in urban planning practice. The first objective was to develop an assessment framework based on the literature reviewed, Secondly, this framework was then applied to the selected case studies. Finally, the case studies were analysed and findings were presented. Undoubtedly, planners are currently confronted with the task of considering a larger number of spatial considerations than in the past. This work would be exceedingly difficult to do without the assistance of digital planning tools. Based on this research, it is evident that UDT is still in a phase of innovation and its influence in urban planning practice is limited at the moment but it has great potential to significantly alter urban planning processes. Within the Netherlands there is a very competent and dedicated community working towards a collective goal. Given a longer period of time for this study, the researcher would have liked to increase the sample size to include more UDT initiatives within the Netherlands. At times the researcher felt this was quite labour intensive as there was no existing research paradigm to operate from. Future research lines It would be worthwhile testing this framework out on further projects, and widening the scope to include more UDT platforms in the Netherlands. Nielsen's (1994) framework is a good analytic starting point, but it should be complemented by contextual variables, which describe the real-world situation of planning practice.

7. *References*

Barricelli, B. R., Casiraghi, E., & Fogli, D. (2019). A survey on digital twin: Definitions, characteristics, applications, and design implications. In *IEEE Access* (Vol. 7). Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/ACCESS.2019.2953499

Batty, M. (2007). *Planning Support Systems: Progress, Predictions, and Speculations on the Shape of Things to Come*. http://www.casa.ucl.ac.uk/

Batty, M. (2018). Digital twins. In *Environment and Planning B: Urban Analytics and City Science* (Vol. 45, Issue 5, pp. 817–820). SAGE Publications Ltd. https://doi.org/10.1177/2399808318796416

Batty, M., & Yang, W. (2022a). *A Digital Future for Planning Spatial Planning Reimagined*. www.digital4planning.com

Batty, M., & Yang, W. (2022b). *A Digital Future for Planning Spatial Planning Reimagined*. www.digital4planning.com

Christmann, G., & Schinagl, M. (2023). Digitalisation in everyday urban planning activities: Consequences for embodied practices, spatial knowledge, planning processes, and workplaces. *Journal of Urban Management*, *12*(2), 141–150. https://doi.org/10.1016/j.jum.2023.02.001

Couclelis, H. (2005). "Where has the Future Gone?" Rethinking the Role of Integrated Land-Use Models in Spatial Planning. *Environment and Planning A: Economy and Space*, *37*(8), 1353–1371. https://doi.org/10.1068/a3785

Eça De Matos, Á. (n.d.-a). *Digital Twins for Cities Citation for published version (APA)*. www.tue.nl/taverne

Eça De Matos, Á. (n.d.-b). *Digital Twins for Cities Citation for published version (APA)*. www.tue.nl/taverne

Ferré-Bigorra, J., Casals, M., & Gangolells, M. (2022). The adoption of urban digital twins. *Cities*, *131*, 103905. https://doi.org/10.1016/j.cities.2022.103905

Geertman, S. (2017). PSS: Beyond the implementation gap. *Transportation Research Part A: Policy and Practice*, *104*, 70–76. https://doi.org/10.1016/j.tra.2016.10.016

Geertman, S., & Stillwell, J. (2020a). Planning support science: challenges, themes and applications. In *Handbook of Planning Support Science*. Edward Elgar Publishing. https://doi.org/10.4337/9781788971089.00007

Geertman, S., & Stillwell, J. (2020b). Planning support science: Developments and challenges. *Environment and Planning B: Urban Analytics and City Science*, *47*(8), 1326–1342. https://doi.org/10.1177/2399808320936277

Geonovum. (n.d.-a). *https://www.geonovum.nl/about-us*. Geonovum. Retrieved June 24, 2024, from https://www.geonovum.nl/about-us

Geonovum. (n.d.-b). *Leidende principes digital twin*.

Gezond Stedelijk Leven. (2023, November 1). *Provincie Utrecht lanceert handboek GGO Digital Twin*.

Gil, J. (2020). *501 BUILT ENVIRONMENT VOL 46 NO 4 CITY INFORMATION MODELLING: A CONCEPTUAL FRAMEWORK FOR RESEARCH AND PRACTICE IN DIGITAL URBAN PLANNING*. www.smartnation.gov.sg/

Grieves, M., & Vickers, J. (2017). Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems. In *Transdisciplinary Perspectives on Complex Systems* (pp. 85–113). Springer International Publishing. https://doi.org/10.1007/978-3-319-38756-7_4

Grieves, M. W. (n.d.). *Virtually Intelligent Product Systems: Digital and Physical Twins*.

Grieves, M. W. (2019). Virtually Intelligent Product Systems: Digital and Physical Twins. In *Complex Systems Engineering: Theory and Practice* (pp. 175–200). American Institute of Aeronautics and Astronautics, Inc. https://doi.org/10.2514/5.9781624105654.0175.0200

Haraguchi, M., Funahashi, T., & Biljecki, F. (2024). Assessing governance implications of city digital twin technology: A maturity model approach. *Technological Forecasting and Social Change*, *204*. https://doi.org/10.1016/j.techfore.2024.123409

Harris, B. (1989). Beyond geographic information systems: Computers and the planning professional. *Journal of the American Planning Association*, *55*(1), 85–90. https://doi.org/10.1080/01944368908975408

Hersperger, A. M., Thurnheer-Wittenwiler, C., Tobias, S., Folvig, S., & Fertner, C. (2022). Digitalization in land-use planning: effects of digital plan data on efficiency, transparency and innovation. *European Planning Studies*, *30*(12), 2537–2553. https://doi.org/10.1080/09654313.2021.2016640

Jiang, H., Geertman, S., & Witte, P. (2022a). Planning First, Tools Second: Evaluating the Evolving Roles of Planning Support Systems in Urban Planning. *Journal of Urban Technology*, *29*(2), 55–77. https://doi.org/10.1080/10630732.2022.2047395

Jiang, H., Geertman, S., & Witte, P. (2022b). Planning First, Tools Second: Evaluating the Evolving Roles of Planning Support Systems in Urban Planning. *Journal of Urban Technology*, *29*(2), 55–77. https://doi.org/10.1080/10630732.2022.2047395

Lei, B., Janssen, P., Stoter, J., & Biljecki, F. (2023). Challenges of urban digital twins: A systematic review and a Delphi expert survey. *Automation in Construction*, *147*, 104716. https://doi.org/10.1016/j.autcon.2022.104716

Lin, Y. (2022). Social media for collaborative planning: A typology of support functions and challenges. *Cities*, *125*. https://doi.org/10.1016/j.cities.2022.103641

Lin, Y., & Benneker, K. (2022). Assessing collaborative planning and the added value of planning support apps in The Netherlands. *Environment and Planning B: Urban Analytics and City Science*, *49*(2), 391–410. https://doi.org/10.1177/23998083211009239

Lin, Y., Geertman, S., Witte, P., & Pinto, N. (n.d.). *Editorial paper: Digital Planning for Sustainable Urban Future (Draft, February 2024)*.

Lin, Y., Geertman, S., Witte, P., & Pinto, N. (2024). *Editorial paper: Digital Planning for Sustainable Urban Future (Draft, February 2024)*.

Nielsen, J. (1994). *Usability Engineering*. Morgan Kaufmann.

Nummi, P., Staffans, A., & Helenius, O. (2023). Digitalizing planning culture: A change towards information model-based planning in Finland. *Journal of Urban Management*, *12*(1), 44–56. https://doi.org/10.1016/j.jum.2022.12.001

Pelzer, P. (2017). Usefulness of planning support systems: A conceptual framework and an empirical illustration. *Transportation Research Part A: Policy and Practice*, *104*, 84–95. https://doi.org/10.1016/j.tra.2016.06.019

Peters, R., Smit, K., & Versendaal, J. (2022). *Validation Challenges for Legal Digital Twins in Dutch Climate Governance*. https://www.researchgate.net/publication/363739766

Provincie Utrecht. (2023a). *Aan de slag met de GGO module*.

Provincie Utrecht. (2023b). *Handboek GGO Digital Twin Provincie Utrecht*.

Ritvo, S. E., & Allison, R. S. (2017). Designing for the exceptional user: Nonhuman animal-computer interaction (ACI). *Computers in Human Behavior*, *70*, 222–233. https://doi.org/10.1016/j.chb.2016.12.062

Russo, P., Costabile, M. F., Lanzilotti, R., & Pettit, C. J. (2015). *Usability of Planning Support Systems: An Evaluation Framework* (pp. 337–353). https://doi.org/10.1007/978-3-319-18368-8_18

Sabri, S., & Witte, P. (2023a). Digital technologies in urban planning and urban management. *Journal of Urban Management*, *12*(1), 1–3. https://doi.org/10.1016/j.jum.2023.02.003

Sabri, S., & Witte, P. (2023b). Digital technologies in urban planning and urban management. *Journal of Urban Management*, *12*(1), 1–3. https://doi.org/10.1016/j.jum.2023.02.003

Schrotter, G., & Hürzeler, C. (2020). The Digital Twin of the City of Zurich for Urban Planning. *PFG – Journal of Photogrammetry, Remote Sensing and Geoinformation Science*, *88*(1), 99–112. https://doi.org/10.1007/s41064-020-00092-2

Tello, A. ;, & Degeler, V. (2021). *UvA-DARE (Digital Academic Repository) Digital Twins: An enabler for digital transformation*. https://doi.org/10.5281/zenodo.7647493

Tygron. (2023, January 27). *Tygron Geo Data*.

Zhang, L., Geertman, S., Hooimeijer, P., & Lin, Y. (2019a). The usefulness of a Web-based Participatory Planning Support System in Wuhan, China. *Computers, Environment and Urban Systems*, *74*, 208–217. https://doi.org/10.1016/j.compenvurbsys.2018.11.006

Zhang, L., Geertman, S., Hooimeijer, P., & Lin, Y. (2019b). The usefulness of a Web-based Participatory Planning Support System in Wuhan, China. *Computers, Environment and Urban Systems*, *74*, 208–217. https://doi.org/10.1016/j.compenvurbsys.2018.11.006