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City Digital Twin Concepts: A Vision for Community Participation †

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Abstract: Community participation is seen as a means of improving the effectiveness of planning to benefit the people by empowering the people. However, a novel approach to enable community participation during the planning stage of smart city infrastructure projects is lacking. Hence, the study presents an approach through the Smart City Digital Twin (SCDT) to support community participation during the planning stage of smart city infrastructure provision. The proposed system architecture comprises five key layers, namely: (a) an acquisition layer, (b) a transmission layer, (c) a digital modeling and data complementary layer, (d) a data/model integration layer, and (e) an application layer. The components of the architecture allow the SCDT to automatically re-create and predict the appearance of infrastructure after community feedback. Volunteered geographic information supported by an agent-based model empowers the process. Unlike other platforms, the architecture of the SCDT is developed to be open to the public. It can be utilized initially in the planning stage and continue throughout the construction stage of infrastructure development. Further, the SCDT would support urban planners, policymakers, and developers to make decisions by considering public needs, perceptions, attitudes, and interests.

Keywords: digital twin; digital twin cities; smart city; volunteered geographic information; game engines; unity 3D; 3D city; citizen engagement; construction; infrastructure

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1. Introduction

Smart and sustainable city concepts must be realized to deal with rising urbanization around the world [1]. During the process, special attention needs to be provided in planning the infrastructure by considering the needs and interests of the community [1,2]. Paul [3] argues that in the wider context, community participation may be viewed as an instrument of empowerment. Yet, in the context of smart cities, many recent efforts are frequently linked to different dimensions of the operation stage of the city, such as e-ticketing, smart street lights, and emission reduction [4]. According to Antonova and Slyvia [4], what is necessary is an information-rich city provided with intelligent models enabling the planning and design of city elements. Therefore, to plan and build infrastructure while involving the community, new tools are needed [5].

In the past several tools and methodologies to achieve community participation have been tested, all of which serve the fundamental principle that cities are made for the community and thus, communities should have a say in how they are planned [6]. According to Thoneick [6], specifically, recent studies focus mainly on two strands: either communicative methods as a way to increase the quality of participation or digital participation procedures facilitated by technological development. Digital participation methods have been used in participatory processes for the past 15 years [7]. Some of these technologies include volunteered geographic information (VGI), geographic information systems (GIS), virtual reality technologies (VR), computer vision (CV), and social media (SM) tools [7]. A Smart

City Digital Twin (SCDT) could integrate these technologies to create a novel and robust system for community participation during the planning stage of infrastructure projects. A digital twin enables changes and representation (e.g., future designs) and minimizes risks and associated costs in the real-world through collaborative planning and participation [8]. However, the complexity of the city and the interdependencies between its elements (humans, infrastructure, and technologies) have made it a challenge to integrate the elements and develop a platform enabling community engagement [9]. Dembski et al. [8] present urban digital twins for smart cities and citizens. The study integrates a mobile application connected to the urban digital twin so that the citizen can be involved in urban planning. However, the study provides limited opportunity to engage the community during the planning stage of the infrastructure developments, which is a key element in smart cities. White et al. [10] present a digital twin that can be used to engage citizens and get valuable feedback on key urban planning and policy decisions. However, citizen feedback has been collected through online forms. Hence, a gap prevails in terms of developing a SCDT that enables the community to share their expectations and needs at the planning stage of the infrastructure project. Condensing the above arguments, the research aim of the study is to develop a SCDT platform with the capacity to incorporate community feedback during the infrastructure planning stage. After integrating citizen feedback, the platform should be able to automatically display the changes to the planned version.

2. Research Process

Figure 1 presents the research process intended to be followed by this ongoing study to achieve the research aim.

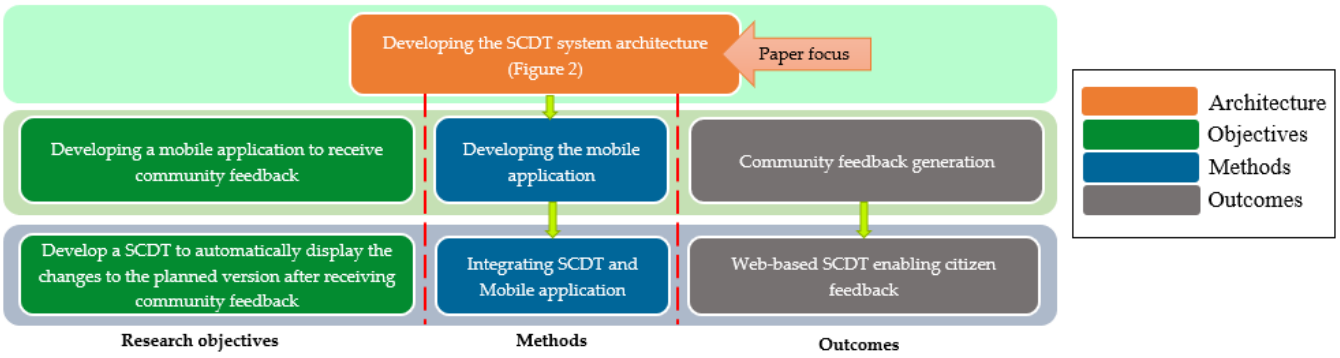

Figure 1. Research process.

Figure 1 shows three main steps, including developing SCDT architecture, developing the mobile application for collecting community feedback, and developing a SCDT platform to reflect changes to infrastructure based on community feedback. This paper presents the initial concept of the SCDT architecture, but the platform should be further developed in the next phase of this project.

3. Literature Analysis

The SCDT architecture developed by the study comprises five layers. The technologies and processes adopted by these layers are summarized in Table 1.

Table 1 provides a detailed explanation of the key layers of DT architecture. These layers when integrated systematically form the DT architecture, which is depicted in Figure 2.

Table 1. Composition of SCDT architecture encompassing technologies and functions.

SCDT Layers	Technologies/Processes	Sources	Functions
Data acquisition layer	OpenStreetMap of Sydney and Sydney 3D city model	[2,8,11]	To model terrain, building and planned infrastructure
	Digital elevation model (DEM) provided by regional authorities	[12,13]	
	Volunteered Geographic Information (VGI)	[14,15]	Incorporating feedback from community
Data transmission layer	Wireless local area network (WLAN) technology (WiFI)	[12,16]	Transforming collected data
Digital modeling and data complementary layer	Building Information Model (BIM)/ City Information Modelling (CIM)	[8,17]	Generate the background of the SCDT and related infrastructure
	Agent-based model	[14,16]	Re-create and predict the appearance of community satisfied infrastructure
Data/model integration layer	3 D city information simulation	[2,10,14,18]	Integrating the key components of the SCDT
	Change in infrastructure simulation	[10]	
	Community feedback simulation	[10]	
	Deep learning algorithms	[15,16]	Analyze data relevant to community needs, safety and environmental concerns to enable decision making
	Unity 3D game engine	[10,18]	Visualization platform
Application layer	Degree of community expectations, satisfactions, recommendations, changes to the planned version	[8,10]	Visualize expectations and whether developments are aligned with it
	Safety concerns/safety warnings	[10,12]	Tag places with an unsafe condition
	Environmental concerns	[18]	Tag places with environmental issues

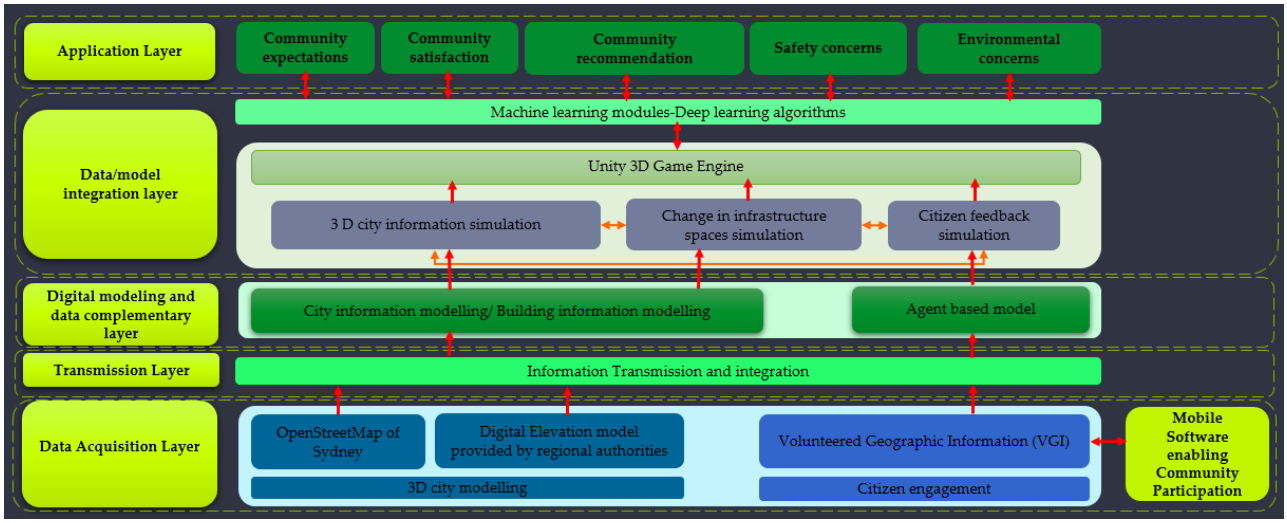

Figure 2. Smart City Digital Twin architecture.

3.1. Data Acquisition Layer

The data acquisition layer provides the foundation for gathering required data in an SCDT architecture [16]. The layer comprises OpenStreetMap, Sydney 3D city model, DEM

and VGI. OpenStreetMap and Sydney 3D city model provide the underlying map data. DEM, provided by regional authorities, acts as a source to simulate planned infrastructures within the SCDT platform. VGI, enabled through a mobile application, is to integrate community participation.

3.2. Data Transmission Layer

The transmission layer's main goal is to convert acquired data and send it to the higher layers [16]. According to Lu et al. [16], Wi-Fi is the most well-known and commonly utilized wireless local area network (WLAN) technology of all available options.

3.3. Digital Modeling and Data Complementary Layer

The digital modeling and data complementary layer display the digital model and add additional information to support the higher levels and connect the bottom layer [16]. The digital model can be displayed through CIM and BIM. Moreover, an agent-based model is used in the architecture to re-create and predict the appearance of infrastructure after community feedback.

3.4. Data/Model Integration Layer

The 3D city information simulation, change in infrastructure simulation and community feedback simulation are integrated into the model integration layer of SCDT architecture. Further, deep learning algorithms are used in the architecture to analyze and present the data for decision-making. The data visualization is performed in a game engine environment through the Unity3D software.

3.5. Application Layer

The final output of the SCDT is presented in this layer. This includes (a) the degree of community expectations, satisfaction, recommendations, and changes to the planned version; (b) safety concerns/safety warnings, and (c) environmental concerns.

4. Future Directions and Conclusions

The purpose of this study is to present a robust architecture of SCDT to enable community participation during the planning stage of infrastructure projects. Hence, the architecture comprises VGI that would facilitate the community to input their ideas and module the expected infrastructure through agent-based models. The next steps of this ongoing study are as follows:

(a) Develop a mobile application to enable community participation during the planning stage of urban infrastructure.
(b) Adopting the SCDT architecture (refer to Figure 2), the study proceeds further to develop DT simulations by integrating OpenStreetMap and the digital elevation model.

The SCDT would support urban planners, policymakers, and developers to make decisions by considering the public needs, perceptions, attitudes, and interests.

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