Smart DCU Digital Twin: Towards Smarter Universities

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***Abstract*—Although both smart city and digital twin are ambiguous and contested terms, there exists a co-creative link between the two. Theoretically, digital twin seems to be a sustainable digital solution for smart cities to achieve ideal city vision by digitization of physical urban spaces. This study investigates and informs the role, benefits and challenges in developing and deploying digital twin solution for efficient decision-making in infrastructure planning and management. This technology is experimented in a 3D cyberspace of Dublin City University, which is also one of the testbeds under the broader Smart Dublin umbrella. It is an ongoing project and expects to develop effective use-cases for monitoring present situations, multi-stakeholder collaboration and action research towards a responsive and adaptive campus environment.**

***Index Terms*—urban digital twin, smart campus, IoT devices, digital models, immersive technology.**

I. INTRODUCTION

Cities are becoming smarter every day by adopting new technology and data-driven solutions. *'Smart City'* being a contested term strategically improves the quality of life and well-being of its citizens, promote urban sustainability, and ensure inclusive socioeconomic growth [1], [2]. With emerging technology, it is possible to transform a physical built-up environment into an interactive and interconnected digital system for easy virtual monitoring and well-coordinated stakeholder collaboration. However, how much these systems can be responsive for dealing with complex urban challenges needs to be explored. Just like smart cities, digital twin is an ongoing trend of digital transformation coupled with advanced 3D modeling technology, IoT devices, 5G communication networks, blockchain security models, edge computing and AI driven urban simulations [3].

While the concept of digital twins has existed for decades, it primarily refers to mirroring physical system(s) and process(es) to their digital counterparts via linking layers of information throughout their lifecycle [4]. According to some of the estimates cited in reference [5], the global digital twin market is expected to increase by almost 90% within 6 years of timeframe between 2019 and 2025. This new emerging technology offers possibilities of advancement from traditional 3D city models to AI driven living city models and simulate urban infrastructure system(s), improve city management process(es) and exploring new user-interfaces between communities, public authorities, service providers and researchers [3]. While in a regular city, city elements aren't expected to be digitally connected, in a smart city, they are digitally connected, and interactions take place between them and different users [6].

While digital twin technology is advancing at a faster pace, research on urban digital twins is still in infancy [4], [6]. The future of city users is still limited to theoretical assumptions and yet to be discovered in realistic and tangible applications. This study aims to discuss the approach used for developing a digital twin of Dublin City University (DCU) campus located

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in Dublin, Ireland and further discusses its potential benefits. This paper is structured into six sections – section 2 covers the literature review pertaining to the concept of urban digital twins, section 3 highlights the case of Smart DCU campus, section 4 discusses the methods and materials used for the study and section 5 covers the findings of the study. Since this study is also work in progress, the next steps, future scope and limitations of this work are covered in the conclusion section.

II. DIGITAL TWINS FOR URBAN PLANNING

A. *Concept of Urban Digital Twins*

Digital twins are widely defined as a virtual representation of a physical asset or system or process capable of representing real-time information and simulating future scenarios [5], [6]. However, the concept has different interpretations based on its application domains, but the general framework can be simplified by understanding three major elements i.e., physical space, virtual environment and information exchange between the two. Based on their integration levels, they can be further classified as digital models with lowest integration levels and digital twins with highest integration levels as graphically depicted in Fig. 1. In urban planning, 3D digital models are visual representations of a physical asset which can be a building, city, or infrastructure facility. Building Information Modeling (BIM) paradigm, however, is a more integrated process of 3D modeling which facilitates building asset management for improved collaboration and optimized design.

There is even a thinner line of distinction between the concepts of digital shadows and twins. While both have an automatic information flow between the physical and digital systems, the direction of this data transfer distinguishes them. Digital shadows are unidirectional where the virtual model receives information from the physical world from sensors whereas digital twins, in real essence, are bidirectional and thus information collected from the physical systems are realized and analyzed by the data processor for instructing changes in the physical system using actuators in the real time. If these are further enhanced by linking them with their spatial information, then they can enhance the overall urban environment [5].

B. *Potential Outcomes*

Digital twin technology enables new dimensions on re-imagined experience of city users in the city's future vision [6]. It is expected that a city digital twin can result in better citizen participation and stakeholder collaboration by realizing the potential of real time remote monitoring for effective decision-making and prompt responses [3]. Urban application of this tool is to understand the city dynamics, develop 'what-if' scenarios, and assess them in advance to optimize the efficiency and impact of new projects [7]. Literature review suggests several potential outcomes of digital twins being used for urban planning and infrastructure management with some being highlighted in Fig. 2. Reference [8] generated some use cases of digital twins using examples of Dublin city and demonstrated how they can be harnessed to perform urban simulations in real time on 3D city model. Another advanced application of digital twins at urban scale can be net-zero energy building, cognitive digital twins and living city information management systems.

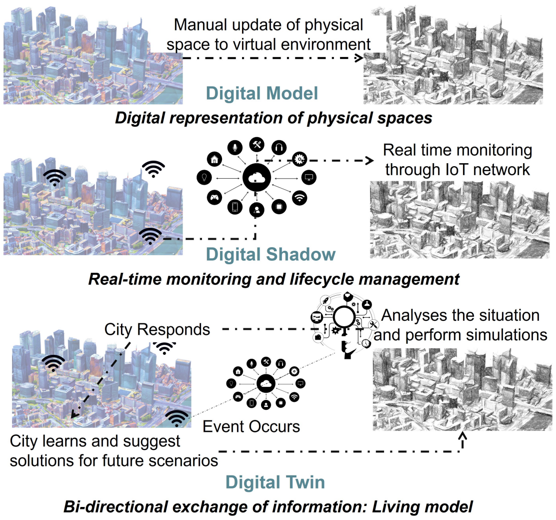

Fig. 1. Distinction based on level of data integration.

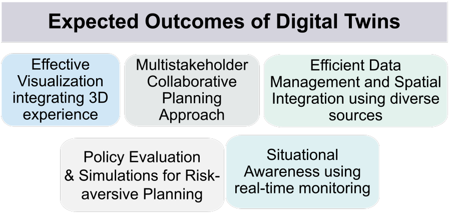

Fig. 2. Expected Outcomes of Digital Twins.

C. *Key Enablers and Implementation Challenges*

There are many ways through which organizations have started building the digital twins of real-life cities, starting by integrating various information layers from diverse data sources in the base 3D digital model. The real challenge has been to diagnose and analyze this massive operational urban data while balancing interests of all stakeholders. According to reference [7], a digital twin deprived of sensors and real-time updates between physical and virtual space are mere traditional digital 3D models of a complex system, process or asset. However, till date, 3D models with real-time component and simulation capabilities are the preferred approach [5].

Besides technological enablers such as IoT sensors, 5G network, edge computing etc, there are many non-technical enablers of digital twins such as governance framework, interoperability standards, skilled staff, etc. Some of the common challenges for the implementation of digital twins are data management, data acquisition, advanced processing capabilities, trained staff, data storage, standard data sharing frameworks, lack of open data, accessibility for public and other stakeholders, interoperability between platforms, digital privacy and scaling pilots to city scale.

D. Smart Universities as Pilot Studies

Smart digital twin campus is appearing to be a popular application of digital twin technology for creating a virtual replica of a physical campus environment. The research in this area is mostly focused on developing intelligent campus systems based on digital twin technology [9] and using IoT networks and cloud computing to transform university spaces into information sources for intelligent decision-making processes [10]. This campus digital twin can be used to manage energy consumption, improve navigation, and provide an augmented reality experience for students, staff and faculty [9], [11]. The University of Glasgow can be seen a potential example which is also focusing on transforming their physical and digital environment to create a Smart Campus - an environment that is open, connected, adaptable and sustainable [12]. The Kaunas University of Technology (KTU) Smart Campus located in Kaunas, Lithuania is another example which aims to create an innovative and sustainable environment for students and staff by using modern technologies and solutions [13]. The project includes the development of a smart energy system, smart lighting system, smart parking system, smart waste management system and many more.

III. CASE OF SMART DCU

Smart Dublin is an initiative launched by the four local authorities in the Dublin region with an aim to future-proof the region by trialing, testing and scaling innovative solutions to tackle issues ranging from climate change to increasing digital divide. It follows a Quadruple helix model of open innovation and builds collaborative partnerships between technology providers, academia, government agencies and people to enhance overall quality of life by co-creating solutions. The programme uses a district (testbed) approach for developing and deploying proof of concept solutions to local challenges. These are strategically selected locations where innovation projects can be fast-tracked without much of hindrance. Smart Docklands was the first smart district under the smart Dublin umbrella launched in 2018 further followed by the launch of Smart DCU, Smart Dun Laoghaire, Smart Balbriggan and Smart D8.

DCU being one of the leading universities in Ireland has many opportunities for innovation and technological solutions. Smart DCU is the collaborative effort between the Dublin City Council (DCC) and research centers viz. Insight, Enable and DCU Alpha, which was launched in July, 2019 to develop, trial and test leading technological solutions in a microcosmic representation of a city environment with core infrastructure such as roads, housing, restaurants, workplaces, shopping and recreational facilities. Digital twin of Smart DCU is one of the pioneering partnership launched in 2021 between Insight SFI Research Centre for Data Analytics at DCU, DCC, Bentley Systems, and KTU. The focus of this project is to investigate the potential of digital twin technology and immersive solutions for real-time visualization of intricate environmental and contextual data and assess its impact on key stakeholders and the public, which comprises staff, students, faculty and visitors in this case.

The aim of this project is to develop Ireland's first higher education digital campus, with the first phase of rapid prototyping a proof of concept that focused on developing a 3D version of the university campus, both indoors and outdoors, overlaid with some light IoT data and 360 degree views. Its potential was soon realized by the DCU Estates, leading to advancement of the ambitious second phase of developing it into a well-functioning digital twin of the campus. The second phase is still ongoing and intends to incorporate AI-driven analysis of real-time data gathered from IoT sensors, including footfall, campus occupancy, waste management, congestion points, energy and water usage, and other crucial data that can inform planning and infrastructure management. It is also proposed to experiment with the emerging immersive technologies for the purpose of user engagement.

IV. METHODS AND MATERIALS

The methodology to build digital twin of the campus(es) is primarily based on the Bentley ecosystem. As shown in Fig. 3, raw data is acquired using the drone surveys, which is then processed and transformed to a digital 3D model using Bentley's Context Capture platform (CC) [1]. These models can be further communicated using different tools based on the target audience and purpose of digital twin. This study has explored Bentley's OpenCities planner [2] for publishing the 3D model of the campus along with some sensors data and 360° views. Also, data from sensors can be streamed via linking URL from 3rd party dashboards or streamed and stored on the Bentley's 4D Analytics (4DA) platform [3]. Bentley's iTwin Platform and Unreal engine are also being explored to create a more immersive experience for different users. This section covers the approach used for building digital twin in detail.

A. Data acquisition

This work uses drone photography captured by DJI Mavic 2 pro to create the digital models also known as reality data. The dataset was created by executing drone surveys on each of the four campuses that belongs to DCU. In order to capture most of the campuses, the drone survey was executed as a grid shape at an altitude of 30 to 40 metres using the DJI Ground

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[1] https://www.bentley.com/software/contextcapture/

[2] https://www.bentley.com/software/opencities-planner/

[3] https://www.bentley.com/software/assetwise-4d-analytics/

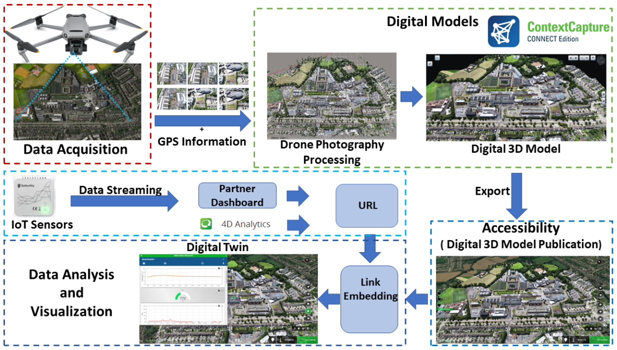
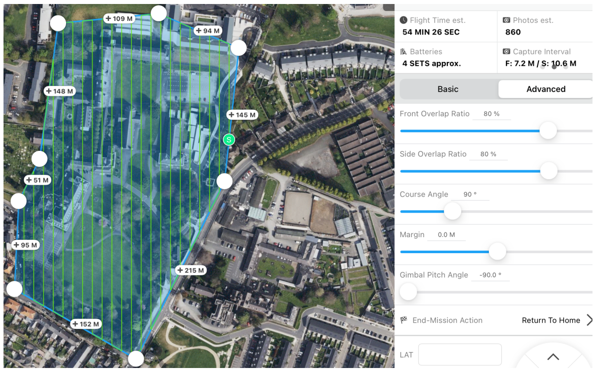


Fig. 3. Digital Twin Methodology.

Station Pro app, as shown in Fig. 4. DCU has four campuses, each survey took about 2 to 3 hours and each dataset is composed of the following number of images: Glasnevin: 1,749. All Hallows: 1,723. St. Patrick's: 893. Alpha: 1,267.



Flight Time est. 54 MIN 26 SEC
Photos est. 860
Batteries 4 SETS approx.
Capture Interval F: 7.2 M / S: 10.6 M
Front Overlap Ratio 80 %
Side Overlap Ratio 80 %
Course Angle 90 °
Margin 0.0 M
Gimbal Pitch Angle -90.0 °
End-Mission Action Return To Home

Fig. 4. Drone survey using DJI Ground Station Pro.

B. Digital Models

Context Capture allows the processing of images along with their GPS position to create digital models. These models can be reality data, point clouds and can be exported in different formats according to the final use. At this point, this model is only a digital asset resembling an object from the physical world, which in this case is a DCU campus, Fig. 5.

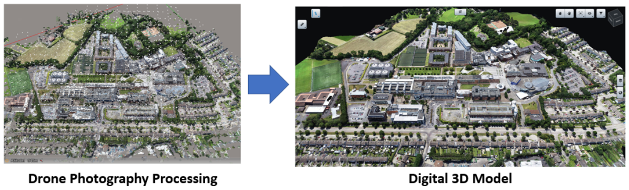


Fig. 5. Context Capture: from drone imagery to digital assets.

C. Accessibility

In order to address the issues of accessibility and shareability, the options below were explored.

OpenCities Planner. A cloud-based platform developed by Bentley that allows for the management and organization of digital assets as well as provides an intuitive space to create projects based on those assets. It is a quicker and easier option to showcase any digital asset by only creating and sharing a URL link. Regarding IoT sensor data, this tool provided a function called link embedding that allows for inserting a public link to external web pages or dashboards. This is useful since each partner that wants to join the project will be able to showcase its data by only sharing their dashboards.

iTwin Platform. Another cloud-based platform developed by Bentley that provides some more flexible functionalities compared to OpenCities Planner. It provides an environment where you can share your digital assets quicker and a direct link between the local assets and the cloud-based platform can be established. For instance, a digital model could be directly exported from Context Capture to an iTwin project as well as make it available to other collaborators. This tool enables a more flexible environment to stream and visualize IoT sensor data. It provides as well a developer platform where you can create your own functionalities on top of your digital assets for better visualization, processing, and analysis of data.

Unreal Engine. This tool is explored for a much accessible and immersive visualization experience. It not only manages multiple digital asset formats along with streaming of IoT sensor data, but also allows exporting of projects to different environments such as mobile phones, virtual reality, and operating systems.

D. IoT Sensors

Digital models created from CC is only a digital asset resembling a campus, but it can't be called a digital twin unless there is an exchange of data with the physical world. That's why, following sensors enable real-time monitoring:

- WIA: forty sensors reporting room occupancy, temperature, noise and illumination level.
- CIVIC: three radar sensors streaming the number of vehicles, pedestrians and cyclists that enter or exit the three main entrances of the Glasnevin Campus.
- HiData: two sensors reporting the number of people, noise and illumination level in a room using computer vision and deep learning techniques.
- Bigbelly: four smart-bins within the Glasnevin Campus providing solid waste collection information.

E. Data Analysis and Visualization

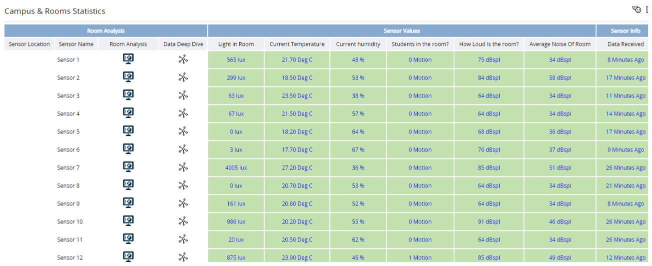
Each sensor device partner has their own APIs to stream and visualize their data on a dashboard. However, this way of managing data can be seen as siloed information, since they do not communicate with each other. To address this challenge, Bentley's 4DA is used to stream, integrate, analyse and store data from the devices in a single platform. 4DA allows creation of custom visualization of data along with easy integration into digital models. It also provides an environment to develop and execute predictive analytic models.

V. RESULTS AND DISCUSSION

The digital twin of DCU campus is a step ahead from the traditional 3D models of buildings, cities and urban environments. The case of smart DCU digital twin demonstrates its application for real-time monitoring, data management with spatially integrated information, collaborative planning, new ways of visualizing information and AI driven urban simulations. This section briefly discusses the findings.

A. *Efficient Data Management and Analysis*

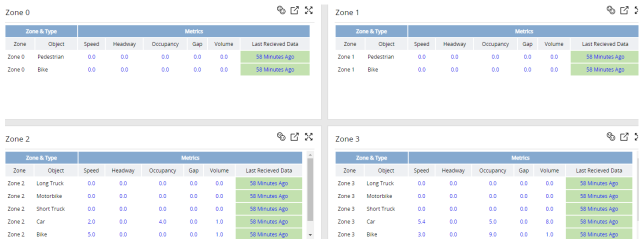
4DA data integration allows to stream, store and fuse data from different sensors creating a common environment where all the sensors can be accessed in real time. From the current partners, we have successfully integrated their data on the 4DA tool for WIA and CIVIC as presented in Fig. 6 and Fig. 7 respectively. 4DA allows data processing, from something as simple as creating alarms based on certain limit set by the user, to more advance analysis such as fusing sensor data located in different places in a building or a whole campus. For instance, if several sensors are placed in one room and the user wants to know the average temperature of that room, this can be easily calculated by 4DA.



Campus & Rooms Statistics

Room Analysis				Sensor Values						Sensor Info
Sensor Location	Sensor Name	Room Analysis	Data Deep Dive	Light in Room	Current Temperature	Current humidity	Students in the room?	How Loud Is the room?	Average Noise Of Room	Data Received
	Sensor 1	🖥	✻	565 lux	21.70 Deg C	48 %	0 Motion	75 dBspl	34 dBspl	8 Minutes Ago
	Sensor 2	🖥	✻	299 lux	18.50 Deg C	53 %	0 Motion	84 dBspl	58 dBspl	17 Minutes Ago
	Sensor 3	🖥	✻	63 lux	23.50 Deg C	38 %	0 Motion	64 dBspl	34 dBspl	11 Minutes Ago
	Sensor 4	🖥	✻	67 lux	21.50 Deg C	57 %	0 Motion	64 dBspl	34 dBspl	14 Minutes Ago
	Sensor 5	🖥	✻	0 lux	18.20 Deg C	64 %	0 Motion	68 dBspl	36 dBspl	17 Minutes Ago
	Sensor 6	🖥	✻	3 lux	17.70 Deg C	67 %	0 Motion	76 dBspl	37 dBspl	9 Minutes Ago
	Sensor 7	🖥	✻	4005 lux	27.20 Deg C	36 %	0 Motion	85 dBspl	51 dBspl	26 Minutes Ago
	Sensor 8	🖥	✻	0 lux	20.70 Deg C	53 %	0 Motion	64 dBspl	34 dBspl	21 Minutes Ago
	Sensor 9	🖥	✻	161 lux	20.80 Deg C	52 %	0 Motion	64 dBspl	34 dBspl	8 Minutes Ago
	Sensor 10	🖥	✻	986 lux	20.20 Deg C	55 %	0 Motion	91 dBspl	46 dBspl	26 Minutes Ago
	Sensor 11	🖥	✻	20 lux	20.50 Deg C	62 %	0 Motion	64 dBspl	34 dBspl	26 Minutes Ago
	Sensor 12	🖥	✻	875 lux	23.90 Deg C	46 %	1 Motion	85 dBspl	49 dBspl	12 Minutes Ago

Fig. 6. WIA: 40 sensors reporting light, temperature, humidity and noise level.



Zone 0

Zone & Type		Metrics					
Zone	Object	Speed	Headway	Occupancy	Gap	Volume	Last Recieved Data
Zone 0	Pedestrian	0.0	0.0	0.0	0.0	0.0	58 Minutes Ago
Zone 0	Bike	0.0	0.0	0.0	0.0	0.0	58 Minutes Ago

Zone 1

Zone & Type		Metrics					
Zone	Object	Speed	Headway	Occupancy	Gap	Volume	Last Recieved Data
Zone 1	Pedestrian	0.0	0.0	0.0	0.0	0.0	58 Minutes Ago
Zone 1	Bike	0.0	0.0	0.0	0.0	0.0	58 Minutes Ago

Zone 2

Zone & Type		Metrics					
Zone	Object	Speed	Headway	Occupancy	Gap	Volume	Last Recieved Data
Zone 2	Long Truck	0.0	0.0	0.0	0.0	0.0	58 Minutes Ago
Zone 2	Motorbike	0.0	0.0	0.0	0.0	0.0	58 Minutes Ago
Zone 2	Short Truck	0.0	0.0	0.0	0.0	0.0	58 Minutes Ago
Zone 2	Car	2.0	0.0	4.0	0.0	1.0	58 Minutes Ago
Zone 2	Bike	5.0	0.0	0.0	0.0	1.0	58 Minutes Ago

Zone 3

Zone & Type		Metrics					
Zone	Object	Speed	Headway	Occupancy	Gap	Volume	Last Recieved Data
Zone 3	Long Truck	0.0	0.0	0.0	0.0	0.0	58 Minutes Ago
Zone 3	Motorbike	0.0	0.0	0.0	0.0	0.0	58 Minutes Ago
Zone 3	Short Truck	0.0	0.0	0.0	0.0	0.0	58 Minutes Ago
Zone 3	Car	5.4	0.0	5.0	0.0	8.0	58 Minutes Ago
Zone 3	Bike	3.0	0.0	9.0	0.0	1.0	58 Minutes Ago

Fig. 7. CIVIC: 3 radar sensor placed at the 3 main entrances of DCU Glasnevin campus.

B. *Collaborative Planning*

The presented methodology has detected and determined the inputs and outputs for each layer of the digital twin. This results in a flexible methodology allowing multiple stakeholders and partners to work simultaneously and ensure easy operation and integration in any stage of the digital twin development. As the digital twin is constituted by different layers of information, any modifications can be presented to the public and stakeholders for their feedback and promote engagement at any stage of twin lifecycle.

C. *Visualization and Situational Awareness*

Dublin City University has 4 campuses, using the mentioned methodology we created a digital model for each of them as shown in Fig. 8. Besides the standard visualization provided by OpenCities Planner and iTwin Platform as show in Fig. 9, we are also exploring UnReal Engine for a more immerse experience. At this stage, we have done some basic integration of reality data, BIMs and basic visualization for air quality, as presented in Fig. 10.

Fig. 8. Dublin City University Campuses

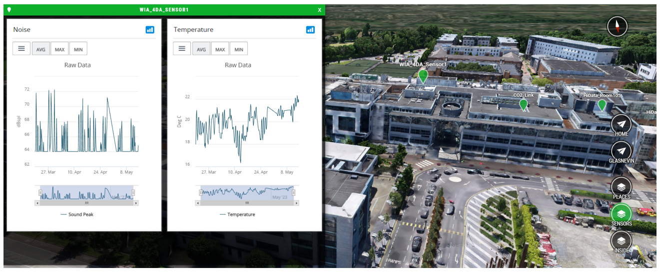


Fig. 9. WIA sensor integrated into digital model of the Glasnevin Campus.

VI. CONCLUSION

Recently, there has been a shift to model entire neighborhoods or city-scale urban environments as digital replicas for

Fig. 10. Unreal Engine: indoor and outdoor air quality visualization.

their efficient management. The purpose to build these urban digital twins are to improve quality of life, city services, local governance, mobility, and environmental conditions. There has already been a notable increase in cities employing digital twins for decision-making. This include examples from Singapore, Wellington, Zürich, Helsinki, Amsterdam, Utrecht, Flanders, Herrenberg, Dublin, Valencia etc. Gaming engines such as Unity and Unreal along with private enterprises such as Dassault, Bentley and Microsoft are also becoming popular in providing cloud-based services for visualization, analysis, and data integration in a geo-spatial environment. However, digital twins are more than digital representations and are expected to be intelligent systems with bi-directional information exchange.

This study takes into consideration the role of digital twins in future urban planning and has experimented it in a campus environment of Smart DCU testbed. The first phase of the study led to the development of reality mesh models of four DCU campuses in the Dublin region using drone imagery. These 3D models were overlaid with light IoT data and 360 views of some relevant points-of-interest on the Bentley's OpenCities Planner. Currently, this project is in its second phase of research and intends to advance the analytical and interaction component of these digital models. Several real-time monitoring IoT devices are placed in the campus and use-cases are being explored for better decision-making by the campus management authorities. Unreal gaming engine is also being explored to better engage with students, staff, faculty and visitors on the campus using immersive technology.

Since this is work in progress, the project expects to develop use-cases for facilities management, real-time traffic monitoring, accessible routing within buildings, occupancy management and efficient building operations. Future researchers can adopt the methodology applied for this study to develop their own digital twin models by gradual integration of data layers. The method adopted for data capture was rapid and could be easily explored. However, the real challenge is to scale this technology to a city environment where the process becomes even more complex with multiple city departments, lack of standard data models, inaccurate information sources, interoperability issues, lack of trained staff, and bureaucratic challenges.

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