3D Dashboard Development for Smart Campus using ESRI Enterprise & Cesium Platforms

Abstract. Smart campus development is fundamentally a response to the campus's increasingly dynamic use and the strain on various resources such as energy, financial, and human resources. Integrating data with advanced visualization and simulation capabilities in a digital twin is critical for developing a quasi-real-time, context-aware decision-support platform for smart campus management that can serve as a testbed for smart cities. This paper presents the procedures, comparisons, and challenges of creating a 3D dashboard for visualizing and simulating campus infrastructure using ESRI and Cesium technologies. The dashboard development shows that ESRI provides more widgets, functionalities, and an easy-to-use API for dashboard development, compared to Cesium, an open-source library that provides fast 3D-Tile transmission.

Keywords: Smart Campus, ESRI, Cesium, Digital Twin, GIS Dashboard.

1. Introduction

Smart campuses are commonly in a similar socioeconomic, environmental, and geographical context to smart cities, which means they share similar infrastructures, communication channels, services, transportation networks, and even challenges and needs [1]. In addition, due to constraints and the COVID-19 epidemic, universities' digital transition accelerated in 2020 through information and communication technologies (ICT), digital management, and online learning [2]. Along with technology, the future university must address the needs of its stakeholders and promote a better quality of life, which is the goal of smart campuses [3].

A smart campus uses cutting-edge network technology and internet-connected gadgets to deliver engaging and supporting experiences. Universities can leverage their IT infrastructure to make data-driven decisions to enhance security and make the most of their resources by connecting people, devices, and apps. Numerous research has been conducted in this field due to the multidisciplinary nature of smart campus research. The development of the smart campus is only possible with a deep fusion of innovative technologies (including cloud computing, IoT, AR, and AI) and educational systems [4]. The most important aspect of the campus smart program is the infrastructure accessed through interactive dashboards [5].

In this research, Toronto Metropolitan University (TMU), located at the downtown core of Toronto, has been selected as a case study campus. There are many types of study places in the various buildings of the university. The TMU campus has 51 buildings with multiple uses, including libraries, classrooms, labs, and faculty offices. The developed dashboard includes the 3D visualization of all campus buildings, TMU facilities, and their infrastructures, including water pipe and sewer systems. Each campus building was equipped with various smart meters for utility consumption monitoring which is accessible through the developed dashboard. In addition, a leak detection approach has been developed and integrated into the dashboard for water leak detection. ESRI and Cesium technologies have been used to generate a replica of the dashboard, allowing us to enhance its usability, accessibility, and compatibility with multiple tools and applications for integrating large and complex 3D datasets.

2. Methodology

For dashboard development, two different 3D visualization technologies have been investigated. One was the ESRI Multipatch data format, a GIS industry standard developed by ESRI in 1997 used to define the exterior shell representation for 3D objects, and the other was Cesium 3D tile format. In this Section, the process and procedures for dashboard development are described. Section 2.1 describes the source of datasets that have been used for dashboard development and the process of data fusion and data conversion. Section 2.2. demonstrates the developed water-leak detection approach, which has been integrated into the dashboard for real-time leak detection Section 2.3 discusses the overall dashboard system architecture using both ESRI and Cesium technologies.

2.1. Data

The following table represents the sources of different datasets used for dashboard development.

Table 1: Dataset used for dashboard development

Data Name	Type	Source(s)
3D Building Data	Multipatch	City of Toronto Open Data Portal
Building Footprint	Shapefile	City of Toronto Open Data Portal, DMTI Spatial Inc.
Building Footprint	GeoJSON	OpenStreetMap
Address Points	Shapefile	City of Toronto Open Data Portal

Local Delivery Unit Region	Shapefile	DMTI Spatial Inc.
Sewer System	Shapefile	City of Toronto
Water Network	Shapefile	City of Toronto Engineering office and TMU facility management office
TMU Facilities	GeoJSON	Scraped from the TMU website
Sidewalk	Shapefile	City of Toronto Open Data Portal
Street network	Shapefile	DMTI Spatial Inc.

Geospatial Data Fusion and Conversion. The required data for the developed dashboard has been collected from various resources, including the City of Toronto, the TMU facility management office and websites. FME software has been utilized for the required ETL (Extracting, Transforming, and Loading) process, including extracting features from various documents and transforming them to the desired format (i.e., shapefiles or Cesium tiles). Then, The GIS data was imported into the ArcGIS Pro software to overlay and reproject them to a proper and common spatial referencing system. Data fusion and conversion tasks are described below for each dashboard development.

- ESRI-based Dashboard:
  - To enrich the building information, attribute information of various building datasets has been integrated into the Multipatch data. Around 80%-85% of building footprints in different datasets were perfectly matched with the Multipatch dataset. The building attribute data was joined spatially using identical footprint conditions to join the attribute of various datasets. Due to the systematic datum shift in the OSM building, the distance between the centroid of OSM and Multipatch footprints has been compared for joining attribute data.
  - To 3D visualize the sewer and water pipe network, the 2D network has been transformed to 3D using their pipe attribute and exported to Multipatch data type. The water network dataset was from different sources in different file formats, including DWG and PDF. To integrate the data from other sources into a shapefile format, FME software has been utilized. Figure 1 illustrates the data conversion and transformation process for the utility network.

Fig. 1. ETL process for data conversion and transformation

- Cesium-based Dashboard:
  - To develop the Cesium-based dashboard, 3D building Multipatch data has been transformed to the CityGML format and then 3D tiles format for 3D visualization (see Figure 2). CityGML is an open-source data format that separates the data into various LoDs. Multipatch data consider each building as one object without differentiating different classes for different building components, including walls, roofs, ground etc. Therefore, for CityGML transformation, each building is considered a single object and mapped under the "CityObjectMember" class.

Fig. 2. Multipatch to the Cesium 3D tile transformation process

2.2. Leak detection

Automatic Meter readings (AMR) obtained from flow sensors installed in different buildings of the University are used to develop a near-real-time leak detection model. The AMRs are available at 15-minute intervals and provide information on the water consumption of the campus buildings. A data-driven classification based on clustering is performed to detect the anomaly in water consumption. The water consumption pattern for the campus building is developed, and any variation from the regular water use is considered an anomaly in water consumption. Anomalies are initially detected, including global anomalies due to an overall increase in water consumption across the campus and local anomalies due to leaks/bursts. The identified leaks are localized based on the standard deviation approach. Once a leak is identified, the model warns the campus facility management office to provide the building-level location of the leak.

2.3. 3D Dashboard System Architecture

To develop the dashboard, two different technologies have been used for 3D GIS visualization. First, ESRI technology was used to create the dashboard, and then the Cesium technology was adopted. In this Section, the system architecture and the approaches to developing the desired dashboards are discussed.

ArcGIS-based Dashboard. To develop the ESRI-based dashboard, the data, including 3D building, water network, sewer system, trees, road networks, sidewalks, and TMU facilities, have been hosted and published as a service on the ArcGIS Online platform to provide the required map service for the dashboard development. TMU university has recently installed various smart meters in all campus buildings to monitor utility consumption, including gas, water, steam, and electricity. The data is continuously streamed and stored in the cloud and can be retrieved through the APIs. Then, the ArcGIS API for the JavaScript library was utilized to develop the 3D web-based GIS dashboard. Figure 3 illustrates the proposed system architecture for ESRI-based dashboard development.

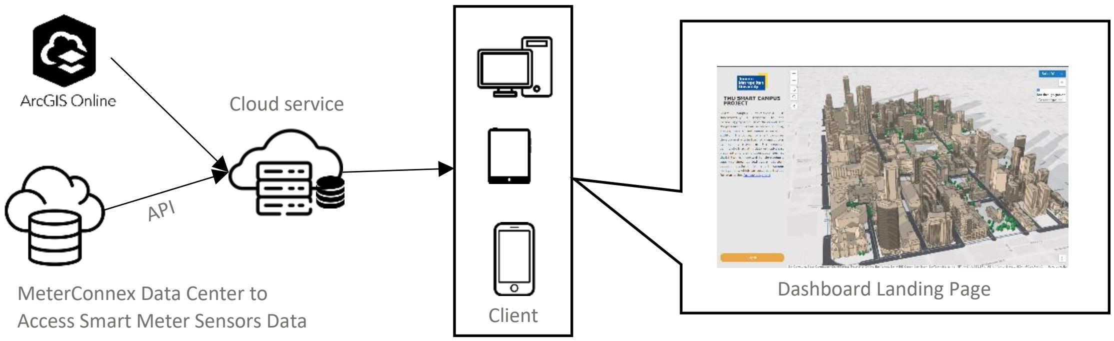


Fig. 3. Proposed system architecture for ESRI-based dashboard development

The developed dashboard application has been deployed in the cloud; users can now access it anywhere through their devices. For TMU privacy protection, some dashboard capabilities, including accessing the meter readings, were restricted to the specified users. You can access the dashboard through the URL db.4dtoronto.ca.

***Cesium-based Dashboard*.** Figure 4 illustrates the overall system architecture for the Cesium-based dashboard development. The building Multipatch data converted to the Cesium 3D tiles format were stored in the S3 Bucket and streamed to the app.

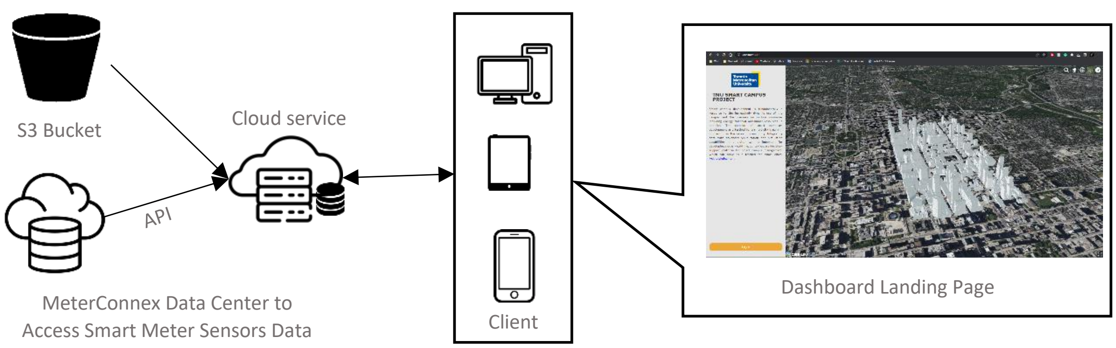


Fig. 4. Proposed system architecture for Cesium-based dashboard development

3. Results and Discussion

Figure 5a represents the landing page of the ESRI-based dashboard user interface, and Figure 5b illustrates the dashboard interface when the user login.

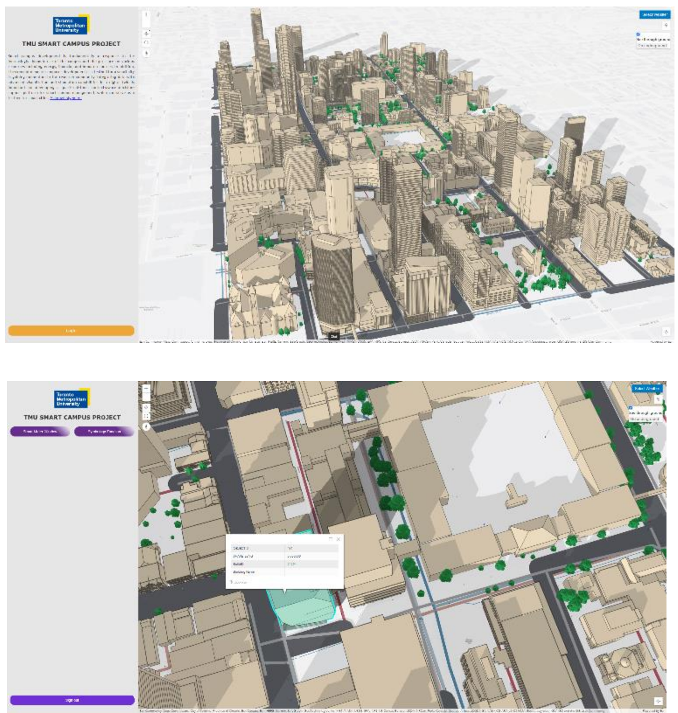


Fig. 5. (a) ESRI-based dashboard landing page user interface, (b) dashboard interface when the user is logged in.

Figure 6 represents the landing page of the Cesium-based dashboard user interface. In this dashboard, only buildings are visualized, and the other city utility infrastructure, roads, sidewalks and TMU facilities will be integrated in future.

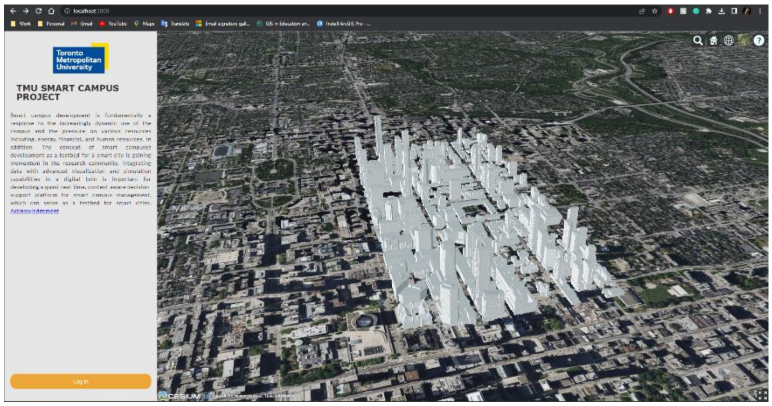
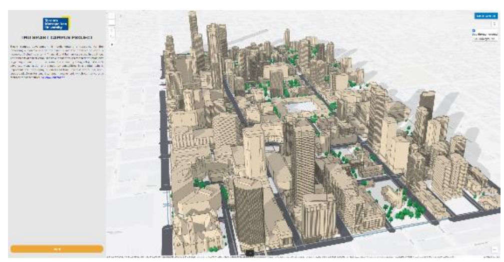


Fig. 6. Cesium-based dashboard user interface landing page

The dashboard capabilities are discussed below. The dashboard is still under development, and more functionalities will be integrated in future.

Shadow Analysis

The shadow analysis tool can investigate the amount of solar access to various campus sites and buildings. It is critical to evaluate the impact of physical obstructions on access to direct solar radiation for green roofs, rooftop solar, and solar wall applications.



Ground Transparency

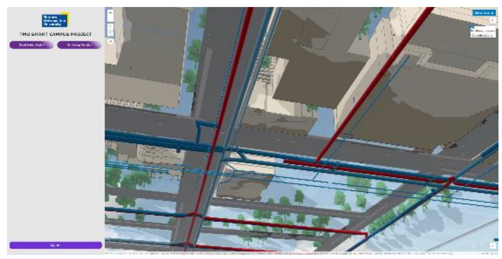
The dashboard also allows us to enable and disable ground transparency, showing the underground infrastructure from above ground.

3D Symbolization

The spatial features can be symbolized by different colours or 3D symbols based on their types or attributes. The feature (i.e., sewer system) can be symbolized by the year of construction, e.g., red indicates older pipes, and blue indicates newer pipes.

Underground Infrastructure Accessibility

The underground infrastructure is accessible by navigating the underground. The attribute information of each feature is also accessible when clicking on that feature.



Water Anomaly Detection (i.e., leakage)

The developed leak detection function can detect water anomalies classified into global and local. The local anomalies could be due to the variation in water consumption at specific sensors, primarily due to leaks/bursts. The developed model had an accuracy of 80% based on the conducted test. The developed model can provide the maintenance department with a warning about leaks and the location of the leaks.

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Anomaly Detected on building MAC at 2019-10-20 0:00
Anomaly Detected on building MAC at 2019-10-12 2:00
Anomaly Detected on building MAC at 2019-12-14 6:15
Anomaly Detected on building ILC at 2019-12-29 10:15
Anomaly Detected on building LIB at 2019-11-08 13:45
Anomaly Detected on building MAC at 2019-11-01 17:30
Anomaly Detected on building ILC at 2019-10-10 23:15
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4. Conclusion

In this paper, two different dashboards using ESRI and Cesium technologies have been presented. The developed dashboards provide the capabilities to visualize and navigate TMU campus infrastructure, including buildings. In addition, the developed dashboard facilitates quasi-real-time monitoring of utility consumption across the campus buildings and uncovers the patterns and trends of consumption, including water, electricity, and gas. Functionalities, including shadow analysis and 3D interactive symbolization, provide a better understating of the university's assets and environment towards developing a more sustainable campus environment. Further, the integrated water leak detection assists the facility management office at TMU in actively monitoring the water consumption and notifying the possible water leakage on the campus.

Compared to CityGML, Multipatch data does not support the Level of Detail, a disadvantage for 3D building visualization. Moreover, it is not an open data format, making it difficult to exchange information with other data sources. By transforming Multipatch to CityGML and transferring the developed dashboard using Cesium technology, the usability and accessibility of the dashboard are extensively improved. The Cesium capability for interoperability of large and complex 3D data sets enables the dashboard to integrate various 3D data types from different sources without any transformation. On the other hand, the structure of 3D tiles has a Hierarchical Level of Detail (HLOD), allowing for only visible tiles to be streamed—and only those tiles that are most crucial for a specific 3D view—which fundamentally enhances the streaming and rendering speed of enormous heterogeneous datasets (Cesium blog site, 2023).

In future, we plan to continue improving the real-time dashboard for analysis, prediction, and visualization (different LODs for the whole campus), including, graphing tools, interface, 3D data improvements, and realistic 3D symbolization by integrating game engines, including Unity and Unreal to the dashboard. Visual alerts of real-time events will be integrated into the dashboard to automate the sense and response of any possible water leak through the campus.

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