Open-Source Solutions for Real-Time 3D Geospatial Web Integration

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Abstract

The recent development of Urban Digital Twin (UDT) structures and the spread of Internet of Things (IoT) technology have extended the concept of Digital Twin (DT) to urban environment representation, enabling real-time connections between geospatial representations and their real-world counterparts. Concurrently, advancements in surveying technologies and web geospatial services have facilitated the acquisition of extensive 2D and 3D geospatial data, making their spatial integration essential. While some proprietary software solutions have recently enabled initial examples of UDT by integrating various 3D geospatial data and real-time sensor acquisition, the development of open-source solutions for real-time web-based geospatial management remains a challenge. This work demonstrates a possible open-source solution for developing a UDT accessible via the web. The case study involves the web visualization platform of the new Faculty of ITC building at the University of Twente in Enschede (The Netherlands), which is connected in real-time with weather data services provided by Visual Crossing (1). The platform is based on an HTML5 framework and employs WebGL JavaScript graphic libraries to visualize different modules of 3D web visualization that integrate various local and remote 3D datasets. The framework adopted in this experiment can be used in the future for developing low-cost UDT web platforms beneficial for researchers, municipalities, and private companies interested in the real-time geospatial management of urban environments.

1. Introduction

With rapid technological developments and improvements in internet connection capabilities, sharing complex 3D geospatial datasets online has become a reality (Zhan et al., 2021; Scianna and La Guardia, 2018). Recent advances in Geomatics allow for acquiring vast geospatial information using Terrestrial Laser Scanning (TLS) mobile and static technologies, and Digital Photogrammetric Reconstructions based on Structure from Motion (SfM) algorithms (Frias et al., 2022, Masiero and Costantino, 2019; Ebolese et al., 2019; Alsadik and Karam, 2021). Recently, the use of WebGIS services has been further exploited for multidisciplinary purposes by municipalities and companies (Yakubailik et al., 2018; Piragnolo et al., 2021; Amado et al., 2018; Scianna et al., 2021). Moreover, the possibilities for integrating real-time sensor data have significantly increased, enabling real-time analyses and visualizations. This integration opens the possibility of creating Digital Twin representations at building and urban scales, offering the ability to connect the virtually represented model with the real one in real-time (Congiu et al., 2023; Mazzei and Quaroni, 2022; Mangiameli et al., 2023). The Digital Twin concept, initially applied in the manufacturing industry (Singh et al., 2021), has recently been extended to the geospatial domain, representing a digital replica of a physical model connected in real-time. In fact, the term Urban Digital Twin (UDT) started to be used (Weil et al., 2023; Xue et al, 2021).

The recent proliferation of Internet of Things (IoT) technology has led to the spread of real-time sensor network connections within UDT experiments and initial applications, allowing for the testing of digital twinning connections with low-cost solutions (Coetzee et al., 2020; Scianna et al., 2022). The integration of IoT technology has expanded the applications for real-time remote analysis and management of buildings and urban areas. The management of urban spaces, through decision support systems (Jia et al., 2023), can now be further enriched by big data information provided by specialists, sensors, and citizens, which need to be integrated in a cohesive manner. Even as technology rapidly progresses, integrating 3D complex datasets into a WebGIS environment and merging heterogeneous geospatial datasets (such as TLS and photogrammetric acquisitions, 3D models, BIM models, and IoT sensor acquisitions) on the web remains challenging (Weil et al., 2023).

Often, it is necessary to employ proprietary software solutions, which pose cost limitations to the widespread adoption of UDT applications, thus limiting the usability of the system. At the same time, open-source solutions if on the one hand avoid the employment of expensive software on the other hand require specialized skills in web scripting and 3D data optimization (Autiosalo et al., 2021; Naserentin et al., 2022).

This work shows an example of real-time data integration inside a 3D geospatial web-based visualization platform developed with open-source technology. The platform allows users to visualize online the new ITC Building of the University of Twente in the city of Enschede, with the possibility to navigate the outdoor and indoor environments of the building through a web browser. The construction of this platform was the subject of previous studies that demonstrated how to integrate different 3D geospatial data (2D, 2.5D, 3D meshes, point clouds) within the same platform to create a multiscale web-based visualization of a complex urban environment using open-source technology (La Guardia and

(1) https://www.visualcrossing.com/

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Koeva, 2023; La Guardia et al., 2022). Specifically, WebGL JavaScript graphic libraries were integrated into .html modules to build the 3D geospatial environments on the web. Three.js and Cesium.js libraries were adopted to integrate different levels of visualization. This was the first step toward developing an open-source UDT web application. This application can be useful in the construction steps of the building, to help specialists on site. It can also be useful for the management of the building, with the possibility of monitoring the structure.

This work represents a further step in the development of the platform. Previously, the platform focused on studying the integration of different levels of visualization on the web. This research, however, integrates the visualization of real-time sensor-acquired data provided by remote servers. In particular, a popup system allowed the real-time connection of the platform with public sensors of weather information made available by the Weather Data Services of the Visual Crossing Weather platform (https://www.visualcrossing.com/) The weather information was considered as an example of real-time integration inside the web platform, to enclose the 3D geospatial web visualization system to a UDT.

The next section will show the state of the art in the field of 3D geospatial data integration to share on the web with open-source solutions, with a particular focus on the main technologies involved.

This work demonstrates the possibilities for creating a digital twin of a newly constructed building by integrating data from various sources on the web (such as multitemporal laser scanning data, UAV, BIM, and real-time sensor data) using open-source solutions. The system adopted in this solution can be further improved in the future by integrating more real-time sensor data acquired in the area.

2. State Of Art

Recent UDT experimentations were born with the aim of public collaborative citizen participation in the design and development of urban spaces (Schrotter and Hurzeler, 2020). In this way UDT can support urban planners and the general public, becoming, in fact, a collaboration and communication tool (Dembski et al., 2020). The adoption of UDT also offers the possibility to integrate several factors (economic, engineering, social, and environmental) for urban road planning (Jiang et al., 2022).
UTD technologies allow real-time control of the territorial asset, with the possibility to forecast flooding for small-scale and large-scale networks (Bartos and Kerkez, 2021).
The development of UDT requires the integration of heterogeneous dataset acquisition and integration to be shared in a common platform. It is necessary to provide sensor network acquisition inside a 3D visualization of the corresponding environment.

In this process, it is necessary to integrate on one side 3D data (meshes, point clouds, BIM models, etc..) and the other side, real-time sensor network acquisitions provided by relational databases. Some commercial software solutions allowed in the last years to create Digital Twin applications for buildings, civil structures, or urban environments (Shariatpour and Behzadfar, 2022).

At the same time, the development of UDT web solutions with open-source technology seems to be interesting for research, industrial, and urban development (Naserentin et al., 2022; Yeon et al., 2023).

The integration of different datasets remains a challenge, however, once integrated, the advantages are numerous, including the simplified and direct management of 3D complex information, the ability to conduct real-time 3D analysis of the environment, and the utilization of freely available web services. For example, a variety of remotely sensed data can be accessed via WebGIS services. WebGIS integration enables the use of open data available on the web using Web Map Services (WMS) and Web Feature Services (WFS), as well as the overlay of geospatial raster information provided by remote web servers. These services, developed by the Open Geospatial Consortium (OGC), have played a significant role in the widespread adoption of GIS applications worldwide over the last few decades (Baumann, 2010).

Recent advances in computer science have enabled the development of 3D WebGIS applications (La Guardia et al., 2022; Gaspari et al., 2024), with the ability to integrate WMS and WFS datasets with locally acquired heterogeneous 3D complex datasets. The geospatial system of a 3D WebGIS employs globe-based models with accurate 3D terrain representations generated by realistic 3D map tiles.

Recent years have seen the introduction of several open-source and commercial solutions in the realm of 3D GIS, offering the possibility to integrate comprehensive information into geospatial globe contexts (Bi et al., 2021; Mobasheri et al., 2020), known as City Information Modelling (CIM) platforms. Beginning with the idea of sharing open data on the web, the preference for open-source solutions, such as WebGL, appears to be the most favourable, offering a sustainable solution available to users and developers worldwide. These solutions, compliant with HTML5, leverage the capabilities of common web browsers, enabling simple and low-cost web accessibility to 3D complex environments. These features can be adopted for developing low-cost digital twinning solutions.

The choice between different WebGL libraries to integrate depends on the aim of the web visualization because each library offers specific features to 3D dataset visualization on the web. For instance, Three.js libraries allow the visualisation of complex 3D environments with deep customization in terms of a variety of 3D data and navigation controls to integrate, Potree.js libraries allow the optimisation point cloud visualization and measurement, Cesium.js allow the integration of 3D datasets in a 3D WebGIS referred environment.

3. Materials and methods

In this work, the research involved the improvement of a UDT visualization on the web, connecting real-time data acquisition provided by remote services to the system. In this way, we tested the development of a UDT web platform employing open-source solutions. The platform construction of this integrated system consists of several parts, including the 3D dataset, the WebGIS globe-based platform, the indoor-outdoor 3D exploration modules, and the real-time weather data acquisition (Figure 1).

Considering the 3D dataset, it includes the ITC building and the surrounding environment inside the city of Enschede. This dataset contained information at different levels of detail, as shown in Table 1. Part of the dataset was obtained with survey operation as the point cloud and the 3D photogrammetric reconstruction, and part was obtained from the geospatial dataset available on the web as the geometric information regarding the surrounding building. Open Street Map (OSM) buildings (https://osmbuildings.org/) and 3D BAG building dataset (https://3dbag.nl/en/viewer) were implemented, the first real-time connected to the platform from OSM server, the second downloaded and stored in the local webserver. The real-time data acquisition involved the weather acquisition openly provided by the Weather Data Services of the Visual Crossing Weather platform.

The platform itself is developed with a framework of connected html pages inside a WebServer, where WebGL JavaScript graphic libraries are implemented. The WebGIS globe-based platform (http://130.89.6.77/) represents the core of the system, that contextualises the building inside the surrounding environment (Figure 2). It is developed inside a .html page where Cesium.js open-source libraries are integrated. This visualization contains a system of popup elements that connect the WebGIS with the indoor-outdoor 3D exploration modules and with real-time weather data acquisition.

The WebGIS platform contains the visualization of the OSM buildings, the 3D BAG building dataset, and the 3D photogrammetric reconstruction of the ITC building.

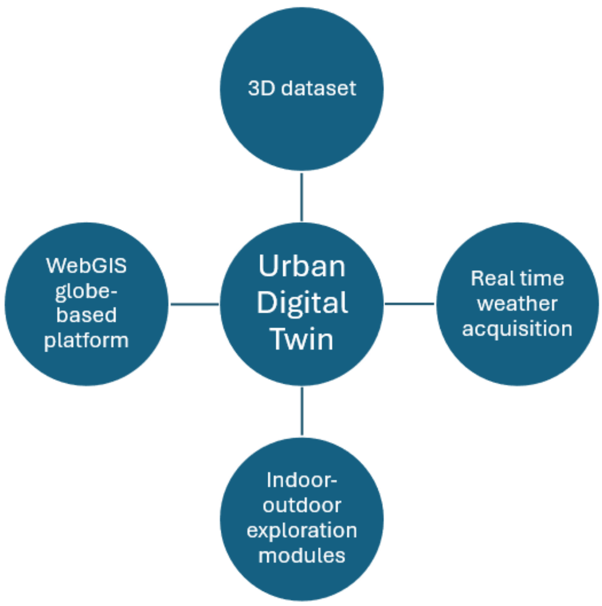

Figure 1. The elements that compose the UDT structure.

WebGL module	3D dataset	Source
WebGIS globe-based platform	OSM buildings	Web services
	Digital terrain	Web services
	3D BAG buildings	Local server (downloaded from 3D bag repository)
	3D photogrammetric reconstruction	Local server
Outdoor module	Outdoor point cloud	Local server
	3D BAG buildings	Local server
Indoor module	Indoor point cloud	Local server

Table 1. The composition of the WebGL modules that compose the UDT.

The indoor-outdoor 3D exploration modules allow for exploring the building more in detail, from a bird-eye outdoor contextual navigation to an indoor first-person visualization.

Figure 2. The WebGIS globe-based platform.

The indoor-outdoor visualization modules are developed inside an HTML page, implementing Three.js open-source libraries. The visualization, connected with the WebGIS globe-based platform, starts from the outdoor navigation, where a system of pop-up elements allows one to go inside the building with the first-person visualization.

The outdoor exploration module contains the outdoor point cloud information of the building and the near constructions extracted from the 3D BAG dataset (Figure 3). Instead, the indoor exploration modules, one for each level of the building, contain the indoor point cloud information (Figures 4-5).

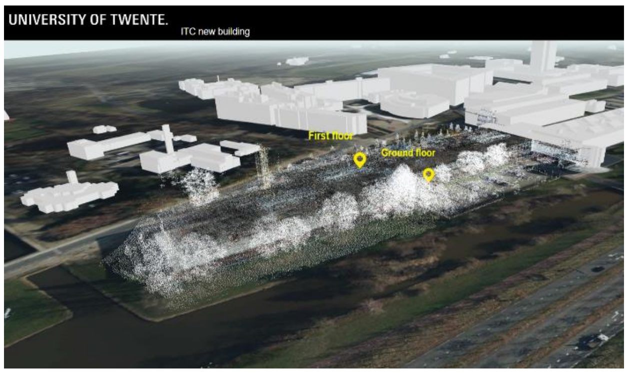

Figure 3. The outdoor exploration module.

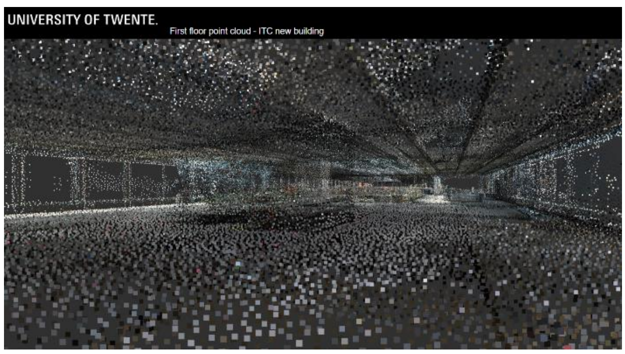

Figure 4. The indoor exploration module of the first floor.

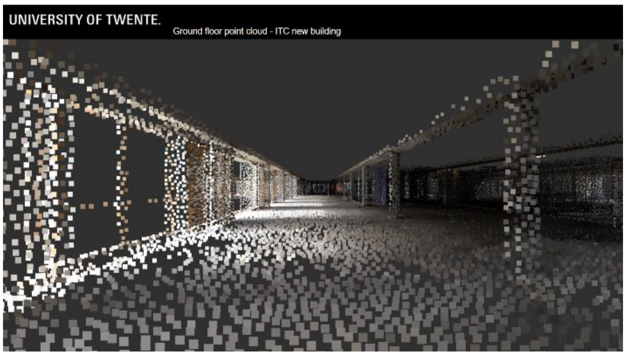

Figure 5. The indoor exploration module of the ground floor.

The real-time weather acquisition is provided by the Crossing Weather platform and visualized in a popup window of the WebGIS platform. The window is connected with an HTML page located inside the web server that gets the information sent by the JavaScript Object Notation (JSON) structure provided by Crossing Weather. This implementation employs the JSON format for establishing communication and visualizing real-time information within the platform. JSON structure is a data interchange format that employs human-readable text for the storage or transmission of data objects. It collects names and values in ordered lists or arrays.

In this way, the connection allows the real-time acquisition of the last measurements in the city of Enschede freely provided by the global Weather API located in the servers of Visual Crossing (Figure 6).

4. Results and Discussion

The developed solution represents an open-source example of low-cost UDT creation on the web (Figure 7). The system is located inside the web server of the University of Twente and available inside the Virtual Private Network (VPN) of TC Twente. It is necessary to configure a web server to integrate this type of dataset on the web. Then, the .html main page should be designed to integrate WebGL JavaScript graphic libraries (based on the OpenGL standard) to build the web 3D visualization environment.

This system integrates two different WebGL open-source libraries, Cesium.js and Three.js. The first one was used to develop the general 3D WebGIS globe-based platform with the geospatial visualization of the building inside the surrounding environment. The second, instead, was used to create the 3D indoor-outdoor exploration modules, in which it was necessary to customize the visualization according to the needs of the web navigation.

Figure 6. The real-time meteo information as extracted from the Crossing Weather platform and visualized into the popup window of the 3D WebGIS visualization.

Figure 7. The structure of the UDT platform.

These JavaScript graphic libraries enable the integration of local 3D geospatial datasets and geospatial datasets provided online by web services into the web platform.

In fact, the system can also be implemented with additional levels of information employing WMS and WFS services, different raster layers as 2D terrain coverage, 2.5D information using TopoJson encoders, 3D Digital Elevation Models (DEM) of terrains, and finally, real-time and historical data from JSON encoders. All these elements can be integrated into the 3D Web GIS platform using JavaScript strings that link the webpage to these open services.

Considering the 3D dataset loaded in the platform, point clouds and 3D meshes should be simplified by filtering the number of points and polygons. To ensure satisfactory web browsing navigation, it is necessary to limit the size of geometrical information.

Still, the visualization of complex BIM 3D data remains a challenge. The system originally also implemented the BIM 3D model visualization of the University in IFC format using Three.js libraries but the huge dimension of the digitalization did not allow its web visualization. Probably it can be solved using other solutions based on tile decomposition of BIM information. The methodology can be applied simultaneously using data organized and stored in a Relational Database Management System (RDBMS).

In this way, the real-time information provided from sensor network acquisition can be visualized in the platform, integrating JSON encoding strings into the JavaScript environment.
Another format, very similar to JSON is the GeoJSON encoder, which provides a similar structure, integrating geographic features as spatial extensions.
This format can be useful in UDT web implementations, for the real-time visualization of moving objects in the geospatial context.

5. Conclusions

The system developed in this research represents a web-based Digital Twin solution developed with open-source technology. The strategy adopted in this work can be chosen as a reference for a low-cost UDT solution for municipalities, specialists, researchers, and companies that want to remotely manage geospatial data, avoiding expensive commercial software implementations. The main challenges remain the limited size of 3D information to integrate into the platform and the need for proficient script skills in HTML, JavaScript, JSON, and CSS languages.

This work demonstrates the possibilities for creating a digital twin of a newly constructed university building by integrating data from various sources on the web (such as multitemporal laser scanning data, UAV acquisitions, 3D tiles, 2.5D GIS, and real-time sensor data) using open-source solutions. This work integrates real-time weather information made available by the Weather Data Services of the Visual Crossing Weather platform with all other geospatial and remotely sensed information available on the web. The system adopted in this solution can be further improved in the future by integrating with the same methodology more real-time sensor data acquired in the area, useful for the management of the building.

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