# Geospatial Digital Twins

OER4SDI

**Open Educational Resources for Spatial Data Infrastructures**

In this OER module, you will learn about the concept of geospatial digital twins and explore some fields of application. You will create a simple digital twin application using publicly available datasets.

ein Kooperationsprojekt, empfohlen durch:

DIGITALE HOCHSCHULE NRW

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# 1. Overview

In this tutorial, you will learn about the concept of Geospatial Digital Twins and their use cases. You will also create a simple digital twin application using open-source tools and publicly available data from the city of Hamburg.

In the practical exercise, we will use:

- CesiumJS, an open-source JavaScript library for 3D geospatial visualization.
- CesiumION, a platform for streaming, storing, and tiling 3D data.
- Real-time water level data from PegelOnline
- Real-time air quality data from AQICN.org
- Docker to set up and run our application

The tutorial is structured as follows:



This tutorial requires some basic knowledge of geodata and geographic information systems. Further to this, no special knowledge or skills are needed, just curiosity and eagerness to learn. You will need about 90 minutes to complete the tutorial.

The tutorial has been developed at the Institute for Geoinformatics (IFGI), University of Münster, in collaboration with 52°North GmbH. Authors are James Ondieki, Simon Jirka and Albert Remke.



# 2. Background

## 2.1 The Idea of Digital Twins

Imagine a world where cities, buildings, or even environmental ecosystems have their digital and realistic replicas. Dynamic replicas that evolve with the physical thing or entity that they represent. A world where urban planners visualize and simulate the impact of infrastructure projects before breaking ground, environmental scientists predict flood risks in real time, and disaster responders rehearse life-saving strategies in a risk-free digital environment. Welcome to the era of Digital Twins, where maps are no longer static snapshots, but living, evolving systems that mirror and even anticipate reality.


Fig. 1: Urban digital twins. Image generated with DALL.E 3 on March 17, 2025.

A Digital Twin (DT) is a virtual representation of a physical system (and its associated environment and processes). It replicates the physical entity in a digital environment, capturing its characteristics, behavior, and interactions in real-time (Ranatunga et al., 2024), (VanDerHorn & Mahadevan, 2021). If the DT substantially relies on geospatial data, e.g. in the case of a digital twin of a city, it is also referred to as a Geospatial Digital twin.

The concept of twinning can be traced back to the 1960s when NASA was working on the Apollo program. During the program, NASA constructed two identical spacecraft for the mission: one was launched into space while the other remained on Earth as a ‘twin’. The twin served critical functions such as training astronauts, conducting simulations and preparing for potential flight issues. It was meant to mirror the operating conditions of the spacecraft that was sent to space.

However, building full-scale replicas for every system was neither practical nor cost-effective. In the early 2000s, Michael Grieves introduced the idea of a virtual twin in the context of product lifecycle management. This marked a shift from physical to digital replication. He proposed a virtual model that interacts with a physical object through a continuous data flow. A change in the state of the physical object results in a change in the state of the virtual representation (Lyu, 2024, 13-29).

This shift from physical to digital replication made the concept of ‘twinning’ scalable. Since then, the concept has expanded beyond aerospace. With advances in Internet of Things (IoT), AI, and data analytics, DTs have been widely adopted across industries, including manufacturing, healthcare, transportation, and smart cities.

## 2.2 Components of a Digital Twin

From the definition, we can break down a DT into 3 primary components. There is the physical reality, the virtual representation and the exchange of information between the physical system and the virtual representation.


Fig. 2: Components of a Digital Twin and their relationship

### 2.2.1 Physical Reality

The physical reality of a DT encompasses the actual world that the twin seeks to represent and monitor. We can further break it down into 3 subcomponents: The physical system, the physical environment and the physical processes

The **Physical System** refers to the tangible, observable entity being twinned. It may be a standalone object like a car or a bridge. It may also be a composite system comprising interconnected components, such as a building or even a whole city. The physical system operates in real-time, and its performance and state are continuously monitored through various sensors.

The **Physical Environment** encompasses everything external to the physical system that influences its operation. This includes environmental factors such as temperature, humidity, and other contextual data that can affect the performance and behavior of the physical system. For example, a wind turbine’s surrounding terrain, weather conditions and proximity to other structures form its physical environment. Understanding the environmental context is crucial for accurately modeling how the system behaves under various conditions.

The **Physical Processes** are the dynamic activities and interactions that occur within and around the physical system that result in a change of state of the physical system. These include processes like energy consumption in a building, traffic flow in a city, or natural phenomena like flooding in a city. The physical processes may also be represented in the virtual space to support simulations and forecasting operations. The real-time data collected by sensors enables the modeling or simulation of physical processes in the virtual world.

### 2.2.2 Virtual Representation

The digital replica of the physical entity captures not only the geometric structure of the physical system, but also its functional behaviors, processes, properties, and the contextual environment. This digital model mirrors the real-world object or system at a level of detail suitable for the intended use case.

Geospatial data plays a crucial role in the creation of geospatial digital twins. This involves data sources such as 3D meshes, BIM, Sensor networks, or simulation models that are being integrated using their specific data models, encodings and interfaces.

Visualization tools supporting virtual reality (VR), and augmented reality (AR) are being used to offer immersive and intuitive ways to observe and interact with the system, its environment and processes. For example, in emergency response planning, a city-scale DT may use 3D visualization to simulate a flooding scenario. Emergency responders can visualize affected areas, blocked evacuation routes, and sensor data from storm drains in real-time, enabling better coordination and faster decision-making.

Depending on the purpose of the DT, functionalities such as data analysis, simulation, and prediction can also be integrated. This means that the twin does not just receive real-time data from the physical entity. It can also apply data analysis methods to derive more insights from the incoming data that enable better decision-making. This is important in cases where the raw data received needs to be processed into useful information, such as determining the extent of a city's flooding from rainfall data.

### 2.2.3 Data Interconnection

Digital twins evolve through continuous data exchange with the physical world. Sensors and IoT devices provide live updates, ensuring the twin reflects current conditions. This is critical for time-sensitive applications like disaster management, urban mobility optimization, and environmental monitoring. Without real-time data, a digital twin is just a static model, accurate at a given point in time but may quickly become outdated.

Depending on the purpose of the digital twin, it can also have a bi-directional flow of information. This means that information also flows from the digital twin back to the physical system. It allows insights and decisions generated by the digital twin to be implemented in the physical system. This can be through actions that result in a change in the state of the physical system or actions that collect additional information from the physical system to further update the digital twin. For example, a flood risk twin may analyze real-time rainfall data and automatically activate flood gates in vulnerable areas.

To manage the inflow of real-time data, DTs rely on standardized protocols and systems that ensure seamless communication between IoT sensors and DTs. The following protocol standards are of particular importance for Geospatial Digital Twins:

- **MQTT (Message Queuing Telemetry Transport)**
  MQTT is a lightweight publish-subscribe protocol that is widely used in IoT for low-latency and real-time data transmission. In the context of DTs, sensor devices in the physical world function as publishers, sending data to an MQTT broker, which acts as an intermediary. DTs applications are the subscribers, receiving the streamed data to update and synchronize the virtual model with real-world conditions. MQTT is often used alongside the SensorThings API, for streaming sensor observations.

- **OGC SensorThings API**
  This is a standardized REST and MQTT-based framework for managing real-time sensor data. It simplifies how DTs ingest, organize and query real-time observations. It provides an interoperable model for observations, sensor metadata, and spatial-temporal relationships. This promotes interoperability by harmonizing inputs from diverse sensors, (eg air quality monitors, traffic sensors etc ) into a unified model. It is also scalable and can handle millions of data points from city-wide IoT networks.

- **OGC API Connected Systems**
  The OGC API - Connected Systems is an emerging standard within the OGC designed to facilitate interoperability and integration between different OGC APIs (eg. SensorThings API, Features API) and external systems. Unlike legacy standards like the Sensor Observation Service (SOS), which it aims to replace, Connected Systems API adopts modern REST and MQTT protocols to streamline cross-platform workflows.

  While it coexists with the OGC SensorThings API (STA), the two serve distinct roles: STA focuses on lightweight, high-frequency sensor data publishing with minimal metadata, making it ideal for small-scale IoT deployments but less interoperable with broader OGC ecosystems. In contrast, Connected Systems prioritizes robust metadata support and harmonization. This is important in scenarios where, in addition to the observation data collected, the metadata about the sensor or observation is also important.

For example, in practice, IoT air quality sensors measure PM2.5, $CO_2$, and temperature across an urban area. The sensors then publish their readings to an MQTT broker. The SensorThings API stores and provides real-time access to the sensor data. A DT application subscribes to the MQTT topic and updates air quality layers dynamically.

## 2.3 What is so special about Digital Twins

You may be wondering what is so special about DTs, since all simulation models, 3D models, and geoinformation systems are also digital models and thus twins of objects in the real world.

The term “digital twin” highlights a special quality of the digital model. It refers to the claim that the state and dynamics of the physical system are represented as holistically and in near real time as possible. In particular, this means that it should look and behave like the physical system.

**Digital Twins vs Simulation Models**

A DT is a living, continuously updated digital replica of a physical system. It receives real-time data from the physical system, allowing it to represent the current and historical states of that system. In contrast, a simulation model is typically a static or standalone representation used to predict how a system might behave under certain conditions. It is based on assumptions or fixed parameters. It is not necessarily connected to a real-time physical counterpart and does not update automatically as the physical system changes.

The two terms are often confused because both involve modeling or representing physical systems. In fact, DTs may incorporate simulation models as part of their virtual representation to forecast outcomes or run what-if analyses. However, a simulation model alone lacks the continuous data exchange and synchronization that define a DT (VanDerHorn & Mahadevan, 2021). We will see how to add a flood simulation to a DT in the practical section of this tutorial.

**Digital Twins vs 3D Models**
A 3D model is a visual representation of a physical object or system. It focuses on the geometry, shape, and appearance, helping users visualize what something looks like. However, 3D models are static. They lack the real-time data integration and do not evolve to represent the current state of the system that they represent. In contrast, a DT goes beyond the simple visualization. While it may include a 3D model as part of its virtual representation, a DT integrates real-time data from the physical system. It also represents the behavior and processes of the physical system. A DT continuously mirrors the current state of a physical system and evolves over time with operational data.

**Digital Twins vs Geographic Information Systems**

A geographic information system (GIS) is a computer system for capturing, storing, managing, analyzing, and visualizing spatial data. It is used to provide spatial information to support analysis and decision-making. GIS can also integrate components such as 3D models, real-time data, and even simulations, just like DTs, but they do not necessarily integrate all data into a holistic and realistic digital replica of a physical system, as is the case with digital twins. GIS are often fundamental data sources for the creation of Geospatial Digital Twins.

On the other hand, digital twins that serve the purpose of providing information (e.g., for monitoring and controlling physical systems) can also be referred to as information systems. This means that both terms are closely related. While the term “digital twin” refers to the special characteristic of the digital representation (“perfect replica”), the term “information system” refers to the purpose of digital representation (“providing information”).

## 2.4 Application Areas of Digital Twins

In an era of rapid urbanization, climate change and resource scarcity, DTs have emerged as important tools for decision making. They have helped to empower governments, industries and communities to make better and sustainable decisions. Applications of DTs include:

- **Real-Time Monitoring and Predictive Analysis**
  One of the defining advantages of DTs is their ability to closely reflect the current state of real-world systems. By continuously synchronizing with data from IoT sensors, DTs offer a live and virtual replica of physical assets such as bridges, railways, or buildings. This enables stakeholders to monitor performance indicators like structural stress, temperature etc.

  For example, a digitally twinned bridge can detect early signs of wear or stress, alerting engineers before a structural failure occurs. A railway line can be continuously monitored for ground movement or subsidence. These insights allow maintenance to be predictive rather than reactive, hence reducing risk and operational costs.

  Hamburg Port Authority created a DT of the Köhlbrand Bridge, an important but old bridge. The twin, SmartBRIDGE Hamburg, allows the bridge to be monitored in real-time, and detect any possible issues before they become full-scale problems.

- **Urban Planning and Smart City Development**
  DTs offer urban planners an immersive environment to visualize and simulate entire cities. These platforms allow planners to simulate how proposed developments would interact with the city’s landscape.

  Planners can assess how a new building would cast shadows, affect wind circulation, or alter traffic patterns. They can also evaluate future needs by modeling scenarios such as population growth or climate change.

  Virtual Singapore, a DT of Singapore, is used by planners to simulate new urban projects and their impacts on existing infrastructure. This helps to minimize disruptions and promote sustainable growth. The twin is also used to track and optimize energy usage. It provides a clear view of energy consumption across different sectors, hence allowing policymakers to make informed and sustainable decisions.

- **Optimizing Transportation and Mobility**
  Digital Twins are transforming urban transportation by creating live, data-rich models of transport or traffic systems. These twins are continuously updated with real-time data from sensors, cameras, GPS devices, and public transit networks. This enables cities to monitor and simulate transport traffic conditions as they unfold, offering a powerful tool for planning and optimization.

  In London, for example, the city's digital twin monitors traffic flows and air quality simultaneously. It can forecast congestion during rush hours, adjust traffic signal timings, or suggest alternative routes to reduce gridlock. This has helped to improve commute times and cut down vehicle idle time, directly contributing to reduced carbon emissions and better air quality.

- **Stakeholder Engagement and Collaboration**
  Digital Twins are dismantling the traditional barriers between disciplines, governments, and citizens, hence transforming decision-making into a collective, transparent process. By serving as a shared digital workspace, they allow urban planners, engineers, environmental scientists, and even local residents to collaborate in real time, regardless of geographic boundaries.

  For instance, an architect might use the model to test different building designs, while an environmental scientist evaluates flood risk, and citizens provide feedback through a public web interface.

  Virtual Singapore acts as a bridge between residents and city authorities. Residents can virtually explore proposed development before they are implemented, and provide their feedback. The twin also serves as a public repository of public data related to urban planning.

- **Environmental Monitoring and Management**
  Environmental systems can be complex and very dynamic. DTs make them comprehensible and manageable by aggregating real-time data from environmental sensors, hence providing an up-to-date picture of the environment.

  Cities can track pollution hotspots or assess the impact of construction on local ecosystems. For example, air quality sensors deployed throughout a city can stream live data to its digital twin, enabling citizens and policymakers to understand pollution patterns and test mitigation strategies virtually. We will implement such a DT in the practical section of this tutorial.

- **Disaster Management and Response**
  DTs are transforming disaster management by providing real-time, data-driven virtual models that mirror the actual real situation. They are used to support preparedness, response, and recovery efforts across all phases of disaster risk reduction.

  During disasters, DTs integrate live sensor data (eg, flood water levels, seismic activity, weather) to provide up-to-date situational awareness. This enables authorities to monitor evolving threats and deploy resources where they are most needed.

  DTs also enable a collaborative and immersive training of disaster responders. This allows teams to practice coordination and decision-making, in realistic virtual environments.

## 2.5 Case Study - Hamburg City’s Digital Twin Initiatives

The implementation of Digital Twins in cities and urban areas has become a cornerstone of smart city development, offering a transformative potential for urban planning, infrastructure, and environmental management. Many cities in Germany have developed their digital twin applications for various purposes. Hamburg City stands out as a pioneering example, with its Connected Urban Twin (CUT) project.


Fig. 3: 3D view on the city landscape of Hamburg. Courtesy of Hamburg Geoportal, accessed 21 August, 2025. [https://geoportal-hamburg.de/](https://geoportal-hamburg.de/)

At the heart of Hamburg’s digital twin is its 3D city model. The 3D model provides realistic impressions of buildings and the entire cityscape from different perspectives. It contains over 380,000 buildings in various levels of detail. The model is hosted in the Geoportal of Hamburg city and is accessible to both planners and citizens.

The model combines high-resolution building geometries with sub-surface infrastructure data such as sewer lines, and utility tunnels. It uses the CityGML standard to ensure compatibility with external systems. It features a 3D project planner tool that visualizes proposed developments in the context of the real-world surroundings.

Hamburg’s twin incorporates data from various sources. The real-time data integration ensures that decisions can be based on the most up-to-date data, e.g.:

- IoT Sensors monitoring traffic flow, energy consumption and flood risks.

- Municipal databases updating construction permits, demographic trends and public transit schedules.
- Citizen-generated data using participatory platforms like Digital Participation System (DIPAS), which crowdsources feedback on human projects.

The Digital Participation System (DIPAS) is a tool designed for public participation and is based on the DT. It enables Hamburg residents to explore 3D visualizations of urban projects using methods such as Augmented Reality (AR). Residents can give their views on proposed developments. The public can access digital maps, aerial photographs, plans, 3D models of buildings and geodata in various projects.

The city of Hamburg is constantly undergoing changes with the development of new constructions and infrastructure projects. Hamburg's digital twin enables the evaluation of "what-if" scenarios in urban development. Planners can:

- Visualize proposed buildings in the context of the existing infrastructure. This enables them to ensure compliance with height restrictions and shadowing regulations.
- Model energy-efficient buildings, taking into account aspects such as the placement of solar panels or the installation of green roofs.
- Engage residents through virtual walkthroughs of proposed projects. This helps all stakeholders to break down barriers to understanding and find consensus-based solutions.

The digital twin enables planners to analyze 3D models of proposed construction projects and go through various building scenarios. Planners can also integrate other geodata such as noise maps and monument maps to assess the construction project's interaction with the environment and improve planning decisions. Augmented Reality (AR) and Virtual Reality (VR) techniques can be used to showcase urban designs to stakeholders and citizens.

Other Digital Twin projects in Hamburg are:

- SmartBridge Hamburg - maintenance and monitoring of the Köhlbrand Bridge
- Digital Port Twin - Port of Hamburg
- TwinSim - EUROGATE container terminal.

Hamburg also participated in the development of a standard for urban digital twins. The DIN SPEC 91607 "Digital Twins for Cities and Municipalities" provides a guideline for the planning, design, and implementation of DTs for cities and municipalities.

# 3. Practical Exercises

In this section, we will create a simple digital twins application that can be used for real-time environmental monitoring and for urban planning purposes. The application will focus on

Hamburg city and use publicly available environmental data from public APIs. We will see how the various components of DTs are integrated to bring to life the idea of twinning.

**Required Tools and Data Sources**

1. CesiumJS and Cesium ION
2. Docker
3. Real-time water level data
4. Real-time air quality data

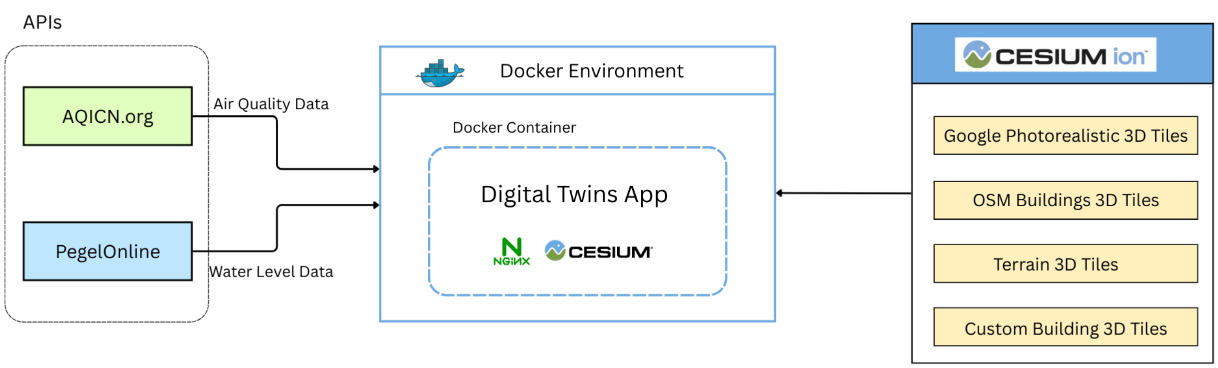


Fig. 4: Components of our DT application

We will use CesiumJS, an open-source library for building 3D geospatial applications. Cesium ION will be used to stream 3D Tiles and to store some 3D data. Our application will monitor air quality using real-time air quality data from AQICN.org. It will also perform some flood simulation using real-time water-level data from PegelOnline.

## 3.1 Setting Up The Digital Twins Application

**Clone the Project Repository**

The code for our DT application can be found at the Github repository of this OER module. You can use one of two ways to download the code:

a) Make sure you have Git installed on your system. Navigate to the working directory that you want to use for this tutorial. Then open your terminal and run the following commands:

```
git clone https://github.com/oer4sdi/OER-DIGITAL-TWINS.git
```

b) Alternatively, you can go straight to the GitHub repository, locate the “code” button, and select the “Download ZIP” option. Unzip the downloaded file inside the working directory of your choice.

**Create a configuration file**

We need to create a configuration file that will store the access tokens used to access Cesium ION and the air quality monitoring platform. Follow the following steps to create it:

a) Open the “app” folder that is inside the project files that we downloaded.

b) Locate a file called “config.sample.js” and rename it to “config.js”.

   Open the file in any code editor of your choice. As you can see, the tokens don’t have actual values. We will create the tokens in the next steps and replace the placeholders with them.

**Install Docker**

We will use Docker to simplify the setup process of our DT application. Docker is a tool that allows us to package and run applications in isolated environments called containers.
If you're completely new to Docker, don't worry! Follow these steps to get everything up and running.

a) Visit the Docker website and download the Docker Desktop installer for your operating system.
b) Run the installer, which will guide you through the installation process. Once the installation is complete, please start up the Docker Desktop application and make sure that it is running.

**Sign Up for Cesium ION**

Cesium ION is a cloud-based platform that enables easy access to high-quality 3D geospatial data and streaming services. It works together with CesiumJS, allowing us to visualize geospatial 3D data such as terrain, buildings, imagery and even custom 3D content in the browser. It also provides freely accessible spatial data such as satellite imagery, terrain, and Google Photorealistic 3D Tiles.

All datasets are subject to Cesium’s Terms of Service and are not distributed with this tutorial. You will need to create your own free Cesium ION account and generate an access token.

We will use Cesium ION to:

- Access and stream terrain and 3D imagery data to our application
- Upload, tile, and stream our 3D models data into our application

Follow the following steps to get started:

a) Open the Cesium ION webpage.

b) Select the “SIGN UP FREE” option. If you already have an account, you can sign in.
c) Choose one of the signup options to create an account.
d) Enter an appropriate username. Click the “Data center location” dropdown menu and choose “Western Europe”. This will reduce the time taken to stream data from the Cesium ION servers to our DT application.
e) Tick the second checkbox to agree to the terms and conditions. Click “Signup”
f) A code will be sent to your email. Enter the code in the input section to verify your email. After the verification, we now have access to the Cesium ION platform.

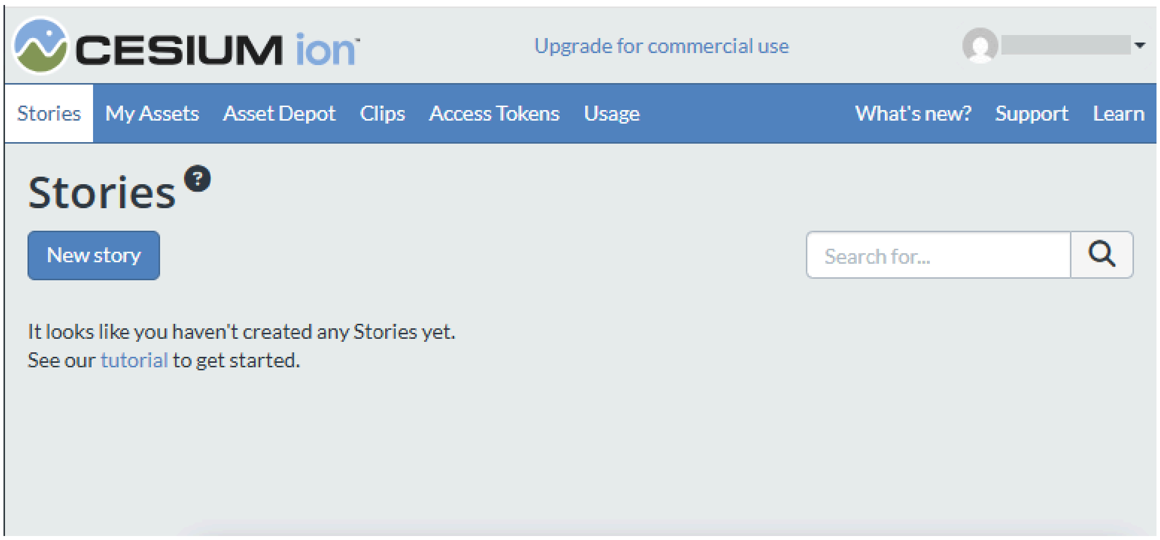


Fig. 5: Cesium platform - landing page of a personal account

g) Select the “My Assets” tab. This opens a list of assets or data that has already been provided to us for streaming. We will use some of the datasets and add a 3D model for streaming, in the later steps.

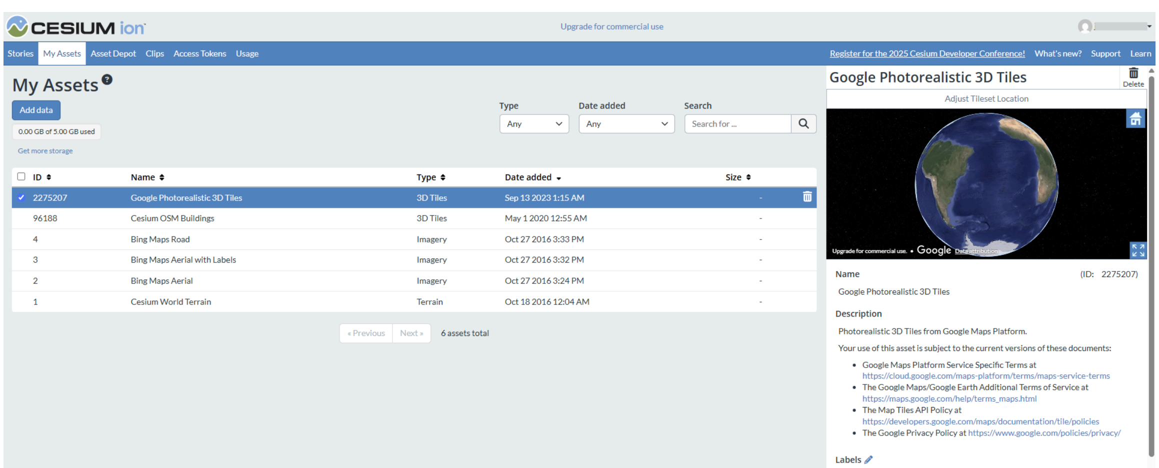


Fig. 6: Cesium platform - list of assets

h) Select the “Access Tokens” tab. There is one default token, but we need to create a new one, that will be specific to our DT application. Click the “Create Token” button. Input a suitable name for the access token, and click “Create”.

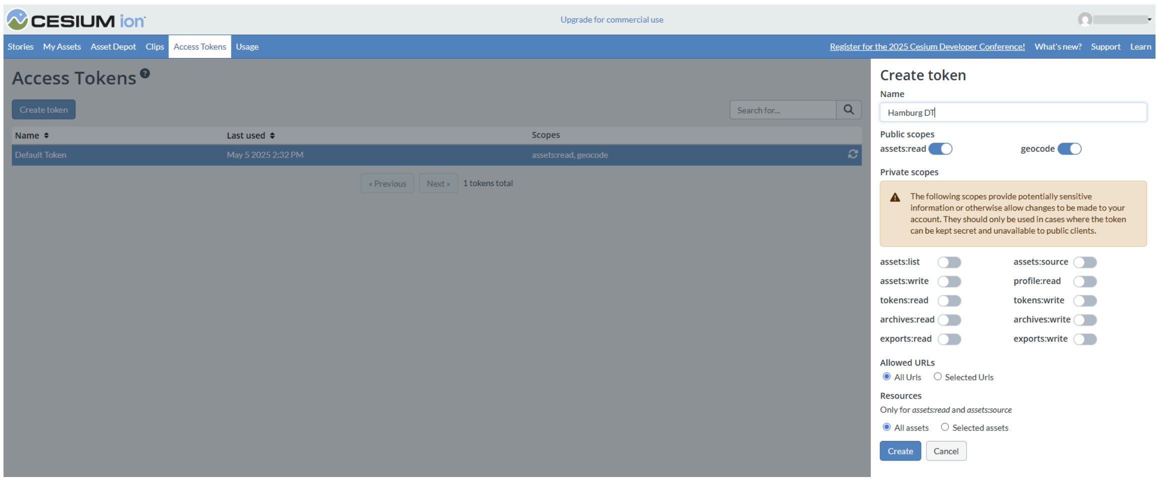


Fig. 7: Cesium platform - access tokens

i) Copy the access token that you have created, and paste it in the config.js file that we created earlier.

### Register for the Air Quality API Token

To integrate real-time air quality data into our application, we need an API token from aqicn.org, a service provided by the World Air Quality Index project. This initiative measures air quality data in more than 80 countries and makes it available through an API. The API is updated at one-hour intervals.

The following air quality metrics are provided by the API:

- AQI (Air Quality Index)
- PM2.5 and PM10 (particulate matter)
- Other pollutants like CO, $NO_2$, $O_3$, and $SO_2$.

The values from various air quality monitoring stations will be displayed in the user interface of our DT application.

> *Integrating the real-time air quality data brings the digital twin closer to reality. This makes it useful for environmental monitoring purposes.*

To get the API token:

a) Visit https://aqicn.org/data-platform/token/
b) Enter your email address and your name. Agree to the “*Terms of Service*” and click the ‘*Submit*’ button to register.
c) You will receive an email with a link to confirm your email. Click the link to confirm the email. The registration is successful, and you can see the token.
d) Copy the token and paste it in the *config.js* file that we created.
e) Save the updates made to the *config.js* file.

**Build and Run the Application with Docker**

We now have all the requirements that are needed to set up and start our DT application. Next, let's build and start the application using Docker.

1. Open the computer terminal in the directory with the application files (docker-compose.yml, Dockerfile etc).
2. Run the command below:

```
docker-compose up -d --build
```

This will build a Docker image of our application and start a Docker container on port 8080.

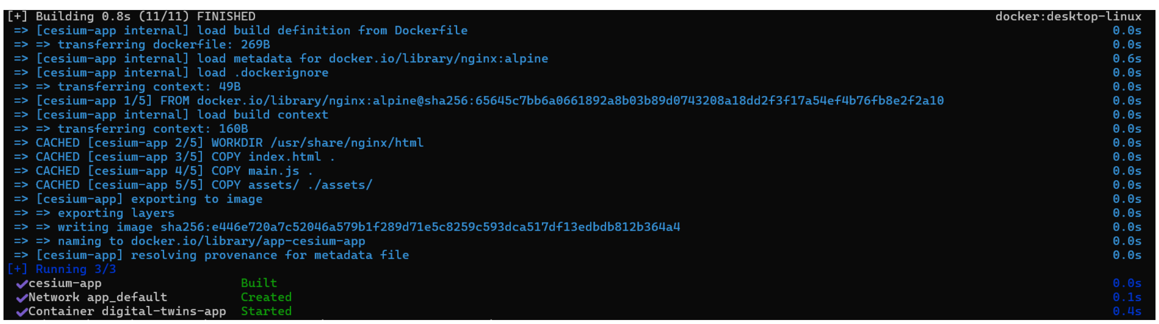

Fig. 8: Building the Docker image and starting up the container with our application

**NOTE**: We just need to build the Docker image once. Afterwards, we can start and stop our application by running the commands docker-compose up and docker-compose down, respectively.

3. Open your browser and navigate to http://localhost:8080/


Fig. 9: First view on our DT application

That was fast! Let us now move to the next exciting part, exploring our twin city of Hamburg.

## 3.2 Exploring the Digital Twin Application

The sample application loads a 3D map centered on Hamburg. By default, the background map uses Google's 3D photorealistic tiles. These tiles contain Google's 3D geodata in OGC 3D Tiles format. The tiles offer visualizations that are as close to reality as possible, hence enabling us or other users of the app to better understand geographic context.

To pan the map view, click the left mouse button and drag. To zoom into various places, click the right mouse button and drag. Alternatively, you can use the mouse wheel scroll. As you zoom into the map, the buildings are displayed in more detail.

The upper left area contains a series of controls for changing the display and an area where the current measurement data from an air quality monitoring station is displayed. We will use these elements for our sample use cases.

### 3.2.1 Explore Air Quality at Different Locations

A core strength of DTs is their ability to reflect changing conditions of the real world in real-time. Our DT application connects to a real-world sensor network through the AQICN API, and displays environmental metrics such as air quality index (AQI), particulate matter (PM), nitrogen dioxide (NO2), and ozone levels (O3). The widget in the upper left corner displays the current readings from a nearby air quality monitoring station.

AQI is an indicator that is used to show how polluted the air is or is forecasted to become. When the levels of air pollution increase, the AQI increases. A high AQI value is associated with a public health risk. If you want to learn more about the AQI, please visit https://aqicn.org/.

Let us now explore the current state of air quality in and around Hamburg.

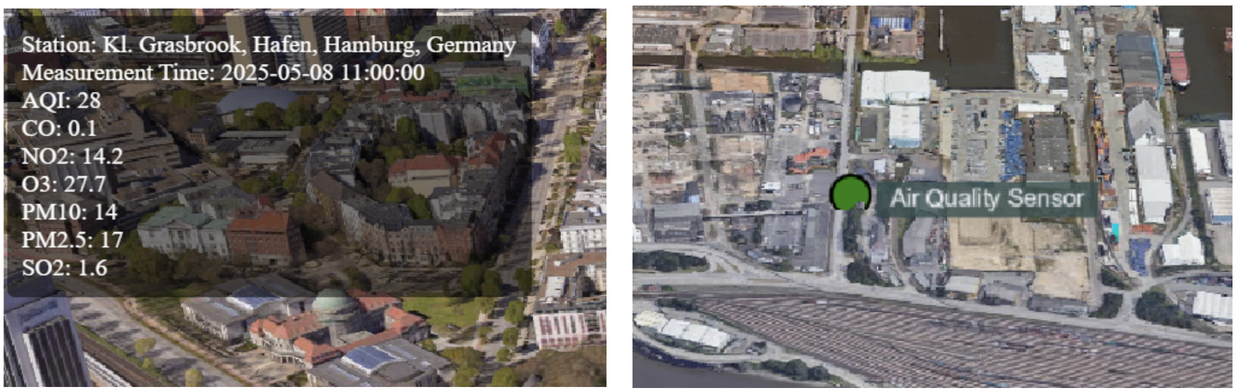


Fig. 10: Air quality measurements (left image) at the “Kl. Grasbrook” measuring station (right image) in the Hamburg port area

a) Zoom out of the map around the Hamburg area until you see a marker that is labeled “Air Quality Sensor”, and zoom into it.

   Check the color of that marker and the air quality parameters on the widget. The color of the marker depends on the AQI value. The ranges are:

| *Color* | *Minimum AQI* | *Maximum AQI* |
|---|---|---|
| Green | 0 | 50 |
| Yellow | 50 | 100 |
| Orange | 100 | 150 |
| Red | 150 | 300 |
| Maroon | 300 | N/A |

b) Zoom out and pan the map around Hamburg, and click on different locations.

Each time you click, the application determines the location of the nearest air quality monitoring station, fetches its data, and updates the information on the widget.

**Task**

Compare the air quality around three different areas.

- A location near the industrial port (Search for “Hamburg Port” on the search bar, click the area then zoom out to see the nearest air quality marker)
- A densely populated area
- A quiet, greener suburb

**NOTE**: *Since we are using a public API that covers many countries, the monitoring stations in Hamburg are not that many. In practice, the measuring stations would be more numerous and closer together, providing a better and more accurate picture of air quality.*

Real-time data gives life to the DT. It is what turns a static 3D model into a dynamic, responsive system that mirrors the actual real-world environment. By visualizing live air quality conditions on the map, the DT can be used for environmental monitoring purposes.

### 3.2.2 Flood Simulation

Flooding is one of the challenges facing urban areas, and the city of Hamburg is no exception. The city has a low elevation and relatively flat terrain. High tides from the North Sea can push water from the sea into the Elbe River, which flows through the city. This makes the city prone to flooding.

Our DT application retrieves the current water level of the Elbe (St. Pauli gauge) from the German PegelOnline web service and uses this information to mark urban areas that fall below this level. PegelOnline is a service that provides daily, real-time data on various hydrological parameters, such as water levels, from inland and coastal gauges along federal waterways.

a) Check the “Water Level Graph” checkbox in the top section of the application.

   An interactive graph appears in the top-right corner of the screen. It shows recent water level readings from the St. Pauli water level measuring station. While the dotted blue line represents the forecast water level, the solid blue line shows the measured water levels. On the right-hand side of the diagram, you can see the absolute height of the water level in meters, relative to the German elevation reference NHN (standard elevation zero, corresponds to the average sea level).

   It is obvious that the water level is influenced by the tides of the North Sea. In fact, even under normal conditions, the water level oscillates by around 3.5 meters every day.

During storm surges, the water level can rise by several meters. In January 1976, during an extreme flood event, the water level was measured at 6.45 meters above sea level.

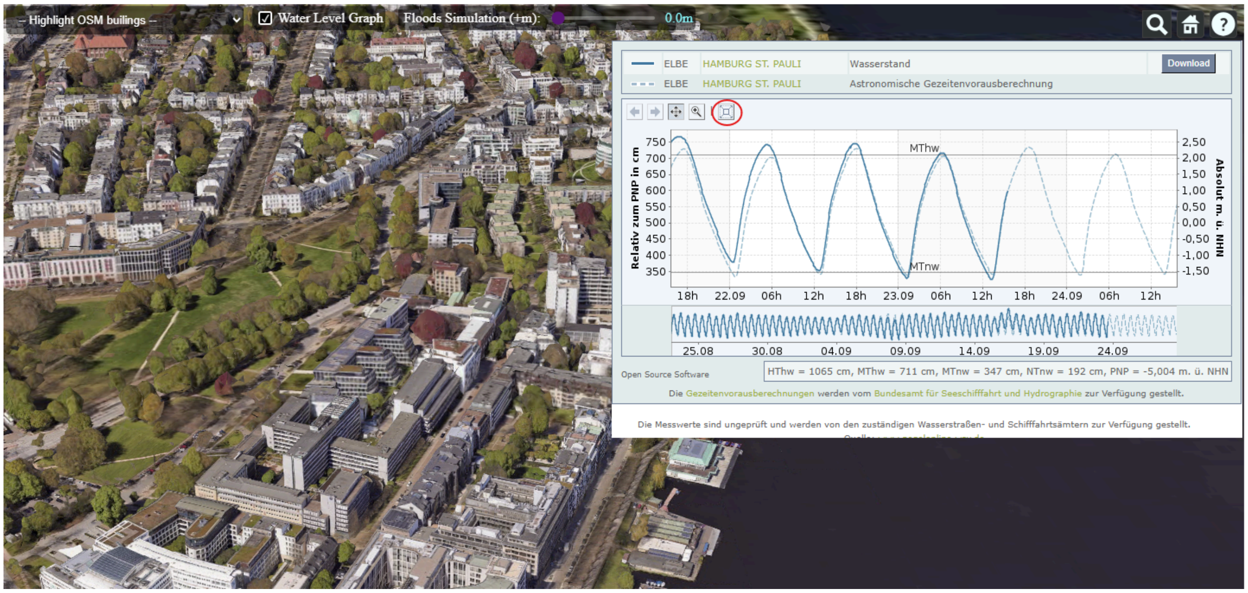

Fig. 11: Water level diagram of the St. Pauli measuring station

**NOTE**: If the interactive graph is blank, the water level data may not have been loaded. Click the ‘Den Zeitbereich zurücksetzen’ button to reload the data. The button is highlighted in color red in Fig. 11.

b) Click on the “3D tiles/terrain” button at the top left of the map and select the “Terrain” option to change the style of the base map.

The application will now display the terrain of the Earth (hills, valleys) with simpler building outlines from OpenStreetMap (OSM).

c) Observe the map closely. The low-lying areas will be shaded in blue.

These are the areas where the terrain surface is below the current water level at the St. Pauli gauge.

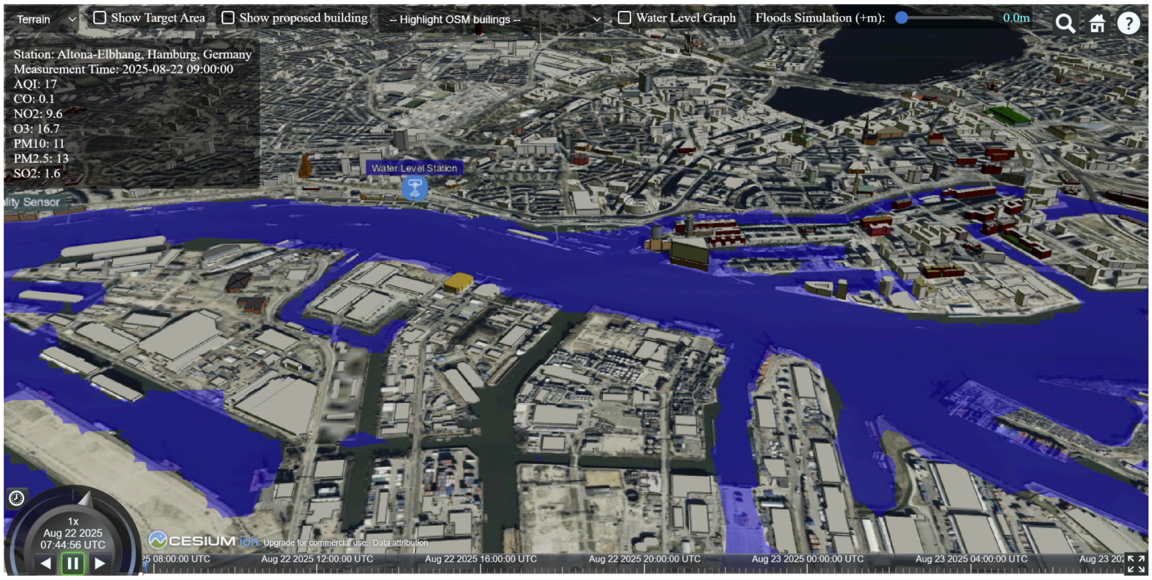


Fig. 12: Blue: Ground level lower than the current water level at the St. Pauli gauge

**NOTE:** *The blue color highlights areas whose terrain elevation is below the current water level at the St. Pauli gauge. This does not mean that all these areas will actually be flooded, as this is prevented by structures such as protective walls and dykes. More distant locations and areas that cannot be reached by Elbe flooding are also not affected.*

*In addition, the actual ground level is not represented exactly due to inaccuracies in the elevation model (different reference systems, spatial resolution), so that the areas that would be affected by flooding are only shown approximately.*

**Task**

- Use the slider at the top right of the screen to simulate a flood situation by raising the current water level by a certain amount.
- Check which areas of Hamburg are below the 1976 flood level. Consider how the current water level should be taken into account.
- Use the “highlight OSM buildings” function to check whether and where “residential buildings” are affected.

This section provides you with an idea, how DTs can incorporate simple and more advanced simulation models to provide more insights from data. Instead of looking at charts or spreadsheets, planners, emergency responders and decision makers can see the impact of changing water levels on a DT. Sophisticated simulations and visualizations support risk assessment, disaster preparedness, and urban resilience planning.

### 3.2.3 Visualize a Proposed Building

Digital twins are not only about visualizing what exists, they are also powerful tools for simulating what could exist. In this section, we are going to add a proposed 3D building model to our DT of Hamburg. You'll download the model from the OER Github repository, upload it to your Cesium ION account, and visualize it within the real-world environment of the city.

As we saw in the case study section, DTs can be used by planners, architects, city officials and even residents to assess the visual impact of a new development before it is built.

**a) Upload the 3D Building model**

The building model is located in the “data” folder in the downloaded files.

1. Sign in to your Cesium ION account.
2. Click *My Assets* > *Add Data* > *Add files,* and select the ‘Residential Buildings 008.fbx’ file
3. In the “What kind of data is this?” prompt, choose “3D Model (Tile as 3D Tiles)”.

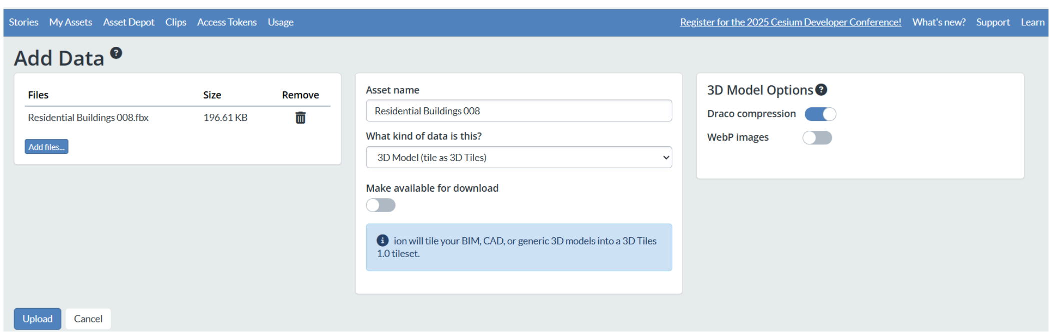


Fig. 13: Cesium platform - data upload

4. Click *Upload*. The tiling process of the 3D model will take between a few seconds and a minute to complete. The model is now listed under the “My Assets” tab.

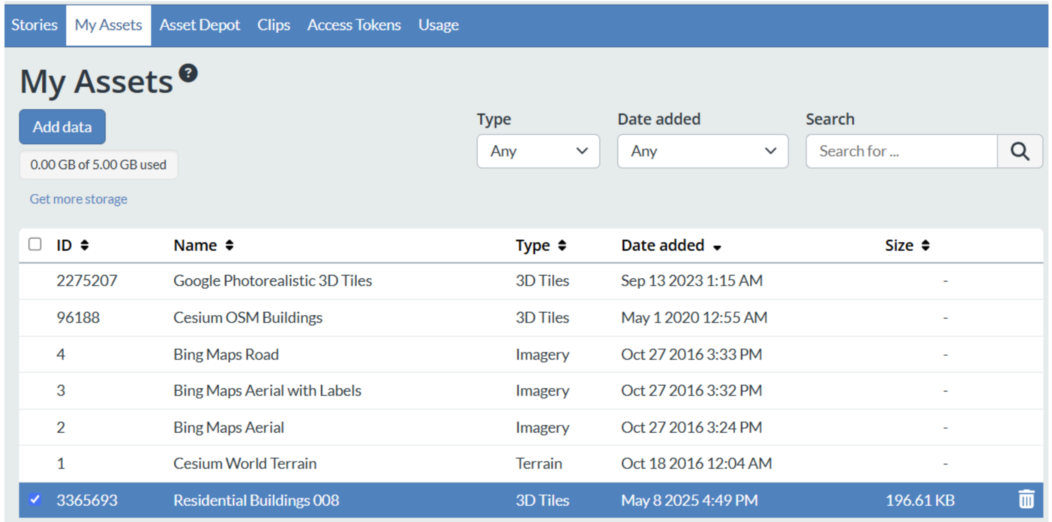


Fig. 14: Cesium platform - list of assets

5. The generated 3D tiles are not georeferenced, hence they will not align well with our DT application. To georeference them, click the "*Adjust Tileset Location*" button above the preview of the 3D building.

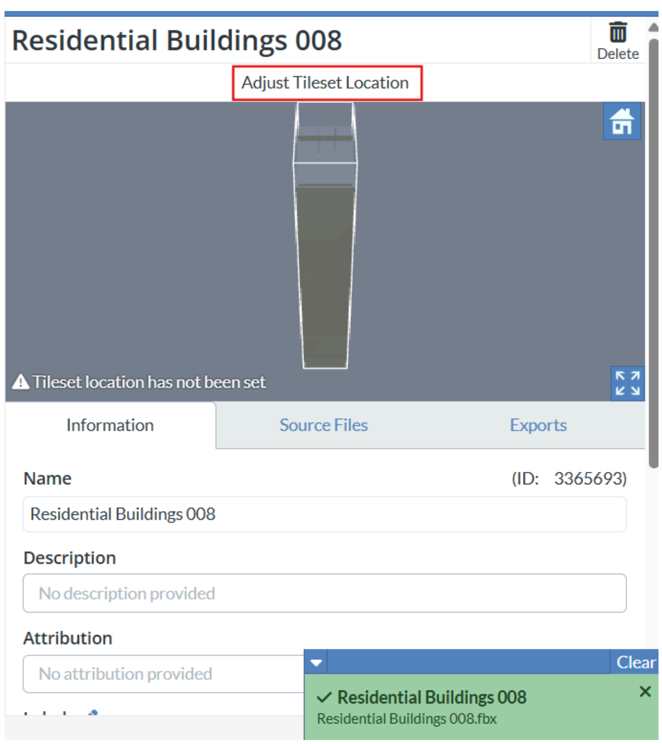


Fig. 15: Cesium platform - adjust tileset location

6. Leave the *Position* and *Terrain* options as defaults and click *Next*.

7. In the next step, we are going to manually enter the coordinates around which the building will be centered. Under the position tab, enter the latitude, longitude, and height as shown below.

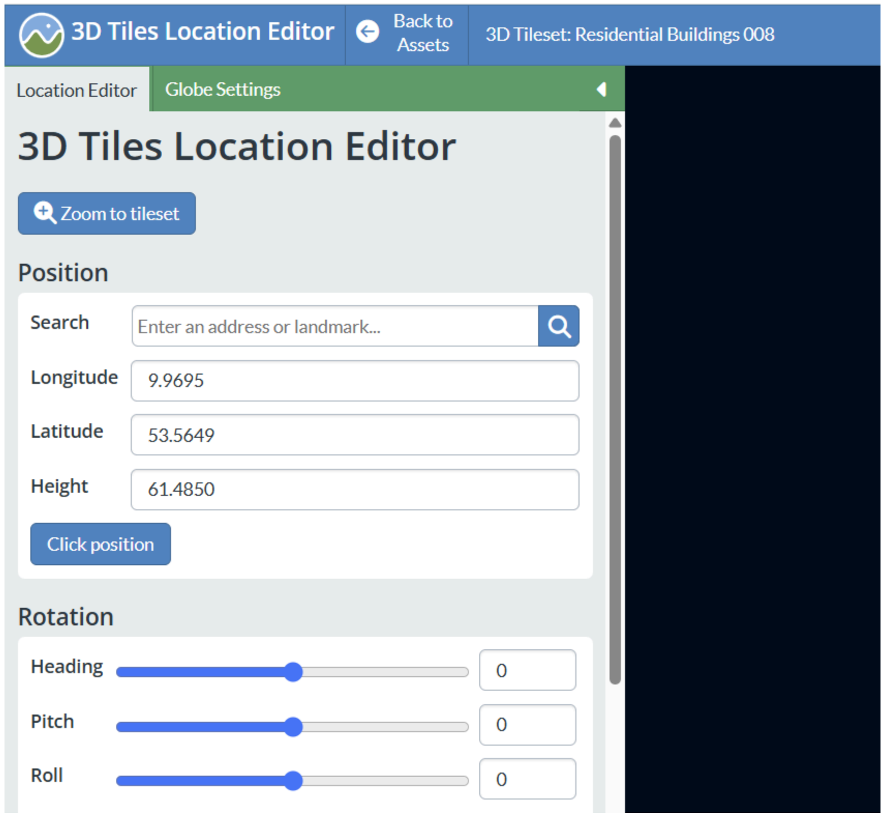


Fig. 16: Cesium platform - location editor

8. Scroll down and click the *Save* button. Then click "*Back to assets*" button at the top to go back to the main view with all the assets.

   Note the ID of our 3D model, as we will use it to fetch its 3D Tiles.

**b) Update Your Application to Load the New Model**

1. Open the config file with the tokens and add the ID of our 3D building model to the "PROPOSED_BUILDING_CESIUM_ION_ASSET_ID" variable.
2. Save the changes and refresh the DT application on the browser.
   Since browsers cache some files for performance optimization, you may need to perform a hard refresh for the changes to reflect.

**c) View the Building in the application**

1. Use the checkbox "Show proposed building" to toggle the visibility of the proposed building.
2. Zoom in on the location and observe how the building fits with its surroundings.

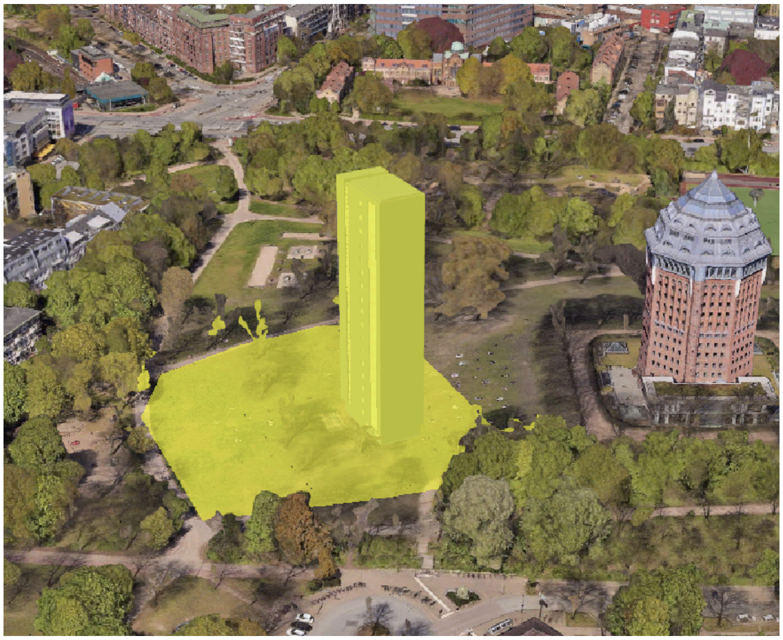

Fig. 17: DT application - visualization of a planned building

Being able to insert and evaluate proposed developments in a real-world 3D context is one of the most practical use cases of a digital twin. It helps stakeholders to visualize future projects, assess their impacts, and make better informed decisions before construction even begins.

Congratulations! You have successfully set up a digital twin application, complete with some real-time data connections.

# 4. Summary and Discussion

Through this tutorial, you have learned about the concept of Digital Twins, and explored both its theoretical foundations and a hands-on implementation. You have learned what Geospatial Digital Twins are, how they differ from 3D models, simulations, and GIS systems. You have learned why real-time data connection is important in helping digital twins to be as close as possible to the physical reality.

In the practical exercise, we created a digital twin (virtual reality) that replicates a physical system (Hamburg city) and the physical environment (air quality, water levels). The exercises show how a digital twin brings together visualization, real-time monitoring, and scenario simulation. These features enable stakeholders to make better decisions by accessing a close-to-reality virtual system.

The adoption of digital twins in various industries and applications is predicted to increase. The widespread deployment of 5G networks will enable faster data transfer, with minimal latency between the digital and physical twins. DTs will increasingly use AI models to generate insights from the big data that flows into the twin. The integration of VR/AR technology will also shape how users interact with digital twins, by providing an immersive digital environment that is as close as possible to the physical system.

# 5. References


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