ENABLING INTEROPERABILITY OF URBAN BUILDING ENERGY DATA BASED ON OGC API STANDARDS AND CITYGML 3D CITY MODELS

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ABSTRACT:

This paper presents an investigation into the interoperability of 3D building energy data management, delivery, processing, and visualization via web clients using Open Geospatial Consortium – Application Programming Interface (OGC API) standard-based data models and web interfaces. Specifically, the OGC API – 3D GeoVolumes enable access to 3D city model geometries and semantics on the web, the OGC API – Features support the 2D version of the same geospatial data, the OGC API – Processes are used for CityGML analytics and building energy computation with the SimStadt urban simulation software and the OGC SensorThings API is utilized to manage related spatiotemporal or time-series datasets. The efficacy of this approach has been demonstrated in the OGC Testbed 18 Innovation Program, which highlighted the capacity of OGC API web services to synchronize building energy data and computation results between client and server for the case study of Helsinki, Finland, and Montreal, Canada. The advantages of using OGC API services for 3D building energy data interoperability are discussed, and it is suggested that the use of OGC API be promoted to the general public as well as extended to other domains and on a larger scale in future research.

1. INTRODUCTION

Cities worldwide are solely responsible for 70% of global energy consumption and, subsequently, the environmental impact in terms of carbon emissions. Despite heavy investments to increase energy efficiency, carbon emission from buildings and construction has drastically increased, leaving the sector off track to de-carbonize by 2050 (UN, 2022). Following the latest round of climate talks in Egypt, COP27, the 2022 Global Status Report for Buildings and Construction found that the sector accounted for over 34 % of energy demand and around 37% of energy and process-related carbon emissions in 2021. Thus, it is clear that to address climate change goals, urban building energy usage and its related emissions should reduce globally.

A common criticism often highlighted in various studies is the lack of integrated urban platforms that helps policymakers to analyze and visualize urban energy data at different spatial scales (Miralles-Wilhelm, 2016). To achieve city-wide energy reduction goals, it is critical to have a comprehensive understanding of energy use at the building scale, which is challenging due to the lack of data availability at such a granular level. Because of the different characteristics of building stock across different regions and socioeconomic factors, policymakers need tools and strategies to understand building stocks at a different spatiotemporal scale that are integrated with energy and socioeconomic datasets and responds to existing and potential urban building energy and emissions policies. Policymakers commonly use geospatial tools to perform these types of analyses. However, a gap exists in the linkage process among the encoding of geospatial datasets and their processing towards creating urban building energy models, which results in discrepancies in accuracy (Saad and Eicker, 2023). For example, the building rating systems that are developed to help quantify the energy usage of individual buildings and, subsequently, their emissions as part of regional and national strategies to reduce energy usage are not often integrated or interoperable with geospatial datasets and tools. The same lack of energy data integration and interoperability with geospatial datasets also exists across a variety of other energy data sources produced by government, utilities, and industry. Lack of interoperability among these organizations' data formats results in duplication of effort, lost potential for energy savings, and lost opportunities for effective policy tools to address energy use and subsequently climate change mitigation and resilience. Such a gap has stimulated different research projects globally, for example, Canada's Canadian Energy End-use Mapping (CEE Map), United King-

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dom's Local Energy Mapping for Urban Retrofit (LEMUR), Germany's Energie-atlas (EnergyAtlas), and many other similar projects. Common objectives amongst these projects reflect the development of a harmonized data model that are characterized based on different spatial scale, integrated with energy use, generation, and performance dataset, and visualized on a georeferenced digital 2D map.

With advancements in geospatial technologies, Urban Digital Twin (UDT) Platform is attracting a lot of attention as an ultimate tool to support sustainable urban development (ABI Research, 2021). A 3D city model is a digital representation of a real-world built environment and forms a fundamental building block for UDT platforms. In the backend of the cities' UDT platform are 3D city models that act as interfaces to connect and integrate different domain-specific urban datasets, e.g., energy, mobility, urban planning, etc. The Open Geospatial Consortium (OGC) standardized semantic data model and exchange format of CityGML, within 3D city models, have been widely used in various studies to integrate diverse urban building energy datasets into a single data model (Malhotra et al., 2022, Rossknecht and Airaksinen, 2020). This integration encompasses CityGML Energy Application Domain Extension (Energy ADE) and facilitates the simulation of current and future energy demand and potential scenarios with the support of different urban energy simulators. Moreover, the integrated urban building energy datasets can also be visualized at an individual building scale on a digital web globe. Until now, studies have used a more traditional way (file-based) of data integration and simulation. For instance, commercial software like the Feature Manipulation Engine (FME) can be utilized to manipulate and integrate energy datasets into the CityGML model enriched with Energy ADE (Rossknecht and Airaksinen, 2020), or directly into the CityGML model (Padsala et al., 2021). These models can then be simulated to generate energy metrics, the results of which are once again integrated back into the CityGML model as inputs. Finally, all the integrated data, along with the CityGML model, are streamed on the web for visualization purposes (Würstle et al., 2020). Certain challenges exist with the traditional way of integration and simulation, such as 1. It causes an increase in the data size of input CityGML models when integrated with energy data, particularly the urban building energy dataset with the spatiotemporal characteristic, such as the hourly building heat demand of each building. 2. data duplication as there will be multiple copies of the same CityGML model and energy datasets, e.g., energy datasets managed and relayed from the data owners and datasets that are dumped on local machines. 3. every time a CityGML model is updated, or new updates are made to the energy datasets, the entire process of integration and simulation must be run again. 4. Data sharing will consume lots of disk space or bandwidth if shared over the internet.

Thus to overcome such challenges, the current research carried out within the framework of the OGC Testbed-18 track of Building Energy Spatial Data Interoperability emphasizes moving from a file-based approach to a web-based API approaches using OGC API standards such as GeoVolumes, Features, Processes, and SensorThings API. The main research question in focus is how the geospatial dataset component, the CityGML 3D city model, and the urban building energy dataset component, SimStadt energy simulator, and its simulation output can be integrated and visualized in one unified workflow using the OGC API approach to test the benefits of API based approach over file-based approach. Two case study areas, Helsinki and Nun's Island in Montreal, were chosen based on the difference in availability and quality of their respective cities' open datasets. The rest of this paper is organized as follows. Section 2 introduces and explains different components used in the proposed workflow, including their state of the art. Section 3 and its subsequent subsections describe how the geospatial and urban building energy components are integrated and developed into one API-based workflow. As a proof-of-concept, section 4 shows the implementation of the developed workflow using the Helsinki dataset, which has a good consistent quality of urban building stock 3D open dataset, and the Montreal dataset with an inconsistent and rather poor quality of their urban building stock 3D open dataset. Section 5 compares the effect of granularity and quality of data on the implementation of the proposed workflow's applicability through the two discussed case studies that drastically vary in quality. Lastly, Section 6 concludes the research outcome.

2. BACKGROUND

2.1 Urban building energy modeling

Urban building energy modeling (UBEM) is crucial in assessing energy efficiency, cost optimization, and carbon emissions reduction in various energy systems. However, the accuracy and reliability of UBEM depend on the quality and interoperability of input data (Battini et al., 2023). As an input to UBEM, geospatial vector datasets are commonly used to capture and process geometrical data for hundreds to thousands of buildings within a district or city. However, due to the lack of building stock digital twins in many cities along with the inconsistency in existing building stock dataset (geometrical) and its related building attributes (e.g., year of construction, building functions, etc.) and urban building energy dataset (non-geometrical) being spatially non-related to geometrical building stock datasets, urban building data should be prepared and synchronized to meet UBEM's requirements (HosseiniHaghighi et al., 2022b).

Building energy data interoperability is a critical issue in energy modeling due to energy systems' increasing complexity and diversity, including various energy sources, infrastructures, and markets (Hosseinihaghighi et al., 2022a). Building energy data interoperability refers to the ability of building energy models to share and exchange data seamlessly across different systems, platforms, and applications. According to (Dabirian et al., 2022), building energy data interoperability requires using standardized data models, formats, and ontologies that facilitate data exchange and integration across different domains and stakeholders. The quality and interoperability of building energy modeling input data can significantly affect the accuracy and reliability of energy models (Hong et al., 2020). Building energy data availability and quality vary significantly across different regions, sources, and time periods (Pasichnyi et al., 2019). Furthermore, input data for building energy modeling often lacks consistency and completeness, leading to errors and biases in energy models. For instance, energy data may have different units, scales, definitions, missing values, and outliers. Therefore, UBEM requires integrating and sharing data from multiple sources and stakeholders, such as energy providers, consumers, regulators, and researchers. Building energy data must be validated and verified to ensure accuracy, completeness, and consistency.

Therefore, a unified workflow is required to consolidate the available building energy data for its use in UBEM. Adopting

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standardized data models and formats can facilitate data exchange and integration, but challenges such as different data formats, the lack of adoption, and the heterogeneity of data sources still remain. The gaps and challenges in building energy modeling input data require further attention and solutions, such as data sharing platforms, data quality and validation services, and data management and analysis workflows.

2.2 OGC CityGML and Energy ADE

UBEM strives for consistent, interoperable, and standardized geospatial urban data as its inputs to accurately model various urban energy systems. The two most commonly used geospatial data formats to store geometries and their attributes are shapefiles and GeoJSON. However, both of them are inadequate data structures to store the semantics and topological information required for UBEM. In contrast, the OGC CityGML data model is increasingly used in many studies as an input to UBEM particularly due to its advantage of storing semantic and topological information of the urban building stock dataset (Kaden and Kolbe, 2013, Chen et al., 2019, Eicker et al., 2014).

CityGML is a standardized based data model and XML/GML encoded data exchange format that covers objects and relations of the urban built environment as a 3D city model concerning its geometry, semantics, topology, and appearance (Gröger and Plümer, 2012). Typically for the existing built environments, its CityGML-based 3D city model is automatically derived from its LiDAR datasets using tools such as 3Dfier, NovaFactory, and vcsBuildingReconstruction. In addition, CityGML datasets can also be generated from base geospatial vector datasets (point, line, polygons) of urban objects in tools such as ArcGIS CityEngine or manually hand sketched using tools such as SketchUp, AutoCAD 3D or Rhinoceros3D and then translating it to CityGML data format using ETL (Extract, Transform, Load) software such as FME (Feature Manipulation Engine) (HosseiniHaghighi et al., 2022b, Padsala et al., 2020). To validate the quality and conformity of CityGML datasets, tools such as CityDoctor, Val3dity, FME Geometry Validator, and CityGML-Tools, have been developed as part of different research projects. Government departments worldwide were fast enough to see the potential of CityGML-based 3D city models; as a result, by 2022, digital twins of around 17 countries comprising 52 regions/cities were released publicly (Wysocki, 2023), and many others privately for its use in city development projects. CityGML datasets are widely used to model and visualize various urban development-related issues (Biljecki et al., 2015), one of them being UBEM.

CityGML is a domain and application-independent data model. Therefore by an international consortium of urban energy modelers and users, CityGML Energy ADE was developed to support UBEM and urban building energy simulation(Agugiaro et al., 2018). On the one hand, Energy ADE closes the data integration and interoperability gap between different urban datasets and toolsets, and on the other hand, it acts as a single unified data input to urban building energy simulators for bottom-up energy assessments of building stocks and their visualization. The Energy ADE extends the thematic CityGML data model of CityObjects and Building and provides abstract classes for five new building energy-based modules. The building physics modules support storing objects and attributes required for building thermal behavior simulation, e.g., simulation of space heating/cooling demand. The occupant behavior module allows storing datasets on the occupancy behavior of the building's occupants. The material and construction module allows for storing properties of construction materials required for energy simulation. The energy systems module allows the representation of energy storage, conversion, distribution, and emission devices of a building and how energy flow between them. The last module is the supporting class modules representing dynamic datasets such as weather, schedules, and time series. Many urban simulation tools have been extended further to support Energy ADE's reading and writing outputs, such as SimStadt, TEASER+, CitySimPro, and EnergyPlus.

2.3 Urban building energy simulation

This study deploys SimStadt as the building energy dataset generator. In its current stable release, SimStadt is a desktop-based urban energy simulator that depends on a CityGML-based 3D city model (buildings and landuse) as its primary input to perform dynamic urban energy simulation tasks. The urban building energy simulation workflow in SimStadt is supported by customizable modules (also called processors) for building preprocessing, building physics, building usage, weather, irradiance, and monthly energy balance. The building preprocessing module takes care of importing the CityGML building dataset, its validation, and creating a SimStadt-specific building model. The building physics module is linked with the building physics library running in the backend to assign the building physics-specific attributes such as building type, U-value, infiltration rate, and window ratio to every building surface based on the building year of construction. The building usage module is also linked with the building usage library in the backend. It defines usage zones according to different building functions. In addition, it also defines the occupancy density, internal gains, set point temperatures, domestic hot water consumption, and ventilation according to usage types. Thus, as a prerequisite to SimStadt CityGML, attributes of building function and year of construction are mandatory to calculate the building physics and building usage attributes from SimStadt. If the required attributes are unavailable, the following default values are applied: (building function = residential) and (year of construction = 1980). Both the building physics library and building usage library are developed based on the local building archetypes of the case study area under consideration. Originally, the building physics and building usage library of SimStadt was developed using German building archetypes as defined in the IWU German building typologies developed in the TABULA project and building energy norm DIN V 18599 (ISO 13790), respectively. The German CityGML building function codes were derived from Germany's real estate cadastre system ALKIS (Authoritative Real Estate Cadastre Information). SimStadt's flexible and modular approach, building physics, and usage libraries for any location based on its local building archetypes can be defined easily. Building physics and usage libraries based on the building archetypes of New York City and Rotterdam are additionally developed and tested in different research projects. For any new location, the building functions from the CityGML dataset can be internally mapped to the German building functions code list and subsequently with the existing German building physics and usage library, or altogether a new building physics and usage library can also be developed.

In the last three modules, the weather processor retrieves the weather data based on the location (coordinates and CRS) of the CityGML building dataset, the irradiance processor calculates monthly average irradiances on every surface, with or without shadows and the monthly energy balance processor calculate a monthly energy balance to each building, in order to determine monthly heating (including domestic hot water demand) and cooling energy demands. On simulation, SimStadt generated a CSV (Comma Separate Value) file with different building energy-related attributes (e.g., CityGML building IDs, yearly and monthly specific space heating demand and cooling demands, domestic hot water demands, etc.). To visualize the SimStadt energy simulation output on a 3D globe at an individual building scale, generated building energy attributes are injected into buildings or building parts of the input CityGML dataset using FME. Subsequently, the enriched CityGML dataset is then converted to a web steaming format such as OGC 3DTiles for visualization (Würstle et al., 2020).

The challenges associated with this process have been previously highlighted in the introduction section. Therefore, the present study investigates the use of different OGC APIs to integrate the geospatial dataset component, e.g., the CityGML 3D city model, and the urban building energy dataset component, e.g., SimStadt energy simulator, and its simulation output into one unified workflow.

3. METHODOLOGY

As a part of the OGC Testbed-18 Innovation Programme, the task aims at investigating the feasibility of combining energy and geospatial data into a single model through mapping and integration techniques. These models comply with OGC Web API standards, allowing for direct analysis, simulation, and visualization of the data without further integration efforts. The final goal is to design an Urban Building Energy Spatial Data Infrastructure (SDI) that can be integrated into the Geospatial Data Infrastructure. The processing services will produce value-added products using the data and serve them through data services with interfaces and data models similar to the original data services, reducing conversion costs. In order to achieve this, the overall workflow had been structured as shown in Figure 1 consists of four main sections including **Data inputs** (3.1), **Data Processes** (3.2), **Web Services** (3.3), and **Data Visualisation** (3.4).

3.1 Data Inputs

The 3D city model in CityGML format serves as a baseline for our work, providing input 3D geometry and semantic data to be used for building-energy analysis and visualization. In most cases, however, the CityGML 3D city model alone is not sufficient for building-energy data analysis and requires further geospatial layers to be integrated in order to enrich the model. For example, these extra layers incorporate building types and stock typologies, as well as the year of construction, whilst environmental data in the area, such as climate and weather data, also be used to further enhance the model. These additional data are then integrated into the 3D city model, enabling the calculation of building-energy data analysis in the Data Processes step (Chapter 3.2). This research was made possible by the contributions of Testbed 18 participants, including the City of Helsinki, Finland, and Natural Resources Canada. Data from Helsinki and Nun's Islands, Montreal, Canada, were sourced, enabling the development of an interoperability framework for managing urban building energy datasets. The two case studies are outlined in Chapter 4.

3.2 Data Processes

As mentioned in chapter 2.3, our main urban building energy processing tool is the SimStadt urban simulation environment, initially developed as a desktop software at HFT Stuttgart[1]. It was employed for the construction of an urban building energy processing service. This software was utilized to generate workflows for simulating energy-related attributes in the CityGML 3D city models provided to the service. Generated attributes included yearly and monthly space heating and domestic hot water demands. The urban building energy simulation workflow in SimStadt is supported by customizable modules referred to as processors, responsible for building preprocessing, building physics, building usage, irradiance, and monthly energy balance. The building preprocessing module performs the import of CityGML building data, its validation, and the creation of a SimStadt-specific building model. The building physics module is connected to a building physics library in the backend to assign building physics attributes, such as building type, U-value, infiltration rate, and window ratio, to each building surface based on the building's year of construction. Additionally, the building usage module establishes usage zones based on building functions and defines occupancy density, internal gains, set point temperatures, domestic hot water consumption, and ventilation according to usage types. Based on this SimStadt application, the urban building energy processing web service is developed to determine the varieties of urban building energy-related attributes such as building heating demand, building cooling demand, and rooftop-integrated solar energy potential. The web service is built to enable most features from SimStadt while conforming to the OGC API – Processes standard.

3.3 Web Services

Once the geospatial datasets and process units have been established, web services are implemented for the delivery of the geospatial data, as well as for interaction with the available process units. To make this possible, the Open Geospatial Consortium (OGC) API Standards are used to ensure a standardized approach to accessing and exchanging geospatial data between multiple systems. This research implements three OGC API standards: OGC API – 3D GeoVolumes and OGC API – Processes.

OGC API – 3D GeoVolumes has been developed to provide an open standards-based solution for accessing and transferring 3D geospatial content over the internet. It enables users to discover and access a variety of 3D content from different providers, regardless of the distribution mechanism or format used (e.g., 3D Tiles, I3S, glTF, CDB, CityGML). This is made possible by a resource model and API, which offers an efficient, space-centric perspective. In this research, the 3D data, preprocessed and converted into the streaming format (glTF, 3D Tiles, and I3S), is hosted as a service conforming to the OGC API 3D GeoVolumes specification. This specification has been developed to allow users to manage data heterogeneity and access data with a unified API retrieval method, providing a 3D dataset in a streamable format to client applications. As part of the OGC API family of standards, GeoVolumes offers the benefit of sharing, consuming, and filtering 3D geospatial resources on the web using the defined resource-centric APIs. The implementation of the 3D GeoVolumes service is based on open-source software (Santhanavanich, 2021). To ensure efficient streaming, only selected attributes, geometry information, and unique building and building part IDs are filtered and converted to glTF, 3D Tiles, and I3S formats, as recommended in (Santhanavanich et al., 2022). In addition to the 3D city model

[1] https://simstadt.hft-stuttgart.de/

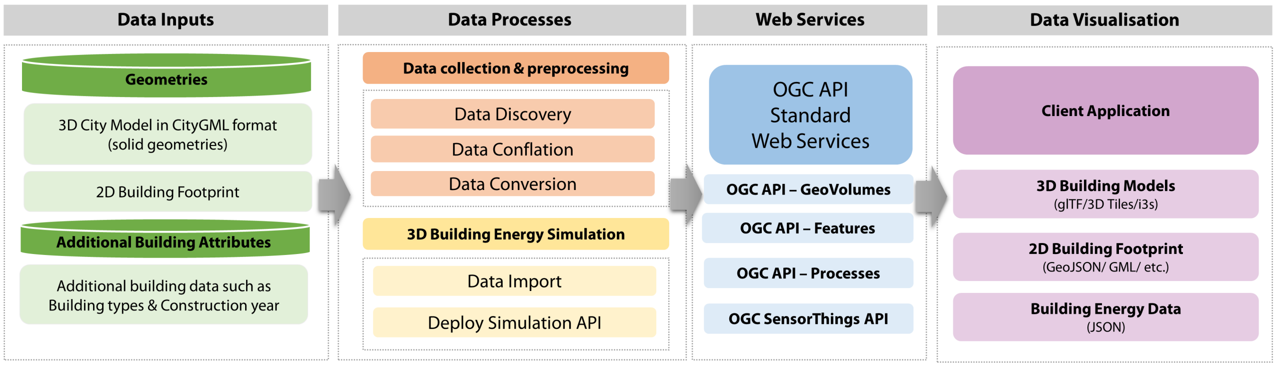

Figure 1. The overall workflow of urban building energy data interoperability via OGC API-compliant web services.

data retrieved from the 3D GeoVolumes service, further enrichment of the model can take place on the client side, such as temporal sensor data from SensorThings API and urban building energy data from OGC API Processes services. These can be conflated to the building model directly on the client side, as discussed in (Santhanavanich and Coors, 2021).

OGC API – Features is a standard for sharing 2D geometry and attribute data. It is commonly used with standard 2D geospatial data formats such as Shapefiles, GeoJSON, KML, CSV, and GML. It also includes support for queries, transactions, and operations on feature collections. OGC API Features also provides an extensible framework for creating custom services that can be used to build applications. Our implementation uses GeoServer with the OGC API extension to provide access to such data in addition to the OGC API – GeoVolumes, which is designed to facilitate the use of 3D geospatial content. In our use cases, the data managed by OGC API – Features is the building footprints along with a selection of associated attributes. The direct benefit of using OGC API – Features is that it already has numerous supported 2D map clients, such as ArcGIS Enterprise, QGIS, and many others, to use the service, allowing them to integrate data from multiple sources and create applications that can be used in a variety of contexts.

OGC API – Processes is developed to wrap the executable process development of computational tasks and provided as a standardized web API that can be invoked or used by a user or client application. The standard defines a processing interface that operates on a RESTful protocol, utilizing JavaScript Object Notation (JSON) encodings for communication. While the standard incorporates elements from the OGC Web Processing Service (WPS) 2.0 Interface Standard, it does not mandate the implementation of a WPS and offers a modern approach to programming and interacting with web resources, enabling seamless integration into current software packages. This standard caters to all the case studies that were previously covered by the former OGC WPS. Also, it utilizes a resource-oriented approach and leverages the OpenAPI specification for better functionality (Pross and Vretanos, 2021). The OGC API – Processes service endpoints are available online[2] and enable users to execute computing processes, as well as retrieve metadata describing their purpose and functionality. Through its use, clients can access the urban building energy processing unit, view the metadata of the service, and identify its requirements, such as request patterns and payload. Moreover, the service supports both synchronous and asynchronous computation, giving clients the option to wait for the computation result or to retrieve it later using a trigger once the job is done. Additionally, the job result is cached on the server, allowing other clients to benefit from retrieving past computed results directly.

[2] https://steinbeis-3dps.eu/ogc-api-processes

OGC SensorThings API provides a unified, geospatial-enabled way to interconnect Internet of Things (IoT) devices, data, and applications over the HTTP protocol(Liang et al., 2016). In this work, the sensing part of SensorThings was implemented using the Fraunhofer Opensource SensorThings-Server[3] (FROST). This offers a standard way to manage and retrieve time series and its associated metadata from various data sources. In our case, instead of the usual sensors or IoT devices, we adapted the SensorThings to collect data from building energy processing services and tools and registered these tools as Sensor entities and each building as a Thing entity in the SensorThings data model. Utilizing SensorThings extends the possibilities for users to interact with the time-series data associated with each 3D building via standardized services.

3.4 Data Visualization

For the visualization, a web application is developed which connects to the previously described services named the OGC API – 3D GeoVolumes and the OGC API – Processes services (see Section 3.3) The 3D web client enables users to interact with, retrieve, simulate, and visualize configurable data based on OGC API web standards. Developed using the React[4] frontend framework and integrating CesiumJS[5], the 3D geospatial web visualization library, it enables the visualization of large geospatial datasets in streamable 3D Tiles[6] format directly in the browser.

The business logic of the user interaction workflow for data retrieval is shown in Figure 2.

Opening the web application triggers the client to fetch the by default registered OGC API – 3D GeoVolumes endpoints for their available collections and displays their available 3D GeoVolumes and their extent (see Figure 2 green). A user may optionally add a custom 3D GeoVolumes endpoint by oneself (see Figure 2 gray dashed)

After selecting a 3D GeoVolume, i.e., a 3D building model, the client fetches the *tileset.json* containing the 3D city model from the 3D GeoVolumes server (see Figure 2 orange), and the map

[3] https://github.com/FraunhoferIOSB/FROST-Server
[4] https://react.dev/
[5] https://cesium.com/platform/cesiumjs/
[6] https://www.ogc.org/standard/3dtiles/

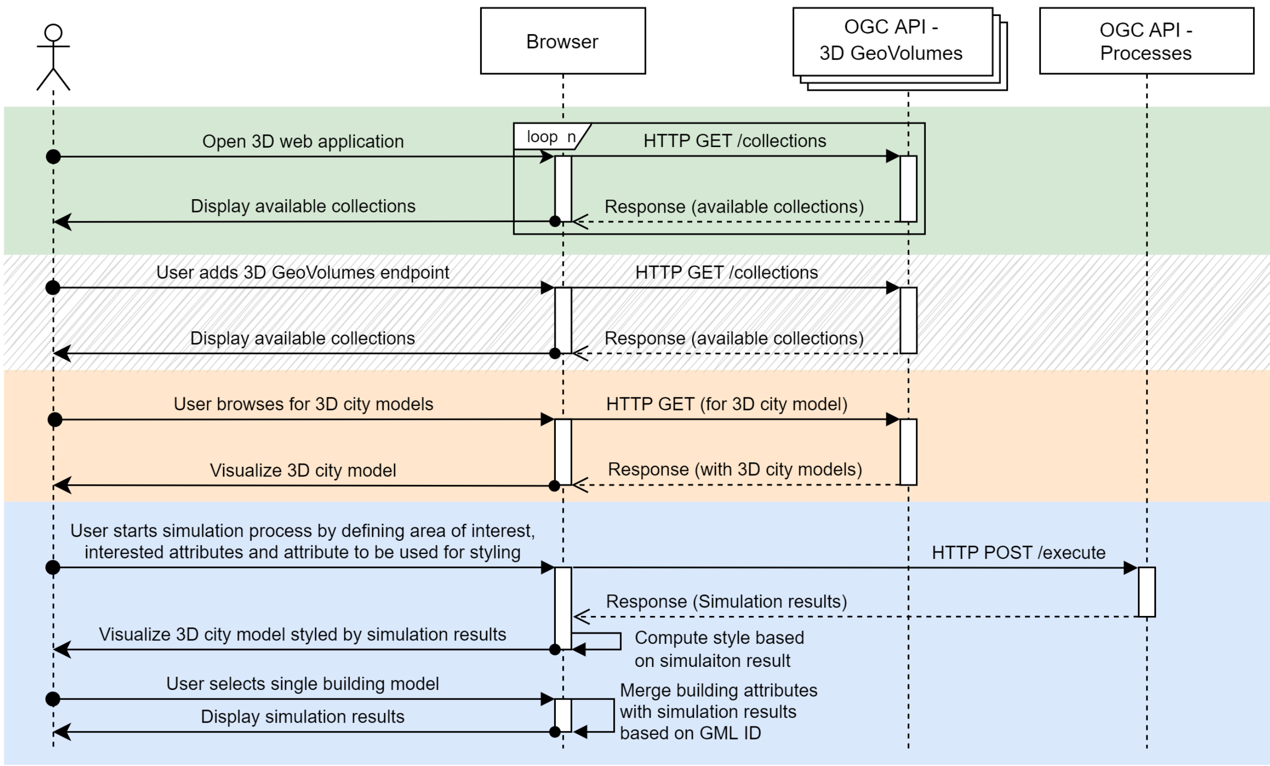

Figure 2. Sequence diagram showing the user interaction and service integration of the Urban Building Energy Client

is centered to the spatial extent of the tileset. The user may inspect already existing building information provided in the 3D Tiles batch table of the tileset.

The user is now able to start a simulation process for registered city models (see Figure 2 blue). Therefore the required process parameters, i.e., *area of interest* and *interested attributes*, are defined by the user. Furthermore, the attribute which should be used for colorization of the city models buildings can be chosen. By submitting the configuration parameters, an HTTP post request (shown in Listing 1) is sent to the OGC API – Processes endpoint. The body contains the required inputs described in the process description of the OGC API – Processes service. The process is executed on the server and returns the results to the client.

For styling buildings to visualize SimStadt simulation results, e.g., the specific space heating demand of a building, a *Cesium3DTileStyle*[7] is created by the client which maps the building identifier, i.e., *gml id*, to the corresponding color depending on its energy demand. Now, when the user selects a building, both the existing and simulated feature attributes are displayed. Also, here, the linkage is archived using the building identifier from the simulation result of a building with the *gml id* stored in the 3D Tiles tileset.

4. CASE STUDIES

In this section, we present case studies of Helsinki and Nun's Island which were conducted using the methodology outlined in Section 3 as part of the OGC Testbed 18 Innovation Programme.

[7] https://github.com/CesiumGS/3d-tiles/tree/main/specification/Styling

```
POST
↪ /ogc-api-processes/processes/simstadt_api/execution
↪ HTTP/1.1
Host:
↪ https://steinbeis-3dps.eu/ogc-api-processes/processes/
↪ simstadt_api
Accept: application/json, */*
Content-Type: application/json
Content-Length: 270

{
  "inputs": {
    "bbox": {
      "bbox": [-73.5488, 45.4536, -73.5416, 45.4564]
    },
    "interestedAttributes": [
      "specificSpaceHeatDemand",
      "monthlyHeating",
      "yearOfConstruction"
    ]
  }
}
```

Listing 1. HTTP POST request with configuration parameters sent to the processes execution endpoint

4.1 Case Study: Helsinki, Finland

For the case study of Helsinki, the openly available CityGML 3D city model is used (City of Helsinki, 2017). First, using CityDoctor, the Helsinki CityGML files are validated using the schema definition of the CityGML standard to ensure that the file structure does not contain any errors. Furthermore, in CityDoctor, they are also checked for geometrical errors. While the CityGML dataset successfully passed the schema validation, certain geometrical issues were found. These geometrical errors were neglected as the goal of the present study is not to perform actual energy simulation of Helsinki's building stock but rather to encapsulate the geospatial dataset and the urban building energy dataset into a unified workflow using the OGC API approach.

Before converting the dataset provided in CityGML version 2.0 to 3D Tiles format, the LoD2 building model is enriched by attributes required for urban building heating demand calculation from the Helsinki Building Energy and Climate Atlas (City of Helsinki, 2018) and modeled in the Energy ADE schema. The information stored in the Energy ADE data model is then included as additional information for heating demand simulations. The optimized dataset for visualization is then published via the OGC API – 3D GeoVolumes. The building stock typology (Section 2.3), representing the building stock of Helsinki and required for the simulation, is taken from (Rossknecht and Airaksinen, 2020) and, as with the city model itself, is registered to the SimStadt simulation processing service (Section 3.3) and can now be used for an urban building energy simulation workflow (Section 3.4). Figure 3 shows the web application with the resulting visualization of Helsinki's 3D city model, which includes information provided by the Helsinki Energy and Climate Atlas.

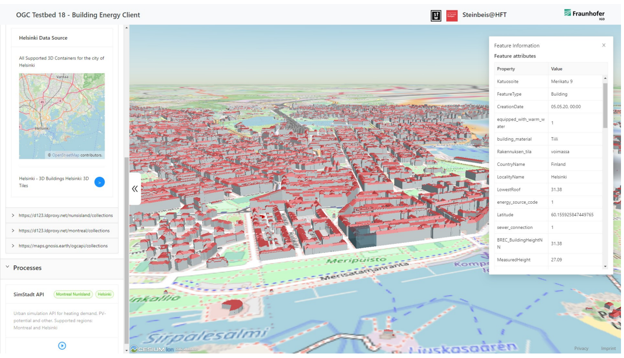

Figure 3. Developed client visualization showing 3D city model of Helsinki with available attributes from the Helsinki Energy and Climate Atlas for a selected building

4.2 Case Study: Nuns Island, Montreal, Canada

This use case section describes the application of Nun's Island CityGML 3D city model for its urban building energy simulation. The Nuns Island CityGML LoD 2 building stock geometry dataset is extracted originally from Montreal's CityGML LoD 2 textured dataset (City of Montreal, 2020). The textures from the original Nun's Island CityGML data are removed to reduce the overall file size. Similar to the Helsinki case study, the geometrical errors are found but neglected on validation with CityDocotor. Unlike the Helsinki CityGML dataset, schematic errors are found in the original Nuns Island CityGML dataset. The gml IDs of certain buildings and surface polygons are found starting with numbers in the original CityGML dataset. This violates the constraints put for XML/GML encoding that an identifier must always start with a letter. This also prevents the CityGML dataset from running the SimStadt urban building energy simulation. Subsequently, new gml IDs are produced for the extracted Nuns Island CityGML dataset. A copy of the original gml IDs of buildings is kept for referring back to the original dataset whenever required. Additionally, in the original dataset, the Coordinate Reference System (CRS) is also found to be missing. Thus, the extracted Nuns Island dataset was correctly referenced to its native CRS of the dataset: NAD83 (CSRS)/MTM zone 8 + CGVD28 height (horizontal CRS in EPSG:2950 + vertical CRS in EPSG:5713). As a prerequisite for SimStadt's urban building energy simulation, the processed Nuns Island CityGML dataset must contain CityGML attributes of building function and year of construction. Therefore, using the CODE_UTIL and ANNEE_CONSTRUCTION attribute fields available from Montreal's property assessment unit shapefile dataset (City of Montreal, 2017), the extracted CityGML dataset of Nuns Island is spatially joined and enriched with the attributes of building function and year of construction respectively. In this process, a building function XML code list dictionary for Nuns Island is developed and integrated with its CityGML dataset to satisfy the schema requirement for any CityGML building dataset.

The enriched Nuns Island CityGML dataset is then converted to streamable 3D Tiles format and published via the OGC API – 3D GeoVolumes, and registered to the OGC API – Processes processing service. The resulting visualization of simulated specific space heating demand for an area of interest of Nun's Island is shown in Figure 4, with buildings colorized by their specific space heating demand, and the monthly heating demand of a selected building displayed in a bar chart.

Figure 4. Developed client application showing 3D city model of Nun's Island styled by its heating demand with available and simulated attributes for a selected building

5. DISCUSSION

In this study, we used the OGC standard-based data models and interface to manage and analyze the information about urban building energy data. The main data source is the 3D city model in CityGML format, which is an efficient exchange format as there are currently several tools and plugins, such as 3DCityDB, GeoRocket, and FME, allowing the basic data ETL and data management with databases. However, it is not possible to interact with the CityGML analytics processors and visualize its result via web services. To counter this, we focused on the use of the OGC API standards, including OGC 3D API GeoVolumes and OGC API Processes, to allow interoperability of 3D content data processing and visualization via the web clients. In this study, the OGC 3D GeoVolumes have been used to organize access to the 3D city model geometries and semantics in various formats, including CityGML, 3D Tiles, and glTF, which had been pre-conversed. Together with OGC Testbed 18 participants, including Ecere, 52N, Ethar, etc., the OGC 3D GeoVolumes services had been provided and successfully interchanged 3D city model contents among all participants. Even though the concept had been proved in the OGC Testbed 18 and prior OGC activities such as OGC Interoperable Simulation and Gaming Sprint and 3D Data Container and Tiles API Pilot. The current limitation of OGC API GeoVolumes is the lack of open-source tools or libraries to incorporate 3D content from GeoVolumes into 3D web clients, desktop clients, and modern game engines. In addition, the OGC API Processes was built as an online web service for CityGML analytics on top of the SimStadt API. The web service allows users to initiate urban building energy data processing by an input bounding area as a payload or retrieve the existing urban building energy data result directly. The tool had been tested and confirmed the interoperability among the OGC testbed participants allowing the urban building energy computation on the fly and visualizing them on the client directly. The issue found during the testbed period was that the OGC API Processes service can be easily overloaded according to the high number of requests and high resource requirements on each computation request. Another limitation of Processes service is also the lack of interactive client tools to interact with the services. Also, the OGC API Processes services require further study to strengthen information security and service accessibility. The OGC API Processes were thus evaluated as a useful tool for CityGML analytics and urban building energy computation. Its effectiveness has been demonstrated through the OGC testbed, which showed the capability of the web service to synchronize the urban building energy data and computation results between the client and server. Future research should focus on improving the performance of the OGC API Processes by better utilizing the existing resources and developing interactive client tools. This will enable the OGC API Processes to become a more accessible and reliable service for CityGML analytics and urban building energy computation.

6. CONCLUSION

This research has demonstrated the potential of the OGC API standard to provide interoperability for 3D urban building energy data managing, delivering, processing, and visualization. The effectiveness of the OGC API Processes for CityGML analytics and urban building energy computation has been analyzed through two use cases in Montreal and Helsinki during the OGC Testbed 18. The proposed standardized API approach benefits the energy spatial data infrastructure through 1. providing a standardized data structure and format that all the systems can understand and thus ensures a high level of interoperability, 2. addressing privacy concerns for domain-specific datasets by allowing the asynchronous and independent data update cycle, 3. duplication of datasets can be removed 4. energy datasets irrespective of their temporal resolution can be integrated at client side with the CityGML model without worrying about the data size and 5. data sharing can be quick without worrying about the dataset size. Future research should focus on improving the performance of the OGC API Processes by better utilizing existing resources and developing interactive client tools to make it a more accessible and reliable service.

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