THE USE OF 3D GEOVISUALIZATION AND CROWDSOURCING FOR OPTIMIZING ENERGY SIMULATION

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ABSTRACT:

As the world continues in the quest to fight global warming and environmental pollution by gradually moving to renewable sources of energy, there is also a need to reduce building energy consumption by refurbishing old and historic buildings to meet the required energy standards. While this approach may differ from city to city across the globe, the refurbishment of old and historic buildings would make a significant impact. That is why it is necessary to educate building owners or occupants by simulating the existing energy consumption and proposing appropriate refurbishment strategies. Because the accuracy of energy simulation is directly proportional to the amount of data available and its reliability, there is a need to find creative ways of supplying incomplete or missing building information. The present paper describes a concept that enables individual building occupants or owners to provide this missing information. Implemented and tested with the 3D city model of Aachen, the proof-of-concept enables individual building owners or occupants to perform energy simulations based on energy information supplied.

1. INTRODUCTION

With energy end-use responsible for a large percentage of its energy demand, Germany has been paying close attention to the building sector as the statistics shows that more than 60 percent of the heat demand in the building sector is spent on space heating (Eurostat, 2020). With these concerns in mind, initiatives have been established to support the refurbishment of old and historical buildings to be energy efficient.

Since most of these buildings are residential buildings, the municipality has to encourage building owners to refurbish their buildings in order to be energy efficient. Accordingly, there is a need for practical examples to show the current state of their energy consumption, how they can reduce energy consumption, and the cost of refurbishment. Energy demand is often simulated with building data, such as building type, usage and year of construction, from three-dimensional (3D) building models. However, these building data are sometimes missing or incorrect, which affects the result of the simulation. Therefore, it is necessary to contact building owners to get missing information or clarify the validity of the current data to ensure data accuracy. Due to the problematic nature of energy-related data and security issues, the municipality demands an innovative and non-binding way to persuade and educate building owners on energy-related topics for refurbishing their buildings to be energy efficient.

This paper aims to describe a crowdsourcing concept that facilitates the collection of missing or incorrect building information that is necessary for performing a more accurate energy demand simulation directly from the building occupants or owners.

2. RELATED WORKS

2.1 Estimation of Heating Demand

Recent research on urban energy modeling seeks to find a balance between simulation at different scales. At the extremities of this spectrum are the use of individual buildings and analysis at the district scale (Nouvel et al., 2017, Monien et al., 2017). The WeBest (*Wärmebedarfsprognose von Gebäuden und Stadtquartieren*) project undertaken at the Stuttgart University of Applied Sciences provided several conclusions relevant to this domain. First, the use of virtual city models strives to strike a balance between the two extremes by being applicable at both scales (single buildings and urban scales) without loss of quality. Second, for performing energy simulation using virtual city models in CityGML format, semantic information such as the age and function of a building is required (Monien et al., 2017).

The CityGML standard is an open data model that allows for the interoperable storage and exchange of virtual models of the urban environment, such as buildings, transportation networks, and terrain. The heating demand for buildings is highly correlated to geometric and semantic characteristics that can be derived from virtual building models. In addition, the CityGML model has predefined attributes for storing semantic information such as building `function`, `yearOfConstruction` and `storeysAboveGround`. However, in most real-world data sets, these attributes are not captured during the creation process of the virtual city models (Carrión et al., 2010, Gröger et al., 2012).

Energy-related properties of buildings may be indirectly derived using a virtual city model (Agugiaro, 2016). In this approach the virtual city model has to provide the required information, which includes geometric information (such as location and height), topological information (such as adjacency to other buildings and shared walls between buildings), and semantic information (such as the date of construction, usage). The aforementioned geometric, topological, and semantic information is also combined in order to categorize buildings into various types such as single-family houses, row houses, and multi-family houses (Carrión et al., 2010, Institut Wohnen und Umwelt, 2005, Nouvel et al., 2017).

SimStadt, an urban energy simulation platform developed at the Stuttgart University of Applied Sciences (Nouvel et al., 2015), is organized into workflows such as the heating demand workflow, which is based on the monthly energy balance as described by the German standard DIN V 18599-2 (Nouvel et al., 2017). The heating demand workflow executed by the SimStadt platform requires three building parameters extracted from the input CityGML data. These are geometric data, building physics attributes, and building usage attributes. The building geometric information that is extracted includes volume, height, surface type (whether the surface is an external wall or a shared wall), and surface orientation (azimuth and inclination). The extracted geometric information is used in conjunction with benchmarking data libraries to estimate the energy reference area. To calculate the building physics attributes, information from the CityGML attributes such as building `function` and `yearOfConstruction` are required. These two sets of information are then used in conjunction with building typology libraries to categorize buildings based on their type and age classes. Finally, building usage is obtained by mapping the values of the attribute `function` (which are codes based on *ALKIS*, the German Authoritative Real Estate Cadastre Information System) to reference building usage of the German building energy standard DIN V 18599-2 (Nouvel et al., 2017).

Apart from the previously mentioned semantic attributes (`yearOfConstruction` and `function`), it has been suggest that additional semantic information that is not typically modeled by the CityGML model such as the refurbishment date, basement type, and attic type may be used to improve simulation results further (Nouvel et al., 2017). Unfortunately, information about building age may not always be available for individual buildings (Carrión et al., 2010, Braun et al., 2018, Zirak et al., 2020). In response to this, a recent study which employed a statistical approach for determining the age of individual buildings from an aggregated census dataset was undertaken (Zirak et al., 2020). However, this study concluded that the resulting estimate of the heating demand was acceptable when analyzed from a regional scale, but this result was not accurate enough at the individual building level.

Energy Performance Certificates (EPC) were issued under the European Union's Energy Performance of Buildings Directive of 2010, as an attempt at reducing the energy consumption by the building sector in Europe. The EPCs are required when a new building is constructed or when an existing building is listed for sale or rent. In addition, for existing buildings, the EPCs should describe the most cost-effective way of improving the building's energy performance (Amecke, 2012, Gonzalez Caceres, 2018).

2.2 Crowdsourcing

There are generally two policy-making approaches. The top-down approach in which decisions are made by political actors without consulting the public and the bottom-up approach in which all stakeholders are involved in decision-making. The modern approach to policy-making is a hybrid of these two approaches, and information technology (IT) innovative tools are useful in encouraging public participation (Dambruch, Krämer, 2014).

The earliest use of the term "crowdsourcing" dates back to 2006 (Howe, 2006). One year earlier, in 2005, the term "wikification of GIS by the masses" which describes a process similar to the editing of a wiki by knowledgeable human actors, had been introduced (Kamel Boulos et al., 2011). This was followed by the term "democratization of GIS" which refers to the provision of basic functions of GIS tools to the average user (Butler, 2006). In 2007, the term "volunteered geographic information" (VGI) was introduced to describe the creation of spatial information by private volunteers who, in most cases, have no formal qualifications in the geospatial fields. The value of VGI is that it allows geographic information to be obtained at the lowest possible cost, and in certain cases, it is the only available spatial data (Goodchild, 2007). In most contexts, VGI can be thought of as "crowdsourced geographic information" (Harvey, 2013). There are a variety of platforms that allow for the collection of VGI. These include OpenStreetMap [1], geotagged Flickr [2] images, Wikimapia [3] and Foursquare [4].

VGI does not aim to replace "conventional" data update and maintenance activities but is meant to provide a useful alternative when judiciously used (Coleman, 2013). In this context, "conventional data" has the following characteristics (Coote, Rackham, 2008): it is data created for specific purposes; there are usually restrictions on its access and use, owing to security, data protection, and commercial issues; it is managed by organizations established specifically for this purpose; it is collected by staff whose job is to do so; there are usually established methods, standards, specifications and practices; and, the data is usually protected by copyright or licenses.

It has been noted that there is a level of skepticism attached to VGI, especially in regard to its reliability. This has in turn led to the formulation of a list of questions that should be answered for the successful use of VGI, including the minimum skill level of the contributors; the amount and reliability of available information; the willingness by users to contribute; difficulties in accessing the knowledge that potential contributors have; the reliability of contributions; and the need for long-term maintenance of the initiatives (Mancini et al., 2015).

Crowdsourcing of 3D data has been in existence for a while now. The earliest studies involved using geometric and semantic information about buildings from OpenStreetMap data to generate Level of Detail (LoD) 1 and LoD 2 models (Goetz, Zipf, 2013). This approach was extended to enable the generation LoD 3 and LoD 4 models from OpenStreetMap data (Goetz, 2013). Furthermore, a concept for a prototype of a web-based platform for the sharing of building models has been described (Uden, Zipf, 2012).

A platform for public participation in urban planning using 3D building models has been developed. Some of the factors that may promote the successful use of such a planning tool include: using realistic 3D models (preferably LoD 2 and textured); the web tool has to be simple to use for all, and the tool should be portable i.e., should be used directly without installation of additional components (Dambruch, Krämer, 2014).

A recent small-scale study presents a "fit-for-purpose" procedure that balances the requirements of acceptable accuracy on the one hand with the benefit of time and cost savings on the other (Gkeli et al., 2019). The authors also emphasize the importance of training on the use of the crowdsourcing tool by making use

[1] https://www.openstreetmap.org/
[2] https://flickr.com/
[3] http://wikimapia.org/
[4] https://foursquare.com/

of detailed descriptions and demonstration videos. Finally, they also mention the importance of considering the legal aspects related to data storage in the cloud.

2.3 Digital Globes

The idea of a "digital earth" was first stated by the former Vice President of the United States of America, Al Gore, in 1999. There are two main characteristics of this "digital earth": first, it is a multi-resolution, 3D representation of the earth; and second, it allows the discovery, visualization, and understanding of large amounts of georeferenced information (Craglia et al., 2012).

The Cesium Javascript library has been developed with this vision of the "digital earth" in mind (Moore, 2018). Some of the unique features of the Cesium library include: support for geospatial coordinates out of the box, streaming of terrain and imagery; users can switch between different data sources on the fly; and, users can change the visualization dynamically (Krämer, Gutbell, 2015).

The foundation technologies required for developing an application that aims to support the visualization of 3D objects are HTML5 and WebGL. HTML5 serves to provide a common platform for application development in addition to multi-threading support. WebGL allows for the visualization of 3D objects in most major web browsers without the need for plugins and extensions. It also provides hardware acceleration in case a suitable graphics card is available (Chaturvedi et al., 2015).

3. CONCEPT

The 3D virtual city model offers large datasets than can be used by urban energy simulation platforms for automatized simulations. SimStadt, for example, as mentioned earlier, can perform a heating demand simulation at an urban level by extracting geometric data, building physics attributes, and semantic characteristics from CityGML datasets. However, in most cases, real-world datasets do not contain building semantic attributes, such as the building year of construction and function, which are required by SimStadt for heating demand simulation, since they are usually not captured during the virtual city model creation process (Carrión et al., 2010, Gröger et al., 2012). Even though a study to determine the age of individual buildings (Zirak et al., 2020) leads to an acceptable heating demand simulation result at the regional level, the result is still not accurate enough at the individual building level.

While the idea of correcting and completing the whole dataset once and for all is unrealistic at an urban scale, allowing building owners adjust their building data when needed at a single building scale, which eventually improves the dataset quality at the urban scale, is achievable. The concept presented in this paper is intended for building owners or occupants who would like to simulate the energy demand of their buildings but are not experts in energy-related fields nor the building physics field. Despite their limited knowledge about energy simulation, they often know about the building attributes that are not visible from the outside or not publicly available due to data protection but could influence accuracy of the simulation result, such as the building year of construction and how many stories the building has.

As illustrated in Figure 1, the data collection approach in this paper aims to enable building owners or occupants to adjust and complete individual building data to allow them to perform a more accurate energy simulation without sacrificing their data privacy. Apart from SimStadt being the energy simulation platform, the illustration also addresses the essential aspects of our approach: the web-based tool that enables the users to supply missing building data and the database to store the updated building data.

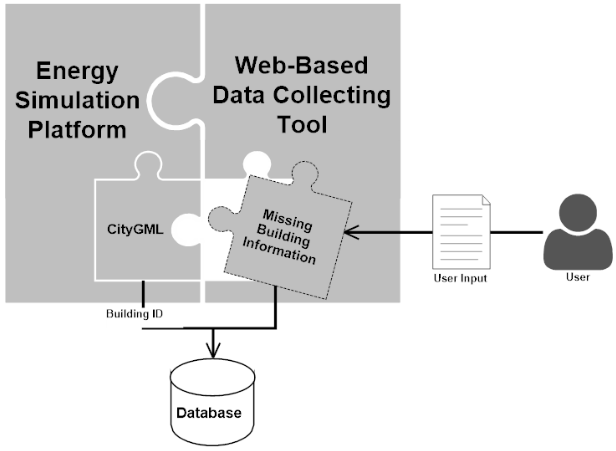

Figure 1. An illustration of how the data collecting tool feeds the energy simulation platform with building data that completes the existing building dataset.

3.1 Web-based 3D Geovisualization

Since the main objective of the tool is to collect the missing energy-related data from building owners or occupants, the user-provided data will be linked to their respective buildings. To achieve this, building owners or occupants will provide their building addresses to determine and visualize only the corresponding 3D building model. After getting the correct building, building owners or occupants can continue the process to complete the building data to perform an energy demand simulation (Fig. 2).

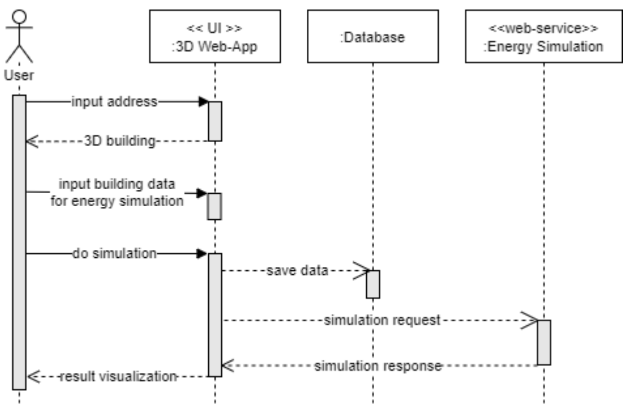

Figure 2. Data collection sequence diagram.

3.2 Collecting and Saving Building Data

A study based on the urban energy analysis of Ludwigsburg in Germany on how geometrical, semantic, occupancy-related and meteorological data quality of 3D city models influence heating demand analysis using SimStadt categorized the investigated building attributes data extracted from 3D city models into the following (Nouvel et al., 2017):

- *Must-have data*: Percentage Error on annual urban heating demand will be over 30% if the data is missing or wrong.These include year of construction, building function and refurbishment details.
- *Relevant-to-have data*: Percentage Error on annual urban heating demand will be between 10% and 30% if the data is missing or wrong. These include the number of storeys; details about the basement (its prescence or absence, whether it is heated or not), building function and details about the refurbishment history.
- *Nice-to-have data*: Percentage Error on annual urban heating demand will be below 10% if the data is missing or wrong. These include the roof type (whether flat or pitched), and details about the basement (its prescence or absence, whether it is heated or not).

In other cities or countries, the influence of the data quality may undoubtedly be different due to different city characteristics. Nevertheless, the importance of the study remains the same: adequate data collection strategies are needed to have reliable and accurate urban energy analysis.

With simplicity being the main target, the web-based data collection tool should enable the users to easily provide the correct and actual building attributes data. However, considering the limited knowledge of the potential users, the approach of this paper focuses on the following semantic and occupancy-related data:

1. Building year of construction
2. Building function: Single-family house; Apartment building for multiple families; High-rise building
3. Refurbishment information: No; Medium; Advanced
4. Story number
5. Information on the basement
6. Information on attic/roof

Upon providing the building attributes, the users are then able to see the energy demand of their building through a simulation process. However, it should also be possible for them to perform the energy demand simulation without completely providing all building attributes. This way, the users are allowed to see how different answers could lead to different energy demand. The tool should make it clear that incomplete or wrong data affect the simulation result.

The collected data from the users plays a vital role in energy demand simulation at the urban scale since it fills the gaps in the 3D city models used by energy simulation platforms. Therefore, these updated building attributes data, and the corresponding building ID need to be saved in a dedicated database (Fig. 1). Moreover, personal data such as the name of the users should not be saved nor logged to ensure data privacy.

3.3 Energy Simulation in SimStadt

SimStadt, an existing urban energy simulation platform that aims to support public authorities and city planners to plan energy transition at an urban scale, is based on the open 3D city model CityGML and its workflow-driven structure is highly modular and extensible. Therefore, it can also be extended and used for a single building energy demand simulation.

It is also possible to simulate heat demand in SimStadt through orchestrated web services (Wate et al., 2016, Rodrigues, 2019). The benefit of this approach is that it makes the simulation available through a network in addition to making the process independent of the operating system and programming language agnostic.

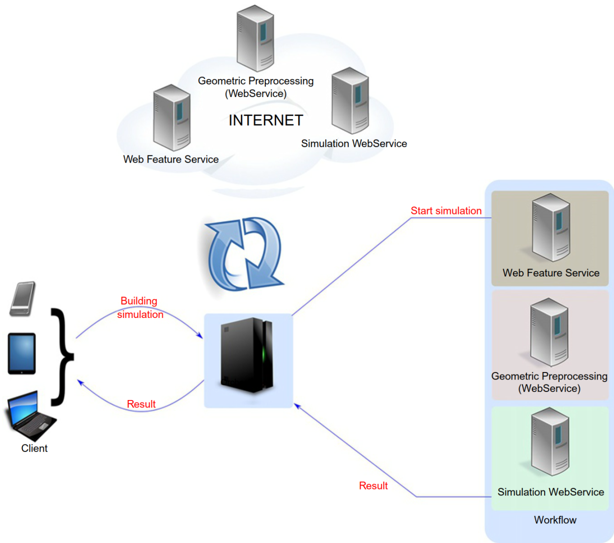

Figure 3. Service oriented architecture for energy simulation. (Rodrigues, 2019).

Three main web services make up this service-oriented architecture (Fig. 3). First, the Open Geospatial Consortium's *Web Feature Service* is used to perform spatial queries i.e. select a building of interest based on latitude and longitude from a spatial database (Section 4.4). Second, the *GeometricPreprocessing web service* runs the similarly named SimStadt workflow which performs geometric quality checks as well as the extraction of relevant geometric properties from buildings (Section 2.1). Finally, the *Simulation web service* runs the heat demand simulation workflow from SimStadt (Section 2.1) and returns the result.

4. IMPLEMENTATION

In this paper, a platform called "CitySourcing" was implemented as a proof-of-concept. The overall system architecture of this platform is depicted in Figure 4 which consisted of four main elements including **3D City Model Database**, **Energy Simulation Service** , **Web Server**, and **CitySourcing Client Application**. The features of each element are explained in the subsequent sections.

4.1 3D City Model Database

The 3D city model database stores and manages the 3D city model (Fig. 4-❶). In this implementation, the CityGML model of a study area in Aachen, North Rhine-Westphalia, Germany was used as a datasource. This model was stored using 3DCityDB[5], which is database software, especially designed for managing CityGML data.

[5] https://www.3dcitydb.org/3dcitydb/

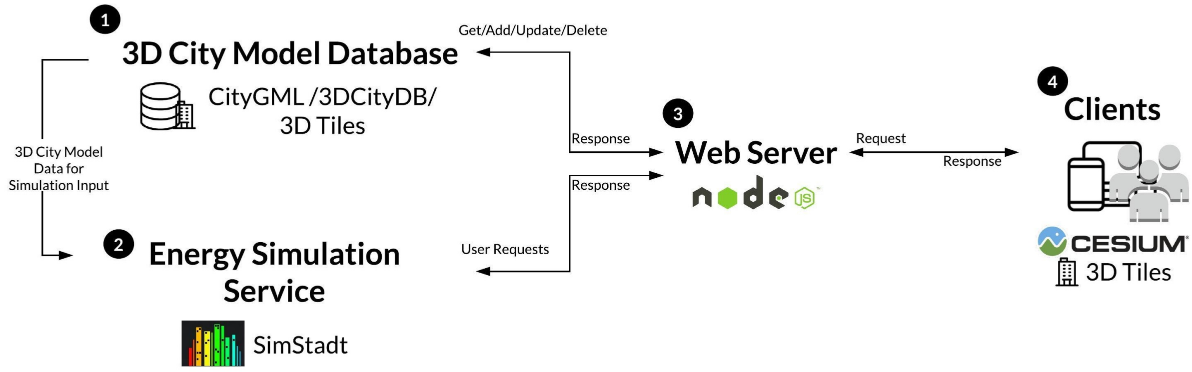

Figure 4. The overall system architecture of CitySourcing platform.

In this study, this database has two main purposes. First, to store the 3D models which will be exported and delivered through the webserver for building visualization. Second, to store the updated 3D model's semantic data. When users interact with the CitySourcing platform, various energy-related questions are posed, as stated in our concept (Section 3.2). The building information provided by owners during energy simulations is then updated into the database. The scheme of collected user information is listed in Table 1.

Parameters	Type	Example
Year of Construction	String	1991
Building type	String	single family house
Refurbishment standard	String	medium
Number of floors	String	3
Has basement	Boolean	false
Is basement heated	Boolean	false
Has flat roof	Boolean	true
Has Attic	Boolean	false
Is attic heated	Boolean	false

Table 1. The input parameters required for the SimStadt heat demand simulation service.

4.2 Energy Simulation Service

To enable the energy simulation (figure 4-❷), the SimStadt tool is set up as a web service. This web service requires parameters to perform the energy simulation. In this paper, we showcase the heat-demand simulation service from SimStadt. It requires the parameters as described in Table 1. A user request is made to the SimStadt web service to perform energy simulation. Then the users' building energy simulation is sent as a response back to users through the web server.

4.3 Web Server

The web server (Figure 4-❸) of CitySourcing is built up with the Express framework[6]. It is a server-side framework with a robust set of features that enables the creation of web applications without obscuring Node.js features. The steps required to set up a web application using the Express framework are explained in its documentation. After setting up the skeleton CitySourcing web application, the necessary dependencies are added.

4.4 CitySourcing Application

The CitySourcing application (figure 4-❹) is built using a 3D virtual globe which enables visualization of real-world objects using the `CesiumJS` JavaScript library. It allows users to visualize the building that corresponds to a requested address. This is necessary to make it easy for users to locate or zoom to their respective buildings and not spend time searching the entire study area for their building.

In support of this requirement, a `zoomToBuilding` function is implemented using the HERE Geocoding API[7], which enables the conversion of building address into latitude and longitude. First, a search is made to find a building address that corresponds to the address provided by the user in the building address attribute available in the 3D model of the study area. If this condition is met, only the matching building model will be visible on the 3D virtual globe. That means all the other 3D building models will not be visible because they have not met the condition for the search.

To be visible, however, does not mean that the user can see the building directly; rather, it implies you can find the building on the Cesium 3D globe. Simply put, the `zoomToBuilding` function's main purpose is to avoid searching for the building on the 3D globe but rather locate the building using its latitude and longitude. The position information computed using the geocoding service is then passed to another function, `flyTo`, which uses the computed latitude and longitude "flies" to the building visualized in the CitySourcing application. The user interface of the CitySourcing application is shown in Figure 5.

Users can input their address and click on the `Search` button to zoom to the building with the corresponding address in the study area as shown in Figure 6. Then, the user answers provides information needed for the energy simulation using a simple multi-option form starting with the Building year of construction as shown in Figure 7. With simplicity and flexibility in mind, users are prompted to select the appropriate data for

[6] http://expressjs.com/

[7] https://www.here.com/products/location-based-services/geocoding-tools

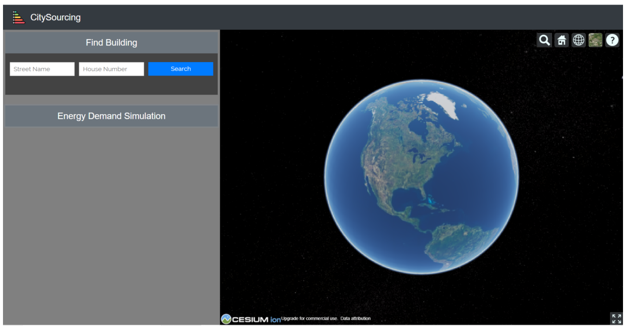

Figure 5. User interface of the CitySourcing application.

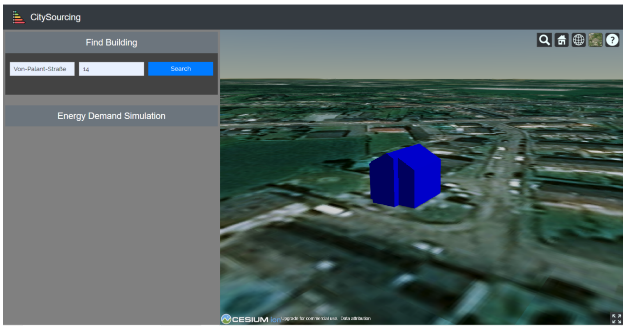

Figure 6. Visualization of a single building that corresponds to the address provided by the user.

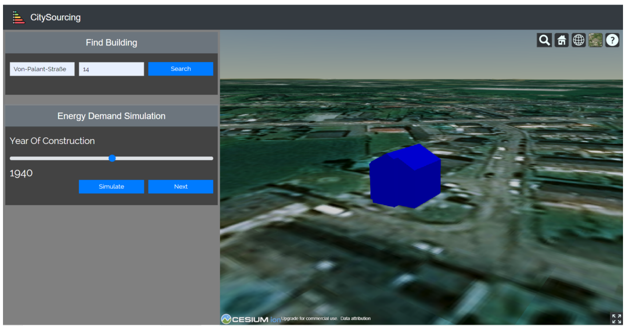

Figure 7. An example a multi-option form providing input information required for energy simulation.

their buildings using the combination of range, checkbox, and drop-down input forms.

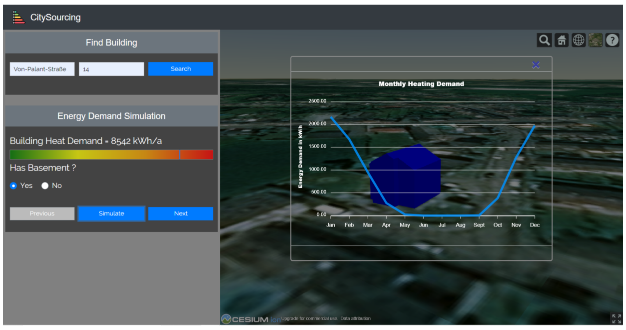

Figure 8. An example of the result of energy simulation visualized on the CitySourcing application

Because default values a set for all the building information, users are allowed to do the energy simulation while providing energy related data needed for the simulation and at the end save the energy data provided for the simulation. This can also be repeated multiple times as the users can see the changes made when the input values change. After performing the energy simulation, the result is shown in Figure 8.

5. DISCUSSION

Several urban energy simulation platforms are developed to calculate the energy demand of an individual building or a district by using the dataset provided by virtual city models. However, the offered real-world dataset is not always complete due to data protection, or in some cases where data cannot be recorded when it was created. In the case of heating demand of an individual building, the absence of some building attributes means the simulation cannot be performed at all. Allowing the building occupants to update and complete the building attributes does not only improve the existing dataset but is also necessary in certain cases as energy simulation can not be performed without building information such as year of construction and building function.

Reducing the energy consumption of existing buildings requires an assessment of the actual energy consumption. This would then be followed by appropriate refurbishment activities to improve the energy efficiency of the building. This paper attempts to fill this void by allowing users to make informed decisions on the current energy consumption and which refurbishment activities are optimal for a particular building of interest. Even though the application does not explicitly give the user a refurbishment option, it is meant to get the attention of the user and serve as a motivation to visit an energy consultant. Furthermore, energy-related information obtained from individual buildings may be combined to gain insights into the energy performance at an urban scale. To address data privacy concerns, the tool does not save sensitive information such as the user's name and address. This is useful for reaching out to users who do not seek personal contact in the initial rollout phase of the tool.

From the perspective of data visualization, the CitySourcing tool uses building models in three dimensions, which give users a better understanding of the spatial extent depicted in the application. The 3D building information can also be extended to include texture information. However, the use of texture information has to be weighed against bandwidth and client hardware requirements.

The main limitation of this tool is the specific nature of contributors who may comfortably use the tool. The target audience that would be knowledgeable on particular aspects of a building, such as its age and nature of heating in the attic, is limited to occupants or owners of buildings. Another limitation of the tool is the validity of collected information owing to the anonymous nature of contributors.

6. CONCLUSION AND FUTURE WORK

This paper demonstrates the use of crowdsourcing in collecting missing building information in the energy demand simulation context. It also shows how the building owners or occupants can contribute to supply missing or outdated information related to building energy simulation. Furthermore, it is also necessary to make sure that the provided data are accurate and reliable as it directly affects the simulation results, and therefore accuracy assessments are needed.

Further research will involve comparing simulation results from user-provided data to those obtained from aggregated census datasets and other energy simulation tools. This way, the effect of the user-provided data on the simulation result can be evaluated. Furthermore, the platform improvement will simulate the energy demand of a large scale neighborhood using the data supplied by individual building owners. Finally, a study on the user perspective, specifically on how to motivate building owners and occupants to use the platform, will be conducted.

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