Online data acquisition and building modelling for building renovation

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Abstract -

The issue of renovating a significant number of buildings has emerged as a prominent concern within the architecture field in recent years. The renovation of existing buildings represents a significant opportunity for reducing energy consumption and greenhouse gas emissions at minimal economic cost. However, achieving effective renovation outcomes can be challenging, particularly for customers who lack technical expertise. To address this gap, this paper presents an online data acquisition platform designed to streamline the integration of building information through a standardized process. Furthermore, this paper presents the optimization of algorithms to address common challenges such as fragmentation, an over-reliance on manual input, and the utilization of disconnected tools in the renovation process. Finally, the feasibility and effectiveness of the platform are demonstrated through case studies featuring 3D building models processed through the platform. These case studies highlight the potential of the platform as a valuable tool for building renovation.

Keywords -

Data acquisition; renovation; energy saving; modeling.

1 Introduction

Since the intensification of extreme weather and climate events resulting from global climate change represents an escalating risk to human society [1][2][3]. Over the past two decades, greenhouse gas emissions have emerged as a primary driver of the climate crisis [4]. The construction industry, in particular, has emerged as a significant contributor to both greenhouse gas emissions and energy consumption [5], thereby exacerbating environmental concerns. As the urgency to mitigate these issues grows, the need for innovative solutions that enhance energy efficiency in the built environment becomes increasingly evident.

In response to this pressing need, this study proposes an online platform aimed at improving energy efficiency and standardizing renovation practices in the construction industry. The prevailing renovation methodologies are characterized by fragmentation, an over-reliance on manual input, and the utilization of disconnected tools. This results in inefficiencies and suboptimal energy assessments. To address these challenges, the proposed platform implements a semi-automated, structured workflow to ensure consistency and accuracy throughout the renovation process.

The platform operates by guiding users through a systematic process, beginning with the input of basic building data, which generates an initial model devoid of openings. Subsequent processing and integration of existing openings generates a comprehensive and normalized model. This structured approach not only eliminates errors but also streamlines energy assessments, improving the efficiency and reliability of renovation projects.

This paper commences with an overview of the prevailing circumstances of the renovation of buildings. Thereafter, the functionality of the online platform is elucidated, whereby all processes are rendered uniform. The processes include the user input of existing basic building information, the creation of an initial simple model based on the user input (without any openings on the walls), the pre-processing of the existing openings information, the combination of the simple model with the existing information, and the generation of the final model, normalization process of the obtained model. Subsequently, the optimization section, which encompasses several technically challenging elements, is addressed. This study presents a series of case studies based on the developed platform. Concurrently, a set of criteria is provided to complete the evaluation of the platform. The findings indicate that the online platform is both effective and straightforward to operate, thereby potentially streamlining the process of building renovation.

2 Related work

2.1 Existing platforms for building renovation

As previously stated in the introduction, the integral functional data acquisition platform designed in this project is not based on any other existing platforms. However, there are some existing renovation systems proposed by other researchers.

For instance, the RINNO project [6] provides a comprehensive solution for the full-lifecycle management of renovations, encompassing the entire project from initial planning and design to the end-of-life phases. The platform incorporates advanced analytical capabilities, interoperability with BIM [7], and a repository for renovation resources, thereby optimizing time, costs, and energy efficiency while enhancing stakeholder collaboration.

The SUNShine platform [8] is an innovative digital tool designed to enhance efficiency, transparency, and standardization in the deep renovation of multi-family buildings. By facilitating effective communication among diverse stakeholders throughout the renovation process, the platform streamlines project management and reduces costs through digitalized and standardized documentation.

It is evident that the majority of contemporary research endeavors are oriented towards the development of a comprehensive renovation platform. However, there is a notable absence of a standardized platform for data acquisition.

2.2 Challenges in building renovation

A substantial body of evidence [9] indicates that the rate of building renovation in the Europe Union (EU) is relatively low, falling far short of the EU's stated targets [10][11][12][13] for such work. Nevertheless, the research [14] indicates that accelerating the renovation of buildings in the near term is a formidable challenge. In addition to identifying the optimal channels for reaching both the demand and supply sides of renovation technology, it is crucial to assess the user-friendliness and efficiency of these channels.

The challenge mentioned above was also proposed by other researchers [15]. In order to achieve the implementation of Nearly Zero-Energy Buildings (NZEB) [16] renovation packages in Europe, it is necessary to shift building renovation strategies towards solutions that incorporate a multitude of passive and active components. This will inevitably result in an increase in the complexity and costs associated with the execution of such strategies.

Besides, in comparison to new construction projects, renovations of existing buildings present a number of challenges, including high design difficulty, demanding quality and safety management, complex construction processes, poor site conditions, and dynamic project management requirements. The design phase of existing building renovation projects is often lengthy and inefficient [17].

Based on these existing challenges, a fully functional online data acquisition platform is required in order to effectively increase the renovation rate of buildings and reduce energy loss.

3 Methodology

3.1 The stepwise data acquisition platform

The data acquisition process comprises several regularized phases. During this process,

1. the user is required to input the relevant information pertaining to the target building, as illustrated in Figure 1.
2. the creation of an initial simple model based on the user input, which does not include any openings (windows, balconies, doors...) on the facades.
3. the pre-processing of the existing openings information. The openings information here can be generated by another platform, which is the culmination of our research group's efforts [18]. Its primary objective is to facilitate the selection of openings on a facade from images captured from disparate viewpoints, subsequently storing them in a normalized `.json` file.
4. the combination of the model with the processed existing openings information.
5. the generation of the final model in the form of a formatted `.json` file, which can be utilized to visualize the comprehensive model with all the openings clearly delineated. This format is particularly well-suited for 3D modeling and BIM applications, offering a streamlined process for architects and designers [19][20][21][22][23][24].
6. the normalization of the obtained final model for being transferred into an `.ifc` file.

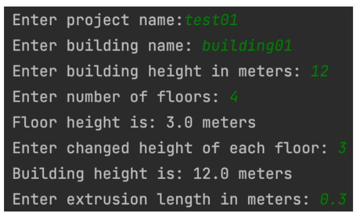

Figure 1. The illustration of user input

3.2 The illustration of the data acquisition process

The provided flowchart illustrated in Figure 2 presents a comprehensive overview of the data acquisition platform, delineating the sequence of operations and offering a more intuitive representation of its efficacy.

4 Optimization

As previously stated in the section on related work, the current challenges make the renovation process a signifi-

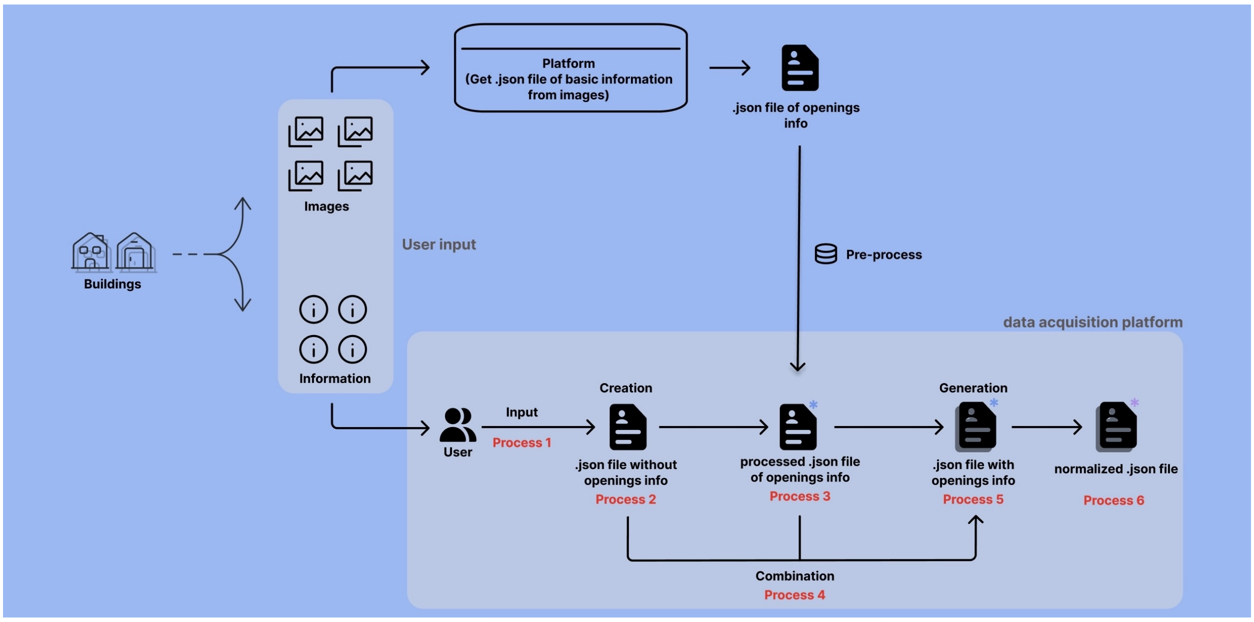

Figure 2. The flowchart of the designed platform

cant undertaking. To surmount these obstacles, it is imperative to augment the efficacy and sophistication of the data acquisition methodology, thereby paving the way for the comprehensive automation of the operational procedure. It is of paramount importance to ensure that the generated model is as close as possible to the actual building in the real world. In light of the aforementioned considerations, a number of optimizations can be implemented with a view to enhancing the platform's automation capabilities, the precision and reliability of the model simulation.

4.1 Roof implementation

The majority of contemporary algorithms fail to consider the impact of a building's roof on its renovation. This is an important shortcoming, as it results in the generation of buildings that bear little resemblance to those found in the real world. The data acquisition platform proposed in this paper addresses this issue by allowing the addition of a variety of roof styles to buildings.

In order to guarantee that the roof appears as an organic extension of the building, it is essential to ensure that there are no gaps between the facades and roof elements. The roof is therefore treated as an additional layer, seamlessly integrated with the rest of the building's geometry. And the structure of the model should be like the structure shown in Figure 3.

4.2 Data filtering

The filtering function was developed with the objective of filtering and processing building data from an external

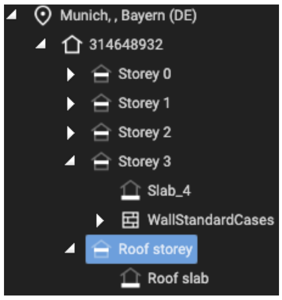

Figure 3. The structure of the building with a roof

`.json` file, incorporating user input for the targeted model. The process commences with the loading of data from a `.json` file, followed by the handling of any potential errors that may arise.

For example, in the majority of cases, only a single building will be processed; however, the `.json` file will contain a series of buildings. The user is prompted to select a specific building by its unique identifier, which is assumed to be an integer. This allows the program to filter the `.json` file and retain only the relevant building data. In the event that no matching building is identified, the script will notify the user and terminate without implementing any changes to the file.

To illustrate, if a `.json` file contains information about multiple buildings, but the user only wishes to process one (e.g., the building with ID= 3), the only thing required to do is to enter the ID of the desired building (3) in the user input field. The platform will then automatically filter out all other buildings with IDs other than 3. This feature also facilitates greater automation of the platform. The illustration of this optimization is shown below in the Figure 4.

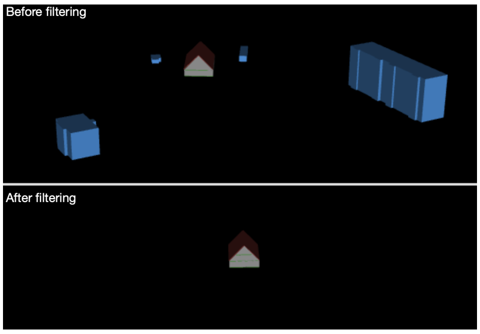

Figure 4. Before and after using the filter function

4.3 Data combination

As previously stated in the `Methodology` section, the file generated externally and the file obtained by user input must be combined. However, since the fundamental data regarding openings is not always consistent, the algorithm is optimized by loading the building data from two sources and identifying the pertinent facade objects (openings) and their geometries.

Subsequently, the data regarding the openings within the aforementioned facades is extracted and stored for subsequent utilization. By iterating through the building structures and their components, the script effectively isolates key data related to facades and their openings, which is essential for accurate building modeling and analysis.

In addition, this phase of the process entails the processing of facade names, whereby they are extracted from the building data and modified to ensure uniformity in format. This guarantees that walls from both data sources can be readily identified and matched, despite minor discrepancies in their nomenclature. And in the event of slight discrepancies in nomenclature between the two files, such as differences in case and initial count, it is imperative to normalize the naming conventions in order to ensure consistency. It plays a pivotal role in aligning the data between the two sources, thereby facilitating a seamless merging process.

4.4 Height estimation

In light of the fact that users are not always able to provide precise building heights, the height estimation was incorporated into the design of the platform as an additional feature. This results in a more precise final model, which the user can then utilise for the renovation of the building with the objective of reducing energy consumption.

The optimized algorithm based on [25] for estimating building height in the absence of external data, specifically addressing the scenario where the camera is angled relative to the building facade. The diagonal distance (D'), defined as the straight-line distance from the camera to the building base, serves as a preliminary reference point. However, it necessitates correction to account for perspective distortions induced by the camera's angle of observation. This is accomplished through the application of the formula:

$$D = D' \cdot \cos(\theta), \tag{1}$$

wherein θ represents the angle between the camera's line of sight and the perpendicular to the facade. The angle θ can be determined through image analysis or by reference to the camera setup data. The correction of D' to D ensures an accurate representation of the horizontal distance between the camera and the building base. With the corrected horizontal distance (D), the real-world height of the building (H_{building}) is calculated using the principles of projective geometry.

$$H_{\text{building}} = \frac{H_{\text{image}} \cdot D \cdot H_{\text{sensor}}}{f \cdot R_h}, \tag{2}$$

where:

- H_{building}: Real-world height of the building (in meters).
- H_{image}: Building height in the image (in pixels).
- D: Corrected horizontal distance from the camera to the building base.
- H_{sensor}: Physical height of the camera sensor (in millimeters).
- f: Camera focal length (in millimeters).
- R_h: Image resolution (vertical pixel count).

In light of the aforementioned details, the user is only obliged to input the letter D; the remainder of the information will be automatically detected and extracted by the platform. This has the potential to markedly enhance the precision and efficacy of our modelling procedures.

5 Case study - Pilot buildings

A number of pilot buildings have been selected for the purpose of evaluating the designed online data acquisition platform. The designed platform was subjected to an examination of its functionality on over 20 different buildings in various locations across Europe. In this section, two models, one relatively simple and the other more complex, have been presented for the purpose of demonstrating the feasibility of the data acquisition platform.

To be mentioned, the input of this platform should be from users as shown in Figure 1 and the output should be the final normalized .json file which can be transferred into the .ifc file for the visualization.

5.1 Pilot building 1 (6 facades)

Initiating the process, the first pilot building presented here is comprised of six facades, each exhibiting a limited number of openings. Subsequent to the data acquisition platform's processing, the resulting model, illustrated in Figure 5, was generated. And the approximate external shape of the model and the address information (Munich, Germany) are provided in the attachment to Figure 6.

Figure 5. Example of the simple building

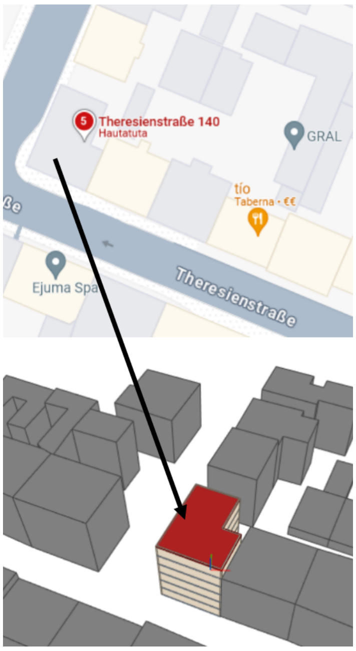

Figure 6. Basic information of the simple building

5.2 Pilot building 2 (22 facades)

To illustrate the capacity of the designed platform to address the complexities inherent in more sophisticated buildings, an additional pilot building is presented here for evaluation. Given the 22 facades comprising this pilot building, a comprehensive comparison for each facade is not feasible. For purposes of reference, the images of this building can be accessed via this URL: `https://www.ensnare.eu/#pilotsites`. The illustration of this pilot building is shown below in Figure 7.

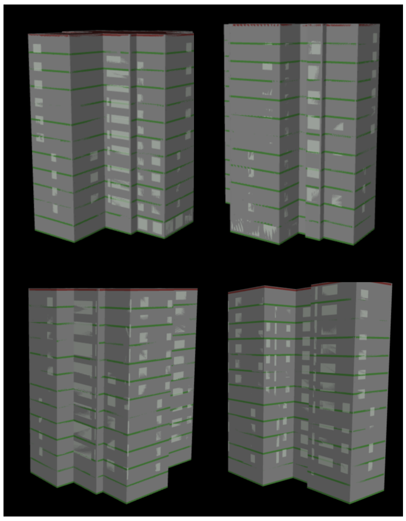

Figure 7. Example of the complicated building

6 Future work

6.1 More roof types

A significant area for future research is the expansion of the methodology to accommodate a broader range of roof types in building height estimation. Although the existing methodology is effective in handling standard roof designs, real-world applications frequently entail more intricate geometries, such as gable, hip, mansard, or even curved roofs. This improvement will facilitate the system's ability to process a more expansive range of building types, thereby enhancing its robustness and versatility in real-world scenarios.

For example, there are a number of different configurations as shown in Figure 8, including flat (or shed), gabled, hipped, arched, and domed. Additionally, there is a wide variety of other configurations. Copyright information can be found at this URL: `https://commons.wikimedia.org/wiki/File:Roof_diagram.jpg`

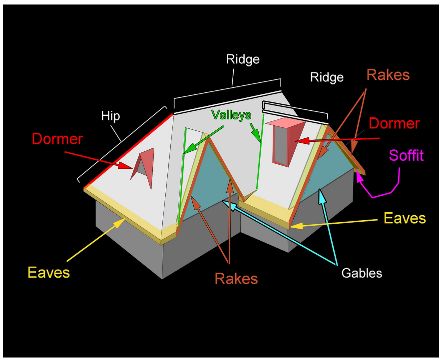

Figure 8. An illustration of different types of roofs

6.2 Multi-Platform Integration

Another crucial objective is the integration of the proposed platform with existing platform [18], with the aim of creating a comprehensive and unified system. Many platforms are currently designed for specific tasks in building renovation, such as initial modeling, data acquisition or simulation. However, they often operate independently. This integration will entail the harmonization of data formats, the optimization of interoperability between modules, and the implementation of automated workflows with the objective of minimizing manual intervention. Such a unified system will not only enhance usability for non-expert users but also provide a seamless end-to-end solution for building renovation projects, aligning with the prevailing industry trends toward automation and digitization.

7 Conclusion

The designed data acquisition and building modeling platform represents a substantial advancement in the ability to address the complexities inherent to building renovation projects. The platform's modular design incorporates features such as standardized data input, pre-processing of structural details, the generation of detailed 3D models and so on, thereby ensuring accuracy and efficiency across renovation workflows. Furthermore, the optimization of key algorithms addresses common technical challenges, thereby enhancing the platform's performance and reliability.

Besides, the feasibility and effectiveness of the platform are demonstrated by the generation of accurate three-dimensional pilot building models, which validate its capability to facilitate complex renovation tasks. The platform not only simplifies data workflows but also enhances the quality of decision-making and project outcomes. Its innovative approach provides a robust foundation for future enhancements, including the incorporation of advanced modeling for diverse building types and integration with comprehensive renovation management systems. In conclusion, the platform represents a crucial instrument for modernizing and simplifying the building renovation process, in accordance with the increasing demand for digital transformation in the fields of architecture and construction.

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