Streamlining Renovation Workflow Through Process Digitalization

Enhancing Information Flow, Accelerating Decision-Making, and Reducing Costs in the Early Stages of the Renovation Process

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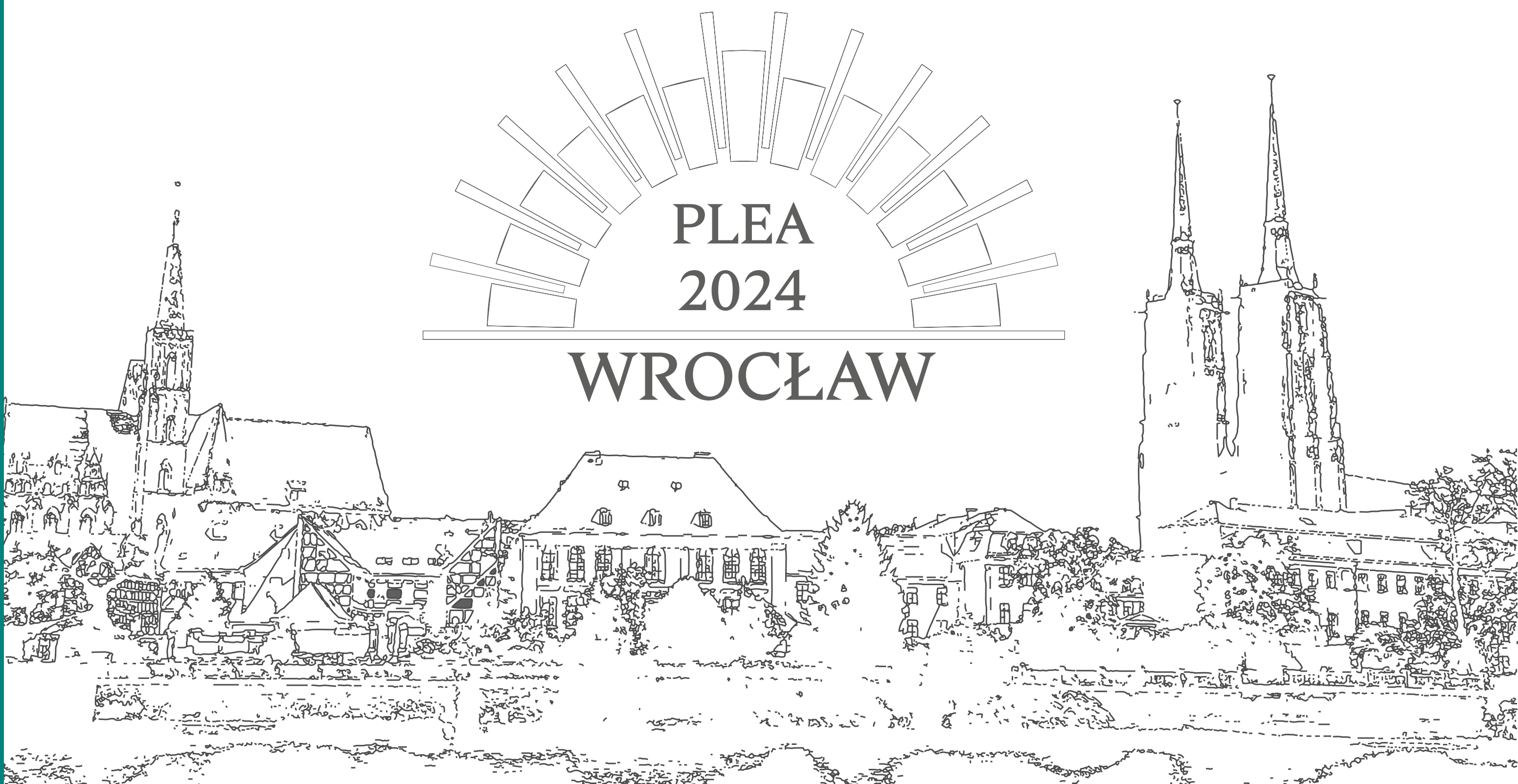

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Streamlining Renovation Workflow through Process Digitalization

Enhancing Information Flow, Accelerating Decision-Making, and Reducing Costs in the early stages of the renovation process

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ABSTRACT: In typical practice of building renovation design, distributed teams communicate through technical drawings, but the construction industry lags in digitalization. This study addresses this gap by proposing a methodological framework integrated into digital tools for early-stage renovation processes. The framework, implemented as a web-based tool, gathers user inputs related to building details and preferences to generate alternative renovation scenarios. It utilizes databases for building characteristics, technologies, and life cycle assessment (LCA)/life cycle cost (LCC) calculations. The information flow involves user inputs, database storage, and processing layers, enabling simulations and scenario evaluations. The framework facilitates quick, cost-effective, and customized decision-making in the early design phases, aiming for energy-efficient retrofits. Results highlight the importance of databases, such as building characteristics and LCA/LCC, while emphasizing a clear communication protocol among stakeholders. Overall, the study seeks to accelerate and streamline the renovation process, promoting efficient collaboration and reducing time and costs.
KEYWORDS: Information flow, Renovation, Digitalization, Scenario generation, Decision-making process

1. INTRODUCTION

Current building design practice involves distributed teams, given the specialization of different professions and their inclination to form independent companies. These teams communicate product design details through technical drawings and specifications. In any discipline with distributed design teams, the timely exchange of information among the involved stakeholders is vital for the progress of the project [1-4]. Several studies on product and design development highlight sources of waste in the process. This includes inefficiencies stemming from subpar engineering leading to inadequate product or process performance, as well as waste within the development process. These studies advocate that emphasizing flow and value generation serves as a crucial complement for comprehending the process. In fact, it forms the foundation for analysis and subsequent improvement efforts in the process development [4, 5].

Furthermore, the process of digitalization is offering fresh possibilities and streamlining the overall construction process by generating intangible assets, which in turn enable more cost-effective and rapid design and production. Despite the progressive transformation of traditional design practices and communication methods through advancements in computer-aided design (CAD) software and building information modeling (BIM), several studies have indicated that the architecture, engineering, and construction sector is relatively slow in embracing digitalization, particularly concerning the creation of digital assets, the expansion of digital utilization, and the development of a highly digital workforce, when compared to many other manufacturing industries [6-8]. In fact, both researchers and practitioners have recognized the imperative need for a swifter pace of digitalization in the construction sector. It's worth noting that, in contrast to the extensive research and implementation efforts in the design and construction phases, there is a notable lack of attention in the area of renovation, retrofitting, and refurbishment, which are integral components of facility management [9-11].

Digitalization is revolutionizing the construction industry, speeding up design and production while reducing costs. However, the sector lags behind other industries in adopting digital technologies [9-11]. Embracing these technologies can boost innovation, enable local firms to access global advancements, and enhance productivity. To facilitate digitalization, the industry needs digital tools that provide common services and data for all stakeholders throughout the construction value chain [12].

Furthermore, several studies have shown that early-stage decisions have a significant impact on the overall duration and cost of the renovation project. A well-implemented framework in the early stages streamlines processes, reducing the time required for decision-making and minimizing unnecessary delays[13-15].

The development and implementation of a structure workflow will facilitate a systematic and efficient flow of information among stakeholders, ensuring that the right data is collected, processed, and utilized in a timely manner. This optimization will help preventing bottlenecks and communication gaps [16]. Therefore, the aim of this study is to develop a workflow framework that supports and expedites early-stage renovation process through the analysis and enhancing of the information flow. This framework aims to be integrated in digital tools that will support the renovation process by providing the different users with tailored solution packages combining the technologies that are best suited to the specific case considered.

2. METHOD

With the goal of assisting early-design choices in renovation processes, this paper determines the key parameters and the information flow of the renovation process among the different stakeholders and with the objective to accelerate and facilitate the decision-making process in the early stages of the design. This workflow framework is based on a process of analysing the key parameters required in the early stages from the design team and delivered by the client, and the outputs of the information processing. In essence, this outline requires comprehensive data gathering on the existing building to establish the most plausible current scenario and generate diverse renovation scenarios. These scenarios align with the goal of achieving energy savings while accommodating or enhancing user preferences. Evaluations, including energy performance simulation, Life Cycle Assessment (LCA), and Life Cycle Cost (LCC), discern environmentally and economically viable options, thereby elucidating key parameters influencing decisions in the early project stages. This approach allows for preliminary estimations of the intervention's viability. Consequently, three main steps were executed: (1) definition of information flow and KPIs, (2) creation of input databases, and (3) implementation in a digital tool.

2.1. Information Flow and KPIs Definition:

The first step is to define the key parameters that the renovation process requires to start the (re) design with obtaining the data from the building in a first iteration, maximizing the reduction of time and costs of the decision-making process and optimizing the information to be provided to the potential client, aiming to achieve a contract with that client.

The outputs obtained by the data processing are used to generate retrofitting scenarios that will be alternative solutions to renovate the building with the main goal to upgrade the building up to a highly energy efficient concept considering a life cycle perspective, calculating KPIs for embodied and operational energy, associated greenhouse gas emissions, comfort impacts, and economic viability.

2.2. Implementation of Databases:

To establish the scenario generation framework, it was essential to define and implement different databases. In the previous step key parameters were defined and it was established that there will be inputs provided by the client directly and some inputs will be a set of standard values that will support the estimation of the buildings' construction technical parameters when little or no information about the building is available.

2.3. Implementation in a Digital Tool

Once the steps of the information flow and the required databases are defined, the aim is to implement this framework in a tool that will be a web-based tool that, by means of simplified calculations, simulates energy, cost, comfort, and environmental indicators. Besides the integration of databases, a communication protocol needs to be integrated to ensure data consistency and stakeholder collaboration throughout the project.

3. RESULTS

To create a systematic workflow for generating renovation scenarios (Figure 1), it was crucial to delineate and integrate various databases. Consequently, it became imperative to identify essential parameters and establish a set of standard values. These values enable the estimation of technical parameters related to the construction of buildings, particularly in cases where limited or no information about the building is accessible (Table 1). Besides the building characteristics' database, a library of technologies was defined that includes technical information about the different technologies that will be considered for the generation of renovation scenarios. Finally, an LCA/LCC database and framework was established to execute calculations related to the environmental impact and cost analysis of the different scenarios. The evaluation of the scenarios also pointed towards the direction of the renovation technologies that provide the best performance over the life cycle of the renovated building.

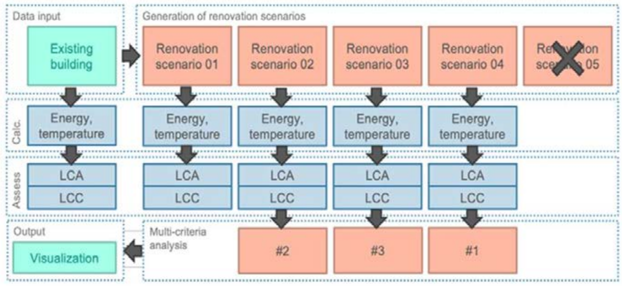

Figure 1. Information flow scheme

3.1 Implementation of Databases:

It is important to establish some key parameters or static information that is necessary for the calculations performed by the different tools: (1) a Building characteristic database setting standard values that help the system make an estimation of the buildings' construction technical parameters when no information about the building is available; (2) a Library of technologies database including technical information about the different technologies that will be considered for the generation of renovation scenarios; (3) an LCA/LCC database with the data necessary for the calculations related to the environmental impact and economic analysis of the technologies.

3.2 Information flow framework description:

Initially, the user inputs fundamental building parameters like shape, age, and location. These details are utilized by the designated database system (Table 1) to estimate probable values for various inputs, such as construction features or existing heating systems. Users can either accept these default values or provide more precise information if available. A preliminary simulation is conducted using these parameters and presented to the user/client for validating their comfort and energy consumption experience. Users can then make adjustments, which calibrate the baseline model. This functionality offers greater accuracy compared to more intricate building modeling software that lacks such feedback. The calibrated model undergoes another simulation, and the results are used to automatically generate proposed renovation scenarios involving a mix of renovation technologies. These suggestions are presented to the user before simulation, allowing them to discard options based on personal preferences or unforeseen constraints. Accepted renovation scenarios are simulated for energy and comfort performance, with an additional assessment of their life cycle's economic and environmental aspects. Lastly, a multi-criteria assessment is conducted to rank these renovation options according to the user's anticipated preferences regarding comfort, financial cost, and environmental performance. Alongside results presentation, users can adjust their preferences and observe the impact on the ranking of renovation scenarios. Notably, users only interact with the web frontend, while the web backend sequentially triggers the calculation modules without requiring user intervention.

3.3 Implementation of the methodological framework in a digital tool:

The integration of this information flow is incorporated into a methodological framework (Figure 2), executed through a digital tool. The comprehensive structure of this framework has been arranged using a layer model, illustrated in Figure 2. Each layer represents a specific set of tools and modules with varying purposes: User information layer, Data layer, and Processing layer.

Figure 2 presents the workflow and the communication among the layers. Communication between layers is provided through REST web services, providing a standard interface that ensures the correct communication between the different modules of the platform.

USER INFORMATION LAYER

The User Information Layer is the direct connection between the technical user and the digital tool. It is composed of the different user interfaces (or alternatively, front-end) that enable end users to interact with the platform and includes the interfaces of the platform and the tools developed. It allows the communication of:

- Inputs from the user regarding the building
- Outputs from the digital tool regarding the renovation process

All the inputs introduced by the users are stored in the databases.

DATA LAYER

The data layer corresponds to the common databases that store all the information necessary for the correct functioning of the platform and is used to share the information among the different modules and platform components.

Table 1. Information flow parameters considered for the scenario generation in the early phases of the renovation process.

<table>
<tr><th></th><th>INPUTS</th><th>FORMAT</th><th>PROCESS
How the information is processed</th><th>DATABASE
Information from a database</th><th>OUTPUTS
Scenarios Generation</th></tr>
<tr><td>DESCRIPTION</td><td>The user enters simple information about the building into the tool to obtain an initial estimation without having expert knowledge of the construction sector.</td><td colspan="3">• Fill-in basic information: location and building type information.
• Obtain initial building geometry information.
• Obtain default technical information of the building.
• Fill-in building use and current building services.
• Obtain baseline energy simulation.
• Fill-in information on current performance.
• Calibrate baseline energy simulation.</td><td>• The user can select from several renovation scenarios created by the framework/tool.
• The user can assess the results of the scenarios and decide which technologies to install in the building.</td></tr>
<tr><td>GEOMETRY</td><td>Floor area

Number of floors</td><td>Upload: Pictures of the building

Upload Pictures of the surroundings

Upload (if applicable) DWG files</td><td rowspan="2">+ open street maps = Initial geometry

Analysis of the surroundings for e.g. shading

Zoning of the façade + height of building</td><td rowspan="2">Climate zone

Weather data file</td><td rowspan="4">Scenarios Generation based on:
• Window-wall ratio
• Wall area
• Floor area
•
• Envelope opening area
• Room height
• Orientation
• Longitude
• Latitude
• Weather data file
• Envelope U-value
• Set point schedule
• Environmental outputs: kg CO2e/m2/a
• Economic outputs: €/m2/a</td></tr>
<tr><td>LOCATION</td><td>Location / address</td><td>Value field or select in map</td></tr>
<tr><td>BUILDING CHARACTERISTICS</td><td>Typology

Year of construction

Information related with the building energy consumption and performance</td><td>Drop-down menu

Value field

Value field (kWh/m2 year)/ Energy bills; Drop-down menu energy source</td><td>Filtering the building characteristics database

Type of construcion/ constrcution system + Location</td><td>Default/standard values: Thermal properties</td></tr>
<tr><td>USER</td><td>User goal and prefenrence

Building function</td><td>Drop-down menu: User ambitions

Drop-down: schedules / operational information</td><td>Define based on scenario generation

Database of standard operation schedules</td><td>Library of technologies, including information about energy savings

set_point_schedule</td></tr>
</table>

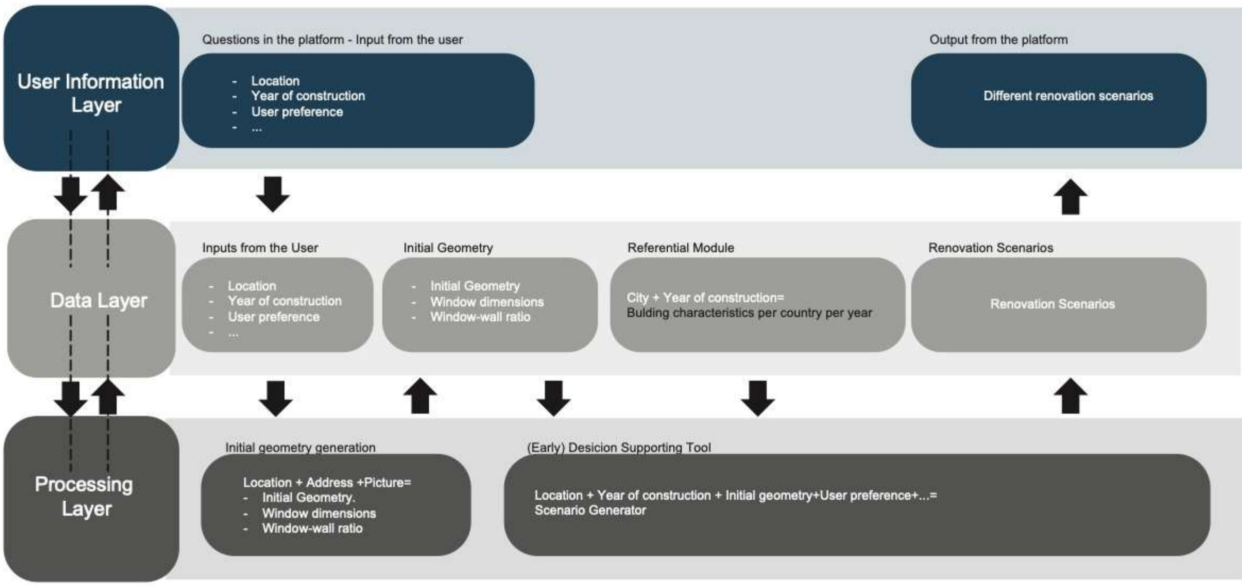

Figure 2. Workflow and the communication among the layers and how the different databases exchange information where the user introduces the firsts inputs of the building and how this information is generating different renovation scenarios.

The data layer is defined to store all the information necessary for the correct functioning and for the calculations that need to be executed by the different processes, including information about the users and their projects (inputs, calculation results, project information related to each phase in the renovation process, etc.). Within this data layer, there is a database of building characteristics [17, 18] of residential buildings that includes a set of standard values that help the framework to make an estimation of the buildings' construction technical parameters when no information about the building is available, including also static information that is necessary for the calculations performed by the different processes in the scenario generation. Furthermore, this data layer contains a 'Library of technologies' which is a catalogue that includes technical information about all technologies considered for the generation of renovation scenarios. Finally, there is an LCA/LCC database which includes the data necessary for the calculations related to the environmental impact and cost analysis of the technologies and the generated scenarios.

LCA calculations require the following data to be stored in the database:

- Material information of façade panels and systems
- Environmental impacts of materials for the various life cycle stages and other material properties
- Maintenance impacts of different panel types
- Carbon emission factors of electricity grids across Europe.

Environmental impacts of materials are sourced from EPDs, or average of EPDs or other generic databases in compliance with EN 15804. Carbon emission factors of electricity grids are sourced from the International Energy Association database or other national or international databases in Europe.

The LCC calculation will require the following additional data to be stored in a database:

- Procurement and installation cost of materials and façade panels.
- Cost of operational energy
- Cost of maintenance of façade panels

PROCESSING LAYER

The processing layer refers to the software modules that perform the main system processing and calculations and includes the digital tools that will generate different renovation scenarios with that will support the decision-making process in the early stages of the renovation. With very few inputs (e.g., location, age of building, simplified geometry, number of floors, use, etc.), this outline would suggest default options (Figure 1) that are most likely to be representative of the building, to perform simplified simulations (i.e., energy simulations, LCA, LCC) that might not be precise but are representative. At a later stage, if a design team gets involved, they could make a more accurate use of the tool for assessing design alternatives. Besides, it is essential that this framework is being implemented as a user-friendly tool that can be used without any specific expertise in building renovation or the construction process.

3.2 Communication and Coordination Protocol:

Another important finding is the establishment of a clear communication protocol among all the stakeholders in the renovation process to facilitate the coordination of the project. This protocol is an informative tool where critical aspects are shown and they must be approved by all the stakeholders to be able to access the new phase or stage of the renovation process, generating agreement files and backup. It also helps the decision-making process by helping the design team or the project manager in providing a continuous overview of the process to guarantee that every decision made has been approved and accepted from all the parties, thus, avoiding future disagreements. It also provides all the information of the project, including logistics, technical responsibilities, changes in the budget/costs, timings on production, deliveries, regulations, etc. Additionally, it can show different levels of information to different stakeholders which will be assigned by the project manager (design team).

4. CONCLUSION

The main objective of this study is to support the renovation project in its early design phases and to facilitate the communication and coordination of the different stakeholders. Overall, this framework involves gathering data on the existing building to establish the most likely current scenario and to generate different renovation scenarios based on predefined databases and constraints. The scenarios are formulated based on the objective of achieving energy savings while maintaining or improving users' preferences, and they are evaluated through energy performance simulation, Life Cycle Assessment (LCA) and Life Cycle Cost (LCC). By examining these scenarios, the study identifies feasible environmental and economic options and determines the key parameters influencing early-stage decisions.

It was found out that it is necessary to develop and integrate different databases to facilitate the decision-making process in the earlier stages of the renovation process and to incorporate a clear communication and coordination protocol that will help managing the project. The framework aims to provide meaningful reductions in cost and time.

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