Discussion

1.1. Reflection on Research Objectives and Findings

This research set out to explore the question:

"How can the ***decision-making process*** *in the* ***early design phase*** *of* ***energy renovations in residential buildings*** *be improved to enable* ***project developers*** *to make* *efficient decisions* *that consider environmental, economic, and social factors?"*

The findings suggest that the decision-making process can be significantly improved through a **structured framework** that combines predefined renovation scenarios, a multi-criteria evaluation system, and clear, transparent output formats. The proposed approach does not aim to automate decisions, but rather to support them—by clarifying trade-offs, making evaluation criteria explicit, and allowing project developers to prioritize according to contextual needs.

Three core dimensions were identified as crucial to improving decision-making:

- **Efficiency** was enhanced not only by reducing time spent but also by minimizing the cognitive burden on decision-makers. This was achieved by organizing inputs clearly, guiding users through criteria selection, and structuring scenario outputs for quick interpretation.
- **Transparency** was facilitated through the use of Multi-Criteria Decision-Making (MCDM) methods such as AHP and TOPSIS, which made it possible to trace and explain how renovation scenarios were evaluated and ranked. This supports accountability, especially in multidisciplinary teams or publicly funded projects.
- **Balance** was introduced through the integration of social factors—such as energy affordability and renovation nuisance—alongside technical and economic criteria. These were often overlooked in prior tools but proved essential for more just and context-sensitive decisions.

While the computational tool reflects these principles in its current prototype form, the broader contribution lies in demonstrating how a scenario-based, criteria-driven approach can reframe early-stage decision-making as a strategic, rather than purely technical, process. The tool thus serves not as a solution in itself, but as a decision support system that enables better choices through structured comparison, weighting, and justification.

Ultimately, the research shows that improving early-phase decision-making in energy renovations requires more than better data or automation. It demands a framework that supports holistic thinking, criteria prioritization, and effective stakeholder communication. These findings are especially relevant in contexts where project developers face conflicting demands on cost, sustainability, and user comfort—yet must act swiftly and decisively.

Addressing the Sub-Research Questions

1. What key decisions must project developers make during the early design phase of energy renovations?

Project developers must choose between renovation scenarios, determine which criteria matter most in their specific context, and evaluate the trade-offs between energy performance, cost, and social outcomes. These decisions are embedded in the tool's structure and reflect the layered complexity of early-stage planning.

2. What factors contribute to making decision-making efficient in energy renovation projects (e.g., time, cost, sustainability impact)?

Efficiency is influenced by more than just speed. This research highlights the importance of structured input, predefined options, and reduced data overload. Making comparisons easier and outputs more digestible allows developers to work more confidently within tight timelines.

3. How can the efficiency of the decision-making process be measured?

While no quantitative efficiency metric was developed, qualitative comparisons with traditional methods (e.g., spreadsheet-based assessments) suggest improved clarity, reduced manual handling, and better information flow between stakeholders. These qualitative gains point to measurable potential in future versions of the tool.

4. Which criteria are most relevant for making efficient decisions in energy renovation projects?

The selected criteria—including energy demand, investment cost, CO_2 emissions, renovation time, nuisance, and energy affordability—reflect a balance of environmental, economic, and social priorities. Their selection was informed by literature and aligned with stakeholder concerns.

5. Which methods are most suitable for ranking the relevant criteria in energy renovation projects?

AHP was employed for criteria weighting due to its ability to capture subjective preferences in a structured way. TOPSIS was chosen for scenario ranking, enabling straightforward, transparent comparison of alternatives. Together, these methods facilitated traceable and repeatable decisions.

6. How does communication between project developers and end-users affect the design and functionality of the decision-making tool?

Although direct input from end-users was limited in this research phase, the tool was designed with usability and communication in mind. The visual outputs, scenario summaries, and criteria explanations are tailored for clarity—supporting developers in communicating with clients or stakeholders. Future iterations could strengthen this by integrating participatory features and feedback loops.

1.2. Reflection on the Tool's Performance

The tool performed effectively during the case study, fulfilling its core objective of guiding decision-makers through a structured and transparent renovation selection process. It successfully integrated economic, environmental, and social criteria into a decision-making framework that balanced complexity with usability.

Initially, the ambition was to build a computationally efficient tool capable of quickly generating optimal retrofit solutions through automation. However, as development progressed, the definition of **"efficiency"** was refined. Lacking a software development background, the decision was made to move away from a full optimization model and instead adopt a surrogate approach using Multi-Criteria Decision-Making (MCDM) methods. This shift allowed the tool to maintain analytical rigor while improving accessibility and ease of use, particularly in scenario simulation and ranking.

While early stages focused on **speed and accuracy**, the framing matured toward supporting deliberative, transparent, and comprehensible decision-making. Rather than delivering a single "best" solution through a black-box mechanism, the tool enables users to explore trade-offs, test assumptions, and make informed choices grounded in clearly weighted criteria and visually structured outputs.

A key technical achievement was **the transition from dual workflows to a unified process**. Initially, energy simulations (using Ladybug Tools in Grasshopper) and the evaluation of economic and social criteria (managed in Excel) were developed separately. This created inefficiencies in scenario alignment and required significant manual coordination. To streamline the process, a VBA script was first used in Excel to generate consistent scenario combinations. This logic was then translated into Python to automate energy simulations, ensuring consistent data production and integration.

This **integration** marked a critical milestone: the shift from a spreadsheet prototype to a fully web-based application. The new version consolidates all core components—scenario generation, automated energy simulation, criteria weighting, decision ranking, and results visualization—into a single interactive platform. This not only improves usability for non-expert users but also increases the tool's scalability, adaptability, and readiness for real-world deployment. Users can easily revisit inputs, adjust weights, and regenerate outcomes with minimal friction, improving both transparency and decision-making speed.

As discussed in the *Section B: Conceptual Framework*, identifying an optimal renovation solution using traditional, **manual methods** typically required about **two weeks**—excluding time needed for energy simulations. In contrast, with the developed tool, the entire process—from 3D model setup to final results—was completed within a few hours, with the **tool operation** itself taking less than **15 minutes**. Users can test alternative priorities, visualize outcomes, and export results easily, thus significantly reducing not only the time investment but also the cognitive load involved.

Evaluation was reoriented to compare the tool's performance against traditional spreadsheet-based workflows. In this context, the tool demonstrated clear advantages: it reduced manual steps, enhanced clarity of outcomes, ensured internal consistency across data sources, and significantly improved communication between stakeholders through structured outputs.

The **sensitivity analysis** revealed that the tool remains relatively stable when criteria weights are adjusted—demonstrating robustness to different stakeholder perspectives. However, it is more responsive to changes in external parameters such as electricity price, loan structures, and interest rates. This indicates that while stakeholder priorities do influence the outcome, assumptions about market and financial conditions exert even greater impact on the final scenario ranking.

Across all tested conditions, three criteria consistently emerged as the most influential:

- EC_C4 (Payback Period),
- EN_C8 (Heating Demand Reduction), and
- EN_C11 (Renewable Energy Integration).

These criteria had the most significant effect on scenario selection, often overshadowing social indicators even when the latter were heavily weighted. This highlights a systemic bias toward quantifiable, short-to-medium-term outcomes—particularly financial and energy-related benefits. These criteria emerged as the most influential based on the specific characteristics and inputs of this case study. However, this finding is context-dependent and not intended to serve as a generalizable conclusion.

While this mirrors dominant logics in renovation investment, it also raises concerns about the limited influence of social values—such as reduced renovation nuisance, occupant comfort, or material durability—within conventional evaluation frameworks. The tool's results, therefore, should not be interpreted as prescriptive recommendations, but as a platform for informed discussion. They make transparent which trade-offs are at play and which priorities are driving outcomes.

The real strength of the tool lies in its **flexible structure**. It allows diverse users—housing associations, municipalities, residents, and energy consultants—to test different configurations, challenge assumptions, and re-balance their decision strategies. In doing so, it supports more inclusive and balanced decision-making, especially in contexts where cost-efficiency, environmental justice, and social equity must be weighed together.

In conclusion, the tool proved to be both **robust and practical**—providing a transparent, efficient, and scalable method for evaluating retrofit scenarios amid competing priorities. Its development journey—from spreadsheet to unified simulation platform to web-based application—underscores its value not only as a research contribution, but also as a foundation for future product development and commercialization through initiatives such as BOLD.

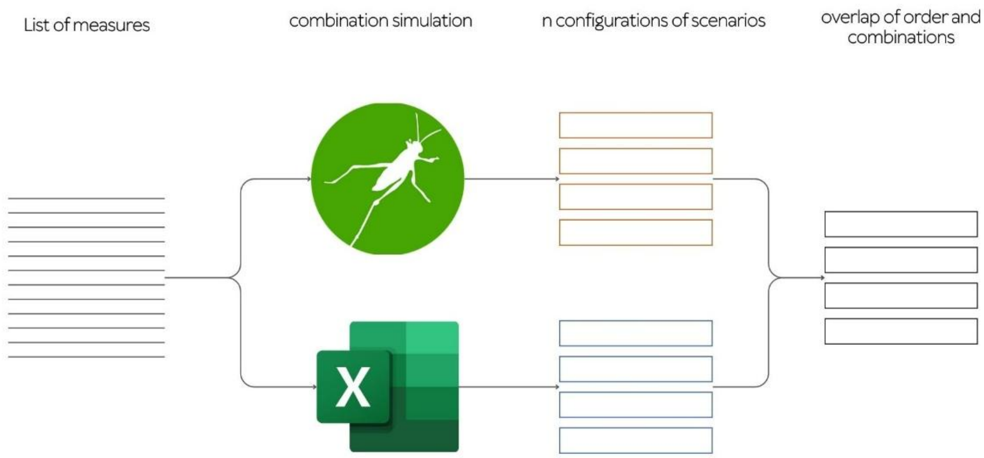

Figure 1 Initial Uncertainty in overlapping of generated scenarios

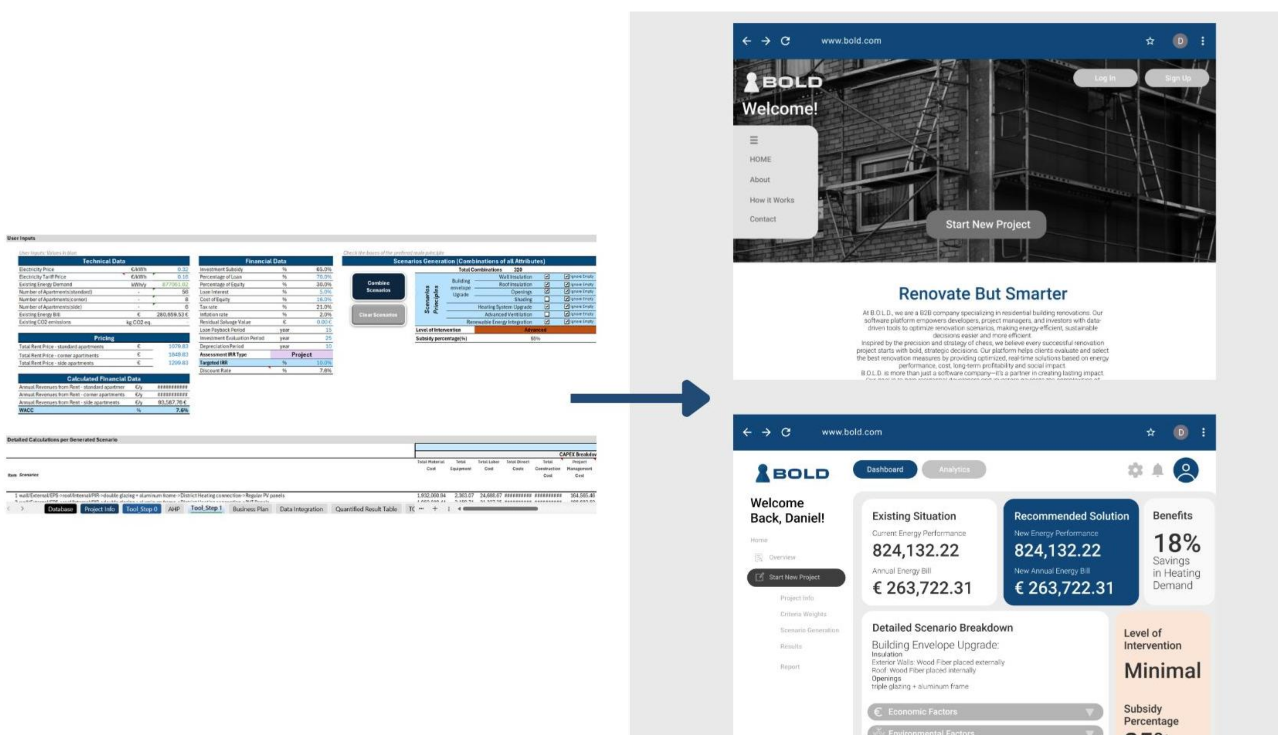

Figure 1 Transition from the excel prototype to the webpage

1.3. Reflection on Methodology

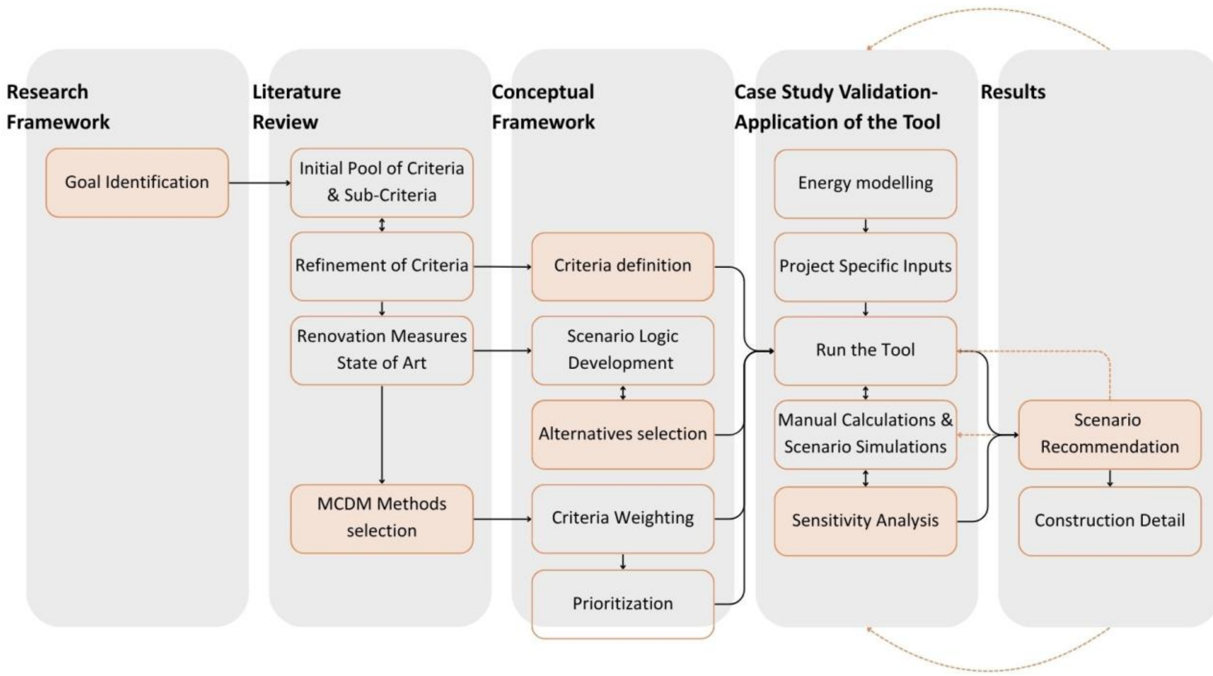

Figure 2 Methodology Loops

The methodology followed in this research was structured into clearly defined stages, yet in practice it was characterized by iterative loops and continuous reflection. The visual representation in the diagram highlights the adaptive nature of the process, particularly during the Conceptual Framework and Tool Application phases.

A key area of iteration was the criteria definition. Beginning with a broad pool of criteria and sub-criteria from the literature, it became clear that a straightforward selection would not result in a manageable or meaningful structure. Multiple rounds of refinement were necessary to ensure that the selected criteria were not only comprehensive but also non-redundant and suitable for use in a decision-support tool. This back-and-forth between the literature review and conceptual framework was critical in shaping a robust evaluation structure.

Similar revisions were required for the alternatives selection and scenario logic development. Defining levels of intervention and grouping renovation measures into meaningful and realistic packages proved to be more complex than initially expected. Several iterations were needed to ensure the logic behind the scenarios aligned with both technical feasibility and decision-making clarity. These adjustments fed directly into the design of the tool and the consistency of its outputs.

During the application phase, repeated manual calculations and scenario simulations were performed to validate the tool's logic and outputs. Calculation mistakes, inconsistencies, and edge cases often required revisiting earlier stages — including the logic of the scenarios, the compatibility of heating systems with insulation levels, and the prioritization process. These technical loops, although time-consuming, were vital to ensure internal consistency and reliability.

In the sensitivity analysis, time constraints limited the scope of exploration. While the baseline scenario was used to assess how different criteria influenced the outcomes, ideally, multiple scenarios would have been tested. This would have allowed a deeper understanding of how decision priorities shift under different project conditions. However, due to the need to correct earlier miscalculations and re-run simulations, the scope had to be kept focused.

Ultimately, while the diagram presents the methodology in a staged format, the dashed arrows represent the necessary **revisions, loops, and interdependencies** that shaped the research. Rather than undermining the process, these iterations were essential to building a decision-support framework that is transparent, reasoned, and adaptable to real-world project complexity. Reflecting on this process, the continuous reevaluation of assumptions, measures, and outputs not only improved the final tool concept but also underscored the importance of **methodological agility**—particularly in the context of multi-criteria decision-making.

1.4. Innovation and Contribution to the Field

Methodological Innovation

The main novelty of the decision-making tool developed in this thesis lies in its **integration process**, which systematically combines diverse criteria and trade-offs to guide decision-makers toward informed, balanced renovation choices. This process achieves a seamless integration of technical, economic, and social factors within a unified workflow, enabling users to evaluate a full spectrum of considerations in a cohesive and efficient manner.

While grounded in established Multi-Criteria Decision-Making (MCDM) methods—such as the Analytic Hierarchy Process (AHP) for criteria weighting and TOPSIS for ranking—the tool distinguishes itself by embedding these methodologies within a quantified scenario database, automated simulation environment, and interactive digital platform. It does not merely apply these methods in isolation; rather, it combines them in a way that allows for the systematic evaluation of trade-offs across multiple dimensions while maintaining clarity and accessibility for non-expert users.

A particularly innovative element is the incorporation of social criteria, including renovation nuisance and energy affordability, alongside traditional environmental and economic metrics. This positions the tool within a human-centered decision-making paradigm, broadening the scope of energy renovation evaluation to include residents' lived experience, vulnerability, and equity—factors often overlooked in conventional tools.

Computational Innovation

From a computational perspective, the tool also makes a significant contribution through the automation of energy simulations and integration of all decision layers into a single framework. Initially developed as two parallel processes (Excel for economic and social evaluation, and Grasshopper/Ladybug for energy simulations), the workflow was successfully unified through a logic-based synchronization in Python. This led to the development of a web-based application that consolidates scenario generation, simulation, analysis, and visualization, drastically reducing the time, manual effort, and cognitive burden required in traditional methods.

This digital transformation—from spreadsheet-based tool to web platform—marks a major innovation, making the tool more scalable, user-friendly, and suitable for professional use. This makes the tool well-positioned for future customization, whether for housing associations, municipalities, or private developers.

Strategic Value

Moreover, the tool's strategic orientation sets it apart. Unlike many existing models that emphasize optimization of cost or energy alone, this tool enables a strategic decision-making process that accounts for long-term goals, occupant impact, and project feasibility. The user is not just presented with an "optimal" answer, but is guided through a transparent, criteria-driven journey toward the most contextually appropriate renovation scenario.

In summary, the novelty of this tool lies not only in its integration of diverse criteria, but also in its computational implementation, its automation of previously fragmented processes, and its translation into a fully functional, web-based decision-support platform. By providing a structured, transparent, and human-centered approach to energy renovation decision-making, the tool contributes a unique and valuable framework to the field—bridging the gap between analytical depth and practical usability.

1.5. Comparison with Literature

The decision-making tool developed in this thesis builds upon established methods in the field of multi-criteria decision-making (MCDM), specifically the Analytic Hierarchy Process (AHP) and TOPSIS. Both methods are widely recognized in energy renovation literature for their ability to structure complex decision problems involving multiple, often conflicting, criteria. As outlined in Section A: Literature Review, AHP is particularly valuable for participatory weight assignment, while TOPSIS offers an efficient mechanism for ranking alternatives. Although their combined use has been explored in previous studies, it remains underutilized—especially in the context of integrated, early-phase renovation tools.

A key distinction of this tool lies in its emphasis on **usability and accessibility during the pre-design phase**. Many tools referenced in the literature are either highly specialized—requiring advanced technical knowledge—or overly focused on energy performance alone. Simulation-based approaches, for example, often depend on proprietary software (e.g., EnergyPlus, DesignBuilder, IDA ICE), creating barriers to adoption among project developers and non-expert stakeholders. In contrast, the current tool simplifies complex analyses into an interactive, user-friendly workflow, supporting rapid, yet informed, decision-making.

Furthermore, while existing literature increasingly advocates for the inclusion of economic and environmental indicators, **social factors are frequently neglected or addressed only qualitatively**. This tool contributes to bridging that gap by incorporating **quantifiable social criteria**, such as *renovation nuisance* and *energy affordability*. These dimensions are rarely operationalized in a way that allows for direct comparison with technical and economic factors. By addressing this omission, the tool responds to recent academic calls for more inclusive and socially informed renovation assessment frameworks.

Another differentiating element is the **real-world validation of the tool through stakeholder engagement**. While most academic models are tested in theoretical or narrowly scoped case studies, this tool was applied in a stakeholder-driven context, involving residents, housing associations, and municipal actors. This offers a stronger demonstration of practical feasibility and strengthens the tool's relevance for real-world applications—an aspect often missing in prior work.

Importantly, the tool aligns with **emerging policy frameworks at both the European and local levels**, which increasingly emphasize not only technical performance, but also equity, affordability, and speed of implementation. By integrating socially relevant indicators into a computationally efficient and scalable system, the tool addresses the multidimensional objectives promoted by the EU Renovation Wave, the Green Deal, and local Just Transition agendas.

In summary, while grounded in established MCDM theory, the tool makes a distinct contribution by operationalizing a **holistic, fast, and transparent decision-making framework**. It responds to gaps identified in the literature related to usability, social inclusivity, and real-world adaptability—positioning it as a forward-looking contribution within the field of sustainable renovation decision support.

1.6. Trade-offs and Design Choices

Several trade-offs were necessary in the development process. The choice to adopt AHP combined with TOPSIS instead of simpler methods like Weighted Sum Model (WSM) or more qualitative ones like MACBETH was guided by a desire to balance methodological rigor with user interpretability. AHP allowed for intuitive pairwise comparisons, while TOPSIS provided a robust way to rank scenarios against an ideal solution.

AHP was chosen for its ability to support structured yet intuitive stakeholder input through pairwise comparisons, which help users focus on one judgment at a time. This was particularly valuable when engaging non-expert decision-makers, as it allowed for more deliberate and transparent prioritization of criteria. Unlike WSM, which requires assigning weights directly—often resulting in arbitrary or biased values—AHP facilitates relative weighting in a way that is easier to validate and justify in participatory settings. Additionally, AHP's hierarchical structure allowed the tool to accommodate both broad goals (e.g., sustainability) and more specific sub-criteria (e.g., CO_2 emissions, energy affordability) in a modular and scalable manner.

Another major design decision was to split the user journey into two steps—first selecting or customizing criteria, then generating and evaluating scenarios. This was intended to reduce cognitive load, allow for better reflection, and mirror how decisions are made in practice. While this added some complexity, it preserved clarity and user control.

A key challenge was the quantification of social indicators such as renovation nuisance and affordability. These metrics often lack standardized measurement, requiring the development of proxy indicators and assumptions based on stakeholder input.

1.7. Stakeholder Perspectives and Real-world Applicability

The case study demonstrated how different stakeholder perspectives significantly influence decision outcomes. The housing association prioritized energy efficiency and ease of implementation, while residents emphasized comfort and indoor air quality, and municipalities sought a balance between environmental impact and social value.

The tool proved capable of accommodating these diverse priorities by allowing separate weighting schemes and clearly presenting the implications of each.

Importantly, the tool supports balancing short-term cost considerations with long-term sustainability goals. By structuring decisions around multiple criteria, it helps stakeholders make choices that are both responsible and feasible, aiding in alignment and consensus-building.

1.8. Broader Implications

The implications of this tool extend beyond individual retrofit projects. For policymakers, it could serve as a valuable resource in subsidy design by identifying renovation scenarios that align with environmental and social priorities. By incorporating social indicators such as affordability and renovation nuisance, the tool helps ensure policy incentives reflect principles of equity and just transition.

For industry professionals, particularly project developers and housing associations, the tool offers a way to reduce early-stage planning time, manage trade-offs more transparently, and mitigate decision uncertainty. At scale, it could support strategic renovation planning across entire portfolios, helping organizations align with long-term climate and inclusion goals.

Academically, the tool contributes a replicable and modular decision-support framework. It invites further development through hybrid MCDM methods, machine learning integrations, or real-time scenario updates. Its interdisciplinary structure also opens opportunities for use in education and research across architecture, urban planning, and sustainability disciplines.

1.9. Limitations

The limitations of the tool could be related to various aspects, including data dependencies, the scope of the criteria, and the complexity of certain processes. Here are some potential limitations to consider:

1. **Data Dependency:**

The accuracy of the tool’s outputs heavily relies on the quality and availability of input data, including energy simulation results, financial data, and building-specific characteristics. Inaccurate or incomplete data could lead to less reliable results or skewed comparisons between scenarios.

2. **Limited Range of Renovation Measures**

The tool relies on a set of predefined renovation principles to generate scenarios. While this approach ensures consistency and comparability, it may not capture the full spectrum of potential renovation strategies. As a result, the tool might not offer suitable solutions for complex building types or unique renovation needs that fall outside the established measure set.

3. Complexity of Multi-Criteria Decision-Making:

While the tool employs multi-criteria decision-making (MCDM) methods such as AHP and TOPSIS, users might find it difficult to define their preferences accurately or assign appropriate weights to criteria, especially in complex or highly technical scenarios. The need for subjective input in the weighting process could introduce bias.

4. Limitation in cross-category comparisons:

The tool applies the Analytic Hierarchy Process (AHP) for criteria weighting, which requires pairwise comparisons to be conducted between elements that belong to the same hierarchical level and the same category (e.g., environmental, economic, or social). While this structure ensures consistency and methodological soundness, it also imposes a limitation: **direct comparisons between criteria across different categories (e.g., comparing renovation cost with CO_2 emissions) are not supported**. This may restrict the flexibility of the decision-making process in cases where stakeholders wish to evaluate trade-offs between fundamentally different types of criteria.

5. Limited Energy Simulation Integration:

The tool integrates energy simulation results from Grasshopper, which might not cover all types of energy systems or renovation strategies in detail. This could be a limitation if users require more granular simulation data or if the tool needs to be adapted for new or experimental technologies.

6. User Interface and Accessibility:

While the tool is designed to be user-friendly, it may still require a certain level of technical expertise, particularly in understanding energy simulations, financial calculations, and multi-criteria ranking methods. Users without a strong background in these areas could struggle with the input process or interpreting results.

7. Scalability of the Tool:

Although the tool is scalable to some extent, its performance and processing time might be affected as the complexity of scenarios or the size of the input data grows. Larger projects or more complex buildings might require additional computational resources or further development to handle large-scale simulations.

8. Limited Real-Time Adaptability:

The tool is based on pre-defined scenarios and renovation principles. As a result, it might not be flexible enough to accommodate real-time changes in building conditions, unforeseen challenges, or new information that could impact the decision-making process.

9. **Focus on Early Design Phase:**

The tool is primarily focused on the early design phase of energy renovation, which means it may not fully address challenges that arise during the construction or post-renovation stages. Users need to be aware that this is a decision-support tool aimed at guiding early-stage planning.

10. **Geographical Limitations:**

The tool may be tailored more towards specific geographic regions (the Netherlands in this case), and may require adaptations to fit local building codes, climate conditions, or energy tariffs in different regions or countries.

These limitations could be addressed in future versions of the tool by enhancing its flexibility, expanding its data sources, or incorporating additional features.

1.10. Suggested Improvements – Future Development

Although the tool provides a structured and efficient approach to support decision-making in residential energy renovation projects, several areas for future development have been identified to enhance its robustness, flexibility, and applicability across a broader range of use cases.

1. **Expansion of Renovation Measures**

The current version is limited to a set of predefined renovation principles. Future iterations could include a more extensive catalogue of measures to capture a wider variety of building typologies and renovation strategies, particularly for complex or non-standard cases.

2. **Improved User Interface and Visualization Tools**

Enhancing the interface with more interactive elements, such as dynamic charts and scenario comparison dashboards, could increase accessibility for users with limited technical backgrounds and improve decision transparency.

3. **Inclusion of Additional Evaluation Criteria**

The tool could be expanded to incorporate additional criteria such as user comfort, indoor air quality, heritage value, or climate resilience, enabling a more holistic assessment of renovation scenarios.

4. **Integration of More Flexible Weighting Methods**

In the current version of the tool, the Analytic Hierarchy Process (AHP) was selected to guide the criteria weighting process. This method provided a structured, intuitive framework for users to define priorities within each main category (environmental, economic, and social). AHP's strength lies in pairwise comparisons within a defined hierarchy, which aligned well with the initial aim of structuring decision inputs clearly and transparently.

However, a limitation of AHP is that it becomes less practical when users need to compare criteria across different categories. For instance, it is not straightforward to directly compare the importance of "CO_2 emissions" with "payback period" within the same matrix unless the hierarchy is significantly restructured. This limits flexibility in complex, real-world decision-making contexts.

To address this in future development, a shift toward a **Weighted Sum Model (WSM)** is suggested. WSM would allow users to directly assign weights across all criteria, regardless of their category, simplifying the input process while maintaining consistency. Additionally, integrating WSM with TOPSIS at the final stage would enable a robust hybrid Multi-Criteria Decision-Making (MCDM) approach. This combination would enhance the tool's adaptability and broaden its application across more diverse and nuanced renovation projects.

5. Adaptability to Different Geographical Contexts

To broaden its applicability, the tool could be adapted for use in other geographic regions by incorporating local climate data, building regulations, cost structures, and policy incentives.

6. Real-Time Data Integration

Linking the tool with live databases or IoT sensors (e.g., energy prices, building performance monitoring) could enable more responsive and context-sensitive evaluations.

7. Support for Collaborative Decision-Making

Introducing features for multi-user interaction could facilitate collaboration among stakeholders such as developers, designers, residents, and policymakers, improving consensus-building in renovation planning.

8. Application of Machine Learning Techniques

Machine learning models could be incorporated to identify optimal renovation strategies based on previous project data and user-defined constraints, enabling smarter scenario recommendations over time.

9. Post-Implementation Feedback Loop

The development of a post-renovation monitoring module would allow comparison between predicted and actual performance, refining assumptions and increasing the reliability of future assessments.

10. Target-Based Scenario Generation

The current version of the tool supports scenario generation based on selected renovation principles and multi-criteria ranking. A valuable future enhancement would be to introduce an alternative path where users define a target — such as a desired energy label, maximum allowable payback period, or CO_2 emissions threshold — and the tool filters or generates only the renovation scenarios that meet this objective. This would enable both exploratory and goal-oriented decision-making, increasing the tool's flexibility and alignment with diverse stakeholder needs.

11. Full Software Development and Validation

Finally, transforming the prototype into a standalone software application, followed by extensive user testing and validation, would ensure its scalability, reliability, and potential for market deployment.

12. Social Factors Quantification Approach

In the current version of the tool, social factors like renovation nuisance and tenant relocation are based on qualitative assumptions. To improve precision, future development could focus on systematically analyzing renovation case studies to identify patterns between specific measures, renovation duration, and the need for relocation. Additionally, interviews or surveys with professionals—such as housing providers or project managers—could provide quantifiable insights into when relocation is typically required. Combining case data and expert input would allow the development of a simple relocation logic, making the tool's social impact assessment more evidence-based and context-sensitive.

13. API Development and Deployment

To enhance accessibility and integration, future development will focus on creating an API that connects the tool's core functions with external platforms. This API would allow users to upload building data, select scenarios, run simulations, and retrieve results through a web-based interface. Deployment is envisioned on a cloud-based infrastructure using containerization (e.g., Docker) to enable scalability and parallel processing. This step would support integration with BIM tools and decision dashboards, making the tool more adaptable for use by developers, consultants, and municipalities.