Graduation Plan

Master of Science Architecture, Urbanism & Building Sciences

Graduation Plan: All tracks

Submit your Graduation Plan to the Board of Examiners (Examencommissie-BK@tudelft.nl), Mentors and Delegate of the Board of Examiners one week before P2 at the latest.

The graduation plan consists of at least the following data/segments:

Personal information	
Name	**Evanthia Soumelidou**
Student number	5933552

Studio		
Name / Theme	AR3B025 Building Technology Graduation Studio / Master Thesis	
Main mentor	Thaleia Konstantinou	Building Product Innovation
Second mentor	Michela Turrin	Design Informatics
Argumentation of choice of the studio	The choice of this studio aligns closely with the main directions of my thesis, which include façade & product design and design informatics. These directions form the foundation of my research, which focuses on examining the decision-making process in energy renovations, aiming to identify key challenges and propose solutions to address them. By integrating advanced design methodologies with practical applications, the studio provides an ideal framework to explore these challenges from technical, economic, and social perspectives. This synergy ensures that my work remains both relevant and practically applicable to real-world energy renovation scenarios.	

Graduation project	
Title of the graduation project	"Improving Efficiency in Energy Renovations: A Decision Support Framework for Residential Buildings"
Goal	
Location:	Rotterdam, Netherlands
The posed problem,	The main problems that will be tackled are: • **Early Design Decision-Making Inefficiencies** a) Multi-Criteria Decision Analysis (MCDA) tools offer theoretical frameworks but lack practical application. b) These tools fail to integrate technical performance,

	economic feasibility, and regulatory aspects dynamically. c) Diagnostics of building states and customized renovation scenarios are not automated, causing manual, time-consuming processes. • **Stakeholder Misalignment and Information Asymmetry** a) Diverse stakeholder priorities (developers, engineers, financial institutions) complicate consensus-building. b) Stakeholder engagement methods largely focus on post-design or implementation, neglecting early design phases. c) Knowledge gaps and conflicting perspectives lead to delays and suboptimal results. • **Need for Standardized and Adaptive Tools** a) Energy renovation requires an interdisciplinary, integrated decision-making approach. b) No standardized methodologies combine technical, economic, regulatory, and stakeholder preferences effectively. c) Current tools fail to address uncertainty in building performance and financial forecasting or adapt to changing project goals.
research questions and	*Main research 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?" *Sub-questions:* 1) "What key decisions must project developers make during the early

	design phase of energy renovations?" 2) "What factors contribute to making decision-making efficient in energy renovation projects (e.g., time, cost, sustainability impact)?" 3) "How can the efficiency of the decision-making process be measured?" 4) "Which criteria are most relevant for making efficient decisions in energy renovation projects?" 5) "Which methods are most suitable for ranking the relevant criteria in energy renovation projects?" 6) "How do the selected criteria define the boundary conditions for the selection of renovation alternatives?" 7) "How does communication between project developers and end-users affect the design and functionality of the decision-making tool?"
design assignment in which these result.	The design assignment of this thesis revolves around the **development of a decision support system** aimed at improving the decision-making process in the early design phase of energy renovations for residential buildings. The primary objective is to create a framework that enables project developers to clearly articulate their goals and make timely decisions, even when limited information is available. By minimizing inefficiencies, delays, and optimizing resource allocation, this system seeks to significantly enhance the energy renovation process. The central hypothesis of this thesis is that the decision-making process in energy renovations can be more effectively supported through a well-structured framework. This framework

	will organize and structure the inputs, criteria, and evaluation processes, allowing for a more efficient and balanced approach to **assessing renovation scenarios**. The framework assumes that its users possess a foundational understanding of energy renovations, as this knowledge is crucial for engaging with the framework's steps, criteria-weighting methodologies, and scenario evaluation processes. With its structured approach, the framework is designed to provide a **solid foundation for the eventual development of computational tools** that can further enhance and automate decision-making in energy renovation projects.

Process

Method description

Table 1 Thesis Methodology

Phase	Methods	Outcomes
1. Research Problem Identification	Literature Review	Research Framework
2. Exploration	Literature Review	• Analysis on the decision-making process • Review of existing tools • Selection of appropriate methodology • Criteria definition • Weighting methods definition • Alternative strategies selection • Stakeholder preferences
3. Framework Development & Tool Design	Concept Development & Prototyping	• Definition and quantification of inputs

			• Quantification of decision-making efficiency • Development of the Decision Support System (DSS)
4.	**Validation**	Case study	Testing and validation through real-world case study data
5.	**Discussion and Conclusions**	Analysis of Results	Conclusions and recommendations based on findings

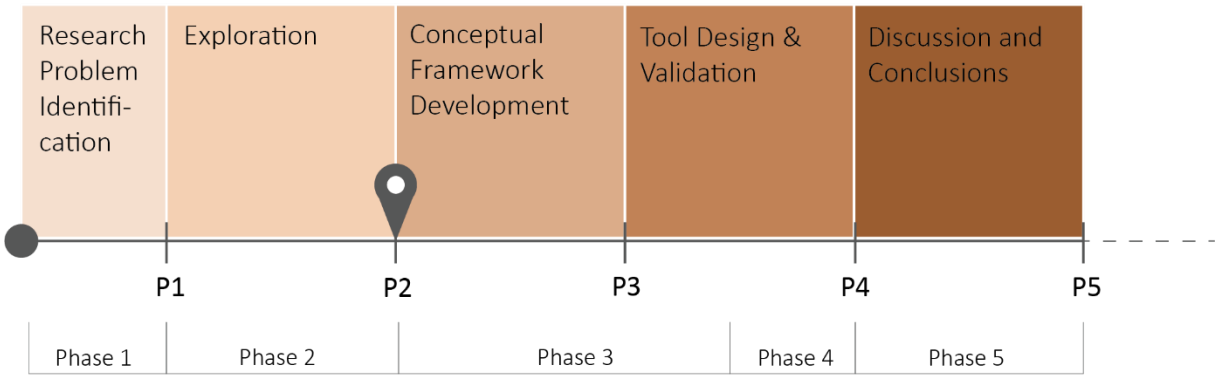

Figure 1 Timeline

Literature and general practical references

For this thesis, a thorough and systematic approach was employed to gather both academic literature and practical references. **Academic sources** were sourced from databases such as Scopus, Google Scholar, TU Delft Repository, and ScienceDirect, utilizing search terms related to decision-making, energy renovation, and multi-criteria methods. In addition, **practical data** was gathered from open sources, including Netherlands Statistics (CBS) and European Commission regulations and recommendations. For the **case study**, data will be provided by key stakeholders such as the municipality of Rotterdam, Havensteder, BAM Advies & Engineering Kwaliteitsadvisering, and Knol Installatietechniek B.V., ensuring a robust foundation for analysis and validation.

Main references:

Jensen, P. A., & Maslesa, E. (2015). Value based building renovation - A tool for decision-making and evaluation. *Building and Environment*, *92*, 1–9. https://doi.org/10.1016/j.buildenv.2015.04.008

Kamari, A., & Petersen, S. (2017). *Sustainable Renovation Framework: Introducing three levels of Integrated Design Process Implementation and Evaluation*. https://www.researchgate.net/publication/318284777

Lindkvist, C., Karlsson, A., Sørnes, K., & Wyckmans, A. (2014). Barriers and Challenges in nZEB Projects in Sweden and Norway. *Energy Procedia*, *58*, 199–206. https://doi.org/10.1016/j.egypro.2014.10.429

Nielsen, A. N., Jensen, R. L., Larsen, T. S., & Nissen, S. B. (2016). Early stage decision support for sustainable building renovation - A review. In *Building and Environment* (Vol. 103, pp. 165–181). Elsevier Ltd. https://doi.org/10.1016/j.buildenv.2016.04.009

Papantonis, D., Tzani, D., Burbidge, M., Stavrakas, V., Bouzarovski, S., & Flamos, A. (2022). How to improve energy efficiency policies to address energy poverty? Literature and stakeholder insights for private rented housing in Europe. *Energy Research & Social Science*, *93*, 102832. https://doi.org/10.1016/j.erss.2022.102832

Papapostolou, A., Mexis, F. D., Karakosta, C., & Psarras, J. (2022). *A Multicriteria Tool to Support Decision-Making in the Early Stages of Energy Efficiency Investments* (pp. 190–202). https://doi.org/10.1007/978-3-031-06530-9_15

Pinzon Amorocho, J. A., & Hartmann, T. (2022). A multi-criteria decision-making framework for residential building renovation using pairwise comparison and TOPSIS methods. *Journal of Building Engineering*, *53*, 104596. https://doi.org/10.1016/j.jobe.2022.104596

Wang, J.-J., Jing, Y.-Y., Zhang, C.-F., & Zhao, J.-H. (2009). Review on multi-criteria decision analysis aid in sustainable energy decision-making. *Renewable and Sustainable Energy Reviews*, *13*(9), 2263–2278. https://doi.org/https://doi.org/10.1016/j.rser.2009.06.021

Reflection

1. What is the relation between your graduation (project) topic, the studio topic (if applicable), your master track (A,U,BT,LA,MBE), and your master programme (MSc AUBS)?

   The interdisciplinary nature of this work contributes to bridging the fields of building technology, environmental science, and decision analysis. By combining these perspectives, the research explores new methods for balancing diverse factors and uncovering innovative approaches for energy renovations.
   Finally, this thesis provides a foundation for future research by outlining a framework that can be further refined, scaled, and adapted. Its methodological contributions, particularly in the integration of decision-making tools with real-world constraints, open opportunities for developing computational tools that enhance practical application in energy renovation projects.

2. What is the relevance of your graduation work in the larger social, professional and scientific framework.

   Societal Relevance
   In the face of escalating climate change concerns, the built environment plays a pivotal role in addressing global energy consumption and greenhouse gas emissions. Buildings account for a significant share of energy use, making energy-efficient renovations a critical solution for mitigating climate change impacts. This research focuses on energy renovation in residential buildings, aiming to develop decision-support tools that facilitate sustainable, efficient, and inclusive renovation processes.
   Energy renovations not only improve energy efficiency but also reduce greenhouse gas emissions, enhance indoor thermal comfort, and decrease energy costs. These benefits contribute to combating energy poverty and promoting equity in access to sustainable living conditions. Recent geopolitical disruptions, such as the war in Ukraine and resulting energy crises, underscore the importance of reducing dependency on volatile fossil fuel markets. Energy renovations leveraging local renewable energy sources can create a more stable and resilient energy system, mitigating the impacts of price fluctuations and external dependencies.
   Despite the clear benefits, energy renovation projects face several barriers, including high upfront costs, fragmented decision-making, and misalignment among stakeholders. This thesis addresses these challenges by proposing a structured decision-support framework tailored to the early design phase of residential energy renovations. By incorporating environmental, economic, and social criteria, the framework seeks to balance these criteria and make a streamline decision-making and provide actionable insights for project developers.

   Scientific Relevance
   This research contributes to the scientific field by addressing gaps in decision-making processes for energy renovations in residential buildings. Existing studies

often focus on specific technical aspects or isolated solutions but lack an integrated approach that combines environmental, economic, and social considerations. This thesis is based on Multi-Criteria Decision Analysis (MCDA) methods, proposing a framework that tailors these techniques to the unique challenges of energy renovation projects.

One key contribution of this research is its focus on the early design phase, where critical decisions significantly influence project outcomes. By structuring and prioritizing decision criteria during this early stage, the framework provides a systematic way to evaluate renovation scenarios under limited data conditions. It introduces a multi-objective perspective that balances criteria and considers stakeholder preferences, creating a more efficient and adaptable decision-making process.

Additionally, this thesis enhances existing knowledge by identifying specific decision variables and constraints related to building envelopes, systems, and regulatory requirements. By integrating these variables into a structured framework, the research fills a gap in tools that help stakeholders navigate the complexity of renovation projects while meeting energy efficiency and sustainability goals.

Professional relevance

The professional relevance of this thesis lies in addressing a critical gap in the field of energy renovations, where experts, such as project developers, engineers, and stakeholders, often struggle to identify the best renovation options due to a lack of a systematic decision-making process. Despite the availability of various tools, there is no comprehensive, standardized framework that integrates technical, economic, social, and regulatory factors to support efficient decision-making during the early design phase. This gap leads to delays, suboptimal choices, and inefficiencies in the renovation process. By proposing a structured decision-support framework, this thesis aims to fill that gap, providing professionals with a clear, process-driven approach to evaluate and prioritize renovation alternatives, ultimately improving decision-making efficiency and project outcomes.