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	**Nefeli Karadedou – Isoua**
Student number	5629535

Studio		
Name / Theme	Building Technology	
Main mentor	Charalampos Andriotis	AI in Structural Design & Mechanics
Second mentor	Michela Turrin	Design Informatics
Argumentation of choice of the studio	I believe that the building sector has evolved to incorporate various domains of optimization to improve the overall process of design. Design informatics focuses on this domain. My aim is to extend the focus outside of the usual optimization domains of Design informatics by incorporating AI technologies to solve social and climate issues that arise.	

Graduation project	
Title of the graduation project	**Optimization of staged retrofitting planning**
Goal	
Location:	There is no specified project location
The posed problem,	In 2020, as part of the European Green Deal, the European Commission initiated the Renovation Wave strategy with the goal of doubling the annual rate of energy renovation for buildings by 2030(European Commission, 2020). However, there is a lag in how quickly we renovate compared to the standards(Bouckaert et al., 2021). The main reasons are mainly economical (Esser Anne et al., 2019) or based on the facts that a lot of owners choose to conduct retrofitting based on trigger points, e.g. when a boiler fails(Energy Saving Trust, 2015).

	Planning the house energy renovation in steps can be more economically feasible in some cases (Fritz et al., 2019) . There has been some research on the correct planning of the retrofitting steps(I. Maia & Kranzl, 2019)(I. E. N. Maia et al., 2023),(I. Maia et al., 2021) and the main idea that arises is that the components should be retrofitted in packages that avoid the lock-in effect. Lock-in effects happen when certain energy savings are not achieved, and due to some circumstances, it cannot be quickly changed, remaining for many years less energy efficient. Even more, planning the cost optimal timing of the steps to find the correct sequence and time of actions based on the uncertainties of the environment (degradation rate of the materials, economic growth) can be impossible with the use of traditional methods(Sutton & Barto, 2018). (I. Maia et al., 2021) proposed to optimize the timings of these retrofitting steps using mixed integer linear programming. Even though their research is pioneering on the domain, the identified limitations on their model as they couldn't account for all uncertainties (degradation rate, economy etc). The problem can be seen as a typical maintenance problem where the materials that need retrofitting degrade in varying rates and each action will have consequences on the actions that can be taken later (Ogunfowora & Najjaran, 2023),(Andriotis & Papakonstantinou,2018),(Krachtopoulos, 2023). For example, if we retrofit now, we might not have enough money to retrofit later. These types of problems are called sequential decision-making problems.

	There are various algorithms that can solve sequential problems, (Littman, 1996) but the most upcoming ones come from the realm of reinforcement learning. Reinforcement learning is a machine learning approach that focuses on finding the optimal policy (optimal action for each scenario we are in now based on what we want to achieve in the future)(Sutton & Barto, 2018). For this reason, reinforcement learning will be used as an alternative to produce a roadmap of the staged retrofitting actions.
research questions and	**The main research question is:** How can we perform staged retrofitting in a cost-effective manner using Reinforcement Learning? The sub-questions are separated per field of research as: - How do we formulate the staged retrofitting as an MDP (Markov Decision Process) problem? - What type of uncertainties can be incorporated? - Which algorithm should we consider for solving this problem? - How do we validate the model? - How can we simulate the scenario of the building components degradation?
design assignment in which this result.	The proposal of this research is to offer a new way to optimize the timing of the staged renovations of a single-family home with the use of Reinforcement learning. The focus will be on how to formulate the deep staged retrofitting as a

	reinforcement learning problem to be solved. The final project will be a sequence of retrofit actions based on cost-optimal scenario.

Process

Method description

The research will be developed in three stages.
First stage will consist of developing the staged retrofitting scenario. This will be the biggest part of the research. In this part the staged retrofitting scenario will be defined, meaning the actual constraints, the house model, the objectives, actions, and other aspects of the environments that will be created. In this stage, reinforcement learning algorithms will be further investigated and discussed – we'll employ one of them based on our evaluation. The basis for this section will be relied on the general theory of reinforcement learning and the way to formulate the scenario can be addressed through similar problems (Krachtopoulos, 2023)(Ogunfowora & Najjaran, 2023).

The second stage will be the implementation:
This phase will involve putting the theoretical model that will develop into phase one into practice. In the second stage, the scenario will be developed using Python. Existing Reinforcement learning libraries will be used for the problem setup. Training episodes will be conducted so that the algorithm can learn the optimal policies for the developed scenario.

The third and final part of the methodology will be the evaluation and discussion section. In this stage, the performance of the algorithm will be evaluated against the objectives and the parameters will be tuned. The implications of the findings will be evaluated and discussed upon. A reflection will be made discussing the overall research process, highlighting key insights and potential areas of improvement.

Literature and general practical references

Andriotis, C. P., & Papakonstantinou, K. G. (2018). *Managing engineering systems with large state and action spaces through deep reinforcement learning*.

Bouckaert, S., Pales, A. F., McGlade, C., Remme, U., Wanner, B., Varro, L., D'Ambrosio, D., & Spencer, T. (2021). *Net Zero by 2050: A Roadmap for the Global Energy Sector*.

Energy Saving Trust. (2015). *Trigger points: a convenient truth Promoting energy efficiency in the home*. https://www.yumpu.com/en/document/view/44329336/trigger-points-energy-saving-trust

Esser Anne, Dunne Allison, Meeusen Tim, Quaschning Simon, & Wegge Denis. (2019). *Comprehensive study of building energy renovation activities and the uptake of nearly zero-energy buildings in the EU Final report*. www.navigant.com

European Commision. (2020). *Renovation Wave: doubling the renovation rate to cut emissions, boost recovery and reduce energy poverty*. Press Release. https://ec.europa.eu/commission/presscorner/detail/en/ip_20_1835

Fritz, S., Pehnt, M., Mellwig, P., & Volt, J. (2019). *Planned staged deep renovations as the main driver for a decarbonised European building stock*.

Krachtopoulos, K. (2023). *Multi-objective Deep Reinforcement Learning for predictive maintenance of road networks*.

Littman, M. L. (1996). *Algorithms for Sequential Decision Making*. https://www.researchgate.net/publication/33697270

Maia, I. E. N., Harringer, D., & Kranzl, L. (2023). *Staged renovation and the time-perspective: Which other metric should be used to assess climate-optimality of renovation activities?* https://doi.org/10.1016/j.segy.2023.100110

Maia, I., & Kranzl, L. (2019). Defining a framework to apply retrofitting optimisation models for long-term and step-by-step renovation approaches. *IOP Conference Series: Earth and Environmental Science*, *323*(1). https://doi.org/10.1088/1755-1315/323/1/012175

Maia, I., Kranzl, L., & Müller, A. (2021). New step-by-step retrofitting model for delivering optimum timing. *Applied Energy*, *290*, 116714. https://doi.org/10.1016/J.APENERGY.2021.116714

Ogunfowora, O., & Najjaran, H. (2023). Reinforcement and deep reinforcement learning-based solutions for machine maintenance planning, scheduling policies, and optimization. *Journal of Manufacturing Systems*, *70*, 244–263. https://doi.org/10.1016/j.jmsy.2023.07.014

Sutton, R. S., & Barto, A. G. (2018). *Reinforcement learning : an introduction*.

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 research "Optimization of staged retrofitting planning" delves into the field of retrofitting from a computational point of view. By defining the scope of the problem already as a maintenance planning problem, this thesis will try to delve into the field of AI and design informatics on how to solve it.
During the master track of Building Technology, we delved into various domains addressing the climate design principles related to the building domain and problems (Climate Design), the Design Informatics domain to learn how to optimize a design through computational means, and the AI domain (through the elective Computational Intelligence for Integrated design) to learn how to use data to solve complex problems regarding the architectural domain.
This topic aims to compile information from all three aspects but focus on the two related to the Design Informatics and AI to solve the issue at hand.

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

   Retrofitting has become a popular domain of action to reach the energy requirements made in the Paris Deal, as buildings are responsible for approximately 35% of energy consumption and 36% of greenhouse gas emissions in the European Union. Even though reaching those climatic requirements is essential the need to consider the social aspect of the problem is too. By adapting the retrofitting in steps and optimizing the retrofitting planning, we can motivate more people to make deep retrofitting as it will be a more economically feasible and will bring the us closer to the requirements of the Paris Deal.
   Even more, the emergence of the AI domain has offered opportunities to tackle complex problems and deal with uncertainties, way much faster and more robustly from the traditional optimization methods.
   This research hopes to be a motivational groundwork on how to deal with retrofitting related issues in the future, using the AI domain as a basis.