

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	Isabella Lucchese
Student number	5852528
Studio	
Name / Theme	Building Technology Graduation Studio
Main mentor	Azarakhsh Rafiee
Second mentor	Willem van der Spoel
Argumentation of choice of the studio	Building Technology Graduation Studio, argument regarding the chosen topic: The building sector leads in operational energy consumption across all sectors, with future impacts of energy use due to climate change-induced cold and heat waves remaining uncertain. To ensure future resilience, it is essential to assess retrofit scenarios that are both economically and environmentally sustainable. While Building Performance Simulation Models offer detailed analyses, they are computationally expensive. Surrogate models, on the other hand, provide cost-effective and high-performance alternatives, especially when integrated with Artificial Intelligence (AI). For these reasons, I aim to develop an AI-based surrogate model for evaluating optimal building envelope measures in retrofits to enhance resilience against extreme temperatures.
Graduation project	
Title of the graduation project	Development of an AI-based surrogate model to identify optimal building envelope retrofit solutions considering the effects of cold and heat waves
Goal	
Location:	The Netherlands
The posed problem,	The building sector accounts for the highest share of operational energy consumption across all sectors. Additionally, the impact of energy consumption in buildings due to cold and heat waves, which are expected to become increasingly problematic in the future due to climate change, remains

	<p>uncertain. Therefore, it is crucial to assess retrofit scenarios that are both economically and environmentally sustainable to ensure future resilience. To investigate optimal retrofit solutions, Building Performance Simulation Models are usually used. These models provide detailed analyses but are computationally expensive. Surrogate models, in contrast, offer less computational costs and demonstrate high performances when integrated with Artificial Intelligence. Therefore, this thesis aims to develop an AI-based surrogate model for evaluating optimal building envelope measures in building retrofits to ensure resilience against cold and heat waves.</p>
<p>research questions and</p>	<p>How can an AI-based surrogate model identify optimal building envelope retrofit solutions considering the effects of cold and heat waves?</p> <p>Sub-questions</p> <ol style="list-style-type: none"> 1. Which are the definitions of cold and heat waves? 2. How can cold and heat waves be predicted? 3. Which type of AI is it better to implement in the surrogate model? 4. Which frameworks and libraries are suitable for the development of the surrogate model? 5. Which are commonly used building envelope retrofit solutions? 6. Are the optimal solutions determined by the model economically sustainable?
<p>design assignment in which these result.</p>	<p>Development of an AI-based surrogate model to identify optimal building envelope retrofit solutions considering the effects of cold and heat waves.</p>

Process

Method description

1. Data Collection and Preprocessing

- Gather datasets on:
 - building characteristics from the considered Building Archetype;
 - building energy consumption, and;
 - climatic conditions.
- Preprocessing Steps such as normalization, handling missing values, smoothing,

2. Cold and Heat Waves Predictions

- Definition of Cold and Heat Waves: establish clear criteria for what constitutes cold and heat waves based on temperature thresholds and duration;
- Prediction Method Selection: Choose a suitable predictive model to forecast future cold and heat waves and identify the prediction periods to be included in the analysis.

3. Common Envelope Retrofit Solutions Determination

Selection of Retrofit Solutions: Identify and select commonly used building envelope retrofit strategies to use as analysis scenarios.

4. Development of AI-based surrogate model

- Model architecture selection and implementation: choose appropriate AI architectures and implement them using suitable frameworks and libraries;
- Training process: train the surrogate model on the pre-processed data;
- Validation process: validate the results by comparing them with those obtained from conventional building energy simulation software like EnergyPlus.

5. Identification Economic Impact Retrofit Solutions:

- Integration of energy costs: incorporate energy costs in the surrogate model to estimate the economic impact of each building envelope retrofit scenario.
- Economic Analysis: conduct a cost-benefit analysis to assess the economic sustainability of the retrofit solutions.

Literature and general practical references

Literature research has been conducted according to the following topic. (general topics)

1. AI-based surrogate models to identify optimal building retrofit solutions;
2. Cold and heat waves predictions;
3. Standard building envelope retrofit solutions.

Bianchi, S., Andriotis, C., Klein, T., & Overend, M. (2024). Multi-criteria design methods in façade engineering: State-of-the-art and future trends. *Building and Environment*, 250, 111184. <https://doi.org/10.1016/j.buildenv.2024.111184>

Chang, S., Castro-Lacouture, D., & Yamagata, Y. (2020). Decision support for retrofitting building envelopes using multi-objective optimization under uncertainties. *Journal of Building Engineering*, 32, 101413. <https://doi.org/10.1016/j.jobbe.2020.101413>

Chakraborty, D., Alam, A., Chaudhuri, S., Başağaoğlu, H., Sulbaran, T., & Langar, S. (2021b). Scenario-based prediction of climate change impacts on building cooling energy consumption with explainable artificial intelligence. *Applied Energy*, 291, 116807. <https://doi.org/10.1016/j.apenergy.2021.116807>

Costa-Carrapiço, I., Raslan, R., & González, J. N. (2020). A systematic review of genetic algorithm-based multi-objective optimisation for building retrofitting strategies towards energy efficiency. *Energy and Buildings*, 210, 109690. <https://doi.org/10.1016/j.enbuild.2019.109690>

Dubey, A. K., Lal, P., Kumar, P., Kumar, A., & Dvornikov, A. Y. (2021). Present and future projections of heatwave hazard-risk over India: A regional earth system model assessment. *Environmental Research*, 201, 111573. <https://doi.org/10.1016/j.envres.2021.111573>

Hey, J., Siebers, P., Nathanail, P., Ozcan, E., & Robinson, D. (2022). Surrogate optimization of energy retrofits in domestic building stocks using household carbon valuations. *Journal of Building Performance Simulation*, 16(1), 16–37. <https://doi.org/10.1080/19401493.2022.2106309>

Gaitán, E., Monjo, R., Pórtolos, J., & Pino-Otín, M. R. (2019). Projection of temperatures and heat and cold waves for Aragón (Spain) using a two-step statistical downscaling of CMIP5 model outputs. *Science of the Total Environment*, 650, 2778–2795. <https://doi.org/10.1016/j.scitotenv.2018.09.352>

Kamel, E., & Memari, A. M. (2022). Residential Building envelope energy retrofit Methods, simulation tools, and example Projects: A review of the literature. *Buildings*, 12(7), 954. <https://doi.org/10.3390/buildings12070954>

Lorenzo, N., Díaz-Poso, A., & Royé, D. (2021). Heatwave intensity on the Iberian Peninsula: Future climate projections. *Atmospheric Research*, 258, 105655. <https://doi.org/10.1016/j.atmosres.2021.105655>

Machard, A., Inard, C., Alessandrini, J., Pelé, C., & Ribéron, J. (2020). A Methodology for Assembling Future Weather Files Including Heatwaves for Building Thermal Simulations from the European Coordinated Regional Downscaling Experiment (EURO-CORDEX) Climate Data. *Energies*, 13(13), 3424. <https://doi.org/10.3390/en13133424>

Molina, M. O., Sánchez, E., & Gutiérrez, C. (2020). Future heat waves over the Mediterranean from an Euro-CORDEX regional climate model ensemble. *Scientific Reports*, 10(1). <https://doi.org/10.1038/s41598-020-65663-0>

Rosso, F., Ciancio, V., Dell'Olmo, J., & Salata, F. (2020). Multi-objective optimization of building retrofit in the Mediterranean climate by means of genetic algorithm application. *Energy and Buildings*, 216, 109945. <https://doi.org/10.1016/j.enbuild.2020.109945>

Seyedzadeh, S., Rahimian, F. P., Oliver, S., Rodriguez, S., & Glesk, I. (2020b). Machine learning modelling for predicting non-domestic buildings energy performance: A model to support deep energy retrofit decision-making. *Applied Energy*, 279, 115908. <https://doi.org/10.1016/j.apenergy.2020.115908>

Sharif, S. A., & Hammad, A. (2019). Developing surrogate ANN for selecting near-optimal building energy renovation methods considering energy consumption, LCC and LCA. *Journal of Building Engineering*, 25, 100790. <https://doi.org/10.1016/j.jobbe.2019.100790>

Singh, A. ., N., B. ., Mehrotra, T. ., & Dubey, S. . (2023). Multi-Objective Building Retrofitting Utilizing Evolutionary Algorithms and Machine Learning Models. *International Journal of Intelligent Systems and Applications in Engineering*, 11(8s), 117–122. <https://www.ijisae.org/index.php/IJISAE/article/view/3029>

Thrampoulidis, E., Hug, G., & Orehounig, K. (2023). Approximating optimal building retrofit solutions for large-scale retrofit analysis. *Applied Energy*, 333, 120566. <https://doi.org/10.1016/j.apenergy.2022.120566>

Thrampoulidis, E., Mavromatidis, G., Lucchi, A., & Orehounig, K. (2021). A machine learning-based surrogate model to approximate optimal building retrofit solutions. *Applied Energy*, 281, 116024. <https://doi.org/10.1016/j.apenergy.2020.116024>

Zhan, J., He, W., & Huang, J. (2023). Dual-objective building retrofit optimization under competing priorities using Artificial Neural Network. *Journal of Building Engineering*, 70, 106376. <https://doi.org/10.1016/j.jobbe.2023.106376>

Zhang, H., Feng, H., Hewage, K., & Arashpour, M. (2022). Artificial Neural Network for Predicting building Energy Performance: A Surrogate Energy Retrofits Decision Support Framework. *Buildings*, 12(6), 829.
<https://doi.org/10.3390/buildings12060829>

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

1. My Graduation Topic is directly related to my Master track and my Master program because it addresses the critical issue of energy efficiency in buildings, a key focus in Architecture. By considering the effects of cold and heat waves, I will identify optimal envelope retrofit solutions to create the current building stock future-proof. Therefore, my thesis contributes to one of the most current and challenging goals of the built environment—decarbonization and resiliency to climate change. This project integrates advanced simulation techniques with practical applications, aligning with the broader goals of architectural innovation and environmental stewardship in my Master program.
2. Since the built environment is the primary contributor to GHG emissions on global scale, it is crucial to reduce the amount of energy consumption as soon as possible. Additionally, climate change, particularly heat and cold waves, will become increasingly severe in the future, and the current built environment is not yet prepared to handle them. My graduation project is dedicated to finding optimal solutions to manage this challenging situation. By identifying optimal building envelope retrofit solutions, the project aims to prepare the existing building stock to be future-proof, while also promoting decarbonization. Therefore, I the project is highly relevant on social, professional, and scientific levels, as it seeks solutions to address challenges such as the energy crisis, decarbonization, and environmental sustainability.