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	Alina Verena Wagner
Student number	5635616

Studio		
Name / Theme	Building Technology Graduation studio	
Main mentor	Dr. Alessandra Luna Navarro	Façade and Product Design
Second mentor	Dr. Eleonora Brembilla	Climate Design
Argumentation of choice of the studio	The building envelope as the intermediator between the outside and inside environment strongly influences the health and comfort objectives of the occupants, and therefore the indoor climate conditions. With the objective to reach a more resource efficient, comfortable, and resilient built environment, facades are in the center of the attention. I enjoy the interconnectedness of the building envelope with multiple sectors of Building Technology. As I am especially interested in the façade's performance in terms of its impact on our daily life, the combination of "Façade and Product design" and "Climate Design" is obvious and powerful.	

Graduation project	
Title of the graduation project	Decision-making framework for enhanced thermal resilience of façade-retrofits
Goal	
Location/Case study:	Munich
The posed problem,	Due to their increased frequency and intensity, climate extremes are becoming more and more present worldwide. Their impacts are enhancing the pressure on the ecosystem, the built environment and humankind. Heat waves are overheating indoor spaces and the thermal comfort as one of the major comfort requirements of buildings is disrupted or, in the most extreme situations, lost. This leads to life-threatening circumstances and explains the high morbidity and mortality during past heat wave events. There is an urgent need for a more climate resilient built environment, which is prepared for future events. However, there is no common building standard, nor thermal comfort metric on thermal resilience, to which professionals can relate while designing retrofits or new constructions. Thermal resilience of façades for now is an abstract term, not tangible for designers and engineers, and thus, so far not considered in the design process. The shift of thinking and the introduction of common assessment methodologies changes main design parameters and demands the debate of new considerations and constraints.

research questions and	This research aims to improve the design process of façade retrofits with improved thermal resilience during heat waves. To achieve the purpose of this study, this study poses the following research question: **"How can we evaluate the influence of façades on building thermal resilience during heat waves?"** The thesis as well as the literature review is divided into three focus topics: "thermal comfort in extreme heat", "resilience" and "façade design". To be able to give a scientific response to the research question, the following sub-questions are raised: **How do future climate related heat waves change building requirements for façade constructions?** **How is the resilience of facades to extreme heat assessed? What are commonly used metrics?** **How could current assessment methodologies of thermal resilience of facades be improved?** **What are relevant façade parameters to be considered for retrofitting improving occupants' thermal comfort during extreme heat events?** **What are the most important façade parameters influencing resilience indicators?**
design assignment in which these result.	This research concludes on a design proposal for a resilient façade retrofit for the archetype of a residential building block from the 19th century in the city of Munich (Germany). The proposal is used as an evaluation for the application of the developed design method: a decision-making procedure which can be used when designing retrofits for improved thermal indoor comfort during present and future heat waves.

Process

Method description

In order to meet the research objectives and to answer the research questions and sub-questions, this thesis is split into five related parts:

Literature review

A first explorative literature review puts the topic of the thesis into a broader context to understand its relevance in the building industry, global society, and climate change consequences. Special attention is given to the definition of temperature extremes, heat waves and their impact on the built environment and its occupants. This also includes thermal comfort under extreme heat conditions. Altogether, the explorative literature review answers the first sub-question.

The second part of the literature review is focused more specifically on the topic of resilience in façade design. Systematically, eleven relevant papers on quantification methods of thermal resilience during extreme weather disruptions are analyzed regarding their definition of resilience, their proposed resilience evaluation method and the therewith tested retrofit options. The main objective hereby is the investigation of available methodologies of measuring resilience of facades to extreme heat, which answers the second sub-question. The consideration of the tested retrofit options, touched upon the fourth research question.

The output of the literature review defines the research gap and is generally important input for the further progression of the research.

Definition of resilience indicators

With an additional literature study, resilience indicators are defined: Resilience criteria are translated to resilience indicators with their corresponding resilience indices, with their common calculation methods found in scientific literature. An analysis of the different calculation methods finally concludes on the third sub-question.

Development of building performance methodology

The application of the proposed quantification method requires the definition of a simulation methodology. The proposed framework combines dynamic building performance simulation (EnergyPLUS engine), with the postprocessing of the results in Python, using multiple additional libraries such as Pythermalcomfort (Tartarini & Schiavon, 2020), SALib (Herman & Usher, 2017), Eppy (Santosh, 2022) and NumPy (Harris et al., 2020). It eventually results in the final rating of the outcome, which indicates the most suitable retrofit design for the chosen location, improving the façade's thermal resilience to heat waves.

Evaluation of method

For the evaluation of the method, a case study is introduced. For the location of Munich, the specific meaning of a "heat wave" is defined. Based on that, an EPW weather file is adjusted in such a way that it includes, over the simulation period of 43 days, real weather data from two past heat waves of 2015 in Munich. Within Munich, the district "Maxvorstadt" is chosen as one to display common German residential, urban blocks. The base case scenario is set up based on the analysis of the given case study data.

Following the proposed workflow, a sensitivity analysis is conducted. The aim is to identify the most influential façade parameters with the highest impact on the façade's performance in each of the resilience stages. Thus, four design cases describe the best performing input variations: the best performing ones per indicator and the one with the assumed best overall performance.

To evaluate the hypothesis of the proposed assessment framework, the final rating of the design cases is analyzed. Hereupon, the "best" design is materialized.

Finally, with a profound knowledge of the topic, limitations of the research and future research possibilities are pointed out. This concludes on the proposed methodology as a decision-making method during the design of retrofits, enhancing thermal resilience, with limitations regarding the actual evaluation of the final performance.

Literature and general practical preference

Systematic literature review (most relevant, selected papers):

Attia, S., Levinson, R., Ndongo, E., Holzer, P., Berk Kazanci, O., Homaei, S., Zhang, C., Olesen, B. W., Qi, D., Hamdy, M., & Heiselberg, P. (2021). Resilient cooling of buildings to protect against heat waves and power outages: Key concepts and definition. *Energy and Buildings*, 239, 110869. https://doi.org/10.1016/j.enbuild.2021.110869

Homaei, S., & Hamdy, M. (2021). Thermal resilient buildings: How to be quantified? A novel benchmarking framework and labelling metric. *Building and Environment*, *201*, 108022. https://doi.org/10.1016/j.buildenv.2021.108022

Ji, L., Shu, C., Laouadi, A., Lacasse, M., & Wang, L. (Leon). (2023). Quantifying improvement of building and zone level thermal resilience by cooling retrofits against summertime heat events. *Building and Environment*, 229, 109914. https://doi.org/10.1016/j.buildenv.2022.109914

Lassandro, P., & Di Turi, S. (2019). Multi-criteria and multiscale assessment of building envelope response-ability to rising heat waves. *Sustainable Cities and Society*, 51, 101755. https://doi.org/10.1016/j.scs.2019.101755

Patterson, M. (2022). Resilience by design: Building facades for tomorrow. In Rethinking Building Skins (pp. 359–375). Elsevier. https://doi.org/10.1016/B978-0-12-822477-9.00002-4

Rajput, M., Augenbroe, G., Stone, B., Georgescu, M., Broadbent, A., Krayenhoff, S., & Mallen, E. (2022). Heat exposure during a power outage: A simulation study of residences across the metro Phoenix area. Energy and Buildings, 259, 111605. https://doi.org/10.1016/j.enbuild.2021.111605

Schünemann, C., Son, S., & Ortlepp, R. (2022). Heat resilience of apartment buildings in Korea and Germany: Comparison of building design and climate. *International Journal of Energy and Environmental Engineering*, *13*(3), 889–909. https://doi.org/10.1007/s40095-022-00476-7

Sun, K., Specian, M., & Hong, T. (2020). Nexus of thermal resilience and energy efficiency in buildings: A case study of a nursing home. *Building and Environment*, *177*, 106842. https://doi.org/10.1016/j.buildenv.2020.106842

Sun, K., Zhang, W., Zeng, Z., Levinson, R., Wei, M., & Hong, T. (2021). Passive cooling designs to improve heat resilience of homes in underserved and vulnerable communities. *Energy and Buildings*, 252, 111383. https://doi.org/10.1016/j.enbuild.2021.111383

Zhang, C., Kazanci, O. B., Levinson, R., Heiselberg, P., Olesen, B. W., Chiesa, G., Sodagar, B., Ai, Z., Selkowitz, S., Zinzi, M., Mahdavi, A., Teufl, H., Kolokotroni, M., Salvati, A., Bozonnet, E., Chtioui, F., Salagnac, P., Rahif, R., Attia, S., … Zhang, G. (2021). Resilient cooling strategies – A critical review and qualitative assessment. *Energy and Buildings*, 251, 111312. https://doi.org/10.1016/j.enbuild.2021.111312

Zuo, J., Pullen, S., Palmer, J., Bennetts, H., Chileshe, N., & Ma, T. (2015). Impacts of heat waves and corresponding measures: A review. *Journal of Cleaner Production*, 92, 1–12. https://doi.org/10.1016/j.jclepro.2014.12.078

Extreme temperatures:

Junk, J., Goergen, K., & Krein, A. (2019). Future Heat Waves in Different European Capitals Based on Climate Change Indicators. International Journal of Environmental Research and Public Health, 16(20), 3959. https://doi.org/10.3390/ijerph16203959

Perkins, S. E. (2015). A review on the scientific understanding of heatwaves—Their measurement, driving mechanisms, and changes at the global scale. Atmospheric Research, 164–165, 242–267. https://doi.org/10.1016/j.atmosres.2015.05.014

Perkins, S. E., & Alexander, L. V. (2013). On the Measurement of Heat Waves. Journal of Climate, 26(13), 4500–4517. https://doi.org/10.1175/JCLI-D-12-00383.1

Perkins, S. E., Alexander, L. V., & Nairn, J. R. (2012). Increasing frequency, intensity and duration of observed global heatwaves and warm spells. Geophysical Research Letters, 39(20), 2012GL053361. https://doi.org/10.1029/2012GL053361

Seneviratne, S. I., X. Zhang, M. Adnan, W. Badi, C. Dereczynski, A. Di Luca, S. Ghosh, I. Iskandar, J. Kossin, S. Lewis, F. Otto, I. Pinto, M. Satosh, S.M. Vicente-Serrano, M. Werner, & B. Zhou. (2021). Chapter 11: Weather and Climate Extreme Events in a Changing Climate (Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, pp. 1513–1766). Cambride University Press.

Zuo, J., Pullen, S., Palmer, J., Bennetts, H., Chileshe, N., & Ma, T. (2015). Impacts of heat waves and corresponding measures: A review. Journal of Cleaner Production, 92, 1–12. https://doi.org/10.1016/j.jclepro.2014.12.078

Other:

Holmes, S. H., Phillips, T., & Wilson, A. (2016). Overheating and passive habitability: Indoor health and heat indices. Building Research & Information, 44(1), 1–19. https://doi.org/10.1080/09613218.2015.1033875

Patterson, M., Kensek, K., & Noble, D. (2017). Supple Skins: Considering the Relevance, Scalability, and Design Strategies for Façade System Resilience. Journal of Architectural Education, 71(1), 34–45. https://doi.org/10.1080/10464883.2017.1260919

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. Building technology as a track within the Master of Architecture, Urbanism and Building Sciences, lies between the fields of Engineering and Architecture. To highlight the interdisciplinarity, the Master thesis combines at least two different disciplines within the broad scope of Building Technology.
   This thesis relates to two chairs within the department of AE+T: Façade and Product Design and Climate Design, which both mark an important part of BT.
   Façade and Product Design is involved in innovation concerning the building skin and its related building components. Thereby, traditional construction and design methods are questioned, and different novel typologies, materials and fabrication methods are being tested.
   Climate Design concerns building climate systems including their energy performance and building installation while putting special attention on user comfort and health.
   With the main research objective of developing an improved thermally resilient facade and therefore assessing various façade parameters, this thesis correlates to major topics of Façade and Product design.

By addressing occupant thermal comfort during extreme heat events and research on climate predictions and weather data, the thesis is strongly connected to topics within climate design.

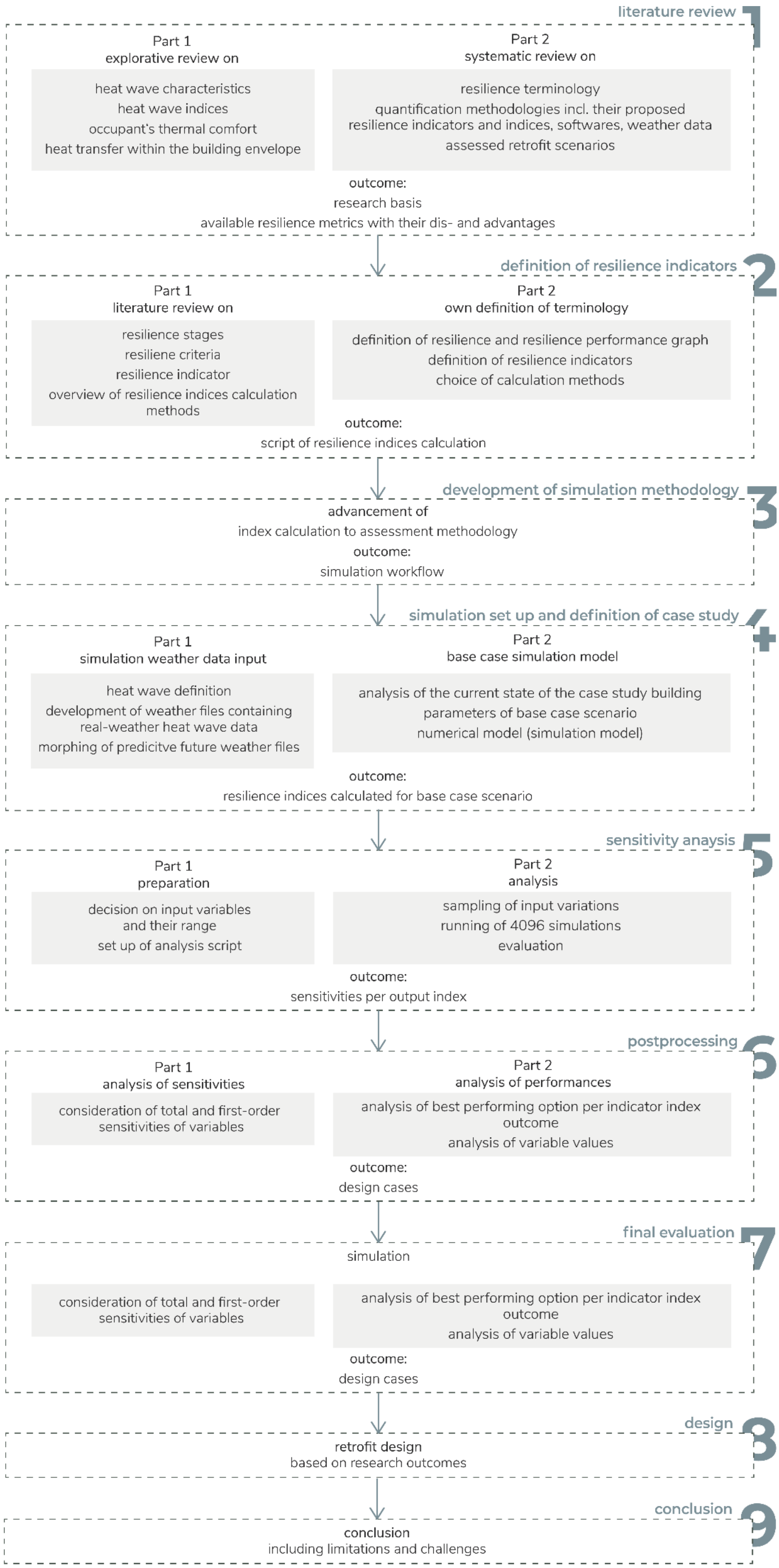
The BT master track focuses on innovation in the built environment with special attention given to sustainable solutions. By addressing the pressing problem of future heat waves with related overheating problems of indoor spaces in under-performing housing, this research is focused on a topic, which is becoming even more relevant in future. Proposing a retrofitting method, existing buildings can be upgraded without the use of mechanical cooling, which saves material and energy and is therefore offers a sustainable solution.

In a broader context, the study can be linked to all the different fields of the Master programme AUBS: Building Sciences for the majority, however it also has a high architectural ambition; a façade retrofit changes drastically the aesthetics of a building and therefore needs to fit in with the building character as well as the surrounding area. Located in an urban environment, outdoor conditions and the Urban Heat Island effect do also play a large role.

2. **Societal relevance:**
   Heat waves count globally as the one of the deadliest of occurring weather events. With an immense impact on human health and the increasing dependency on active cooling systems, thousands of deaths can be related to past heat waves. Especially within the vulnerable groups of the population like elderly and children, a high morbidity is recorded during past heat wave periods. With increased morbidity being the most dangerous impact of heat waves, extreme heat is also influencing productivity and the general well-being of human beings. To improve thermal resilience of facades during heat events therefore means to improve the general quality of life, but, in the most extreme cases, to save lives.

   Scientific relevance:
   The state-of-the-art research offers different approaches of resilience performance methodologies for facades. However, they are based on a varying terminology of resilience-related terms, with an important part of a "resilient" system neglected. The introduction of multiple thermal resilience indices highlights the importance of considering different abilities of a resilient façade to improve its performance during a heat wave period. The "iterative", "cyclic" resilience process is mentioned in previous research; however it is never considered as part of the assessment methodology. Like this, the proposed evaluation strategy adds important depth and is able to give comprehensive design indications for improved performance of facades during heat waves.

   Professional relevance:
   The term "resilience" is broadly used in the context of the sustainable built environment; however, it often lacks a clear definition or even when clearly defined, it might stay on an abstract level and is not applied on actual applications. Linking research and practical application, this thesis contributes to an improved understanding of the translation of "resilient" façade design to an actual retrofit – which is an important step for the industry.


literature review
1
Part 1
explorative review on
heat wave characteristics
heat wave indices
occupant's thermal comfort
heat transfer within the building envelope
Part 2
systematic review on
resilience terminology
quantification methodologies incl. their proposed resilience indicators and indices, softwares, weather data
assessed retrofit scenarios
outcome:
research basis
available resilience metrics with their dis- and advantages
definition of resilience indicators
2
Part 1
literature review on
resilience stages
resiliene criteria
resilience indicator
overview of resilience indices calculation methods
Part 2
own definition of terminology
definition of resilience and resilience performance graph
definition of resilience indicators
choice of calculation methods
outcome:
script of resilience indices calculation
development of simulation methodology
3
advancement of
index calculation to assessment methodology
outcome:
simulation workflow
simulation set up and definition of case study
4
Part 1
simulation weather data input
heat wave definition
development of weather files containing real-weather heat wave data
morphing of predicitve future weather files
Part 2
base case simulation model
analysis of the current state of the case study building
parameters of base case scenario
numerical model (simulation model)
outcome:
resilience indices calculated for base case scenario
sensitivity anaysis
5
Part 1
preparation
decision on input variables and their range
set up of analysis script
Part 2
analysis
sampling of input variations
running of 4096 simulations
evaluation
outcome:
sensitivities per output index
postprocessing
6
Part 1
analysis of sensitivities
consideration of total and first-order sensitivities of variables
Part 2
analysis of performances
analysis of best performing option per indicator index outcome
analysis of variable values
outcome:
design cases
final evaluation
7
simulation
consideration of total and first-order sensitivities of variables
analysis of best performing option per indicator index outcome
analysis of variable values
outcome:
design cases
design
8
retrofit design
based on research outcomes
conclusion
9
conclusion
including limitations and challenges