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

<table>
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<tr>
<th>Name</th>
<th>MÁRIA</th>
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<tbody>
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<td>+31646541146</td>
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### Studio

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<tr>
<th>Name / Theme</th>
<th>Building Technology _Sustainable Design Graduation Studio</th>
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<tbody>
<tr>
<td>Teachers / tutors</td>
<td>dr.ir. MSc.Arch Michela Turrin</td>
</tr>
<tr>
<td></td>
<td>dr.ir.arch. M.J. (Martin) Tenpierik</td>
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<tr>
<td></td>
<td>dr.ing. Marcel Bilow</td>
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**Argumentation of choice of the studio**

Technological advancements continue to offer the opportunity for further advancements in building performance. The main reason for choosing this studio is the fact that I am very interested in new technologies and innovative building systems, materials, and construction methods appeared in the building industry. Moreover, manufacturing improvements, new materials, understanding building science, and renewable energy technology are some areas of my studies in the BT track that help me to enhance my skills in designing high-performance buildings.

### Graduation project

<table>
<thead>
<tr>
<th>Title of the graduation project</th>
<th>ADAPTIVE FAÇADE SYSTEM BASED ON PCMs</th>
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**Goal**

**Location:**

Two different locations: Rotterdam (Netherlands) Athens (Greece)

**The posed problem,**

Nowadays, there is a strong tendency to regulate the indoor environment of a building by using mechanical heating and ventilation systems. However, these
systems sometimes can cause poor indoor air quality due to the lack of natural ventilation and health problems in the occupants of the building. Some studies made clear that the mechanically controlled indoor environments that function completely separated from the outdoor environment can even be far from comfortable and healthy (Mahdavi & Kumar, 1996). Moreover, high amounts of energy are consumed in all buildings so as to improve the indoor environmental quality. More specifically, in the library buildings there are increasing demands for artificial lighting and mechanical ventilation and heating systems so as to retain a pleasant atmosphere for the students and a comfortable working environment for the employees of the building. In other words, in libraries large amounts of energy used by the extensive use of air-conditioning and lighting systems. Consequently, there is a need of using passive heating and cooling systems for climate regulation instead of active ones so as to reduce the energy loads of the libraries.

The problem of the excessive energy consumption of the building is presented also as there is absence of thermal storage components which can be used to store or use the waste energy flow and minimize the energy costs. As far as the building’s envelope is concerned, it is noticeable that most modern facades lack flexibility and multi-functionality so as to respond to climate change and temperature fluctuations in order to provide thermal comfort without any expenditure of conventional auxiliary energy. On the other hand, traditional buildings were built with considerations to climatic conditions for keeping the inside spaces cool in summer and warm in winter by adapting passive (façade) systems. This lack of climate responsiveness in the
Facades can create an unpleasant indoor environment with overheating or undercooling problems in the summer and winter respectively.

<table>
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<th>Research Questions and</th>
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<td>• What should be the design of an adaptive façade system based on PCM and how should it respond to different climate conditions so as to provide thermal and visual comfort in the indoor spaces of libraries with the use of minimal auxiliary energy?</td>
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<td>• How a passive heat storage strategy based on PCMs can be integrated in the building’s envelope as a strategy to reduce building energy consumption in temperate and Mediterranean climates?</td>
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<td>• Which are the ventilation principles of the façade system for each climate separately in order to achieve optimal indoor air quality in libraries?</td>
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<td>• Which are the façade design principles in order achieve optimal climate responsiveness to Mediterranean and temperate climates?</td>
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<td>• How can the geometry of the kinetic façade elements influence the heat absorbing and releasing ability (amount of heat and speed of absorption/release) of PCMs?</td>
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<td>• What should be the most efficient melting temperature for each climate (temperate and Mediterranean) and season separately so as to ensure maximum levels of thermal comfort in the indoor space of libraries?</td>
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<td>• What should be the optimal quantity of the PCM in each...</td>
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climate separately (temperate and Mediterranean) so as to absorb and release high levels of heat in the indoor space of libraries?
• What should be the kinetic façade performance in the summer/winter so as to achieve thermal comfort and minimise the cooling loads (for each climate separately)?
• What is the optimal façade configuration in terms of thermal comfort for the night and the day mode relatively in each season and climate?
• What is the ideal proportion of the kinetic and fixed parts so as to achieve thermal comfort and natural ventilation?

**design assignment in which these result.**

The main aim of the project is to design a modular adaptive façade system based on PCM opaque and translucent kinetic components. This facade is going to perform as a heat storage system that will have a responsive character to the changing climate conditions so as to ensure optimal thermal performance in the inner space of libraries.
The final product will be a façade prototype, composed of kinetic PCM based parts.

[This should be formulated in such a way that the graduation project can answer these questions. The definition of the problem has to be significant to a clearly defined area of research and design.]

**Process**

**Method description**

RESEARCH BY DESIGN

This research follows the “study by design” logic as it aims to develop knowledge about PCM applications in the field of the façade design. This will be achieved by
designing and studying the effects of a climate responsive façade design based on PCMs on the thermal comfort in libraries, changing the façade design itself or its context and studying the effects of the façade transformations. The procedure will have an experimental character as physical experiments and digital tools are used to investigate the thermal performance and the heat storage possibilities of an adaptive façade system based on PCM. The data collection techniques that are used are lab measurements and simulation models that will check the thermal performance of the façade system with a specific PCM applied undergoing climate changes, changes in each geometry or in its kinetic behaviour.

RESEARCH PLAN

1) INTRODUCTION_KNOWLEDGE BACKGROUND
Firstly, the literature research was based on the climate-responsive facades which use kinetic mechanisms and their main characteristics (flexibility, acclimation, learning). On a second level, the knowledge background was enriched by studies focusing on smart materials and more specifically PCMs, their characteristics and their applications in the building industry. Moreover, ways on how PCM materials can be implemented in passive heating storage systems were explored so as to form a general understanding on thermal energy storage with phase change materials (PCMs) in building applications.

2) INITIAL DESIGN CONCEPT
In a next step, an initial exploration in different façades and thermal principles is done by creating a series of conceptual sketches. The first designs are created in Rhinoceros 3d and Grasshopper software in order to manipulate parametrically the size and the geometry of the façade components.

The façade components are composed of the PCM containers and the PCM, the window frames and the glazing of the façade.

3) SIMULATIONS
a) MAT_LAB
To start with the simulations specific properties of the PCM used should be introduced in the model:
1) thickness of PCM (m). The thickness indicates the quantity of the PCM material inside the container.
2) density of PCM (kg/m3)
3) specific heat capacity (J/Kg*K)
4) heat conduction coefficient (W/m*K)
5) Latent heat (J/kg)
Moreover, the depth of cavity between the PCM containers and the window glazing should be taken into account (m).
Similarly to the PCM material the physical and the thermal properties of the glazing should be included in the simulation model.

In order to study the effect of the geometry of the PCM panels on the overall energy consumption (only heating) the following simulations are going to be performed. All the simulations will be carried out for a winter period ([1st of Oct – 30th of Apr]) taking into account climate data for Athens and Rotterdam relatively.

1) Room without PCM façade components just fully double glazed façade
2) Room with PCM façade components (first geometry) and double glazing
3) Room with PCM façade components (second geometry) and double glazing
4) Room with PCM façade components (optimized geometry) and double glazing.
The energy required for heating will be used to evaluate each scenario in terms of thermal performance.

b) DESIGN BUILDER

Further energy simulations will be done in Design Builder, doing a series of calculations:
1) variations in the opening sizes
2) a) PCM VS Fully glazed single skin façade
   b) PCM (optimized geometry) VS Fully Glazed double skin façade
3) COMSOL

With the use of Comsol the kinetic aspects of the façade system can be simulated.

4) PHYSICAL MEASUREMENTS

Lab tests will be done in the Building Physics laboratory at TU Delft so as to get to know the thermal conductivity of the PCM material used and the thermal behaviour of the façade modular system undergoing different climate conditions. In order to achieve these goals specific measurements should be done:
- Temperature of the air inside the climate chamber (assuming well-mixed air) - 2x thermocouple
- Temperature of the air just outside the climate chamber – 1x thermocouple
- Temperature of the surface on both sides of the sample – 2x thermocouple
- Heat flux on both sides of the sample – 2x heat flow sensor
- Use IR camera to inspect for differences in temperature along the surface (showing if the PCM has a regular way of melting/solidifying).

4) EVALUATION

Finally the results are going to be evaluated and compared with the simulation models and the calculations made out of them.

5) OPTIMIZATION

After evaluated the previous results coming out of the simulations and the physical tests, the design is going to be optimized so as to enhance its thermal performance.

6) DETAILING

The optimized design is going to be further developed in a more detailed scale and construction details are going to be designed.

7) CONSTRUCTION / FINAL PRODUCT

A small façade prototype is going to be constructed so as to visualize the kinetic behavior of the façade system.
Literature and general practical preference

Some references used for this research are shown below:

1. Rob Nave, educational Thermodynamics material (Introductory Part), Hyper Physics educational website hosted by Georgia State University
8. Harald Mehling, Luisa F. Cabeza, “Heat and cold storage with PCM: An Up to Date
Reflection

Relevance

- Societal
  The product aims to develop comfortable indoor climate conditions in the libraries that will have a positive impact on occupants’ health, psychology and efficiency. In reality, there is a strong connection between improved indoor environment and augmented performance of employees or students in the educational buildings. For this reason, the goal of this façade system is to create pleasant indoor atmosphere that will ensure thermal and visual comfort in the users' of the library building.

- Scientific
  The value of this research aims to investigate a new adaptive façade system that it is possible to provide new functions with an innovative operation method. The aim is to challenge the benefits that PCMs provide in the building industry and introduces a new innovative façade system that will provide passive heat storage through PCMs and will have a smart behavior in order to respond in different climates. This research intends to give as a solution for a new smart product in the scientific community and
the facade industry.

### Time Planning

**WEEKLY WORKING PLAN**

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<tr>
<th>MONTH</th>
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<th>NOVEMBER</th>
<th>DECEMBER</th>
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<td>LITERATURE REVIEW</td>
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- 1a. Design working principle/terrestrial properties
- 2a. Design components facade design/characteristics
- 3a. Purposes engaged in PCW
- 4a. GLASS X solutions
- 5a. PCW in building applications
- 6a. Photovoltaic conversion
- 7a. Photovoltaic conversion
- 8a. Photovoltaic conversion
- 9a. Study on DoubleCoat color methodology
- 10a. Experimental studies on PCW-based projects

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