Graduation Plan

Master of Science Architecture, Urbanism & Building Sciences

Graduation Plan: All tracks

Personal information	
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Studio		
Name / Theme	Building Technology Graduation Studio - Façade & Products - Urban Facades	
Main mentor	Alejandro Prieto Hoces	Architectural Facades & Products
Second mentor	Serdar Asut	Design Informatics
Argumentation of choice of the studio	The choice of the present topic lies on the fact that facades are the threshold between the built and urban environment and play a significant role in regulating the building's performance. Minor interventions on the facade level can have a strong impact on the environmental and urban one. Especially the UHI is of critical importance in the latest decades and Athens is one of the cities that experiences this phenomenon the most. It concerns a multifaceted problem and so it is a promising challenge to investigate the impact of smart low-tech and -energy facade technologies on mitigating the building's footprint on the UHI effect.	

Graduation project	
Title of the graduation project	Solar Morphing Kinetic Envelope: Integration of thermo-responsive Shape Memory Alloys in an autoreactive facade system to reduce the building's impact on the Urban Heat Island effect in the Mediterranean climate (case study: Athens, Greece)
Goal	
Location:	Athens, Greece
The posed problem,	The urban built environment is one of the main attractors of population shifts from rural to urban areas, creating extreme changes in land use that result in unintended environmental, economic, and social consequences. This growth leads to the development of the so-called Urban Heat Island (UHI) phenomenon, characterized by higher temperatures in the density of built areas than the ones of the rural surroundings and is directly and indirectly related to serious energy, environmental, health and economic problems [Santamouris, 2007]. This phenomenon is especially intense in the Mediterranean basin with a fast growth of energy consumption in the last years, due to the widespread of air conditioning systems and the increase of cooling demand. This situation is highly associated with the climate change of the last decades and a significant rise of Heat Waves (HW) [Salvati et al., 2017].

	Especially in Athens, Greece, UHI has been present already since the 1980s and many research studies have been focusing on the area to identify and evaluate the scale, causes and impact of the phenomenon and to propose certain mitigation strategies. Based on the outcomes of these studies, there has been an increase of the energy building demands, thermal risk and vulnerability of urban population and it has been reported that during the HWs, there is even an intensification of the average UHI magnitude by up to 3.5 °C. This is highly due to the widespread use of air conditioning in residential buildings resulting to a fast increase of electricity consumption over the last few decades. The heat that is dissipated from the buildings to the external environment increases the UHI phenomenon, and therefore, has a strong indirect impact. More specifically, in Athens an average increase of the cooling load of about 13% is estimated, with an annual global energy penalty for unit of city surface and degree of UHI intensity of 0.74 kWh m-2 K-1 [Santamouris et al., 2017]. Due to the complexity of the UHI phenomenon and the multifaceted factors that are dynamically intertwined, although certain mitigation strategies exist and have proven applications in urban environments, it concerns in general an environmental issue, which is hard to tackle and identify in a precise manner. However, what is evident is that there is a strong connection to the given climatic context, where it emerges every time. Based on research studies, most of them agree that there is a high indirect impact of the building's energy performance on the increase of the UHI in the cooling dominated areas, such as Athens, especially given the frequency of HWs. An improvement of the energy efficiency of the building sector may, therefore, drop down the ambient temperature and decrease the amplitude of the UHI [Santamouris et al., 2018]. In this direction, a certain level of climatic responsiveness and adaptiveness to extreme heat changes in an energy efficient way can arise as a promising strategy, in order to reduce the building's energy consumption in the present cause-effect relation. This also gives way to the development of responsive technologies, such as passive dynamic adaptive façade systems. Thanks to their adaptive mechanisms and the ability to implement smart technologies and autoreactive materials, they are favored due to the real-time responsiveness to the also dynamic and unpredictable environmental changes, acting as the threshold between building and exterior environment. The above-mentioned framework, composed by problem and promising mitigation strategy, is the direction that is followed in the current thesis and will be further explored and developed with a focus on the incorporation of smart and shape-changing materials.
research questions and	The main research question is the following: *"How can thermo-responsive Shape Memory Materials be integrated in an autoreactive facade system to reduce the building's impact on the Urban Heat Island effect in the Mediterranean climate, with a focus on the case study of Athens, Greece?"*

	To be able to address the main research question from different inter-linked perspectives, a few sub-questions are identified that answer various aspects which are encountered throughout the research process. These can be grouped in the following clusters, based on the process stage and focus sub-topic: **Theoretical Framework:** **Contextual Framework** (Problem analysis and Façade System Strategy): *- What is the effect of responsive dynamic facade systems in respect to climate adaptiveness and UHI?* **Material and Mechanism analysis:** *- How can thermo-responsive SMM integrated technologies have potentially an impact on the building's energy performance and contribute to UHI reduction in the Mediterranean climatic context?* *- How can the dynamic responsiveness parameters of the SMM be controlled and pre-determined to achieve the desired material dynamic effect in an adaptive facade system?* *- Which are the main principles and strategies of natural systems and how can they be relevant to the SMM behavioural ones and to responsive mechanisms in controlling the building's thermal behaviour in a climatic context?* **Design Integration:** *- How can thermo-responsive SMMs be integrated in a passive adaptive solar morphing envelope combining autoreactive and bio-inspired responsive mechanisms?* *- How can motion be achieved in an integrated facade system by using latent energy in an energy-effective and autoreactive way, with optimal use of sensors and actuators, where material, form, function, structure and motion are interdependent in a fit combination?* **Design Evaluation:** *- To what extent are SMM-based facade technologies feasible solutions and what are the challenges, restrictions and potentials for future facade applications?*
design assignment in which these result.	The thesis focuses the research on the material properties, behaviour and potentials of thermo-responsive SMMs to be implemented on adaptive façade applications due to their high level of direct

	responsivess and adaptation to real-time environmental changes and the ability to program their behaviour and, therefore, predict their dynamic performance and deformation. Of special attention are the inherent abilities of these materials, by applying the shape memory effect to control thermal transmission at the building envelope, increase the solar radiation reflectivity and reduce the thermal transfer. At the same time, some of the applied existing UHI mitigation strategies include reflective and articulated surfaces (either through the material's thermal capacity or through the roughness level of the envelope's surface) with a direct impact on the heat and solar radiation reflection, as well as the reduction of warm air-emissions from air-conditioned buildings and the reduction of the inner operational energy through means of (self-)shading as an indirect intervention. Within this frame, the thesis' research objective attempts a connection between the two and lies on a hypothesis having both scientific and societal relevance. The hypothesis developed is *"whether, how and to what extent the implementation of SMMs on an integrated passive adaptive solar morphing façade system can contribute to the reduction of the UHI effect in an energy-efficient and autoreactive way".* The goal is to propose a "living" envelope, a low-energy and low-tech façade system capable of predictably changing in shape in response to heat and/or applied air pressure through the ingrained properties of the material it is made of, without the need for external energy or complex mechanical parts and by optimizing the use and number of actuators required to achieve the desired result. In this way, by applying the shape memory effect of the material, a control of the thermal transmission of the building envelope can be achieved and a reduction of the thermal transfer through an optimal dynamic performance of the facade skin.

Process

Method description

Theoretical framework

At the core of the research, a **theoretical framework** has been formulated, to explore the main aspects of the problem statement and research question.

This can be divided into two parts: First, the **contextual framework** with a focus on the addressing problem, the UHI in its climatic context, impact and strategies, and on the dynamic adaptive facades as the chosen mitigation strategy implementation. And secondly, the **material and mechanism analysis**, with a focus on the inherent material characteristics and dynamic behaviour, both in a material and a component level to form a better understanding of the responsive mechanisms.

A contextual research has been conducted to provide a background information concerning the nature of the UHI in the studied area. A research and analysis based on literature reviews from journals and statistical data from related agencies have been realized, to collect the relevant information, which will be used as a background to elaborate on the design decisions and strategies for façade implementation.

These studies provide information about the causes, impact and existing mitigation strategies of the UHI effect, with a direct connection to the effect of the global climate change and the synergy to the increasing Heat Wave phenomena of the recent years. In parallel, the literature study aims to collect data about the relevance of the UHI and HW with the building's energy performance and inner comfort as an indirect impact with increasing influence over the years. For the purposes of the current thesis, the design strategy is also focused on the impact of a passive adaptive façade system to address the UHI. A literature study is conducted in this respect as well, to provide a classification and an overview of the available technologies and dynamic responses and types, both in terms of materiality and systems and to study the several operation systems and purposes of each type. This is used as a guideline for the initial design decisions, to choose the most apt system based on the research's objectives and goals.

Regarding the material and mechanism research, as a main objective is to provide a passive adaptive façade system that can realize the change in geometric configuration through the ingrained properties of the material it is made of, without the need for external energy or complex mechanical parts. A large part of the research is, therefore, realized in the existing smart and multifunctional materials, with a focus on the thermo-responsive ones, due to the nature of the environmental issue and climatic context and the actuation mechanisms that would trigger the dynamic behaviour. In this direction, scientific papers, research studies and experimental lab tests have been consulted to understand the state-of-the-art and material performance. The available materials are then compared based on their intrinsic features, properties and dynamic performance, as well as availability and implementation potentials, based on existing applications, material experiments and case studies, both realized in the building industry as well as in other fields, such as biomedicine and aerospace. A further subdivision is made between the different material families, as in SMAs, SMPs and SMHs, and an evaluation and comparison are realized, based on the above research and the feedback from experts in the field, which are being consulted in parallel, to be able to opt for the most promising, suitable and feasible one to be implemented in an adaptive façade system.

As for the mechanism, the aim of the literature study is focused on dynamic mechanisms that are based on mostly hinge-less movements, minimizing the use of required actuators, with minimum external energy and a real-time climatic responsiveness. Because of these features, there is a relevance between the SMMs intrinsic characteristics and the principles found in the strategies of natural systems to adapt to environmental changes. This leads to the exploration of bio-inspired mechanisms, both in realized biomimetic applications and by directly exploring natural organisms and disassembling the principles behind their response mechanisms for thermal control and heat regulation to apply the principles in an integrated façade system.

Methodology workflow & evaluation

The design methodology can be divided into three distinct stages, which are realized either in a linear chronological sequence or in parallel. The first phase consists of the literature study, where the background information is accumulated to be applied in the design integration. This includes also studies on the material properties and dynamic behaviour to enable a better understanding of its inherent performance. After setting a theoretical base, the following stage involves the design phase, which will be informed in parallel by research and iterative performance evaluation studies in a feedback-loop process, where material and geometrical explorations will be conducted.

In the performance analysis and evaluation phase, parametric simulations and design optimizations will be realized to fine-tune the selected shading prototype design. This will be assisted by the feedback from the performance validation, to provide parametrical design variations in conjunction with daylight and solar radiation simulations throughout the design process. These simulations receive weather and solar radiation data and attempt a connection to the UHI and its impact on the microclimate and surrounding environment. Besides that, a thermal behaviour modelling under targeted conditions will be realized, as well as energy, radiation and daylight simulations in different operation periods of the SMM-based shading device.

The above iterative process will be based on an interoperability toolchain workflow, with the aim for most of the digital tools to be integrated in the same parametric software environment (Grasshopper). This approach will allow for a better data interchange and modelling compatibility between the various energy simulation engines, a more direct comparison of the different simulations and results, while optimizing the overall workflow in a systematic and comprehensive way.

Based on the above workflow, the evaluation methodology consists of assessing the SMM adaptive facade system's performance, based on the mentioned performed energy and environmental simulations. The objective is to estimate the impact of the system on the urban microclimate from the reflection of the solar radiation, as well as the effect on the reduction of the building's cooling demands. Besides that, a feasibility assessment will be conducted, by evaluating these smart technologies based on certain criteria, involving cost effectiveness, technical feasibility and physical integration, among others, in order to reflect on their potentials for facade applications, also in comparison to similar technologies. These evaluations will provide with both a quantitative and a qualitative overview of the challenges, restrictions and potentials of future SMM-based facade developments, as well as a feedback to the proposed hypothesis of the thesis on the level of contribution, feasibility and consideration of this approach as a UHI mitigation strategy.

Literature and general practical preference

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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 graduation studio combines the Facade Design and Design Informatics fields, which are inherent part of the Building Technology Track. The focus of the project lies on the implementation of smart material technologies in the architectural facades and the evaluation of the design's performance through the development of a computational workflow and toolset. There is, therefore, a strong relation between the graduation topic, the Master Track and Study Programme in general. The building envelope is the threshold between the built environment and the urban conditions and, as such, the current research aims to reduce the impact of the building on the Urban Heat Island effect and to exploit innovative technologies and materials. The goal is to mitigate the environmental issue by means of passive thermal self-regulation mechanisms of a kinetic shape-changing facade. There is, therefore, a connection between building technology practices that are applied to enhance the building's energy performance and, consequently, improve the conditions of the built environment.

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

Scientific relevance

The objective of the thesis is to additionally contribute with some knowledge as part of the framework commissioned to the Adaptive Facade Network set by the EU COST (European Cooperation in Science and Technology) in 2014. The main aim of this COST Action is to harmonize, share and disseminate technological knowledge on adaptive facades at a European level. By harnessing this knowledge, it will contribute to the generation of new ideas and concepts at a fundamental and product/system development level. Especially in the case of smart and autoreactive materials and mechanisms, the current lack of knowledge in the implementation of such technologies in building envelopes opens the way to investigate such potentials and propose innovative solutions and ideas. By exploring their applicability in the field of architecture, these could potentially offer some possibilities to be broader used in the built environment and to assess the challenges and restrictions they could entail.

Societal relevance

From a social and environmental perspective, there is a need to achieve a high level of user well-being and indoor environmental quality, to reduce building energy consumption and neutralize building-related environmental impacts. The integration of passive and active design technologies in the building envelope, as studied here, can have high potentials to improve indoor comfort conditions and reduce the environmental impact during the life cycles of buildings. In this respect, the dynamic adaptive facades have a significant effect on achieving the performance requirements, by adapting to changing boundary conditions in the form of short-term weather fluctuations, diurnal cycles, or seasonal patterns. Another important aspect concerns the potential reduction of energy demand in buildings, heat regulation and CO_2 emissions with the conversion of building envelopes from passive to active regulators of energy balance, which is promoted as part of the Climate and Energy Action Plans (Directive 2010/31/EU). In order to work effectively as a surface-regulator, the building skin must adopt different physical features at different times of the day, requiring different levels of environmental intelligence.

With the UHI phenomenon at its rise and its foreseen increasing intensity in the Mediterranean region over the next years, the current thesis aims to address a challenge with scientific and societal relevance and, by so doing, to achieve sustainability targets in the built environment.