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Holistic Assessment of Active Multi Functional Building Envelopes

Research Proposal for the Doctorate of Science Program
Department of Architecture (D-ARCH)
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Abstract

Buildings play a large role in the global energy consumption portfolio, and the building envelope becomes an interesting area to address this issue as it is the interface between the interior and exterior environments. The application of multi functional building envelopes is being put forward as a method of greatly reducing the building loads, while still maintaining user comfort [1]. A multi functional building envelope is defined here as an active envelope that can control solar thermal gains, natural lighting, and generate electricity on site. Preliminary studies already shows that a retrofit of such a facade on a south facing office in Switzerland can offset the entire energy expenses of the office space behind the facade [2]. This thesis will further investigate the energy savings potential of a multi functional envelope, and compare the results for varying levels of envelope complexity, location, building typology and the interaction with the building system itself. The thesis will also utilise the Adaptive Solar Facade (ASF) built in June 2015 as a case study and run experimental investigations to validate the numerical results, and see how such a system behaves in a living lab experiment. This allows us to not only compare the energy savings through direct measurement, but also analyse the user acceptance. To complete the holistic picture, the study will also analyse the technology from a life cycle perspective, to test whether the embodied and operational energy expenditures offset the energy savings. The primary outcome is to enable architects and engineers to determine if a multi functional facade is appropriate for their building, and if so what type of building system would match their envelope of choice.

Contents

1. Introduction

1.1. **Motivation.**

Buildings are at the heart of society, and have a large impact on global health, economics and the environment. Europeans alone spend on average 90% of their time in buildings [3] whether it be for work, rest or the multitude of activities that exists in modern society.

In 2010 buildings accounted for 32% of global final energy consumption and 19% of energy related greenhouse gas emissions [4]. Furthermore, in developing countries, buildings embody the largest unmet need for basic energy services, thus resulting in a potential three fold increase in energy consumption by 2050. Nevertheless the building sector has a 50-90% emission reduction potential, and widespread implementation could see energy use in buildings stabalise or even fall by 2050.

The building envelope plays a key role in building energy consumption as it is the interface between the interior and exterior environments [5]. Most conventional building envelopes focus on providing shelter and protection with very little sensitivity to its surroundings. The issue here is that heating, ventilation, cooling and artificial lighting is generated to satisfy comfort requirements, at the expense of energy consumption [1]. The shift towards multi functional dynamic envelopes offers the ability to utilise the variable meteorological conditions that change throughout the day and year. This enables a shift in focus from manufactured indoor environments which are required when using static envelopes, to mediated environments through multi functional envelopes [6].

Multi functional building envelopes can influence the physics between the internal and external environments through thermal, optical and electrical properties. The control of direct radiation can enable reductions of cooling loads in summer, and heating loads in winter. The control of diffuse light and exterior views can reduce the artificial lighting loads and increase user comfort. And recently, with the rise in efficiency of this film photovoltaic technology [7], the facade can be composed of modules that generate electricity for the building itself, or be coupled with thin film solar thermal units. Preliminary results show that a retrofit of a multi functional envelope, when coupled to an efficient building system, can convert the office space behind the envelope into a zero-energy space [2].

1.2. **Problem Statement.**

We know that a multi functional envelope is beneficial in reducing building energy gains [2]. However this simplified simulation is just an example of one type of multi-functional envelope built on one type of building system. The effect of the building typology, location, orientation, and adaptability of the facade plays a large role in the overall energy savings. In Dubai for example, where only cooling is required with little seasonal variation, a static louver system positioned at the optimum angle reduces energy consumption by 31% while a dynamic system reduces energy consumption by 34% [8]. So while an active multi functional facade can have a large impact in an office in Switzerland [2], it may not be worth the added cost in Dubai.

It is also important that the simulations are validated with experimental investigations. A first prototype of a multi functional envelope, known as the Adaptive Solar Facade (ASF) was constructed in June this year. The optimal configurations of this facade however, are not yet known, and the user behaviour could play an important role which would not be picked up in a simulation. As user comfort is a priority, it is also important to study their comfort and acceptance.

In the field of this research it is also important to understand the lifecycle effects of carbon emissions and grey energy from both embodied and operational sources. This becomes increasingly complex due to the trade secrets of photovoltaic manufacturers and the number of components involved in the ASF.

1.3. **Objectives of Research.**

Based on the problem statement, the objectives are to

- Determine the energy saving potential of different variations of a multi functional envelopes
- Cost optimize the multi functional envelopes for increasing levels of design complexity
- Determine the effects of the building typology, systems, orientation and location on the energy savings of a multi functional envelope
- Find optimum starting configurations for the constructed adaptive solar facade (ASF) and use this facade to experimentally compare the ASF to an external fabric shading system
- Study user behaviour and acceptance
- Study the life cycle analysis of multi functional envelopes in terms of embodied and operational energy/CO2, and eco-toxicity.

1.4. **Methodological Approach.**

This PhD will be driven through peer review publications and can be divided into the following four steps

Step 1: Literature Review.

The process will begin with a literature review of multi-functional facades and photovoltaic technologies. This will result in an understanding of existing multi functional systems and the roll they play in building integrated photovoltaic installations.

Step 2: Numerical simulation of multi functional facades.

My initial simulations of multi-functional facades demonstrates a reduction of energy consumption by 25% [2]. This simulation was a simplified problem and further numerical analysis is required. This simulation will also look at how different levels of adaptability effects the overall building energy performance in order to cost-optimise the best solution, Figure 1.

Step 3: Analysis of the relationship between a multi functional facade and the building system.

From the initial simulations, the next step is to start analysing a multi functional facade in relation to the building systems. Variations in the type of heating, cooling

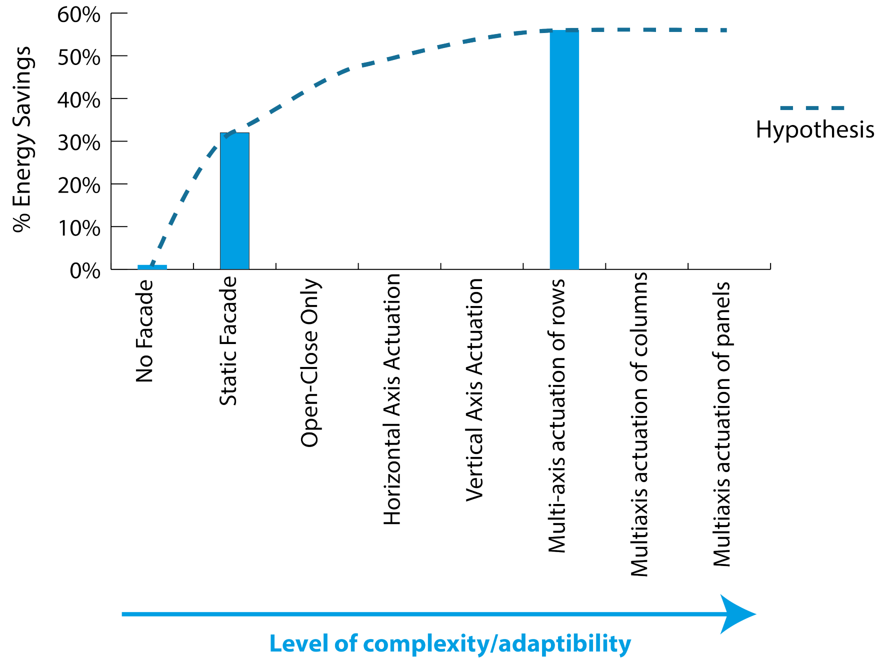


FIGURE 1. Hypothesis of how the energy savings will increase with increasing level of adaptability for Step 2. Current data is based off my first conference paper [2]

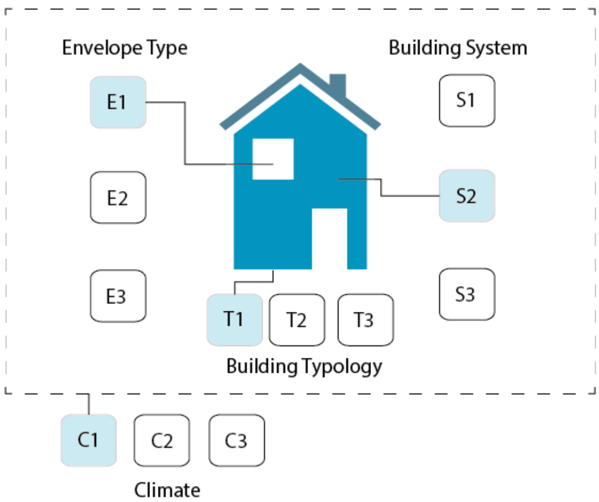


FIGURE 2. An conceptual schematic of the simulations in Step 3. The letters in the curved rectangle show the different variables. The goal here is to find the best relationship between the envelope (E) and building system (S), for different building typologies (T) in different climates (C)

and lighting system will play an important role in the over all energy saving, and cost effectiveness. The orientation of the building, location and typology will also be analysed in this step

Step 4: Experimental investigations.

Numerical simulations require experimental validation. I was involved in the construction of an Adaptive Solar Facade at the House of Natural Resources and embedded thermal sensors into the building. We can use the ASF as a case study of multi functional envelopes to validate our numerical calculations, and compare the performance of the ASF to a control room next door which has a fabric external shading system. This investigation will also briefly analyse the user behavior and their acceptance of a multi functional envelope. This will be done through set surveys.

Step 5: Life Cycle Analysis.

Alongside the simulations in Step 2, I will be running life cycle assessments to calculate the embodied and operational emissions of both grey energy and CO_2. The first round of assessments has been done and are planned to be published in Solar Energy Materials and Solar Cells Special Issue due in December 2015.

1.5. Research Questions.

Five key questions are presented to test if the objectives of this research have been met:

(1) What are the energy saving advantages of multi functional envelopes?
(2) What is the optimum level of design complexity that a multi functional envelope should have?
(3) How sensitive is the energy savings potential of a multi functional envelope in relation to the building system, orientation, typology and location?
(4) How does the Adaptive Solar Facade, an example of a multi functional envelope behave in a living lab test study in relation to a manually controlled external fabric shading system?
(5) What is the overall life cycle emissions of multi functional envelopes in terms of CO_2, grey energy, and eco-toxicity?

1.6. Novelty of proposed research.

The concept of multi-functional envelopes which combines thermal, optical and electrical properties is in itself a novel piece of technology. Although there is a lot of research which optimises active shading systems [8] [9] [10], there is no such research to optimise a complex system which optimises heating, cooling, lighting and photovoltaic production. Furthermore there is no existing research which then takes such a multi functional system and analyses it on a holistic level, taking into account the building systems, user comfort and life cycle analysis.

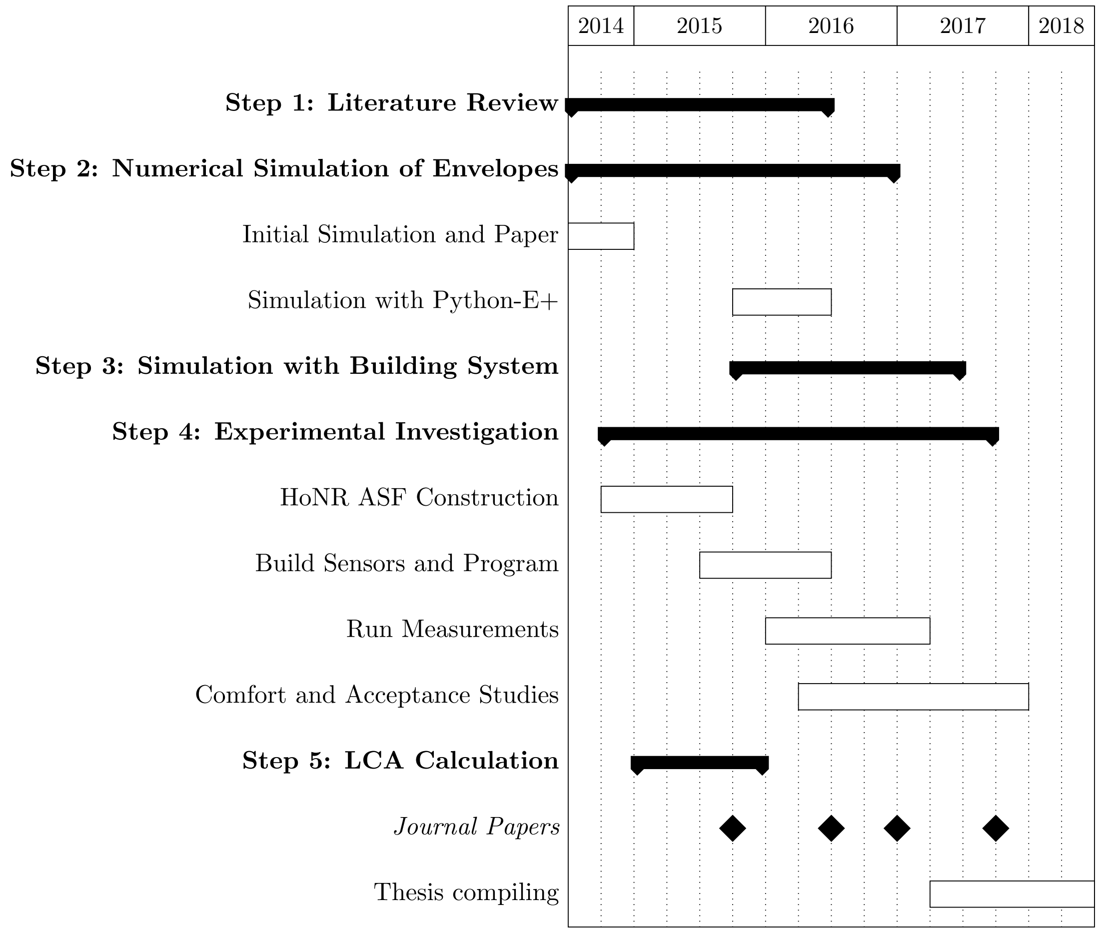
1.7. Audience.

This thesis will target engineers and architects that can use the results to make optimum design choices for the building that they are designing. They will be able to use the results to see if a multi functional envelope is appropriate for their building type, and if so, what building systems would work for their envelope of choice. This has the further possibility of being compiled into a handbook.

2. Background / State of the Art

Compared to conventional static envelopes, active multi functional have the potential for higher levels of sustainability, as well as the improvement of indoor environmental quality. The functionality of an envelope can be divided into four building physics catergories: Air Flow, Electrical, Optical and Thermal. Dynamic external shading systems that control thermal and optical properties are the most commonly found examples [1], due to their large energy saving potentials [11]. These shading systems exist as simple open close mechanisms, or those that rotate in varying degrees of freedom [12]. Applications of dynamic external shading systems for energy savings include the Al Bahar towers [13], vetro ventilato [11], and the sliding house [14]. Active shading systems themselves are well studied field with a lot of literature explaining their advantages over static systems [9] [10], and their potential drawbacks in terms of costs [8].

3. Time frame and current progress



4. Expected Results

The expected results for the afore mentioned workpackages are as follows:

- Step 1: Produces a body of literature analysing the state of the art in multi functional building skins and BIPV
- Step 2: Understand the energy savings potential of a multi functional facade, and cost optimize the level of complexity required
- Step 3: Understand how a multi functional facade relates to the building system, its location, and orientation
- Step 4: Experimental comparison of the Adaptive Solar Facade to a fabric shading system
- Step 5: Life cycle analysis of the adaptive solar facade
- Comfort and Acceptance Studies: An understanding of how the user interacts with a multi functional envelope.

5. Impact

The research will enhance knowledge in climate adaptive building skins and use the ASF as a case study to analyse energy saving potentials of dynamic multi-functional facades. The results will enable architects and engineers to determine whether a multi functional envelope is appropriate for their building type, and if so, what building system would work for their envelope of choice. The results will also validate the case for multi functional building envelopes, not just in terms of energy savings, but life cycle emissions and user acceptance.

6. Preliminary Work and Publications

The following activities have already been completed:

- Design and construction of two Adaptive Solar Facades
- A conference paper with initial numerical simulation results accepted by the Advanced Building Skins Conference [2]
- Installment of floor sensors at the HoNR rooms
- Life Cycle Analysis of the ASF

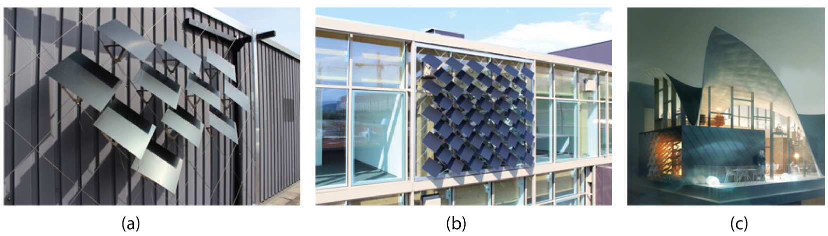


Figure 3. Constructions of the Adaptive Solar Facade (ASF): (a) ASF constructed at the HPZ building, (b) ASF constructed at the House of Natural Resources, (c) ASF to be constructed at the HiLO building at NEST

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