REFLECTION

Graduation Process

The topic of my graduation thesis first started as a response to the question whether high-rise buildings can meet future energy regulations, given the considerable effect that building height has over the overall energy consumption per m^2. It will be quite challenging for Architects and Engineers to design high-rises that comply to future energy efficiency targets, which is why with this study I intend to provide some facade design assessment guidelines that will help designers to define the most optimal facade design in terms of energy, daylight and thermal comfort to achieve a nearly zero-energy residential high-rise building.

This research project focuses on Climate Design and Facade Design, but a high degree of Computational Design was also involved for the assessment process. In terms of Climate Design, the focus lays on sustainability since the aim of the proposed facade system is to improve the energy efficiency of residential high-rises while providing enough daylight and thermal comfort for the occupants. The Facade Design was developed hand in hand with the Climate design and was derived from the performance results of different facade design strategies.

As any other research project, I started my study by undergoing some literature research which helped me define the research question and objectives. After the literature research, I was able to filter out the most influential facade design parameters which served as variables in the optimization process. The main part of my thesis was setting up the right workflow in Grasshopper which includes all the variables, and assesses all the different combinations in terms of energy performance and indoor comfort conditions.

Residential buildings involve a substantial amount of detail when it comes to the energy performance assessment. Each apartment consists of multiple rooms with different functions, which need to be differentiated in simulation programs, as they require different ventilation rates and present different internal heat loads. This already adds a lot o complexity to the workflow.

Calculating the heating, cooling, lighting and mechanical ventilation loads for all these rooms, while considering all the different facade variables prolongs the simulation time, which could be a limitation in practice. I believe that the results are much more accurate due to the substantial amount of information involved. However, it is important to mention that it took my computer 5 days to run a simulation with 480 parameter combinations for one floor with the following variables: WWR (4), glazing type (5), shading system (4), natural ventilation strategy (3), thermal insulation (2) and energy generating systems (2).

The proposed facade redesign was chosen because it has a balancing effect on fulfilling both thermal comfort and a high energy performance. However, after the simulation, the obtained results were not yet within the preset boundaries and the energy produced on the facade walls alone was insufficient to reach BENG 2* (including energy production) and BENG 3. After integrating additional energy production elements on the balconies, I was able to reach BENG 2 for 25m, with 50 kWh/m^2 primary energy need and almost reach the target limit at 130m, with 53 kWh/m^2. However, I was still not able to achieve the BENG 3 requirement of 40% with energy generating systems integrated on the facade alone. The energy demand was minimized through passive design strategies, but the energy production was still not high enough to meet the minimum share of renewable energy. In order to comply with the regulations, also other renewable energy sources need to be employed.

As an overall conclusion about the future design of high-rise buildings, it is questionable whether it is worthwhile to run such a detailed simulation in order to make some preliminary design decisions. The more information is added to the workflow, the longer the simulation time. On the other hand, the overall results will be more accurate and more realistic. This study provides an overview of the amount of information which is involved in simulating a residential floor plan, when taking into consideration all the different room functions, internal loads and ventilation rates as specified by the *Bouwbesluit*. One of the goals of this study was to evaluate the building performance under conditions which are as close to reality as possible.

Societal Impact

This study shows the importance of a multi-objective optimization process to filter out the most effective passive design strategies towards designing nearly zero-energy high-rises. With this research, I was able to demonstrate that a 30 kWh/m^2 energy reduction is possible with an optimized facade design alone. However, because of the long simulation time required to assess the performance of residential high-rises, the simulation time might be a limitation in practice. Therefore, this study is intended to offer preliminary facade design guidelines for Architects and Engineers towards designing nearly-zero energy residential high-rises.

Although this study is based on a specific case, the analyzed design parameters are believed to have similar benefits for other types of high-rises, located in a different urban context. In order to verify this, the entire workflow of the optimization process is described in detail, with the aim to encourage designers to consider similar criteria and develop comparative assessments for high-rise buildings, also in different climates and urban conditions.

To date, high-rises are assessed in practice usually by simulating just one middle floor, where average values are considered for climatic influential factors. However, making design decisions based on just one floor could lead to an unrealistic overall performance and unpleasant indoor conditions at higher levels. For the analyzed case study, only a slight increase of 7 kWh/m^2 was recorded at 130m compared to the performance at 25m. However, for high-rises reaching 600m this difference can be more significant, 39 kWh/m^2, with heating loads increasing exponentially and cooling loads decreasing after a certain height limit. Subsequently, it can be concluded the facade design should be chosen based on the last floor for low high-rises and based on the middle and the highest level for super-tall high-rises, taking into consideration also the effect of the surrounding context on the building. The analyzed case is located in a low urban context and therefore, a variation in facade design with height would not lead to a better performance, considering that the facade design combinations which perform best at 600m are the same as the ones which perform best at 25m. On the other hand, a variation in facade with orientation is more important.

Looking at the output values of the simulation it became clear that reaching future energy targets is very difficult for residential high-rises. Another important feature which must be considered when designing the facade of future nearly zero-energy high-rise buildings, are facade integrated energy generating systems.

Due to the changing outdoor climate conditions, the energy consumption per m^2 tends to increase with height - the higher a high-rise building is, the more difficult it is to comply with energy efficiency targets. In order to compensate for the higher energy demand with height, it is essential to make use of renewable energy produced on plot. As demonstrated in this research paper, the facade of high-rise buildings provides a large area available for energy generating add-ons to be integrated. If the building is located in a low urban context, the annual energy produced can compensate for the energy demand substantially. Nevertheless, it is still questionable, whether it is a sustainable and visually appealing solution to fill the facades for example, with PV panels, if we consider the environmental cost which is involved during the manufacturing process of PV panels and the compromizes in terms of architectural aesthetics.

All things considered, we can conclude that the future design of high-rises will not be driven by architectural design any more, but by performance optimization. Architects and Engineers will be complied to design buildings in accordance to strict energy regulations, which might involve making certain design compromises, necessary to improve the performance of the building in order to mitigate the harmful impact of buildings on the environment.