THERMAL MORPHOLOGY

GRADUATION REFLECTION

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This paper reflects upon the Sustainable Design Graduation studio of the Building Technology track at the faculty of architecture in Delft. An analysis regarding the research topic within the graduation theme will be provided, followed by an evaluation on the graduation process. Lastly, the research’s societal impact and relevance will be discussed.

GRADUATION THEME

It is known that geometry has an impact on thermal performance, however information regarding alternatives for material distribution was found to be limited. This research therefore focused on geometry and its effects on thermal storage in the context of architecture. It combined two fields within the Building Technology track (Climate Design and Design Informatics) to initiate a process of geometry generation and exploration to promote passive climate design whilst strongly being enforced by a computational work flow. More specifically, it was aimed at the geometrical optimization of translucent Phase Change Materials (PCM) in the context of a trombe wall to improve the thermal performance of an open office room.

Within the ‘Sustainable Design Graduation Studio’, the topic of sustainability is evident in this research. This research topic presents a case of function and form exploration which could benefit the three goals of sustainability; the people, the planet and the profit. The most obvious connection to Sustainable Design is through the planet. One of the international sustainable development targets is to ensure sustainable energy use and eliminate the reliance on finite fossil fuels. This research promotes the reduction of energy use in building environments by utilizing available materials as energy storage and taking advantage of the abundant solar energy. In this research, it was found that altering the geometry of a thermal storage wall to improve the thermal performance can have a positive impact on the room air temperature. This can lead to a reduction in energy required to condition the space, which would have a significant effect on a larger scale if more or larger spaces are considered.

The people are ultimately the main drivers to arrive at sustainable objectives and their needs should be addressed. Through enhancing the concept of a trombe wall, the intent of this research was to improve the indoor conditions for occupants by providing a passive climate design solution with heightened thermal comfort. It also expected to change the common perception of thermal mass by transforming it into a customizable, desirable and lightweight solution.

Rather than increasing the thermal storage volume to lower the energy consumption, this investigation highlights another alternative. It deals with optimizing the material distribution, and thereby controlling heat transfer solely by geometry, to achieve material use reduction whilst lowering the energy demand. A reduction in material and the integration of PCM entails a lightweight element which is ideal for a retrofit solution enabling its integration into the built environment. It therefore promotes an accessible and potentially profitable passive climate design product. Currently PCMs are considered to be costly, however the recent surge in research and applications indicates a market growth for PCMs. Some PCMs are derived from non-renewable resources such as paraffin wax, however bio-based PCMs are also currently available.
GRADUATION PROCESS

The first part of the graduation process was aimed at understanding the effect of geometry on thermal performance in the context of thermal energy storage in existing research. This research was found to be scarce, especially within the field of thermal mass and the material used. Mechanical engineering sources were required to be consulted due to this research’s focus on heat transfer. This phase also focused on research regarding PCM which has soared in the last decade and the amount of information regarding the material’s behaviour was abundant. An insight into the physics behind the trombe wall and thermal energy storage was also necessary. From existing research projects, it was possible to determine potential designs strategies which can offer beneficial outcomes that can be used as concepts. This greatly facilitated the conceptual design phase.

The information collected was used to determine the parameters that the intended wall design was required to address. The parameters were based on the two climates, the office typology and the material. These parameters provided boundaries to the research and provided a realistic context. This phase established a number of hypotheses which guided the design of the geometries. This task required a further understanding of heat transfer and a detailed observation of the heat flows within the room. Due to the lack of available research regarding geometry effects in the context of buildings, the proposed designs were speculative, indicating that the digital design phase required should also be of an exploratory nature.

In the Digital Design Phase, the computational methodology to collect the various required results was set-up and elaborated. Many alterations were made to the methodology throughout the research process, particularly after getting familiar with the software (COMSOL Multiphysics) which was used to obtain the results. This presented the greatest challenge. Firstly, using the software, establishing the virtual model and setting up the boundaries required more time than I had envisaged, particularly since I had only previously worked with whole-building performance simulation software and COMSOL is a finite element analysis software. Boundaries previously set, such as the heating and cooling thermostats, were altered to constant night-cooling to be able to identify patterns in air temperature between one simulation and another. Even though the software has many positive attributes as it is highly graphical and accepts all forms of geometry, it also comes with limitations.

One of the limitations which changed the original methodology was the computation time required for simulations, particularly where airflow is concerned. Due to the fact that airflow simulations are very computationally expensive, the simulations were limited to only 2D geometry. The initial and ideal proposal was to morph a flat trombe wall in several steps, run a full heat transfer and airflow simulation for each step and to observe the effect on the air temperature and the air flow. The methodology had to be simplified to accommodate these limitations whilst still acquire the desired results to answer the main research question within the time allocated for this research project. This was done by splitting up the methodology into a number of smaller and more computationally attainable studies, at different wall scales. Simulations neglecting airflow (only considering heat transfer) were used to collect the main quantitative data, whilst shorter airflow simulations were used for smaller scales.
RESEARCH + DESIGN

To achieve the research aim of this graduation project, a continuous loop of research and design was set-up. The design strategies were based on literature research and hypotheses developed in the conceptual phase (research informing design). These strategies were then tested to determine their impact on thermal performance (design informing research). In this phase, new ideas were formed whilst old ones were discarded based on the feedback from the simulations. Lastly, the results from the simulations were transformed into guidelines for the design of the trombe wall aimed at enhanced thermal performance for the two climates considered in this study (research informing design). Even though considering two climates doubled the simulation time required, it initiated a comparison study between two different trombe walls thereby establishing further knowledge into the cause-effect relationship between geometry and heat transfer.

SOCIAL IMPACT

The use of thermal mass is often regarded as monolithic, heavy and plain. Although it has a great potential to balance the air temperatures, its use has declined by time in favour of more lightweight buildings and a different aesthetic. In this context, this research encourages the use of thermal storage in architecture through the use of a material which is more lightweight than the conventional thermal mass materials. Therefore, this research challenges the existing concept of thermal mass, whilst still addressing the functional requirements of a trombe wall situated in an office context. It also provides insights into geometrical alternatives for thermal mass, thus providing a sense of freedom for the designer, facilitating its integration into contemporary buildings. The digital design phase has taken advantage of the recent advancement in simulation and digital manufacturing to manipulate materials into performance-based designs. Furthermore, this research complements or links with the current ongoing TU Delft Double Face project, where an innovative adaptive trombe wall along with several alternatives have been designed.

The same approach of material redistribution can be applied to trombe walls in typologies other than offices such as atria, residential and commercial applications which can all benefit from an increase in heat transmission. Experimentation with form and material distribution enhancement is not only applicable to trombe walls, but can also be applicable to any architectural thermal storage component. The same approach can be applied to external walls with PCM, PCM panels used as external solar shading as well as other thermal storage materials. Nonetheless, the study is still not directly applicable in practice because the concept is still in exploratory stages. Further elaboration needs to be made together with physical testing to strengthen the gap between a passive climate design concept to a passive climate design product.
C O N C L U S I O N

Even though it was not possible to carry out the envisaged ideal methodology due to the dependency of this study on computational capacity, ideal geometries were still highlighted and similar trends were recognized. I believe that it would have also been beneficial to focus the study on one module to avoid complications arising from the context of the study, which included several continuously changing variables. This would have helped me analyse the heat transfer principles more closely. However, by situating the study within a real-life context of an office I was able to recognize the effects that changes at a small scale have on the overall air temperature. Nonetheless, the innovation in this study has been achieved through different geometries for material use and through the reintegration of thermal mass buildings.