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DOI
10.7480/spool.2018.2.2090

Publication date
2018

Document Version
Final published version

Published in
Spool. Journal of Architecture and the Built Environment

Citation (APA)
Tenpierik, M., Turrin, M., Wattez, Y., Cosmatu, T., & Tsafou, S. (2018). Double Face 2.0: A lightweight translucent adaptable Trombe wall. *Spool. Journal of Architecture and the Built Environment*, *5*(2). https://doi.org/10.7480/spool.2018.2.2090

Spool

Open access journal for design in architecture and the built environment

Vol 5 No 2: Expo #1
BK Booths at Time Space Existence during 2018 Venice Architecture Biennale

https://journals.open.tudelft.nl/index.php/spool/article/view/2090

Double Face 2.0: A lightweight translucent adaptable Trombe wall

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Abstract

Double Face 2.0 is a novel solar wall, joining a strong design identity and high technical performances. In response to the need for energy saving, new high-performance building elements are shape-optimised for passive climate design and to increase user engagement. Given a design concept, computational approaches help to optimise and to customise high-performance building elements for any environment. Double Face 2.0 has been developed by research through design involving designing, 3D modelling, robotic FDM printing, prototyping, experimenting, simulating, and simulation-based optimising. An adjustable, lightweight, translucent Trombe wall has been developed, using an insulator (aerogel) and heat storage (phase change material) encapsulated in optimised and customizable shapes. In winter, it captures, stores, and re-radiates heat from the sun (heating); in summer, it captures internal heat (cooling).

Project video. https://vimeo.com/277038530

Technical requirements are sometimes seen as factors that limit creativity. However, they can also become drivers that help shape a design and become part of its identity. During the Double Face 2.0 project thermal, daylight and manufacturing performance aspects were such design drivers in the development of an innovative lightweight translucent Trombe wall (solar wall). The proposed wall overcomes the limitations of traditional Trombe walls, which are usually massive and obstructive. It uses new materials like phase change material (PCM) for heat storage and aerogel for thermal insulation, has an optimised shape for best thermal performance, is manufactured using robotic 3D (FDM) printing, allows daylight to pass through and can be adapted according to the varying conditions at hand. By optimising and shaping geometry, the final design has good engineering performance and at the same time offers new creative opportunities for the designers.

Introduction

As Barragan pointed out, "if there are many equally valid technical solutions to a problem the one which offers the user a message of beauty and emotion, that one is architecture" (Ziff, 2000). Technical requirements may be perceived as constraints limiting creativity or, more interestingly, as inspiring principles triggering design concepts and being integral part of the design identity. Given the urgency for reducing building related energy use, taking aesthetic advantage from energy-related technical aspects is crucial and an interesting alternative to an only engineering the technical aspects as detached from the main architectural concept and design identity. Building products that express aspects related to sustainability and include these as integral part of their design identity are needed.

With this approach, the Double Face 2.0 project developed a passive approach to reducing the energy demand of buildings by harvesting the energy from the sun using a Trombe wall (solar wall) and by inducing heat transfer by natural air flow. A traditional Trombe wall typically is constructed from stone-like material placed behind a layer of glass and thin air, which is a very effective way to capture the heat from the sun in winter and release it again at night into the indoor spaces. However, these traditional Trombe walls are rarely used, as they are heavy and thick, and block daylight into buildings.

This research aimed to develop a novel Trombe wall system with high technical performance but also with its engineering performances as an integral part of the design identity of the product, solving the massiveness and obstructiveness of the traditional wall. The new Trombe wall uses new materials like phase change material (PCM) for heat storage and aerogel for thermal insulation, has an optimised shape for best thermal performance, is manufactured using robotic 3D (FDM) printing, allows daylight to pass through and can be adapted according to the conditions at hand.

Thermal principles and materials

The new Trombe wall is meant to work both in winter and in summer. In both cases, the system uses a double layer with one face to capture, store and release heat and one face to provide high thermal resistance. In winter the system captures the heat from the sun during the day and releases it towards chosen areas in the evening; in summer the system cools down by a cold ventilation flow at night in order to be able to take up heat from indoor sources during the day (fig 1).

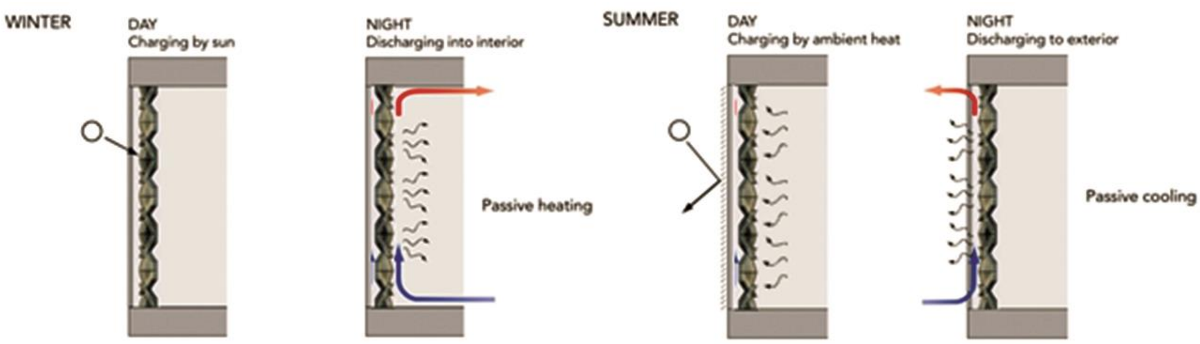

Figure 1: Winter (heating) and summer (cooling) mode of the Trombe wall.

The material that stores the solar heat in the wall is PCM. A PCM can store a significant amount of heat when it changes from solid to liquid state; it will again release this heat when it changes from liquid to solid state. Water is one of the best known examples. However, it melts / solidifies at around 0oC which is a temperature people generally do not find comfortable. The PCM used in this wall is a salt-hydrate with a phase change temperature of around 25oC. One of the advantages of the selected PCM is that it is transparent when liquid and may show beautiful crystals during the solidification process (fig. 2 top right). The thermal resistance in this wall is achieved with Aerogel , a highly insulating material in form of translucent particles, that create a diffused light transmittance (fig. 2 top left).

Figure 2: Top right: Beautiful crystals that start to emerge during the solidification process. Top left: Daylight passing through an insulating layer of Aerogel. Bottom: PCM's crystals in front of Aerogel.

Development of shape

The new Trombe Wall system is based on several thermal principles and aims to include these into the aesthetics of the design. As a result, several customized design variations may be developed for different indoor conditions. First, the thermal principles were studied based on experiments, measurements and simulations; then they were incorporated within design principles. The ideal surface of the Trombe wall considers that heat transfer to and from the PCM occurs via solar radiation, via infrared radiation and via convection from the surface towards the air. Experiments highlighted that solar radiation very rapidly melts the PCM layer. However, cooling the PCM down at night via an air flow along the surface takes very long. Therefore different surface textures were investigated.

Figure 3: Samples and mock-up with different surface texture.

Figure 3 shows some of these surface textures. Also the internal cross-section had to be optimised in order to ensure a relatively constant temperature throughout the PCM, to create places of translucency and openings to look through. Simulations for instance showed that if a pocket of PCM is too big, a large temperature difference between the top and the bottom may arise, quickly leading to overheating and thereby destroying the material. Designing the right patterns inside the wall allows to better control both the temperature and the translucency. All these considerations together led to the final design as shown in figure 4.

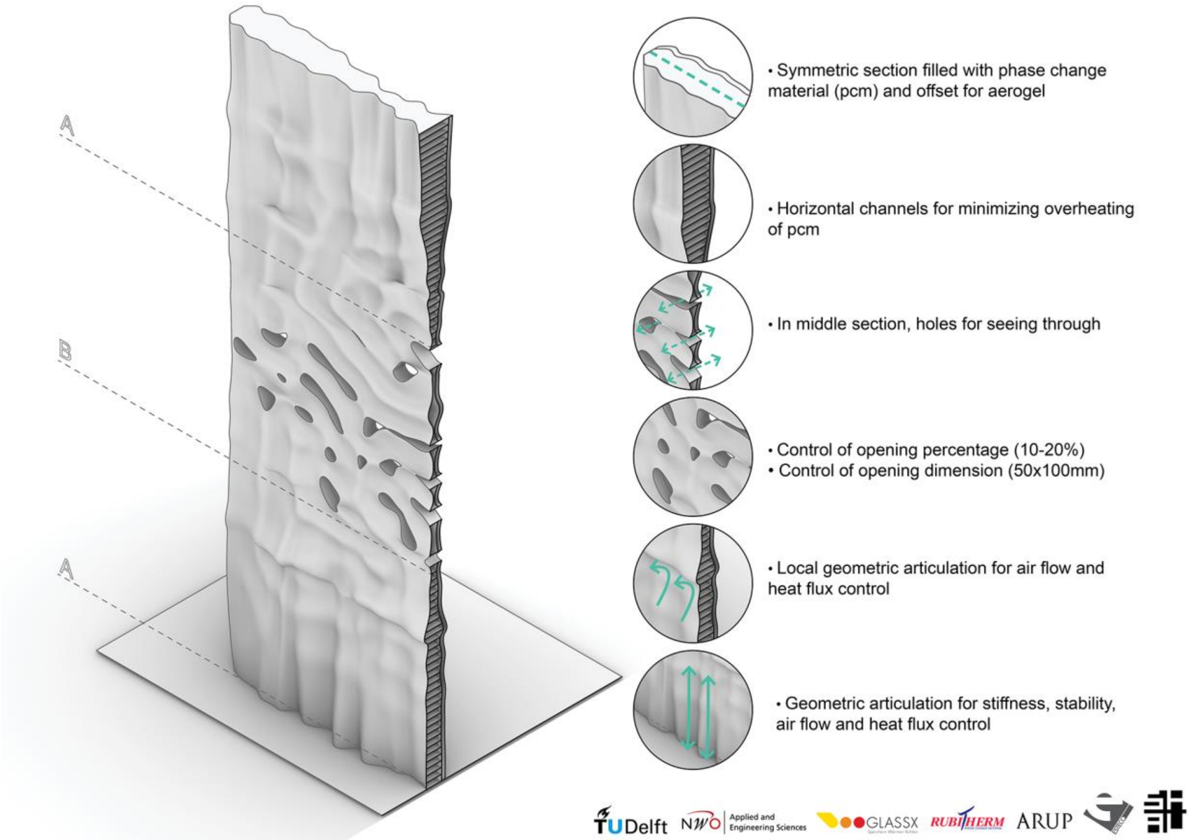

Figure 4: Artist impression of the final design of the new Trombe wall system.

(Robotic) 3D printing

Due to the complex shape that came out of the design process, 3D printing appeared a good option for fabrication. Furthermore, due to the sheer size of the wall (elements of 0.8 m wide times 2.4 m high) FDM printing with a robot arm was selected as the best option (fig. 5).

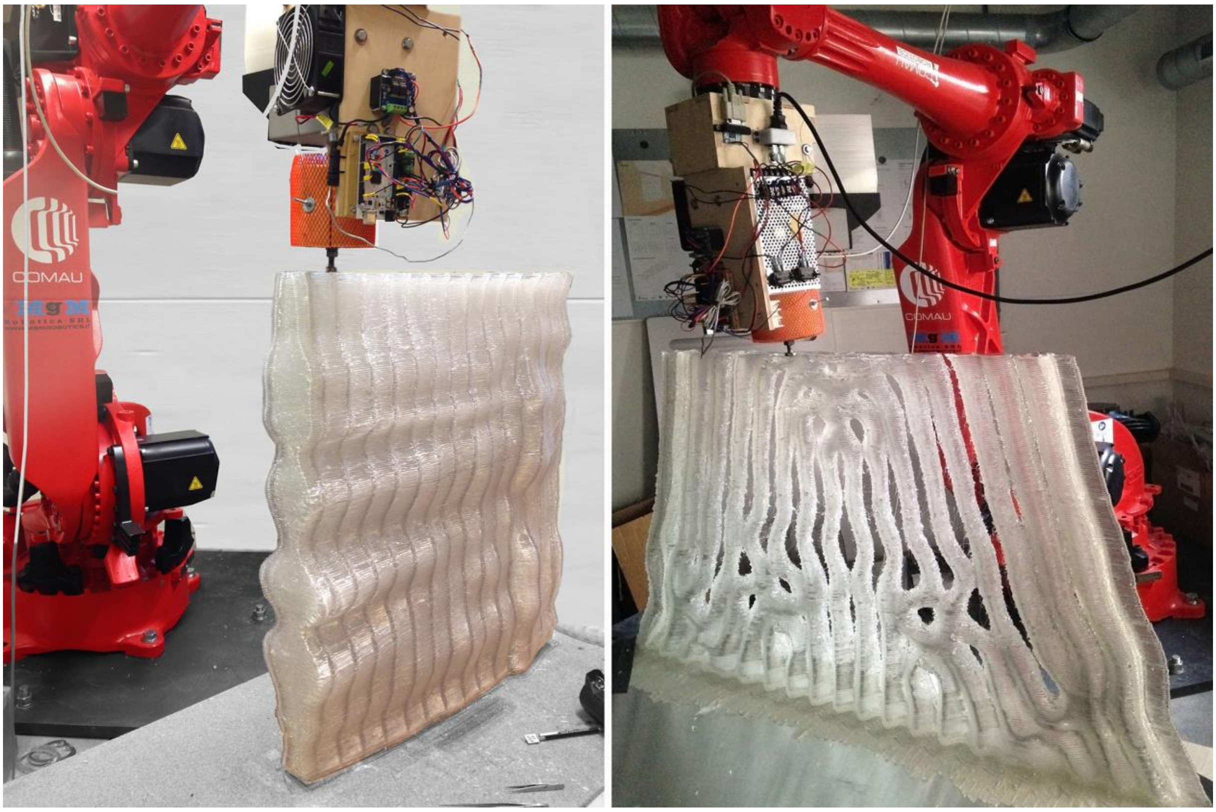

Figure 5: Robotic FDM 3D printing of the final prototype.

The polymer PETG was selected among other materials, due to its translucency ideally allowing the crystal growth of the PCM to be visible. Although (robotic) 3D printing allows for great freedom in shape, a proper use of this technique also implies the incorporation of design constraints for production into the geometry of the design. In this respect, the development of the shape of the Trombe wall also took into consideration the fabrication process; e.g. avoiding critical angles and excessive inclinations. Moreover, the process had to deal with current limitations of the fabrication process; e.g. issues of water tightness were hard to overcome.

Adjustability

A strength of this novel Trombe wall is that it can rotate. The position of the PCM can therefore either face the window or the room. In winter, during the day the PCM should face the window where it collects the heat from the sun and slowly melts traversing from whitish opaque to translucent. In the evening, the PCM should face the room where it gradually releases its heat and slowly solidifies traversing from translucent to opaque. In summer, the position of the PCM is reversed. Simulations have shown that this adjustable Trombe wall – as part of a fully glazed South façade - with 2 to 3 cm of PCM and 1 cm of aerogel may lead to an energy reduction of around 30% for a typical office size room in the Netherlands (fig. 6).

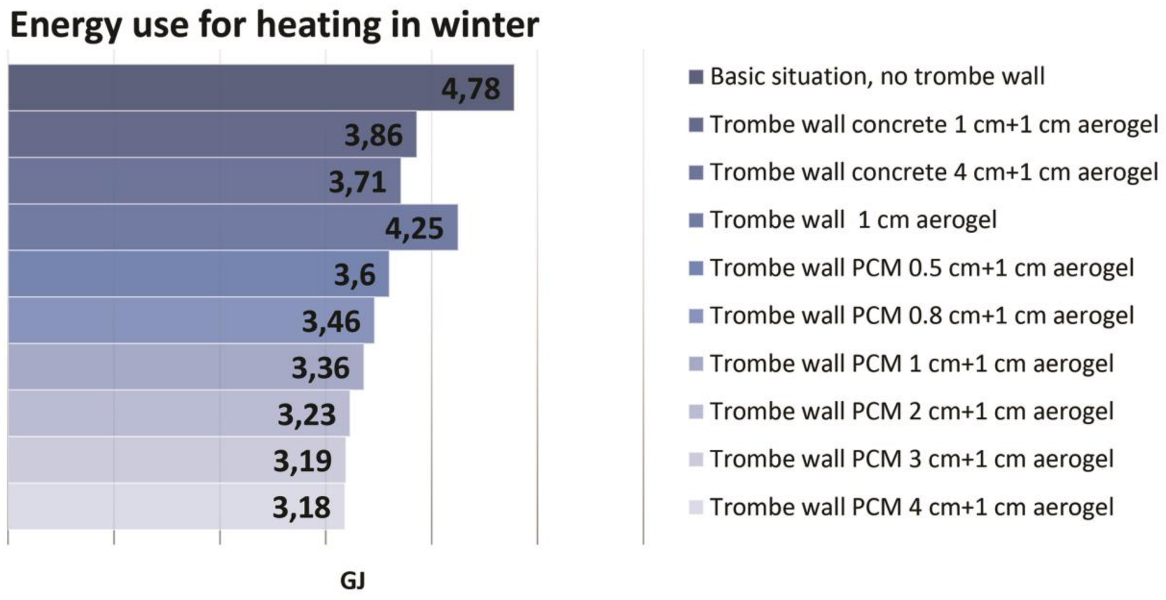

Figure 6: Simulated energy use of a standard office room in the Netherlands with and without the Trombe wall.

Conclusion

The Double Face 2.0 project has led to an innovative, lightweight, translucent and adjustable Trombe wall using innovative materials and manufacturing techniques. One of the strengths of this system is its ability to rotate enabling it for both heating cooling mode. Besides, by using certain materials and by optimising the inner structure and surface texture a system of beauty has been created that shows us how principles for high technical performances can benefit architectural design. Furthermore, the design of the system allows for customization according to different indoor conditions and user preferences, likely allowing for a better market uptake than the traditional Trombe wall.

Acknowledgement

This work is part of the research programme Research through Design with project number 14574, which is (partly) financed by the Netherlands Organisation for Scientific Research (NWO) and Taskforce for Applied Research SIA. The project includes the following partners from industry: Shau Architecture and Urbanism, GlassX AG, Esteco SpA, Rubitherm GmbH and Arup. The researchers would like to thank also MgM Robotics for the technical support and advice when using the Comau robot.

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