An overview of transparent and translucent 3D-printed façade prototypes and technologies

Marzieh GHASEMIESHKAFTAKI*[1], Marco A ORTIZ[1] and Philomena M BLUYSSEN[1]

[1] Delft University of Technology, Delft, The Netherlands
* Corresponding author: *M.Ghasemieshkaftaki@tudelft.nl*

ABSTRACT

3D-printing has transformed traditional manufacturing by enabling the fabrication of individually designed complex systems. The building's façade is one of the most challenging systems because it affects the control of the built indoor environment and allows to provide energy-saving.

The objective of this research is to distinguish 3D-printing technologies and applied materials in them that improve transparency in the façade to decrease artificial lighting consumption, to control solar energy, and to improve energy-savings.

A literature study was performed, firstly, different 3D-printing techniques and their materials for producing transparent outcomes were reviewed from academic databases. Then, transparent 3D-printed façade prototypes were identified.

The outcomes indicated that most of the prototypes used the FDM 3D-printing technique and Polyethylene Terephthalate Glycol as a material. These prototypes didn't consider the disadvantages of the FDM technique for the lighting transmission. Additionally, some prototypes have control over daylighting discomforts but some of them not. Prototypes tried to improve energy-saving which ranged from applying recyclable materials to controlling solar gain.

INTRODUCTION

In 1983, Charles Hull proposed the idea of the first 3D-printing apparatus, which was able to create objects in a layer-by-layer procedure (Hull, 2015). After Hull's patent, 3D-printing technology rapidly spreaded across various industries including architecture and other design disciplines. Quan and colleagues (2013) mentioned that in 3D-printing, objects are manufactured by following the layer-by-layer procedure, despite their complexity. This capability of producing complex objects comes up with great geometric design freedom.

In the building sector, the façade can be a complex element because of the multifunctional nature of its components, which are meant to control the indoor environment. Additionally, building services components can be integrated into the façade; thus the façade is one of the more challenging parts of a building (Strauss & Knaack, 2016). The façade has an impact on both energy consumption and on the indoor environmental quality (IEQ)(Klein, 2013).

People focused on the façade of the building for providing thermal comfort in indoor environment because the façade separates indoor from outdoor thermal discomforts. Therefore, static façades with solid walls were produced to decrease heat transmission loss. These static façades materials block the natural light and therefore, artificial lighting is required. Because of this demand, energy consumption in buildings has increased (Goia et al., 2013; Perino & Serra 2015). As a result, with respect to the need for daylighting, large glazed surfaces became available. These glass façade configurations cause significant heat transmission loss during the winter and huge solar heat gains in the summer (Cetiner & Özkan, 2005). One of the challenges for buildings' façades is to provide a balance between daylighting and energy-saving. Moreover, the façade is the most visible part of the building and sometimes for aesthetic reasons, it has complex shapes. Therefore, this research focused on 3D-printing techniques that can generate complex geometries for integrating multiple materials and functions.

The potential of 3D-printing in façade manufacturing has been investigated, for instance, by Sarakinioti et al., 2018 and Grassi et al., 2019. These researchers conducted research into the panel improvement process, material selection, printing process, structural attributes, energy efficiency, and thermal heat storage.

3D-printing methods have many advantages compared to other production methods, such as the reduction of resource needs and labour costs, generation of complex forms, and accelerated construction process (Sarakinioti et al., 2018; Niaki et al., 2019; Han et al., 2021). These advantages can also help the façade which demands the integration of several functions. For instance, one of these functions is the transparency of façade that helps to decrease artificial lighting consumption. Moreover, another function of façade is its impact on controlling solar energy and improving energy in the building. The purpose of this literature review is to distinguish 3D-printing technologies and materials that can improve transparency and translucency in the façade of the buildings in order to improve energy saving. Thus, identifying new 3D-printing façade materials that can improve transparency is important, which leads to the research questions of this review:

- Which 3D-printing techniques can produce transparent materials and façade prototypes?

- What is the impact of these transparent materials and prototypes on lighting and energy-saving?

First, 3D-printed methods and technologies that can give transparent results were selected. Then, transparent and translucent 3D-printed façade prototypes were identified based on what was extracted from the review. Finally, the relationship between transparent prototypes and their impacts on lighting and energy-savings was analysed.

METHOD

A literature study was performed with the main keywords including 3D-printing, façade materials, transparency, and energy-saving. Then for finding more information, keywords' synonyms were identified as shown in Table 1. Then their combinations were used.

Table 1. Search queries per concept

<table>
<tr><th>concept 1</th><th></th><th>concept 2</th><th></th><th>concept 3</th><th></th><th>concept 4</th></tr>
<tr><td>Façade material</td><td rowspan="6">And/or</td><td>3D-printing</td><td rowspan="6">And/or</td><td>Transparen*</td><td rowspan="6">And/or</td><td>Energy-saving</td></tr>
<tr><td>Façade panel</td><td>FDM (PLA, ABS, PMMA, PC, PETG)</td><td rowspan="5">Translucent</td><td>Artificial lighting consumpti on</td></tr>
<tr><td rowspan="4">Façade envelope</td><td>SLA/DLP 3d printing (Polymer resin)</td><td>Use of artificial lighting</td></tr>
<tr><td>Poly jet</td><td>Material saving</td></tr>
<tr><td>3D-printed plastic</td><td rowspan="2">Heat storage</td></tr>
<tr><td>3D printed Glass panel</td></tr>
</table>

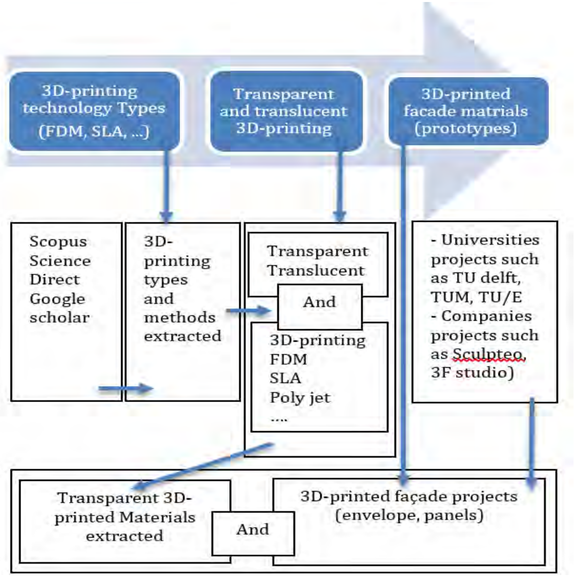
Different databases were used to find literature:

- Academic databases (e.g. Google Scholar, Science Direct, and Scopus).

- Reports, publications, and websites of universities and projects of companies where transparent and translucent 3D-printed façade prototypes are used (Eindhoven Technology University, Delft Technology University, Technical University of Munich, Sculpteo Company).

In order to achieve reliable sources and information, the Impact Factor of the journals was evaluated. Sources that were written by authentic authors or university authors in the field of 3D-printing with more citations were selected. Moreover, about 3D-printed prototypes, the tests which were used to check and evaluate prototypes' features and qualities (e.g. transparency tests, insulation tests) were extracted. The resource finding process is mentioned in chart 1.

Chart 1. Resource-finding process



The prototypes were compared based on their lighting transmission and energy-saving to static, glazed, and adaptive façades. Static, glazed, and adaptive façades were used because they are divided based on lighting flexibility and energy-saving.

RESULTS

Transparent 3D-printing

Transparent 3D-printing refers to 3D-printed objects of varying levels of transparency that vary from translucent to fairly transparent (Sculpteo, 2019; Park, 2018). Additionally, this diversity in transparency is related to various factors including the nature of the 3D model, the type of 3D-printer, 3D-printing settings, material selection, and the post-production treatment (Sculpteo, 2019; Park, 2018; Moore, 2020). These mentioned factors have impacts on the transparency of 3D-printed objects, and extracted from real tests and experiments of various research.

FDM 3D-printing

The Fused Deposition Modelling (FDM) is a non-laser application and low cost in use and maintenance (Liu et al., 2019). FDM 3D-printing heats a filament and squirts layer-by-layer in the shape of the object. Because of the FDM printing nature, very small gaps can form between the layers which resulted in passing less light through the surface of the 3D-printed object. Layer lines produced by FDM 3D-printer are visible and disperse light. This light refraction interferes with transparency, which can be reduced through the design and production process (Luo et al., 2020). Sun et al. in 2008 mentioned that settings of FDM 3D-printing should be adjusted based on material extrusion temperature and flow rate, print bed temperature, printing speed, layer height thickness, and nozzle diameter. Sculpteo in 2019 concluded that using an FDM 3D-printer for transparent printing needs to find the optimal settings which is a challenging process and related to trial and error.

Liu et al., 2019; Sculpteo, 2019; Wu et al., 2015; Bressan et al., 2019; Suwanprateeb & Suwanpreuk, 2009; Luo et al., 2020; Barrios & Romero, 2019, propose the following transparent 3D-printing filaments for FDM:

- Polylactic Acid (PLA) usually has a slight yellowish tinge because it is made from natural raw materials. PLA transparency is related to used materials' quality.

- Acrylonitrile Butadiene Styrene (ABS) is blended with a non-natural additive to make it clear, so it is translucent rather than transparent. Thus, it needs post-printing finishing for more transparent results.

- Poly (Methyl Methacrylate) or (PMMA) prints in a clearer way compared to other materials and is available in various colours.

- Polycarbonate (PC) is a clear, glossy, and durable 3D-printing filament.

- Polyethylene Terephthalate Glycol (PETG) is one of the clearer and more available 3D-printing filaments.

SLA 3D-printing

Son and Lee in 2020 mentioned that Stereo Lithography Apparatus (SLA) 3D-printing uses resins. Clear resins are not thoroughly transparent before post-production; however, they manage to deliver optically viable pieces. Additionally, Sculpteo in 2019 explained that objects produced with resins may have a blueish tinge that is more notable in pieces with a thickness of 2 centimetres or more. SLA transparent resin can be coloured by adding pigment.

By using particle-laden resins, SLA is an economic alternative to attain parts with higher geometric complexity. This higher complexity is compared to extrusion processes in applications that tolerate the high shrinkage related to this technique (Wong and Hernandez, 2012; Wu et al., 2011).

Polyjet 3D-printing

Polyjet printing overlays liquid polymer layers then uses ultraviolet (UV) radiation to cure each added layer (Chen et al., 2016). The outcome is very smooth surfaces with high dimensional accuracy. Polyjet resins can be polished to create the most transparent finish. Thus, Polyjet printing is suitable for tooling, visual prototypes, and finished products (Sculpteo, 2019). As a disadvantage Chen et al., (2016) mentioned that sometimes during the printing process, support materials are required that must be manually removed after printing.

VeroClear resin used for Polyjet printing and is an ideal resin for both prototyping aims and end-products. Its applications range from providing a more resistant alternative to glass lenses and light pipes, to making clear covers. VeroClear has water-resistant and heat-resistant features (Harr et al., 2020).

3D Printed façade prototypes

This section presents how 3D-printed samples can enhance daylighting transmission and energy-savings. Besides, their materials, types of applied 3D-printers, and other features and characteristics are also presented.

New façade designed by Munich-based start-up 3F Studio

3F Studio's founders, Moritz Mungenast, Oliver Tessin, and Luc Morroni (2018), created a façade prototype at the Technical University of Munich (TUM). This façade act as the temporary main entrance of the Deutsches Museum (Figure 1). This multifunctional façade was made of PETG plastic (FDM) which can be 100% reused for façades. The façade offers protection against the summer heat, while it lets in as much daylight as possible into the building in the winter.

Other essential functions such as thermal insulation and natural ventilation can be integrated without the need for costly systems technology thanks to vertical closed air ducts. These air ducts provide stability for the façade and also insulate the building. By considering these essential functions and details during the planning process, they can be created in the form-finding process. Thus material consumption and production time will be minimized (Hemming-Xavier, 2018).

Figure 1. Entrance to the Deutsches Museum TUM (Hemming-Xavier, 2018)

Thin glass with 3D-printed trussed and hypar core patterns

Akilo's (2018) project focuses on the creation of a thin glass composite with a 3D-printed polymer core. An optically more open structure is provided by the trussed core. Moreover, a translucent and textured appearance is provided by a perforated hypar-shaped core (Figure 2). To illustrate this concept and to explore its viability, 210 x 297 mm thin glass composite panels were built at TU Delft, using either a trussed core or a hypar-shaped core with perforations. By means of the FDM technique, the 11 mm thick core was printed from PETG filament. Leapfrog's "Creatr HS" and Kossel XL printers were employed for the trussed core and the hypar-shaped core respectively. This panel with the two mentioned cores is stronger and lighter than conventional laminated glass (Louter et al., 2018).

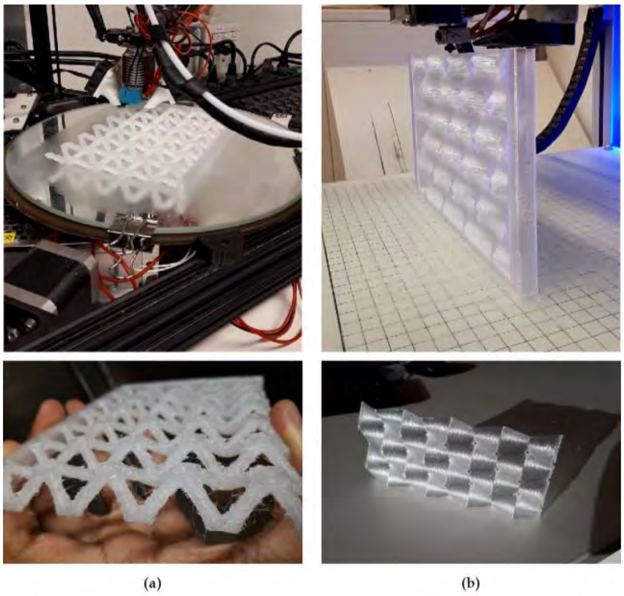


Figure 2. 3D printing strategy used for (a) the trussed core, and (b) the perforated hypar-shaped core (Akilo, 2018)

Thin glass with 3D-printed Voronoi core pattern (generation 2)

A 3D-printed core principle for the improvement of a thin glass composite panel has been applied in Neeskens's project (2018). They built a structurally optimized core pattern by using core material only where it is most effective to secure weight and materials (Figure 3). The panels were made up of the 3D-printed PETG cores with a nominal thickness of 8 mm and two external facings of chemically reinforced Aluminosilicate glass each with a thickness of 1 mm. A TESA 51966 PET tape with an Acrylic adhesive sheet or a Delo Photobond UV curing Acrylic adhesive was used to bind the 3D-printed Voronoi core pattern to the external glass layers.

Figure 3. Glass panels (3D-printed PETG Voronoi core) (Neeskens, 2018)

The Double Face project

In 2014 Turrin et al. worked on the Double Face project (Figure 4) to passively enhance the thermal comfort of indoor spaces through lightweight materials and to allow daylight to pass through them.

The thickness of the Double Face based on the digital simulations was 7 cm: 5 cm PCM (phase-changing material), 1 cm Aerogel (translucent insulation), and 1 cm container wall. The lightness and transparency of the Double Face prototype were achieved by the applied layers. First samples were manufactured by FDM 3D-printing method and PLA and PETG filaments were used. This system is adaptive to increase thermal advantages because PCM elements can be rotated. Therefore, by exposing PCM elements to winter solar radiation, they cause passive heat gain, and by protecting them from the summer solar radiation, they help to passive cooling. First samples were tested for their thermal behaviour and light transmittance in the Eindhoven University of Technology and Delft University of Technology.

Figure 4. The Double Face project (Turrin et al., 2014)

The Double Face 2.0 project

The Double Face 2.0 project was done by Tenpierik et al. in 2018 and is illustrated in Figure 5. This project aims to reduce the building energy consumption by using a so-called Trombe wall which harnesses the sun energy. This wall is based on innovative materials like PCM (phase change material) and Aerogel (thermal insulation), and was created with the FDM printing method. The used PCM is a salt-hydrate with a phase change temperature of around 25°C for heat storage. It is non-flammable and can be transparent when liquid. Therefore, it allows daylight to enter the building and can be adapted to change environmental factors or use conditions.

The Trombe wall is adjustable, so the position of the PCM can be adjusted to face either the window or the room. In winter, during the day the PCM faces the window where it slowly melts because of the sun's heat therefore changes from solid to liquid and becomes translucent. In the evening the system turns so that the PCM faces the room where it slowly releases the gained heat and changes from liquid to solid and becomes opaque. In summer, the direction of the PCM is inverted so it can capture heat from internal sources during the day and at night it cools down with cool outside air when facing the window (Tenpierik, 2018).

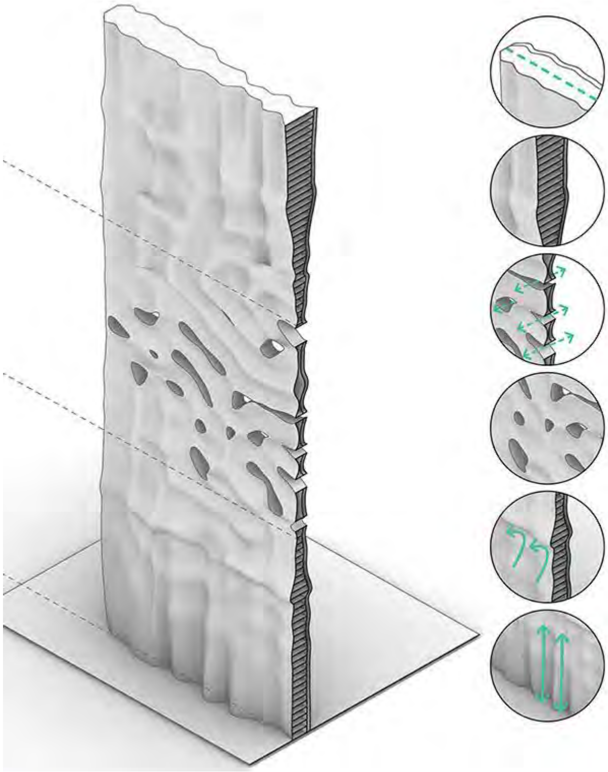


Figure 5. The Double Face 2.0 project (Tenpierik, 2018)

The research project "SPONG3D"

Sarakinioti et al. in 2018 worked on the project "SPONG3D" (Figure 6). This project aimed to create a 3D-printed façade panel that combines insulating properties with heat storage in complex, mono-material geometry. The development phase was carried out by simulations and experiments, employing the FDM printing method to manufacture the prototype. Transparent PETG was selected as it has a high solar light transmission, it has higher stiffness and strength compared to PLA, and it is 100% recyclable.

SPONG3D is an adaptive façade system that combines two sub-systems to control the heat exchange between the interior and exterior conditions of the building. The first system applies a porous internal core with air cavities to provide thermal insulation. The second system consists of exteriors channels that allow the flowing of liquid. To provide adaptive heat storage the liquid performs as a movable thermal mass. The liquid can move from one side to the other side of the façade in order to absorb and release the heat based on the need.

Figure 6. SPONG3D project (Sarakinioti, 2018)

DISCUSSION

Shi et al., 2020; Yan et al., 2019; Soudian and Berardi, 2021; Marco and Valentina, 2015, divided and defined façades in three following categories based on their lighting flexibilities, energy-saving potentials and users' control on them:

- Static or passive façades consist of massive opaque walls with only a few transparent windows.
- Glazed façades or façades with large windows which the most proportion of them is glass.
- Adaptive and Dynamic façades can change their properties passively or actively over time to decrease the energy consumption of the building.

These categories were selected because they are based on their lighting transmission and energy-saving. This research also mostly focused on lighting transmission and energy-saving of 3D-printed façades. Therefore, according to these categories, 3F studio's prototype, two double face projects, and Spong3D are adaptive façade samples. Moreover, thin glass with 3D-printed trussed, hypar-core patterns and 3D-printed Voronoi core are glass panels and new materials so they can be applied in the glazed façade or façade with large windows because are stronger and lighter than conventional glass. Thus, the lighting performance of the demonstrated 3D-printed prototypes in this article was compared based on the mentioned categories.

Yu and Su, 2015; Tabadkani et al., 2021, refer to different parameters that should be considered to improve energy savings enabled by the façades:

- Solar gain control: it has direct influences on indoor temperature, therefore, having control over it can improve energy efficiency and occupant comfort.

- Natural ventilation: The façade can control the natural air exchange and circulation, thus, decreasing the use of mechanical ventilation.

- Daylighting vs. artificial lighting: An appropriate combination of daylight and artificial lighting is the main strategy to reduce energy consumption. However, daylight penetration needs control strategies for energy savings.

Table 2 presents the aforementioned parameters demonstrating the energy efficiency features of 3D-printed façades prototypes.

Table 2. Common features of translucent 3Dprinted façade materials in energy savings

3D-printed façade prototypes (size)	Category	Technique and material	Solar gain control	Natural ventilation	Other saving energy features	Tests	Daylight vs artificial light
3F Studio's prototype (280x160 x6cm)	Adaptive façade	PETG plastic (FDM)	Yes - Combination of translucent material and vertical closed air ducts	Yes - Thermal insulation -Vertical closed air ducts	- Reducing production time and material consumption - No need for costly systems technology - 100% reused	Installed on the solar station on the roof of the Technical University of Munich and tested by accurate sensors	- Compare to static façade and glazed façade, can control lighting and reduce discomforts (overheating) - More transparent than a static façade (opaque walls)
Thin glass with 3D-printed trussed and hypar core (Thickness around 1.3cm)	Glass panel	PETG filament (FDM)	No	No	- Stronger and lighter than conventional laminated glass	In a 3-point bending test was structurally efficient	- Compare to static façades (opaque walls), has more transparent surfaces - Cannot control daylighting
Thin glass with 3D-printed Voronoi core (Thickness around 1cm)	Glass panel	PETG cores (FDM)	No	No	- Stronger and lighter than conventional laminated glass	In a 3-point bending test was structurally efficient	- Compare to static façades (opaque walls), has more transparent surfaces - Cannot control daylighting
The Double Face project (17x17x 7cm- Thickness 6-7cm)	Adaptive façade	PLA and PETG filaments (FDM)	Yes -PCM (phase-changing material) - PCM rotation	Yes - Aerogel (translucent insulation - Cavities trapping air	- Lightweight materials	- Simulation with DesignBuilder, Matlab and Simulink: energy reduction of 40% compared to the 'no Trombe wall' - Thermal behaviour: measured by heat-flow sensors and thermocouples	- Controls lighting and reduces lighting discomforts (glare, overheating) compared to other types - More transparent than a static façade
The Double Face 2.0 project (Thickness4 cm)	Adaptive façade	PETG filaments (FDM)	Yes - PCM (phase-changing material) - Adjustable PCM	Yes - Aerogel (translucent insulation)	- Lightweight materials	- Simulations with Matlab and Simulink - Physical experiments - 1 cm of PCM lead to an energy reduction of around 30% for a typical office size room in the Netherlands	- Controls lighting and reduces lighting discomforts (glare, overheating) compared to other types - More transparent than a static façade
SPONG3D (150x50x 36 cm)	Adaptive façade	PETG filaments (FDM)	Yes - The liquid inside channels	Yes - Thermal resistance core - Air cavities - Water channels	- Recyclable - Lightweight - Reducing production time	- A Trnsys model for analysing energy system - Thermal tests - Resistance and water tightness tests	- Compare to static façade and glazed façade, can control lighting and reduce discomforts (overheating) - A little transparent than a static wall (opaque wall) because of its thickness.

All prototypes used the FDM technique and as mentioned previously, FDM 3D printing heats filaments and creates layer lines on objects. These layer lines have negative impacts on light transmission and light dispersing, but these panels didn't conduct any tests about these layer lines. Additionally, the SLA 3D-printing and the Polyjet 3D-printing methods don't produce these layer lines but these prototypes did not select and test them. Moreover, all prototypes used PETG and did not try other filaments such as PMMA which can also be clearer than others.

The thin glass panel with a 3D-printed trussed and hypar core (about 1.3 cm) and also the thin glass panel with a 3D-printed Voronoi core (about 1 cm) could offer decreased weight and improved strength and stiffness compared to typical laminated glass units. Table 2 demonstrated that two thin glass prototypes were tested for the efficiency of their structure. These two panels did not conduct any test for the light transmission, reflection, or glare factors which are very significant aspects for glazed façades. Moreover, these two panels compare to other prototypes didn't have any control over the solar gain and the natural air exchange.

Based on table 2, the simulation was selected for testing the energy efficiency of some prototypes such as two Double face projects and the SPONG3D prototype. Two prototypes Double Face and Double Face 2.0 projects tried to act as a Trombe wall and solved some problems of traditional Trombe walls such as heaviness and blocking daylight. The SPONG3D doesn't have enough opportunity for transmitting sunlight, but it demonstrated that 3D printing can integrate different façade functions such as controlling heat exchange, providing lightweight and recyclable components. Moreover, sensors were also applied for testing solar gain and thermal behaviour of the 3F Studio's prototype and the Double face 2.0 project.

Other projects and researchers also used 3D-printing to improve façades transparency and energy-saving in other ways. For instance, COOKFOX Company provided 3D-printed window frames and moulds to produce a crystal façade. This façade was designed as a self-shaded envelope and optimized to decrease energy consumption for cooling. Moreover, Mosalam et al., 2018 demonstrated another 3D-printed building façade for daylight permeability in an anabolic way through the opaque sections of exterior façades and roofs. A prefabricated transparent concrete panel with implanted optical fibres was linked to a layer with compound parabolic concentrators. For producing these panels they used a PLA filament. Therefore, for improving transparency in the façade, different projects used 3D-printing technology in different ways.

CONCLUSION

The main question of this research was to understand which 3D-printed façade materials can improve building transparency and energy-savings. Thus, by analysing new transparent and translucent 3D-printed façade prototypes and techniques, it can be concluded that:

1- Polymer 3D printing introduced new opportunities for formal and functional integration to building façade design. It combines various aspects of light permeability, climate control, and structure into a single functional prototype.

2- FDM 3D printing is important for producing transparent and translucent façade materials. All mentioned prototypes in this article used the FDM technique but one critical analysis is that the function of these samples is different and some of them acted as an adaptive façade and some of them are like glass. Moreover, based on reviewed 3D printing methods, the FDM 3D printing technique produced layer lines on the objects which these lines are visible, pass less light and disperse light. Mentioned prototypes did not focus on these problems of the FDM technique. Therefore, the effectiveness of other 3D printing techniques should be tried for façade prototypes.

3- PETG was the most applied material for producing transparent 3D-printed façade prototypes. Based on the review this material is more available than others but it cannot be a logical reason that PETG will be applied for most of the prototypes. Additionally, PMMA is clearer than others, therefore, it can be a critic that why prototypes and specifically glass panels didn't select this filament.

4- Several 3D-printed prototypes perform like an adaptive façade and try to control daylight and reduce discomfort such as overheating and glare. Among adaptive façade prototypes, the Double Face project not only has energy-saving features but also has more lighting transmission compare to other adaptive prototypes. Moreover, some 3D-printed prototypes are like glazed façades but they do not have any control over daylighting discomforts and energy saving compared to an adaptive façade. Another problem related to these glazed facades is that just structural tests were conducted for them and experiments related to light transmits, reflection, and glare weren't conducted.

The focus of this research was on the transparency of 3D-printed materials, but maybe other features of lighting such as glare and reflection in the 3D-printed façade materials will have impacts on energy-saving and lighting efficiency.

REFERENCES

Akilo, M. A. (2018). Design and analysis of a composite panel with ultra-thin glass faces and a 3Dprinted polymeric core [Master thesis, University of Bologna]. https://corsi.unibo.it/2cycle/CivilEngineering

Barrios, J. M., & Romero, P. E. (2019). "Improvement of Surface Roughness and Hydrophobicity in PETG Parts Manufactured via Fused Deposition Modeling (FDM): An Application in 3D Printed Self–Cleaning Parts". Materials (Basel), 12(15), 2499. https://doi.org/10.3390/ma12152499

Bressan, L., Adamo, C., Quero, R., Jesus, D., & Silva, J. (2019). "Simple procedure to produce FDM-based 3D-printed microfluidic devices with integrated PMMA optical window". Anal. Methods, 11(8), 1014-1020.11. https://doi.org/10.1039/C8AY02092B

Cetiner, I., & Özkan, E. (2005). "An approach for the evaluation of energy and cost efficiency of glass façades". Energy and Buildings, 37(6), Pages 673-684. https://doi.org/10.1016/j.enbuild.2004.10.007

Chen, Ch., Mehl, B., Munshi, A., Townsend, A., Spence, D., & Martin, R. (2016). "3D-printed Microfluidic Devices: Fabrication, Advantages and Limitations-a Mini Review". Anal. Methods, 8(31), 6005-6012. https://doi.org/10.1039/C6AY01671E

Cookfox. (2020). One South First. https://cookfox.com/projects/one-south-first/

Goia, F., Haase, M., & Perino, M. (2013). "Optimizing the configuration of a façade module for office buildings by means of integrated thermal and lighting simulations in a total energy perspective". Applied Energy, 108, 515-527. https://doi.org/10.1016/j.apenergy.2013.02.063

Grassi, G., Lupica Spagnolo, S., & Paoletti, I. (2019). "Fabrication and durability testing of a 3D-printed façade for desert climates". Additive Manufacturing, 28, 439-444. https://doi.org/10.1016/J.ADDMA.2019.05.023

Han,Y., Yang, Z., Ding, T., & Xiao, J. (2021). "Environmental and economic assessment on 3D printed buildings with recycled concrete". Journal of Cleaner Production, 278, 123884. https://doi.org/10.1016/j.jclepro.2020.123884

Harr, M., Moy, P., & Yu, J. (2020). "Mechanical Properties of Transparent Laminates Fabricated Using Multi-Material Photopolymer Jetting". In Dynamic Behavior of Materials, 1, 47-51. https://doi.org/10.1007/978-3-030-30021-08

Hemming-Xavier, A. (2018). "3D printing innovation: New facade designed by Munich-based start-up 3F Studio for the Deutsches Museum is the first of its kind worldwide". 3F Studio. https://uploadsssl.webflow.com/5c1285987ed0613c22f8b698/5cc722b153fa1219d35f6d39_Presse%20release%203Dprinted%20facade%20Deutsches%20Museum%203F%20Studio.pdf

Hull, C. (2015). "The Birth of 3D-Printing". Research-Technology Management, 58(6), 25-30. https://doi.org/10.5437/08956308X5806067

Liu, Z., Wang, Y., Wu, B, Cui, C., Guo, Y ., & Yan, C. (2019). "A critical review of fused deposition modeling 3D printing technology in manufacturing polylactic acid parts". The International Journal of Advanced Manufacturing Technology, 102(9), 2877–2889. https://doi.org/10.1007/s00170-019-03332-x

Louter, C., Akilo, M., Miri, B., Neeskens, T., Ribeiro Silveira, R., Topcu, Ö., van der Weijde, I., Zha, C., Bilow, M., Turrin, M., Klein, T., & O'Callaghan, J. (2018). "Adaptive and composite thin glass concepts for architectural applications". Heron, 63(1/2), 199-218. http://heronjournal.nl/63-12/9.html

Luo, Y., Canning, J., Zhang, J., & Peng, G. D. (2020). "Toward optical fibre fabrication using 3D printing technology". Optical Fiber Technology, 58, 102299. https://ui.adsabs.harvard.edu/link_gateway/2020OptFT..5802299L/doi:10.1016/j.yofte.2020.102299

Marco, P., & Valentina, S. (2015). "Switching from Static to Adaptable and Dynamic Building Envelopes: A Paradigm Shift for the Energy Efficiency in Buildings". Journal of Facade Design and Engineering, 3(2), 143-163. https://doi.org/10.3233/FDE-150039

Moore, D.G., Barbera, L., Masania, K., & Studart, A.R. (2020). "Three-dimensional printing of multicomponent glasses using phase-separating resins". Nature Material, 19(2), 212–217. https://doi.org/10.1038/s41563-019-0525-y

Mosalam, K. M., M.ASCE, P. E., & Casquero-Modrego, N. (2018). "Sunlight Permeability of Translucent Concrete Panels as a Building Envelope". Journal of Architectural Engineering, 24(3), 04018015. https://doi.org/10.1061/(asce)ae.1943-5568.0000321

Neeskens, T. (2018). Thin glass composites: based on a structural efficiency increasing design strategy [Master's thesis, Delft University of Technology]. http://resolver.tudelft.nl/uuid:676851fc-0556-4e1e-ac6a-dcdf4b7cfc0a

Niaki, M.K., Torabi, S.A., & Nonino, F. (2019). "Why manufacturers adopt additive manufacturing technologies: the role of sustainability". Journal of Cleaner Production, 222 , 381-392. https://doi.org/10.1016/j.jclepro.2019.03.019

Park, H.K., Shin, M., Kim, B., Park, J.w., & Lee, H. (2018). "A visible light-curable yet visible wavelength-transparent resin for stereolithography 3D printing". NPG Asia Materials, 10(4), 82-89. https://doi.org/10.1038/s41427-018-0021-x

Perino, M., & Serra, V. (2015). "Switching from static to adaptable and dynamic building envelopes: A paradigm shift for the energy efficiency in buildings". Journal of Facade Design and Engineering, 3(2), 143-163. https://doi.org/3. 143-163. 10.3233/FDE-150039

Quan, Z., Wu, A., Keefe, M., Qin, X., Yu, J., Suhr, J., & Chou, T.W. (2015). "Additive manufacturing of multi-directional performs for composites: opportunities and challenges". Materials Today, 18(9), 503-512. http://dx.doi.org/10.1016/j.mattod.2015.05.001

Sarakinioti, M. V., Konstantinou, T., Turrin, M., Tenpierik, M., Loonen, R., De Klijn-Chevalerias, M. L., & Knaack, U. (2018). "Development and prototyping of an integrated 3D-printed façade for thermal regulation in complex geometries". Journal of Facade Design and Engineering, 6(2), 29-40. https://doi.org/10.7480/jfde.2018.2.2081

Sculpteo. (2020). Transparent 3D Printing: what are your options. https://www.sculpteo.com/blog/2019/11/27/transparent-3d-printing-what-are-your options/

Shi, X., Tablada, A., & Wang, L. (2020). "Influence of two motion types on solar transmittance and daylight performance of dynamic façades". Solar Energy, 201, 561-580. https://doi.org/10.1016/j.solener.2020.03.017

Son, J., & Lee, H. (2020). "Preliminary Study on Polishing SLA 3D-Printed ABS-Like Resins for Surface Roughness and Glossiness Reduction". Micromachines, 11(9), 843. https://doi.org/10.3390/mi11090843

Soudian, S., & Berardi, U. (2021). "Development of a performance-based design framework for multifunctional climate-responsive façades". Energy and Buildings, 231,110589. https://doi.org/10.1016/j.enbuild.2020.110589

Strauss, H., & Knaack, U. (2016). "Additive Manufacturing for Future Façades". Journal of Façade Design and Engineering, 3(3-4), 225-235. https://doi.org/10.7480/jfde.2015.3-4.875

Sun, Q., Rizvi, G. M., Bellehumeur, C. T., & Gu, P. (2008). "Effect of processing conditions on the bonding quality of FDM polymer filaments". Rapid Prototyping Journal, 14(2), 72–80. https://doi.org/10.1108/13552540810862028

Suwanprateeb, J., & Suwanpreuk, W. (2009). "Development of translucent and strong three dimensional printing models". Rapid Prototyping Journal, 15, 52-58. https://doi.org/10.1108/13552540910925063

Tabadkani, A., Roetzel, A., Xian Li, H., & Tsangrassoulis, A. (2021). "Design approaches and typologies of adaptive facades: A review". Automation in Construction, 121, 103450. https://doi.org/10.1016/j.autcon.2020.103450

Tenpierik, M., Turrin, M., Wattez, Y., Cosmatu, T., & Tsafou, S. (2018). "Double Face 2.0: A lightweight translucent adaptable Trombe wall". SPOOL, 5(2). https://doi.org/10.7480/spool.2018.2.2090

ThreeFstudio(3Fstudio). (2020). 3D PRINTING INNOVATION. https://www.3fstudio.de/press

Tse, K. (2020). Polymer FDM for High-Performance Facades: Digital Tools for Designing Performative Aesthetics with Polymer FDM[master's thesis, University of Calgary, Calgary, AB]. http://hdl.handle.net/1880/112580

Turrin, M., Tenpierik, M., de Ruiter, P., van der Spoel, W., Chang Lara, C., Heinzelmann, F., Teuffel, P., & van Bommel, W. (2014). "DoubleFace: Adjustable translucent system to improve thermal comfort". SPOOL, 1(2), 5-9. https://doi.org/10.7480/spool.2014.2.929

Wong, K. V. & Hernandez, A. (2012). "A review of additive manufacturing". International Scholarly Research Notices, 2012. https://doi.org/10.5402/2012/208760

Wu, C., Luo, Y., Cuniberti, G., Xiao, Y. & Gelinsky, M. (2011). "Tree-dimensional printing of hierarchical and tough mesoporous bioactive glass scafolds with a controllable pore architecture, excellent mechanical strength and mineralization ability". Acta Biomaterialia, 7(6), 2644–2650. https://doi.org/10.1016/j.actbio.2011.03.009

Wu, W., Geng, P., Li, G., Zhao, D., Zhang, H., & Zhao, J. (2015). "Influence of Layer Thickness and Raster Angle on the Mechanical Properties of 3D-Printed PEEK and a Comparative Mechanical Study between PEEK and ABS". Materials (Basel), 8(9), 5834-5846. https://doi.org/10.3390/ma8095271

Yan, S., Li, X., Wang, B., & Lyu, W. (2019). "Free-running temperature of room equipped with pipe-embedded double skin façade: a case study in Guangzhou Sci". Science and Technology for the Built Environment, 25, 1132-1142. https://doi.org10.1080/23744731.2019.1616983

Yu, X., & Su, Y. (2015). "Daylight availability assessment and its potential energy saving estimation-a literature review". Renewable and Sustainable Energy Reviews, 52, 494-503. https://doi.org/10.1016/j.rser.2015.07.14