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Composite thin glass panel with a 3D printed sine wave core pattern

THIN GLASS COMPOSITED WITH 3D PRINTED POLYMER CORES

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Abstract

Thin glass is currently mainly used for displays on electronic devices, but it also offers interesting characteristics for architectural applications. Due to its high strength and small thickness the glass can easily be bent in architecturally appealing curvatures, while the small glass thickness (≤ 2 mm) offers a significant weight reduction compared to traditional window glazing. Research at TU Delft and TU Dresden focuses on exploiting these beneficial characteristics for the creation of lightweight composite façade panels. More specifically, composite panels are developed that consist of thin glass outer facings which are adhesively bonded to an inner stiffening 3D-printed open-cell polymer core. Besides the benefits of high strength, high stiffness and low weight, the composite panels also offer the potential to influence daylight entry through customisation of the 3D-printed core pattern. The current contribution highlights the current state of the research activities and describes the concept of the thin glass composite panels, their constituent components and the related digital fabrication process.

Introduction

The current contribution focuses on composite panels that consist of thin glass cover layers and 3D-printed polymer core structures that are adhesively bonded to the glass, see Figure 1. The main benefit of such panels is that they are lightweight, strong and stiff. Furthermore, the panels are to a large degree transparent and offer a certain insulating performance through the sealed cavity between the glass layers. These composite panels thus offer interesting characteristics for architectural applications, such as façades (see Figure 2), separation walls, or even floors. Compared to traditional glazing solutions, the use of thin glass with a thickness of less than 2 mm in combination with the stiffening polymer core offers a potential reduction of up to 80% of the glass used. Besides (raw) material and embodied energy savings, this translates into a significant weight reduction of the panels, making transport, handling and installation much more (energy) efficient and convenient. Furthermore, due to the small thickness and high strength of (pre-stressed) thin glass, it can also be easily bent in architecturally

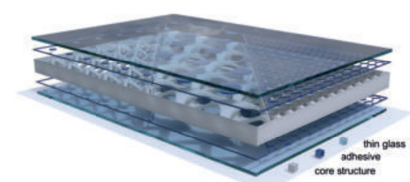

Fig 1: Rendering of the composite panel with thin glass as cover layer, an adhesive bond and a 3D-printed core structure.

appealing curvatures, offering further possibilities for architectural applications.

Research on these composite panels has been ongoing for the past years. While the initial concept was developed at TU Delft [1] and explored on small scale prototypes, the research has now evolved towards large-format prototyping and experimental testing at TU Dresden. Further studies are performed in a joint effort between the institutions and additional R&D projects with industry partners have started.

The subsequent paragraphs provide an overview of the constituent components of the composite panels, their fabrication process, the result of an exploratory wind load test, followed by an outlook into future research. Parts of the current contribution are based on [2].

Fig 2: Rendering of a composite thin glass façade panel with 3D-printed core structure.

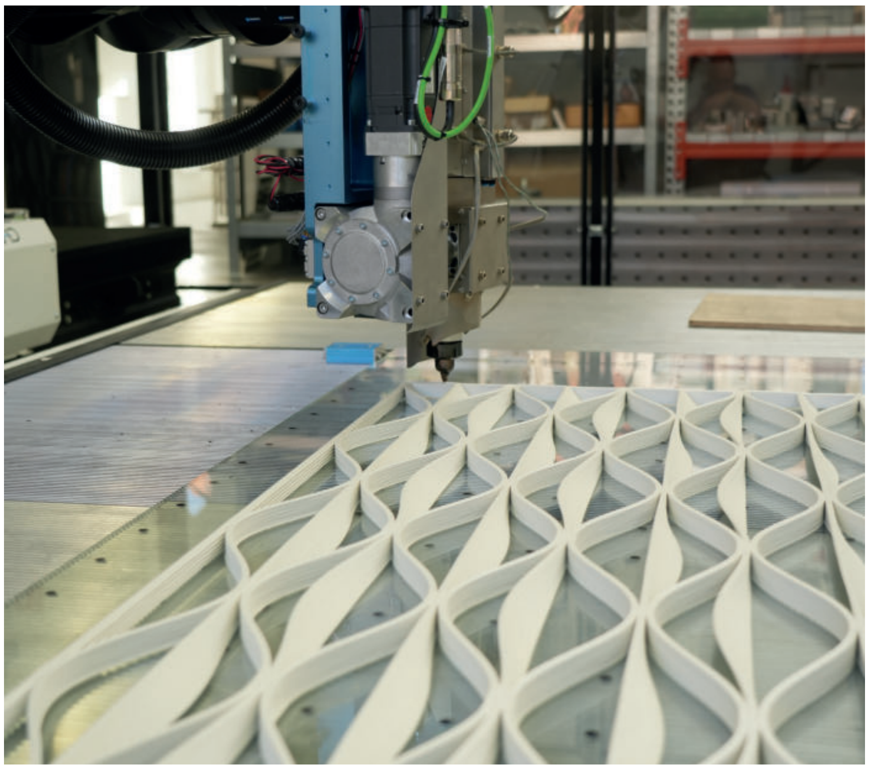

Fig 4: 3D-printing of the composite thin glass panel with a 3D-printed sine wave core pattern

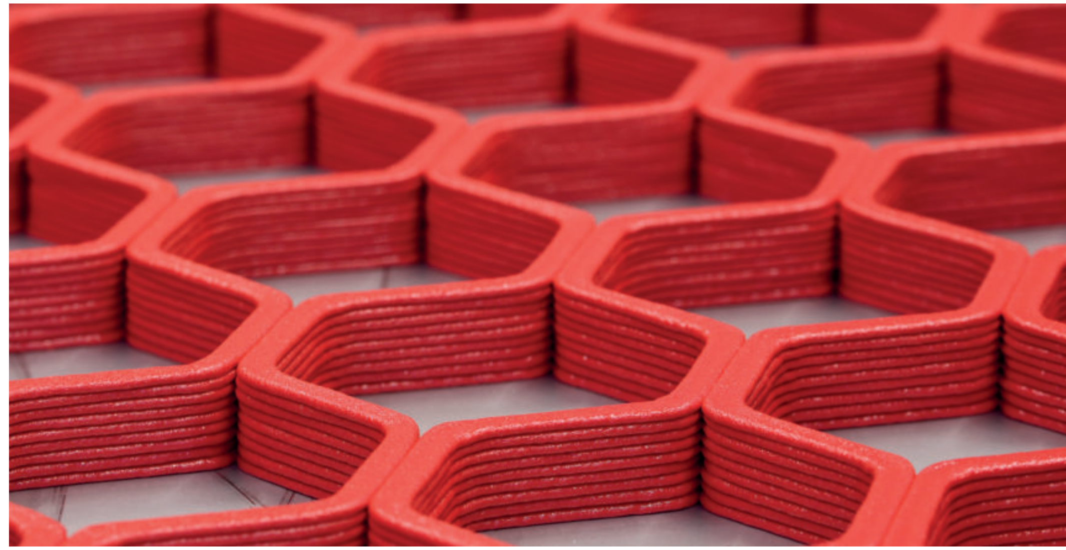

Fig 3: 3D-printed honeycomb core pattern.

Thin Glass Cover Layers

The thin glass that is used usually for displays on devices such as smartphones and tablets, offers promising characteristic for the building industry. Due to its high strength and low thickness, very light and material-efficient façades can be designed. The low geometric stiffness allows a high degree of design flexibility, such as cold bend curved glass panels. Of particular interest for this research is aluminosilicate glass with a thickness in the range of 0.5 – 2.0 mm and a high strength that is obtained through a chemical prestressing process. Additionally, also standard soda-lime silicate glass with a thickness of 3 mm and below is used.

Core Structure

The 3D-printed polymer core structure is an essential element of the composite panel as it provides stiffness to the panel and prevents too much out-of-plane deformation. Besides enhancing the structural performance of the panel, the core structure can also be exploited for daylighting purposes through either blocking or redirecting of incoming light through the shape of the core structure. Moreover, the shape of the core structure also provides a specific aesthetical quality to the panel and can be used for individualised designs.

In preliminary investigations, some core structures were examined for their structural design suitability [3]. From a mechanical point of view, the triple-periodic minimal surface of the Gyroid core pattern turned out to be particularly efficient at a smaller scale. Alternatively, stress line generation could be a possible approach for optimizing the stiffness of the core while keeping weight as low as possible [4]. However, the honeycomb core pattern, which is widely used for sandwich structures, is currently used as a reference core structure in recent research developments, see Figure 3. This basic shape brings rapid progress in manufacturing, especially through simple tool path programming. Its properties in composite panels have been extensively investigated [5–7] and the appearance can be changed in a variety of ways through the use of parameterization and can also be used for initial optimization concepts.

Based on that honeycomb core pattern and inspired from polymer 3D-printed interior wall panels [8], the wave pattern has been developed to open new design perspectives, see Figure 4 and 5. It consist of orthogonal frame lines and inclined function lines, which can be adapted to provide further features like shading and aesthetical preferences.


Fig 5: Composite thin glass panel with a 3D-printed sine wave core pattern.

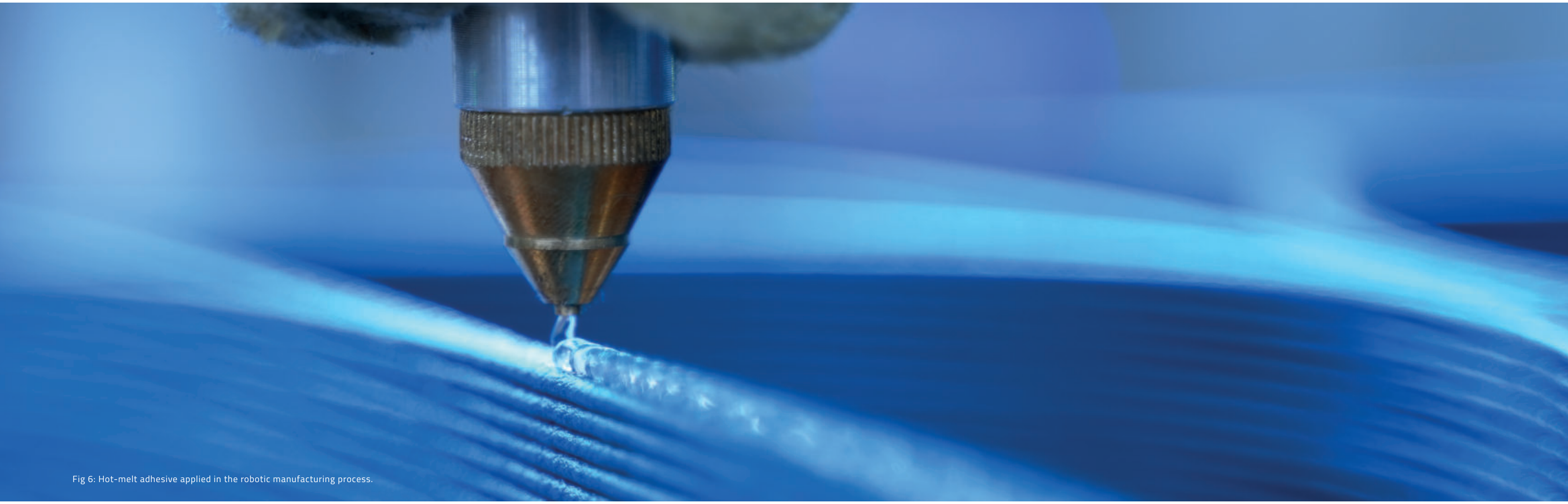

Fig 6: Hot-melt adhesive applied in the robotic manufacturing process.

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Core material

When selecting the polymer for the core structure, a wide range of thermoplastic polymers can be considered with the applied extrusion process (fused deposition modelling). Initial preliminary investigations of small-format materials have already reduced the number of polymers that are considered suitable for use in a façade [3]. Polycarbonate (PC) and Polyamid (PA) is currently most promising because of its heat and UV stability as well as its high stiffness. Due to the additional technical and monetary effort involved in processing PC, glycolmodified Polyethylene Terephthalate (PETG) is being used for the production of the first prototypes. This is particularly straightforward to process at relatively low temperatures and bears a lower risk of thermal stresses and distortion in the component. The prototypes shown in the current contribution are made from a post-recycled PETG with a glass fibre content of 20%.

Adhesive

To join the thin glass with the core structure, different adhesives are investigated [9]. The adhesive provides a mechanical connection transferring loads through the composite panel. When it is exposed to bending moments, the adhesive joint is under shear stress. Therefore, stiffer adhesives are favourable to reduce deflections. Here, UV-curing acrylates have served as a starting point for the research. But to take thermal stresses into account, certain strain levels must be allowed, which benefits the choice of an adhesive with lower stiffness. This led to the choice of hot-melt adhesives, which can be very well integrated into the robotic manufacturing process, see Figure 6. The applied hot-melt cools down and can then be reactivated in a separate lamination process to provide an adhesive bond to the glass.

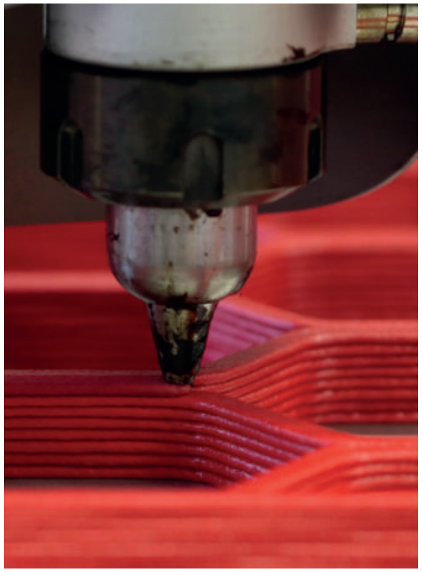

Fig. 7A: 3D-printing process of the polymer core

Fig. 7B: Robotic milling of the core surfaces

Fabrication Process

To take advantage of the possibilities of additive manufacturing and the flexibility of thin glass, the entire process is aimed to function digitally and parametric. Grasshopper is used as a visual programming interface to design a façade as well as the individual panels. Different optimization algorithms are included, to improve various objectives like mechanical and thermal properties, light control or the overall visual aesthetics of the façade.

The program processes the developed core structures in machine readable G-Code and prepares the additive manufacturing, subtractive post-processing and adhesive joining with glass. Figure 7 shows the fabrication steps supported by a robotic arm. In the first step the core structure is 3D-printed onto a heated bed.

In the second step the surfaces of the core structure are milled to allow for an optimal adhesive bond with the thin glass cover layers. In the third step the adhesive is applied. Finally, the glass cover layers are positioned and the adhesive is cured.

Wind Load Test

The structural response of the thin glass composite panels was investigated by means of an exploratory wind load test. For this, a prototype of about 2 m by 1 m was produced and mounted airtight into a façade testing frame, see Figure 8. Within this façade testing an air pressure or suction is created behind the panel, thereby loading the composite panel in out-of-plane direction. The load was applied in steps of 1 kN/m2 until a maximum of 4 kN/m2. During the test, the deformation of the panel was monitored by means of displacement sensors and a Digital Image Correlation system. This exploratory test demonstrated that the panel could resist extreme wind loading. The panel remained intact and the deformations remained within the required limits.

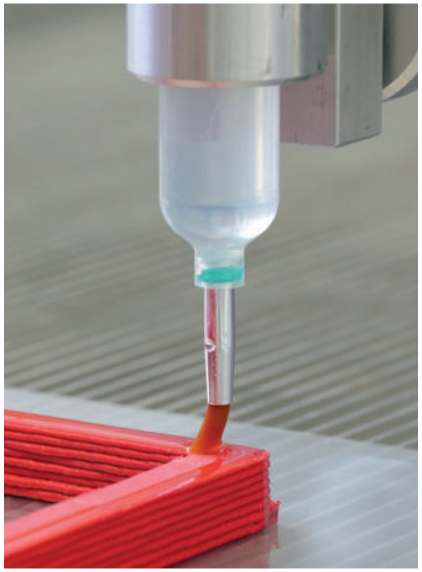

Fig. 7C: Robotic application of the adhesive

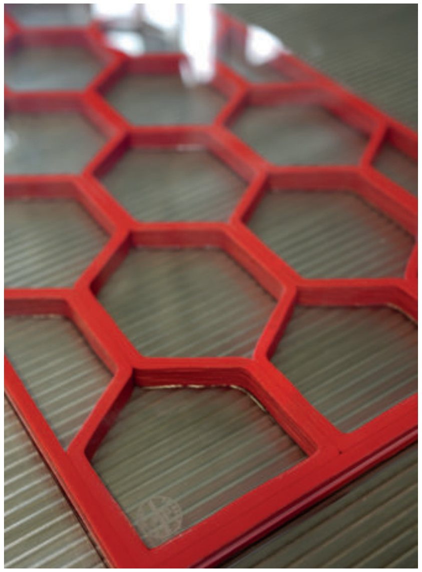

Fig. 7D: Application of the glass cover layers and curing of the adhesive

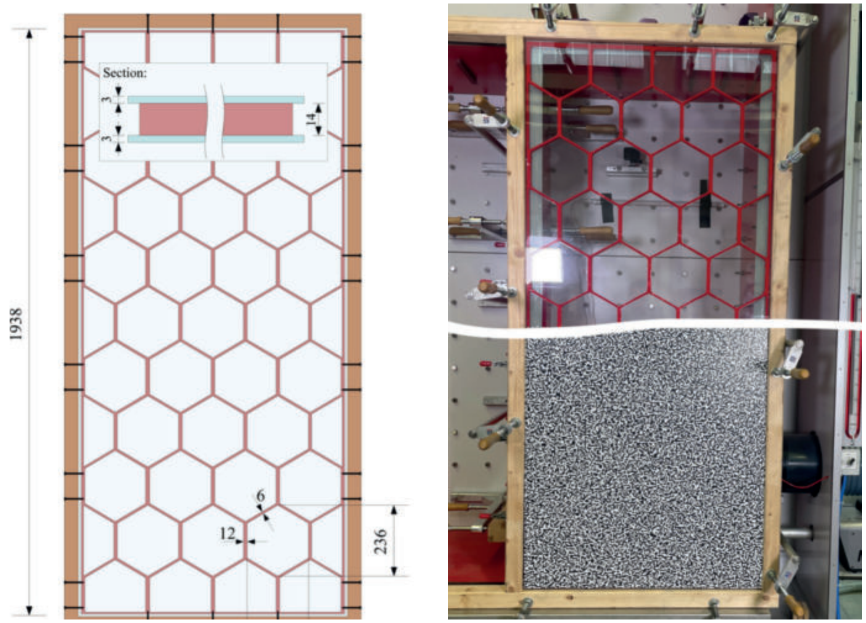

Fig. 8: Composite panel prototype mounted in a façade test rig for investigating the effects of wind loading. The bottom-right image shows a speckle pattern on the glass, which is needed for the digital image correlation system

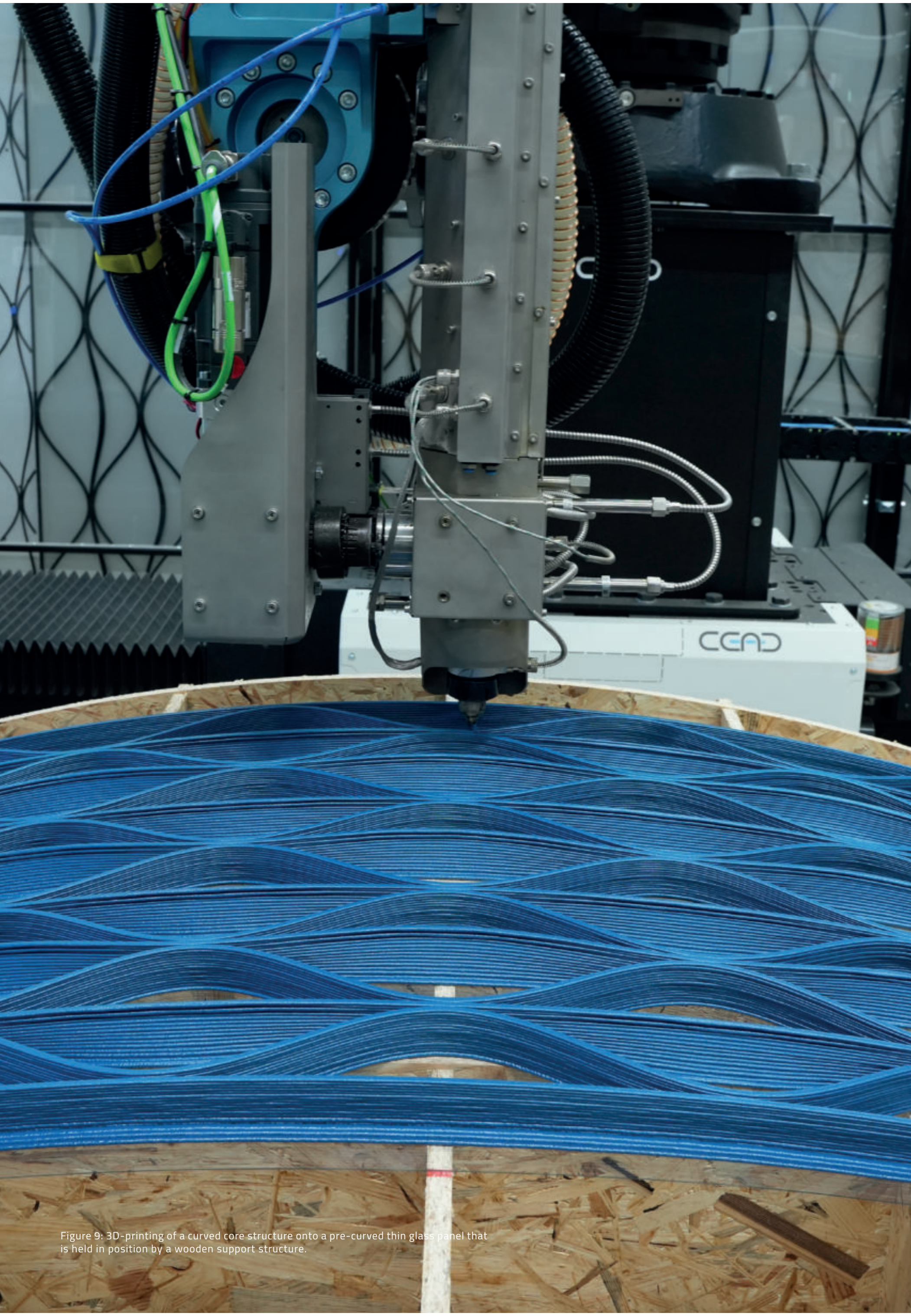

Figure 9: 3D-printing of a curved core structure onto a pre-curved thin glass panel that is held in position by a wooden support structure.

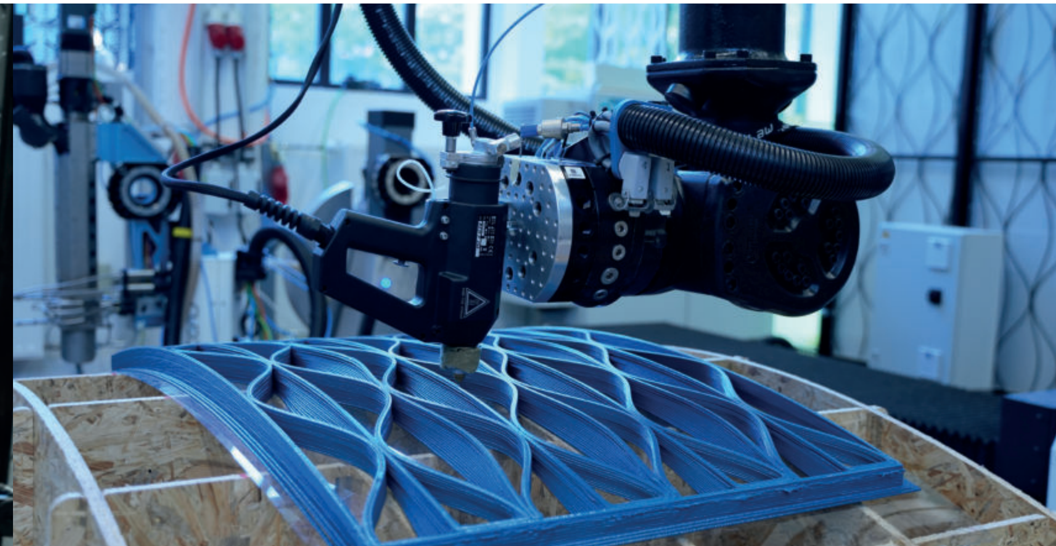

Figure 10: Robotic application of the hot-melt adhesive on the curved core structure.

Outlook

One of the next main challenges in the research is the creation of curved composite panels. This allows to take full benefit of the easy bendability of the thin glass in creating architecturally appealing curvatures. First attempts have revealed promising results, see Figure 11. To avoid the need for 3D-printing of support material, the curved core structure is printed directly on a surface with predefined curvature supported by a wooden support structure, see Figure 9. Afterwards the hot-melt adhesive is applied on the core structure, see Figure 10. The hot-melt is allowed to cool down during this process and is re-activated in a following lamination process. The thin glass is pressed in the curved position onto the core structure. Now it can be reheated to melt the adhesive and provide a load bearing connection after cooling down. The use of physically curing adhesives facilitates possible disassembly after use and offers advantageous recycling possibilities. Further prototyping results and investigations of their structural performance are expected to be published soon.

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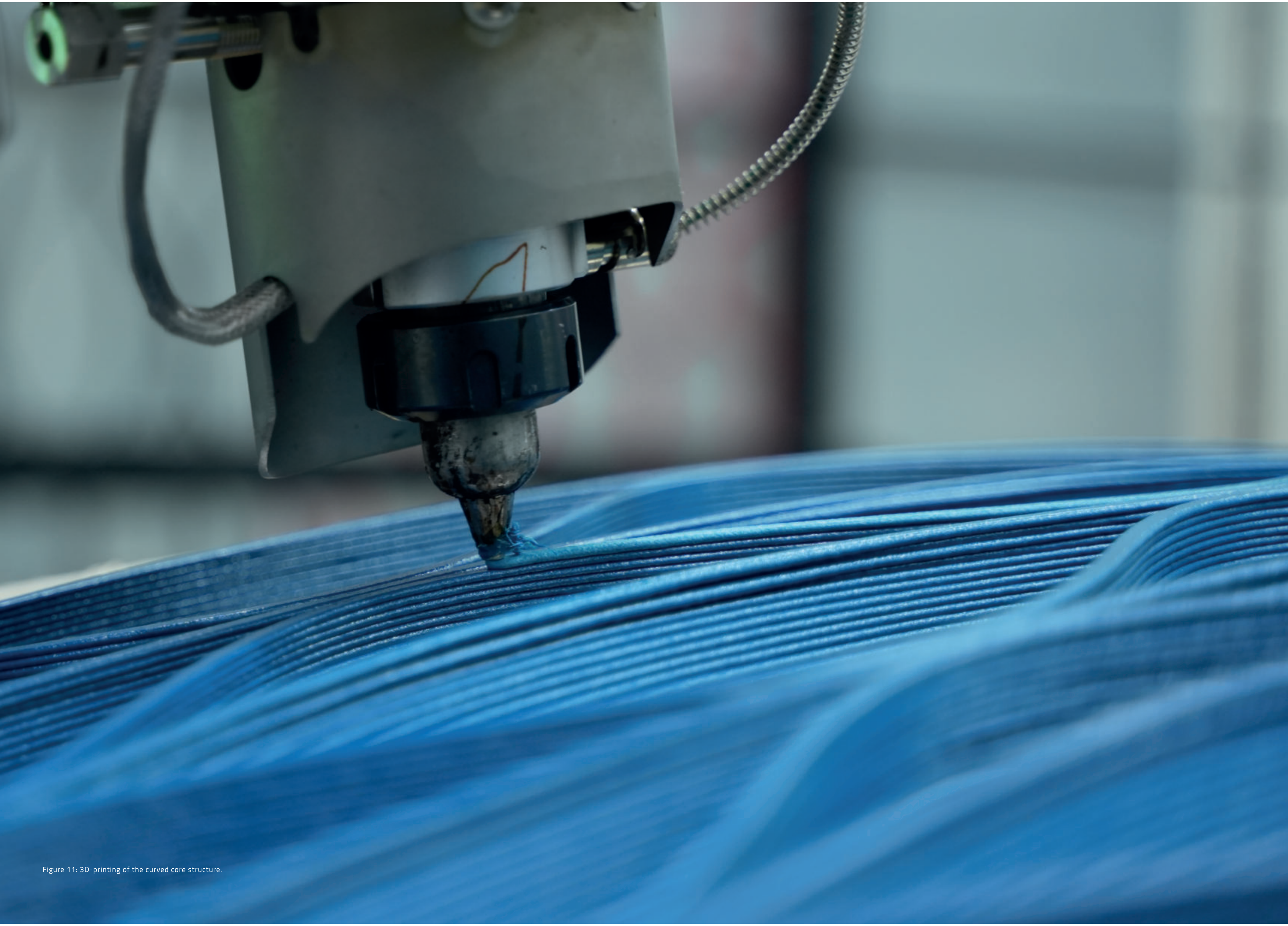

Figure 11: 3D-printing of the curved core structure.

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