Desert tectonics

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Abstract

The research hereby proposed illustrates the project of a 3D printed facade shading system for a service pavilion at Expo 2020 in Dubai.

Through computational design the facade concept, consisting in horizontal lamellas in the shape of waves with a complex geometry generation, has been optimized for additive manufacturing. At first many tests have been conducted on polymeric printable materials, through a climatic chamber in Politecnico di Milano, to ensure material performances and durability at high temperatures. Then a campaign of digital fabrication tests has been started to optimize, simultaneously, the shape of the facade and the printing settings (such as retraction value, layer height, speed). The printing tests have been held at WASP, in Massa Lombarda, through a 3MT printer with a pellet extruder allowing large scale production and reduced printing time.

Keywords: additive manufacturing, 3d printed façade, computational design, advanced customized design, digital fabrication, material testing

1. Introduction

Additive manufacturing, in the last years, has been growing from a niche industry to a fully-edged manufacturing technology [1]. However large-scale 3D printing is still facing many difficulties due to the few technologies available, lack of regulations in the building sector [2], large amount of testing required. The 'press and print' ideal simply bears no relation to reality [3], indeed, AM involves a range of complementary expertise such as design for additive [4], material properties knowledge, machine constraints and potential awareness.

In this paper the whole design to production chain or direct digital manufacturing (DDM) [5] of a 3D printed facade is going to be explained, shedding light on the advantages of the combined use of computational design, digital fabrication, material testing.

1.1 Design concept

The façade is a second skin providing shade for a service pavilion for Expo Dubai 2020, the design is easy replicable and can be feasible also for other overlay spaces. Hence the design for this facade had to fulfill the typical features of temporary architecture for Expo:

- lightweight (ease of transport and on-site construction)
- modularity (easy assembly and designed for production)
- flexibility (ability to cover many functions and to adapt to different constraints)
- identity (reflection of the identity of the hosting country)

The concept, designed by Renaud Danhaive (PhD Candidate, MIT) is inspired by the local environment and architecture: the pattern is created by the winds drifting through the dune sand related to the tradition of filtering light and creating privacy through ornamental screens. Algorithms modulate landscapes of curves, which are materialized into three-dimensional geometries displaying gradients of porosity, curvature, and thickness. Hence it is possible to physically "slide" these parameters on the Grasshopper definition that assess the design. As a matter of fact, one of the main benefit of the combined use of computational techniques and fabrication is exactly advanced customization [6]. However, some constraints driven by the AM process have to be taken into account, such as the dimension of the machine or of the nozzle of the extruder.

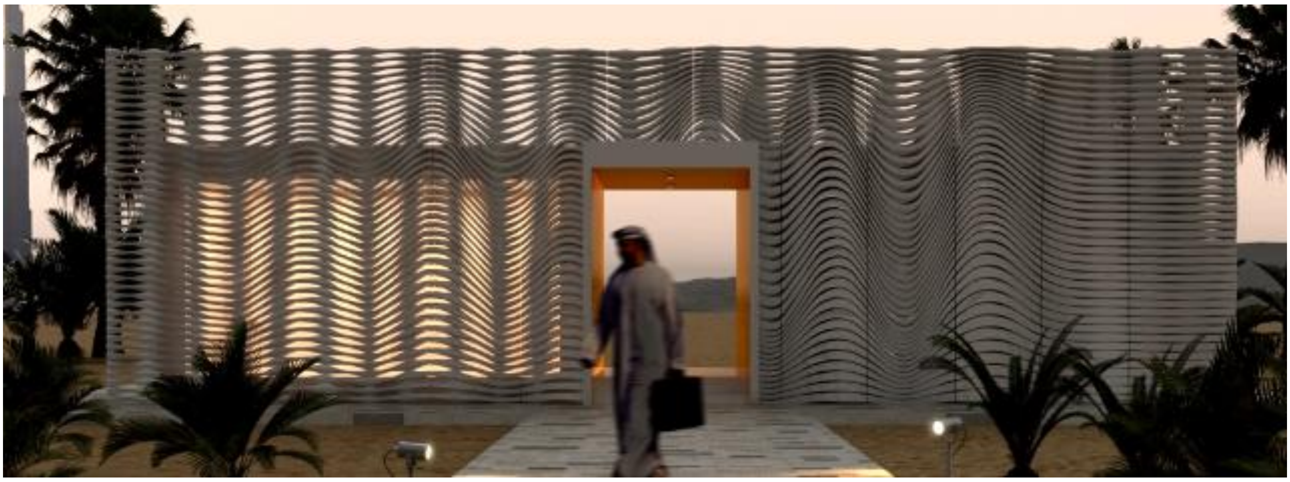

Figure 1: Rendering of the facade

1.2 Panelization

The facade is divided in panels in order to facilitate the printing and the assembly. Panels are 72 cm wide with a height that can vary according to the lamellas shape, these dimensions perfectly fit into the printer plate enabling to print them horizontally. This direction of printing (as will be further illustrated in section 2.1) makes the pieces stiffer and aesthetically pleasant showing curves in layers direction.

Every lamella has an opening in its terminal portion to allow mullions fitting in it, the façade is simply assembled by slipping panels into mullions, one on top of the other. Since the system is self-bearing the panels have been designed to less porous, thus heavier, at the bottom, becoming lighter while increasing in height. At the same time the lamellas have a thicker frontal section in the right part of the facade while they are thinner where the windows occur. The anchoring system (Fig.2) consists of mullions with a T section that prevent the panels from any horizontal or lateral movement, these vertical profiles are attached to the wall trough plates.

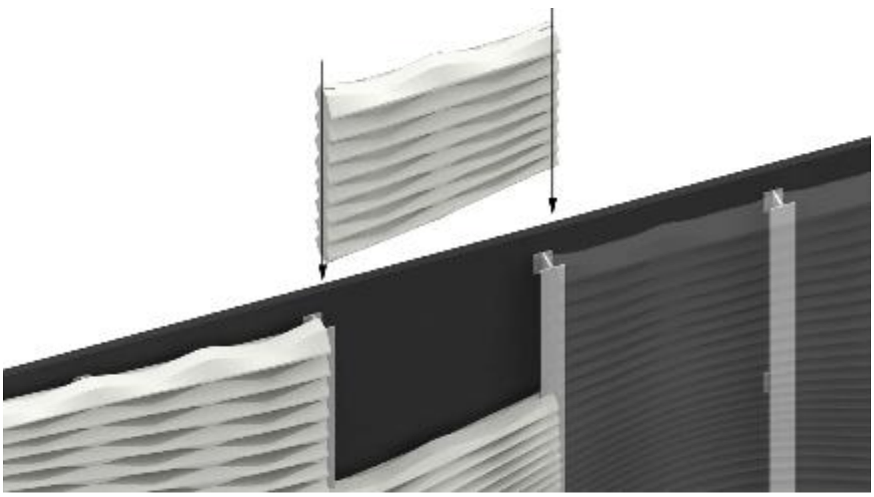

Figure 2: Rendering of the anchoring system

2. Testing

2.1 Design optimization for AM

For the fabrication with AM, the orientation of the geometry during the printing process is very important. In fact, the final product is the result of the overlapping of several layers of material, it is fundamental to consider that the material will have an anisotropic mechanical behaviour and a different aesthetic yield, strongly influenced by the presence of the layers [7].

In particular the anisotropy of the material occurs with a greater resistance both in tension and compression in the orthogonal direction to the one of printing, while a low tensile strength parallel to the printing direction.

For these reasons it was decided to print the panels starting from the rear face, thus making the characteristic layering of the FDM process emphasizes the geometry of the panel and the manufacturing process became an element of value and not something to hide. Whereas for the mechanical resistance, the plane where the tensile strength is greater is the one in which the greatest effort is given by the bending moment given by the fixing system of the panels.

2.2 From digital to tangible

The printing tests started in December 2017 at WASP in Massa Lombarda. The 3MT printer allowed to print the panels horizontally and, in order to have a better adhesion between the polymer and the plate, a wooden plate was employed. The panels were directly screwed to it (through the brim) preventing from their detachment that could have possibly happen due to the large contact surface and long printing time (around 8 hours for each panel). Lamellas have been printed basically following the contour of their shape, without an infill, since the wall thickness (derived from the dimension of the nozzle of the extruder of 3 mm) was enough to provide stiffness to the piece. The tests enabled also to verify the feasibility of the geometry in respect of the printer’s features at each section of the sliced three-dimensional piece (every 0.8 mm, corresponding to layers’ height).

Moreover, many materials have been tested: HT (high-temperature) PLA with 20% of wood fibers, white PLA with 1% of wood fibers, PP (printed with a perforated stainless steel plate to increase adhesion). Nevertheless HT-PLA was very promising in terms of thermal resistance (as illustrated in section 2.3), the high concentration of wooden fibers was causing delamination between the layers, thus excluding its suitability for additive. On the other hand, PLA and PP were both easy to print, whilst PP is stiffer and more adequate for exterior applications.

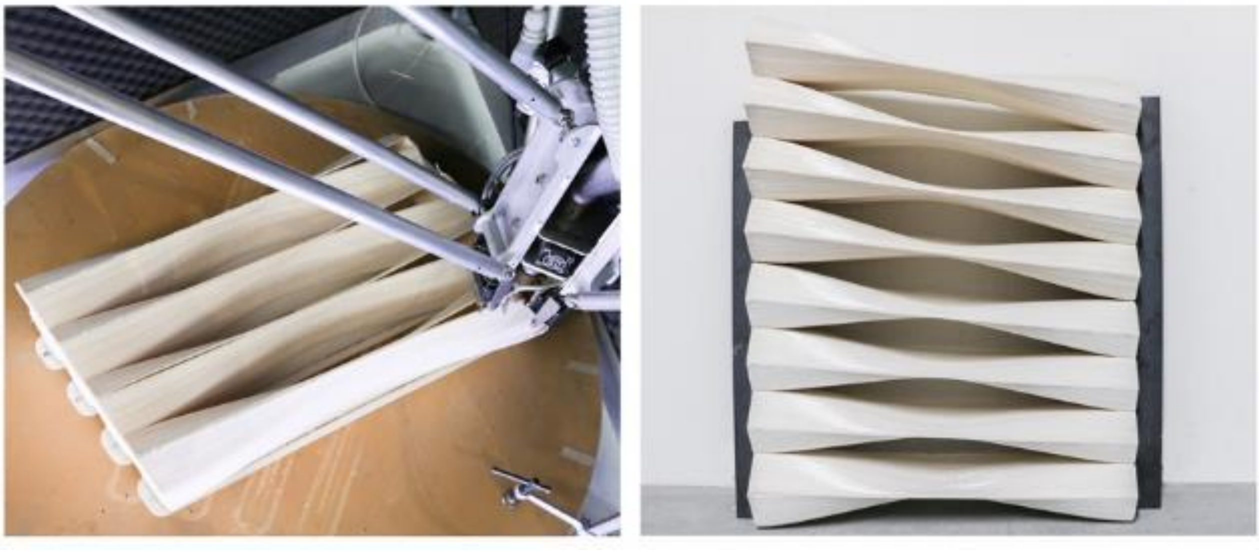

Figure 3: on the left the 3MT while printing the panel, on the right two panels assembled

2.3 Durability

One of the main scope of durability management is to predict reference service life (RSL) which can be crucial in the design phase as well as for maintenance planning (Daniotti and Spagnolo 2007 [8]). In this case the main objective was to select the right material for 3D printing that was feasible to be exposed in Dubai climate. We applied concepts used in the evaluation of RSL in order to discard the low-performance ones. Accelerated ageing (by means of a climatic chamber) has been employed to understand different materials behaviour under hot climate conditions to foresee thermal material expansion, eventual cracks, change in colour due to UV rays.

We conducted an analysis on Dubai climate to characterize tests with realistic assets based on data that we collected online trough “Weather Underground” and “Meteonorm”. We calculated Sol-Air Temperatures for the years 2016 and 2017 combining data of global radiation from Meteonorm with maximum daily temperatures from WU. This first study allowed to set a maximum temperature (70°C) that was kept constant in the test as well as RH 90% and UV rays by means of a UV lamp. In this phase it was not considered necessary to induce thermal shocks or implement the system with rain.

The test has been held through the climatic chamber at LPM (Laboratorio Prove Materiali) for one week (12th-19th of February, 2018). The sample dimensions were 8x8x1 cm except for some prototypes of the lamellas in different materials.

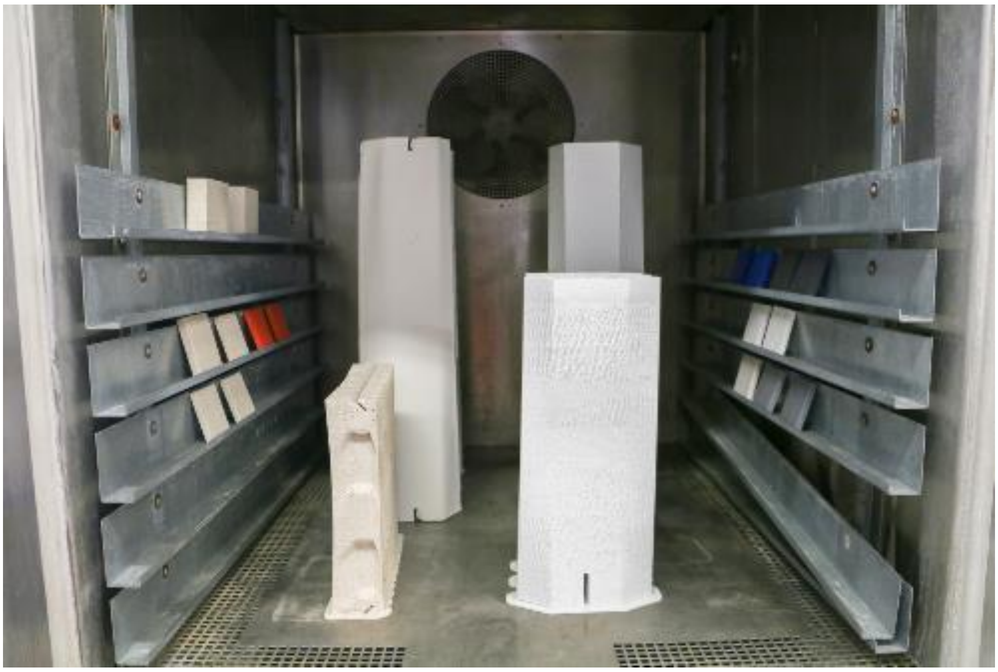

Figure 1: The climatic chamber loaded with samples and prototypes in LPM Lab

Each sample was printed both with horizontal and vertical layer orientation and each one had a twin copy that was used for comparison at the end of the test. The settings of the printer (Delta Was 20x40) were: nozzle size 0,7 cm; layer height 0,4 cm; wall thickness 0,8 cm; top/bottom thickness 0,8 cm; infill 5 %; brim 3mm. Polypropylene samples were printed through a 3MT with 3mm nozzle size, due to difficulties in printing with the smaller printer, they were already laterally deformed before the test. Printing temperatures (extruder and bed) were varying according to material properties.

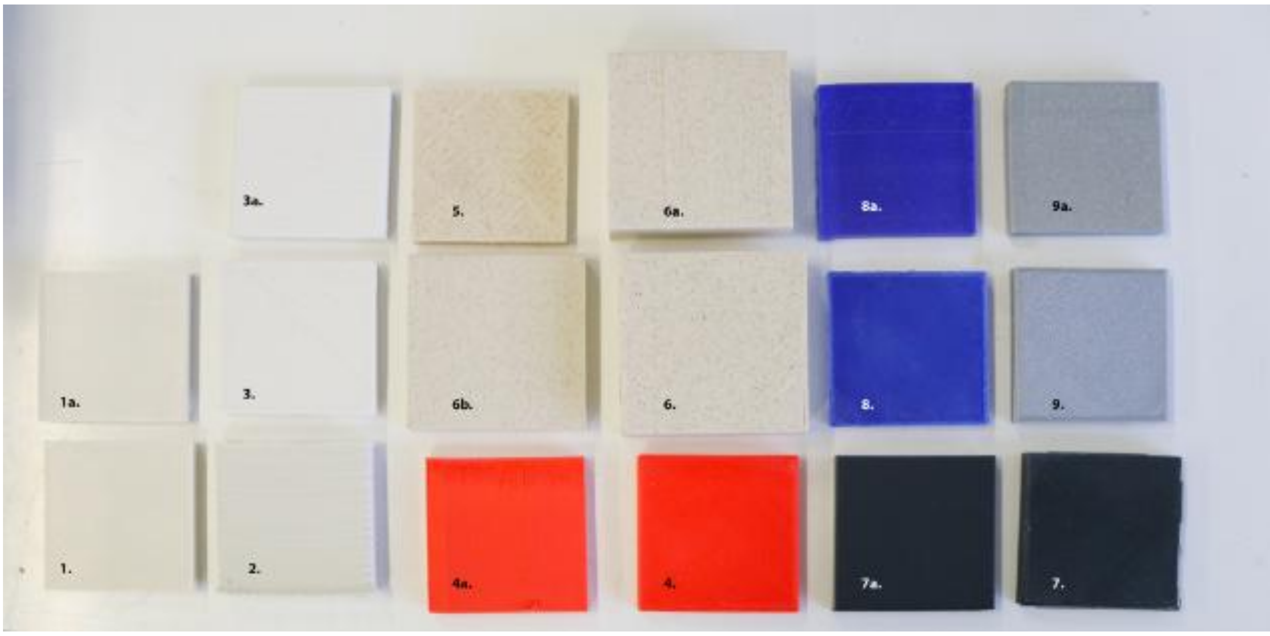

Figure 4: materials samples before undergoing climatic chamber

The materials employed were (see Fig.4):

- 1-1a ASA (Acrylonitrile Stirene Acrylate)
- 2 PP (Polypropylene)
- 3-3a PLA (Polylactide)
- 4-4a PLA (Polylactide)
- 5 HT-PLA with 20% wood fibers (High Temperature Polylactide)
- 6-6a-6b HT-PLA with 20% wood fibers (High Temperature Polylactide)
- 7-7a PLA (Polylactide)
- 8-8a PETG (Polyethylene Terephthalate Glycol-modified)
- 9-9a PLA (Polylactide)

In conclusion this test allowed to select better performing materials which were ASA, HT-PLA and PP. However, ASA is not feasible to use with AM for this project because of costs and high temperatures needed for extruding the material (250°C). HT-PLA with wood fiber was well performing under heating but it was not a suitable material for AM because the fibers themselves were causing layer delamination; therefore one possible solution would be to employ HT-PLA without fibers. PP was becoming yellowish which is a risk for a material that have to stay almost 1 year exposed to large amount of high UV rays, it would be possible to use this material if, for instance, applying an UV resistant coating.

3. Conclusion

In May 2018 a first mock-up of 2.5 mt height of a portion of the facade was printed in PLA and exhibited in Dubai. Actually, the most feasible material for this application, as highlighted in section 2.3, is PP, therefore it has been tested with addition of colouring agents and sand. Tests with sand (silica) have to be still implemented, and further improvements would include the application of UV resistant coating to prevent ageing (mainly yellowing).

Moreover, the flexibility of the design would open the possibility to replicate the facade for different overlay spaces providing shade and unique identity, especially with the employment of sand.

4. References

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