vMESH : How to print Architecture?

vMESH : Cómo imprimir Arquitectura?

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Abstract

The use of 3D printing in architectural research, education and practice has been almost exclusively destined to produce physical representations – models— of designed building. Recent advances in Additive Manufacturing (AM) have exponentially increased the mechanical properties of 3D printed parts, opening new opportunities for this technology to be directly applied to functional architectural components at an increasingly larger scale. Thus, this paper examines the design, structural and aesthetic implications, as well as the feasibility of advanced 3D printing technologies in the production of functional architectural components through the design and prototyping of a customized, non-regular spatial frame system.

Keywords: Metal 3D Printing, Volumetric Mesh, Digital Fabrication, Parametric Design, Spatial Frames

Introduction

The application of Additive Manufacturing (AM) — widely known as 3D printing — in architecture and structural engineering has been limited to the creation of physical models for representation purposes, primarily due to the relatively low mechanical strength of 3D printed parts. However, recent developments in metal AM technologies, open new opportunities for manufacturing functional and structurally consistent components, as the strength of metal parts is compatible with construction requirements. Due to its novelty, the application of metal AM in architecture remains nowadays largely unexplored, with only few exceptions, such as the tensegrity node by ARUP (Galjaard et al 2015). A

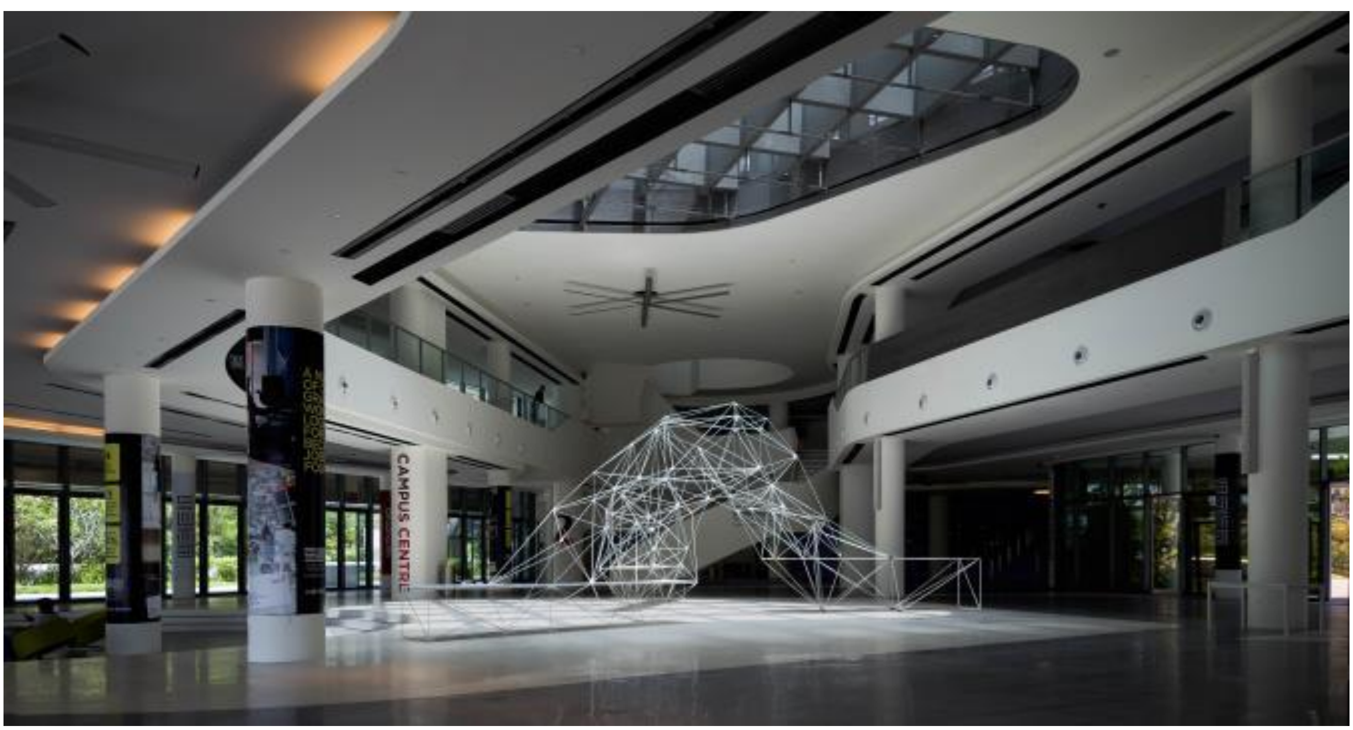

Figure 1: View of the vMESH Pavilion from one of the entrances.

survey of existing work has been done by C.Mueller (2016).

This research aims to shed light on how the use metal AM can increase structural, material, and spatial performance of buildings. We propose to investigate this application from the case of Spatial Frames (SF), a structural type consisting of nodes and bars organized into three-dimensional configurations. SF's remarkable long-span capacity and its very low self-weight make its use widespread in civic buildings. SF constitute a very promising application for metal AM because:

1. SF consists of relatively small complex parts (nodes) and large simple parts (bars). The small size and complexity of nodes makes them ideal for 3d printing technologies, in which size is a limitation and complexity an opportunity.

2. AM enables the customization of each node, overcoming current limitations of node standardization and opening the way for more efficient structures.

3. Current SFs are visually unpleasant and therefore usually hidden under cladding. The use of AM can significantly increase the "appeal" of spatial frames with a new expressive quality.

The main hypothesis of this research is that **the application metal AM can maximize structural, material, and spatial performance of SF.** Therefore, our goal is to propose, develop and test a new SF construction system based on AM technologies. The methodology includes development of design and analysis tools, development of manufacturing and assembly processes, physical experiments and prototypes and study of applications.

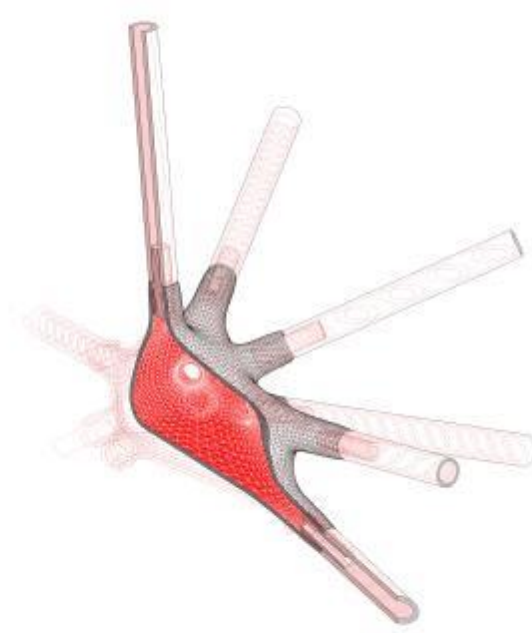

Figure 2: Section detail of the node and bars connection.

Precedents

AM in architecture

Application of AM methods beyond representation is currently limited to furniture design (e.g Studio Fathom's space frame table) or non-structural architectural elements (e.g. Adrian

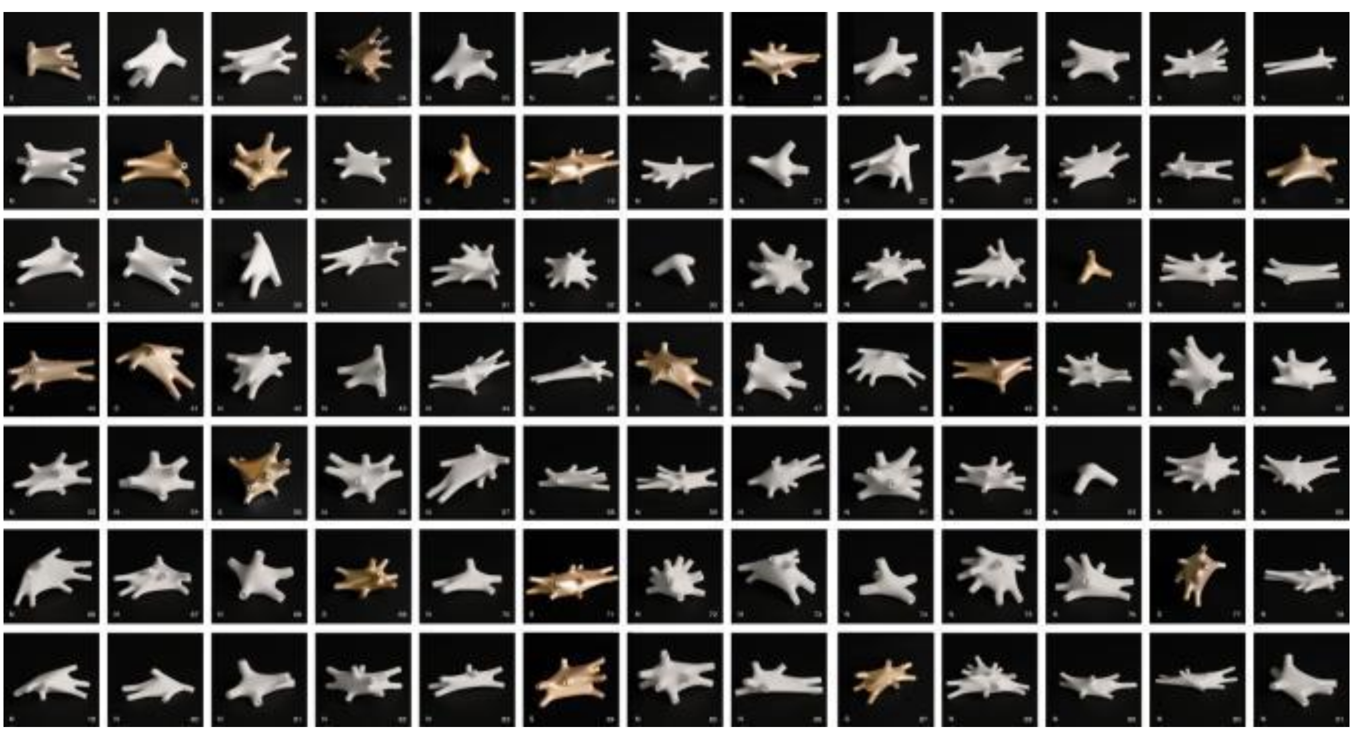

Figure 3: All the 91joins were parametrically tailored specifically for each complex geometric conundrum, according to the number of concurring bars, and the angle between them.

Priestman’s 6 Bevis Marks). Based on this study, it proposes and develops a structural system which implements AM as a main fabrication method.

Spatial Frames

Spatial frames are widely used today in a large number of civic buildings, including stations, sport complexes, and museums. This research aims to increase the design possibilities and efficiency of this already efficient structural type with a VMESH.

VMESH

The proposed system, VMESH, is loosely based on Konrad Wachsmann’s studies on spatial frames (Wachsmanm, 1961), consisting of custom 3D printed nodes and standard, off-the-shelf bars. The VMESH system is supported by an integrated design to fabrication approach (file-to-factory), in which a robust associative model accurately solves all the physical 3D joints and node-to-bar attachments prior to its physical assembly in a real scale, generates the files to 3d print the nodes and cut the bars, and describes all the geometric singularities of the spatial mesh. The design for each structural node is unique, containing labels and connection details to be directly 3D Printed in the selected material.

As a proof-of-concept, the VMESH system was applied in a 1:1 pavilion to test the performance of the parametric model and the fabrication process. The design and production process were altogether very successful, although the connection between bar and node became the bottleneck during the assembly process and requires further refinement. Spatial qualities and lightness of the resulting physical prototype surpassed the initial expectations, showing different nuances depending on the light conditions and the point of view of the user.

Design

As a prerequisite for this pavilion, an exhibition space was meant to be designed to showcase a selection of architectural projects as well as SUTD materials. Hence, the lightweight structure serves also as a support for three five-meter-long solid flat platforms which, hovering at different heights, displays physical models and student’s designs (Figures 1, 6 and 7).

By means of this design, this peace become a familiar and almost imperceptible piece due to its low ratio between mass and volume, such that visitors walk through it when crossing the lobby space; it ultimately brings a local subtle change in density, light and matter to an otherwise neutral and boundless space in the core of SUTD new Campus.

The design of the structure involve the development of an ad-hoc parametric model that takes as input a wireframe of the mesh to build and generates an number of bars and a code number to each bar and node. For each node, the parametric model generates the 3d mesh file, which also contains the numbers of the bars and nodes for easy assembly (Figure 2, 3, 4 and 5).

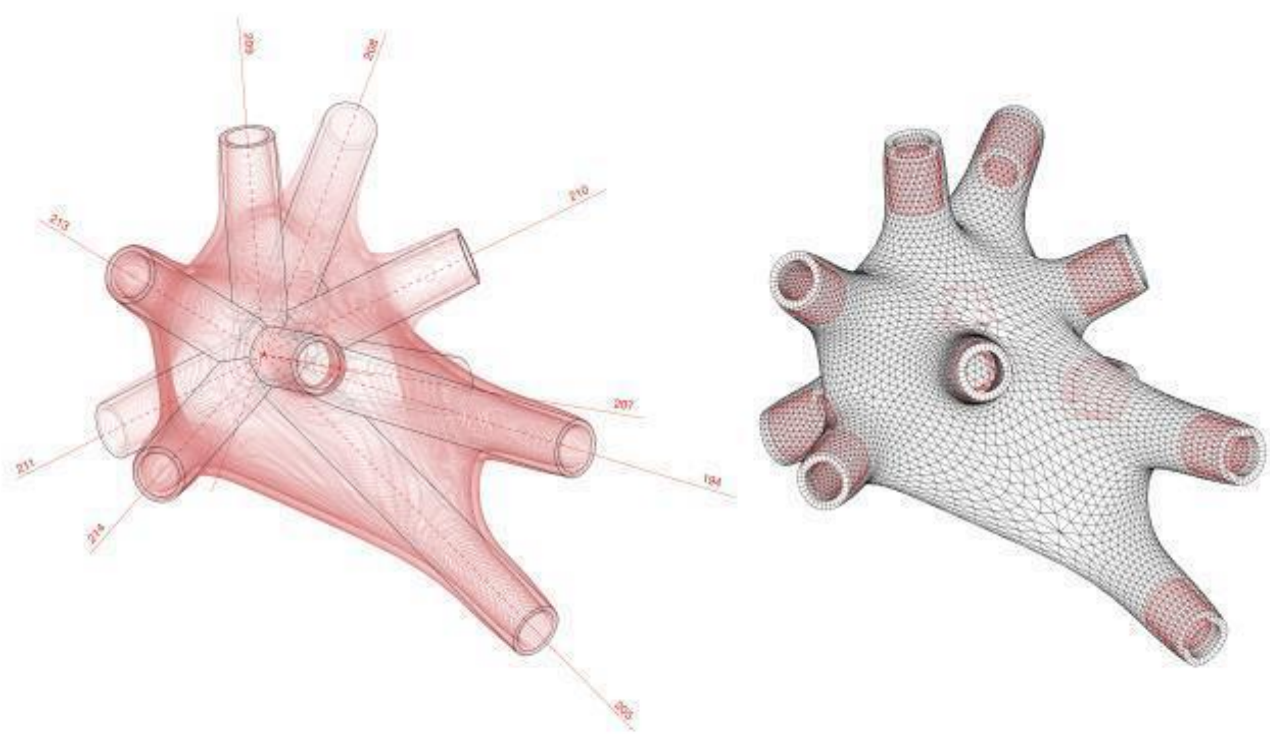

Figure 5: The geometry of each node is parametrically defined according to the angle of each incoming concurring bar. When bars are coming at sharper angles, the node “extends” in those bars to avoid collisions.

Figure 4: Polymer (above) and Metal (below) nodes**.**

Manufacturing

The manufacturing process involved two main building components: 91 nodes and 369 bars. The bars consist of aluminum tubes of 10mm diameter, individually cut to the length specified in the parametric model.

For the nodes, several 3D printing technologies were tested. Initially, desktop 3d printers such as Makerbot and Edison were tested, but soon moved to IOS polymer and metal additive manufacturing stations. For the final project, the 63 nodes were printed in Nylon and 28 in Bronze-Steel alloy. Figure 4 displays a close-up of the nodes in each material.

The assembly process was carried out during five days. During the first three days, a team of three SUTD students assembled the “legs”, while in the last two days, a team of fifteen students assembled the “dome” that bridges between legs.

The connection between the bars and the node was solved with an aluminum peg, inserted in the node and bar. For this structure, the parts were glued with two-component transparent epoxy (Figure 2).

Conclusions

This project validates the use existing 3D Printing to design complex and non-standard architectural forms that take into account aesthetics as a key feature of the design. Its level of accuracy, lightness, structural continuity and visual sleekness makes this system to be scalable and subject to be applied in different fields of Architecture, from the scale of furniture design to more structural-driven structures as in bridges or light-weight spatial shelters.

The uniqueness of the proposed construction system is that, through the application of metal Additive Manufacturing technology, it enables a singular design for each node, leading to unseen structural freedom.

The associated benefits of a much larger design space include economic and environmental gains through minimization of material usage, as well as social and artistic advantages through a more affordable and striking buildings.

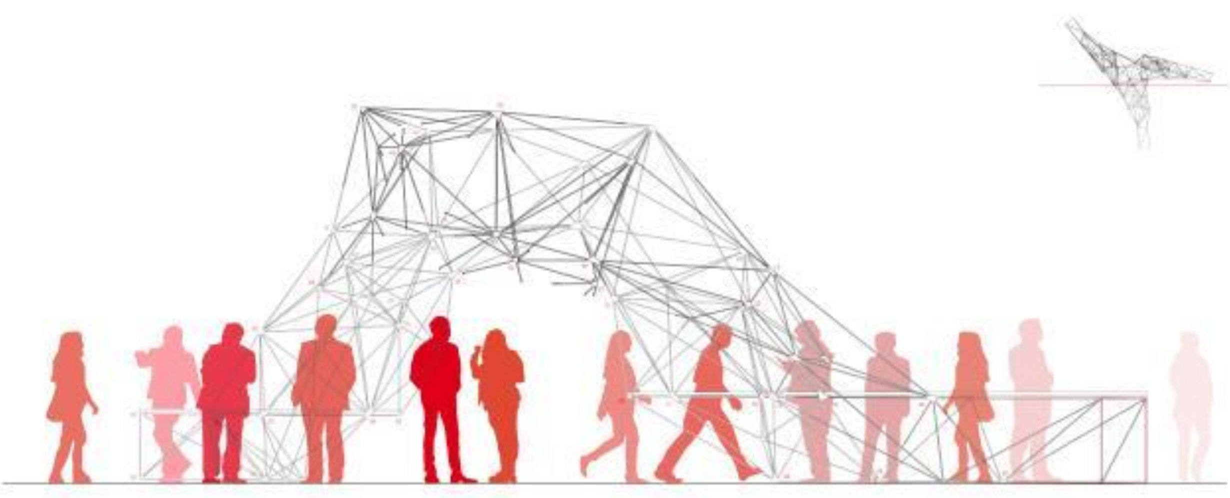

Figure 6: Vertical section of the structure.

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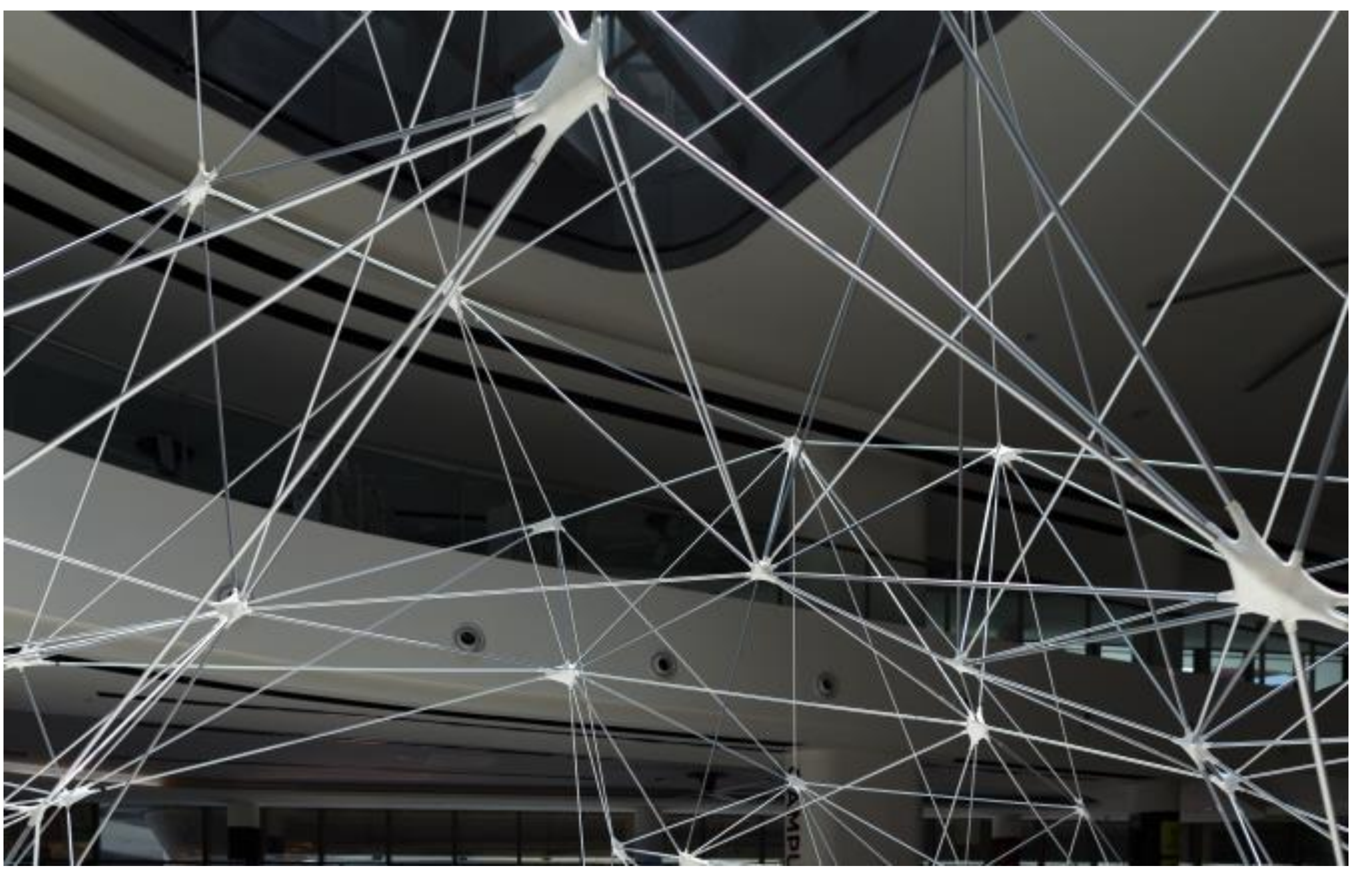

Figure 7: Close-up photograph of the structure.