# 3D PRINTED ARCHITECTURE

*A New Practical Frontier in Construction Methods.*

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**Abstract.** It is important to discuss and compare the rationale behind the success of the additive manufacturing technology in particular industries and at a particular scale versus full-scale building construction. The comparison should include structural qualities of the possible used materials, the cost effectiveness of the process, the time factor and its value in the construction process, the mass customization potential of the technology and its effect on building forms. The current state of technology in architecture, despite huge potential, has not produced new architectural forms.

## 1. Introduction

There is much literature regarding the benefits of additive manufacturing, or AM for short. While the adding of layer-upon-layer approach appears to be simple; there are many applications of AM technology with different degrees of sophistication that would meet several diverse needs. This includes design visualization, the creation of highly customized products for consumers and professionals, industrial tooling, construction in difficult environments, and one day the production of human organs. However, the strong potential behind the technology lies in its mass customization ability; that there is no more need for mass production to cut the cost of parts (Gibson *et al.*, 2015). Lately, the possibility of utilizing the technology to produce full-scale architecture has been seriously tested.

In May 2016, the city of Dubai launched the world's first “functional” 3D printed office building of 250 square meters. A structure of a single floor with all amenities printed in 17 days, and “assembled” on site in two days (Figure 1). The goal behind the project, as mentioned by officials, was to push the envelope on technological development, innovation and creativity. The machine responsible for printing out the office building was a massive warehouse-size printer that stands at about 6 meters tall, 40 meters long and 13 meters wide. The resultant building form, despite being slightly unconventional, still respects the traditional building shapes of vertical walls and horizontal slabs.

*Figure 1.* Dubai's first 3D printed office building.

Another company in China in January 2015, has produced a 5-storey residential house and the world's first 3D printed villa. The villa measures 1,100 square meters and comes complete with internal and external decorations (Figure 2).

*Figure 2.* 3D printed villa in China (3ders.org).

Moreover, back in 2014, ten 3D printed houses, each measuring 200 square meters, were produced in Shanghai, China. The buildings were created entirely out of concrete using 3D printing technology. The machines responsible for printing out these buildings are massive warehouse-size printers that stand at about 6 meters tall, 40 meters long and 12 meters wide.

However, the parts that were generated using the technology qualify as having been produced with alternative production methods. In the case of the Dubai office building, many repetitive similar looking parts were produced using 3D printing, then transferred to the site for assembly, a process that is very similar to precasting. The form of all the resultant building examples was not unique to the production method. The units making the parts for the roof are reinforced to create possible horizontal elements.

In fact, it is a replica of regular everyday architecture. The form of the produced buildings did not require mass customization. The only gain was time and cost.

On the other hand, to answer the question of the form, a Thai cement maker showcased in 2016 a small pavilion that adheres in form to the structural possibilities of the new medium (Figure 3). The resultant form is the only possible form without reinforcement. Despite the aesthetic qualities of the produced solution, the pavilion only qualifies as a piece of art rather than usable architecture. No meaningful spaces or horizontal planes are created.

*Figure 3.* A 3D printed pavilion with very interesting spaces and volumes by SCG Thai cement maker.

With this trend gaining momentum, many questions are raised about the logic and feasibility of utilizing such technology to produce full-scale buildings. Moreover, more questions about architecture aesthetics are raised: Would the 3D printing techniques produce different architecture?

## 2. Form follows Building Technology

The architectural form across history has always been affected by the technology producing it. Throughout history, we can pinpoint certain examples that can showcase the effect of building material and building technologies on the architectural product. Since caves of the caveman, spaces were shaped following the used technological tools and the structural properties of the natural stones in natural settings. Stone has been the dominant building materials throughout history with distinct structural qualities that enabled certain shapes only. The use of wood as a building material resulted in some different architectural forms as well (Figure 3).

*Figure 3. Left:* The Parthenon is the most important surviving building of Classical Greece. *Right:* The Thorncrown Chapel in Eureka Springs, Arkansas, 1980 by E. Fay Jones.

Hadrian's Villa, a large palace built near Rome on A.D. 125, used plain concrete extensively for its dome structure. The building materials are bricks, lime and pozzolana.

Frank Lloyd Wright was one of the designers who explored the possibilities of using concrete in a very creative way both reinforced and unreinforced creating many master pieces such as the 1920 the Millard House, the home Wright lovingly referred to as "La Miniatura". (Figure 4)

*Figure 4*. Hadrian Villa 125 BC and the 1920 the Millard House. Different ways concrete is used and its effect on form.

High rise buildings of the 20th century are clear evidence of how architectural form follows building technology. The invention of reinforced concrete has changed the profession and what it can achieve.

Additive manufacturing technology has the potential to be as interruptive as the introduction of reinforced concrete when formwork can be eliminated and any shape can be, potentially, produced with cost effectiveness and in a timely manner.

## 3. What Is Additive Manufacturing?

Additive manufacturing is the formalized term for what used to be called rapid prototyping and what is popularly called 3D Printing. The term rapid prototyping (RP) is used in a variety of industries to describe a process for rapidly creating a system or part representation before final release or commercialization. In other words, the emphasis is on creating something quickly and that the output is a prototype or basis model from which further models and eventually the final product will be derived. Gibson *et al.* 2016)

### 3.1 MASS PRODUCTION VS. MASS CUSTOMIZATION

Since the industrial revolution, mass production was the process with which manufacturers were able to significantly reduce the price of production, making products cost very competitive to consumers. The 20th century development was marked mainly by the mass production market.

Architecture as everything else has benefited from this trend which easily availed parts that contributed to the construction industry from construction equipment to assembly lines of doors and windows.

However, this did not change the form of the produced architecture. The building technology that shaped the form in the turn of the $20^{th}$ century did not change in an interruptive way to change the main lines of the architecture form.

By the nineties, the introduction of computers in the construction process and form shaping started casting its shadow on the form of architecture. Marked by the computer generated forms, that decade was a culmination of several advancements which enabled unprecedented architectural forms.

The ability to structurally analyze very sophisticated forms by computers, combined with the power of detailing parts that are not all mass produced, has started a new revolution. Mass customization of steel members, curtain panels and glass sheets began a brand new movement.

Mass customization is “the new frontier in business for both manufacturing and service industries. At its core is a tremendous increase in variety and customization without a corresponding increase in cost.” (Wikipedia, n.d.)

However, everything is still limited by the structural properties of the used materials. In the case of Additive Manufacturing, concrete, or more accurately, cement mix, is the most common material used to produce architectural solutions. As per the current technology development, the shown examples are all made of some type of concrete. It is not very clear how the horizontal elements of the buildings were solved structurally though, some have showed steel reinforcement being used in the process.

## 3.2 CONCRETE

Concrete is a universal low cost, extremely versatile construction material and it is the most feasible and suitable material for additive manufacturing in architecture, yet it does not have the qualities required to achieve desired structural qualities. As interruptive a technology as it can be, it is still limited to replacing precasting techniques. The examples previously showcased did not result in new architectural forms.

Concrete is also the only major structural material commonly manufactured on site, it has no form of its own, and more importantly has no useful tensile strength. Reinforced concrete in which steel bars are embedded to resist tensile forces, was developed in the 1850s by several people simultaneously.

## 3.3 THE CONCEPT OF REINFORCING

Concrete has no useful tensile strength. Historically, its structural uses were limited until the concept of steel reinforcing was developed. The compatibility of steel and concrete is a fortuitous accident. The two materials have similar coefficients of thermal expansion, and the two materials are chemically compatible. Also, concrete adheres and bonds strongly to steel surface providing a convenient means of adapting brittle concrete to structural elements that must resist not only compression, but tension, shear and bending as well. (Allen & Iano, 2016)

## 3.4 THE HORIZONTAL SURFACE STRUCTURAL PROBLEM

Without reinforcement, and due to the binding moment, it would be technically difficult to achieve horizontal elements out of concrete. This calls for other solutions that should affect the architectural form significantly.

The bridge project, which began by the Joris Laarman Studio and Petr Novikov and Saša Jokić from the Institute for Advanced Architecture of Catalonia (IAAC) to be placed across the Oudezijds Achterburgwal canal proposed for Amsterdam is one clear example of how to optimize the structure to achieve the desired form (Figure 5) and obtain horizontal usable surface; however, the material used had to be metal.

*Figure 5*. The bridge project, by Joris Laarman Studio proposed for Amsterdam (Source: 3D Printing Industry 2015)

## 4. Discussion

Despite the novelty and potential of the technology, no new meaningful and usable building form has been produced by it yet.

It is very exciting to imagine the future structures 3D printed out of steel or concrete, or maybe both of them combined, as a solution to the issue of structural stresses. A 3D printing machine that is capable of printing two materials intertwined together to make stronger members would enable much more diverse form to be achieved. A new material such as carbon fiber reinforced concrete or similar might fill the gap for the appropriate structural qualities.

The choice is either to adhere to current technologies and add traditional reinforcement to the material in order to achieve usable horizontal surfaces, or accept the generated form with less than efficient material usage and possibly less efficient spaces and volumes.

In order to describe what has been produced at the moment, it is safe to say that it is a traditional form that is produced with a new technology which would cut the production cost and time, but will not, in its current state, produce the possibilities envisioned by the technology.

Possibilities are endless if we can close the gap between the technology and the structural properties of the materials used. (Figure 6)

*Figure 6.* 3D printed buildings for Mars (Source: www.marscitydesign.com).

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