Analyzing the Competency of 3D Printing Technology in Architectural, Interior and Product Design

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Abstract. The new computational technologies and 3D printers have the ability to alter how we construct our surroundings. The additive manufacturing (AM) is a novel way for creating three-dimensional objects by layering materials like plastic, metal, concrete, sand, and other materials. The impact of 3D printing in the construction sector should not be underestimated, as it has the potential to reduce a variety of determining elements such as the construction process, material costs, and the overall project timeline. The 3D printing allows creating a work of art quickly, easily, and in great detail. 3D printers can create a wide range of objects, including buildings, sculptures, automobile components, toys, shoes, furniture, clothing, weaponry, machines, electronic gadgets, human body parts, and much more. The application of 3D printing in architecture and building construction has evolved from scale modelling to a full-size final product. The paper analyses this novel technology, as well as its possible applications and future prospects. The purpose of this paper is to investigate the use of 3D printing in the architectural, interior and product design sector through newly constructed pioneering examples, research, and discussion of some of the future trends that will make this technology more cost efficient. The systematic literature review has been explored through internet and secondary data from relevant published academic literature from journals articles and research papers. The case study method is used to identify extensive information through an in-depth analysis of existing cases in architectural, interior and product design.

1 Introduction

The 3D printing technology is currently one of the world's fastest growing technologies. The concept of 3D printing has advanced since the 1980s, albeit few studies have focused on specific 3D printing methods. As a result of these developments, 3D printers are becoming increasingly popular. It has also resulted in significant change/transformation in the field of architecture. Their use in architecture has progressed from scale modelling to a finished product that is full-size [1]. The global spread of technology has had an impact on all parts of life, including the creation of visual creations. 3D Printing technology is one of the visual work's creations. 3D Printing technology has made a number of significant
developments that can aid the advancement of the realm of interior designing. 3D printing is a printing process that can now make true three-dimensional objects, including work that has never been imagined before. The needs of the learning process of interior design student creativity are met by 3D printing technology. Designers go through a lengthy creative process that includes selecting design concepts, sketching alternative designs, digital modelling, and prototyping works. According to the M. Heleihil research about 3D printing technology as innovative tool for math and geometry teaching applications, explains that 3D printing requires higher levels of thinking, innovation and creativity. It has the power to develop human imagination and give students the opportunity to visualize numbers, two dimensional shapes, and three-dimensional objects. The combination of thinking, design, and production has immense power to increase motivation and satisfaction [2]. The 3d printing technology makes it possible for interior designers to explore their creativity in creating visual works. Heidegger, a philosopher, said about ‘technology perspective‘ that " the technology perspective is a perspective that is challenging, embracing (framing) and dissecting that is revealing and exposing [3].

3D printing is a technique for creating actual objects by layering materials based on a digital model. All 3D printing methods necessitate the collaboration of software, hardware, and materials. Different technologies are used by different types of 3D printers to process diverse materials in different ways. SLS (selective laser sintering) is a 3D printing technique that involves using a laser to fuse powder particles together to form an object. The materials used in the SLS method are usually robust and flexible. The most frequent materials are nylon or polystyrene [4]. As a result, studying the relationship between creativity and technology is particularly important since technology allows designer to experiment with new forms and creative products. A need to embody an idea or a perspective is accommodated through form [5]. In comparison to the traditional method, designers will be able to develop innovative designs with endless geometric shapes as a manifestation of their creativity using this technology. Figure 1 shows the worldwide 3D printing industry forecast.

![Worldwide 3D Printing Industry Forecast](image)

**Fig. 1.** The worldwide 3D printing industry forecast.

### 2 The 3D Printing Technology and Additive Manufacturing

Additive manufacturing (AM) is a novel way for creating three-dimensional objects by layering extraordinary materials like plastic, metal, concrete, sand, and other materials. 3D printing is a relatively new technology that can be quite useful in the design process. Initially, and in accordance with their capabilities, these technologies were viewed from the
standpoint of modelling or prototyping, in which complicated one-off things could be produced more quickly and cheaply than traditional model-making techniques [6]. This technology can print all of the simple shapes we require, as well as others that aren't conceivable with existing procedures. Since the mid-1960s, additive manufacturing has been used, and there have been numerous improvements in terms of materials used in the process. PLA (Poly Lactid Acid) and ABS (Acrylonitrile Butadiene Styrene) plastics are currently the most commonly used materials, as they have melting temperatures low enough to use in melt extrusion outside of a dedicated facility while high enough for prints to retain their shape at average use temperatures [7].

The utilisation of a computer, 3D modelling software (Computer Aided Design or CAD), machine equipment, and layering material are all prevalent AM methods [8]. The CAD file may need to be converted into a format that a 3D printer can comprehend, depending on the CAD programme used [9]. In next step, printer begins layering the material on top of each other to construct the thing in three dimensions. All 3-D printers make use of 3-D CAD software, which measures hundreds of cross-sections of each product to calculate how each layer should be built [10]. These objects can be made out of powder, liquid, or sheet metal. Additive Manufacturing technologies such as Rapid Prototyping (RP), Direct Digital Manufacturing (DDM), Layered Manufacturing (LM), and 3D printing may all produce identical goods quickly. The 3D printers may work with a variety of different materials, each of which is provided in phases (powder, filament, pellets, granules, resin etc.). Figure 2 shows the museum of the future, the first 3D printed building in Dubai, UAE.

Fig. 2. Museum of the future: first 3D printed building of Dubai.

3 The 3D Printing Technology in Architectural Design

The 3D printing architectural models has emerged as a viable option. Architectural models are typically formed of cardboard, wood, or other easily mouldable materials. Architects require models in order to research many parts of their designs. In both architectural and interior design, it is frequently changed to get a flawless concept of their vision. 3D printing on a large scale in the building industry will have a wide range of uses in the private, commercial, industrial, and public sectors. Faster construction, cheaper labour costs, improved complexity and/or accuracy, greater function integration, and less waste are all potential benefits of these technologies. Several different approaches have been demonstrated to date, including on-site and off-site manufacture of buildings and construction components, as well as the use of industrial robots, gantry systems, and tethered autonomous vehicles [11]. Fabrication of dwellings, construction components
(cladding and structural panels and columns), bridges and civil infrastructure, artificial reefs, follies, and sculptures have all been demonstrated utilising construction 3D printing technologies. It may also allow construction to take place in tough or dangerous locations where a human labour is not acceptable, for as in places with specific circumstances [12].

3.1 Case Study 1: Office Building in Dubai, UAE

Apis Cor's 9.5-meter-high and 640-square-meter-floor-space office building (Figure 9) in Dubai is the world's largest 3D-printed structure to date [13]. It is stated that the construction was completed with half the number of craft workers and produced 60% less waste (Figure 3). The building was built far faster than a traditional construction project, especially the on-site 3D-printed sections, which took only two weeks [14, 15]. Nonetheless, according to [16], the printing time for the general contractor integrated ceiling, electronics, and fittings was roughly two months. Furthermore, when the printing process was completed, the project required an extra two months to complete [17]. Table 1 shows several building components and their construction processes in general. As can be observed, all of the walls that account for the building's principal concrete works were 3D printed. Furthermore, column formworks were printed, which saved a great deal of time and formwork materials. The remainder of the construction work was completed using traditional methods (Figure 4). As a result, the potential savings from 3D printing, such as a 50-70 percent reduction in construction costs, a 50-80 percent reduction in labour costs, and a 60 percent reduction in material waste [18], are only applicable to the 3D printed building components, not to the entire construction project.

Fig. 3. The world’s largest office building in Dubai, UAE.

Fig. 4. Construction process of the world’s largest building in Dubai, UAE.
Table 1. Construction method of the various components of world’s largest building in Dubai.

<table>
<thead>
<tr>
<th>Building Components</th>
<th>Construction Method</th>
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<tbody>
<tr>
<td>Foundation walls</td>
<td>Conventional construction method by general contractor</td>
</tr>
<tr>
<td></td>
<td>3D printed</td>
</tr>
<tr>
<td>Columns</td>
<td>Reinforcements were placed manually</td>
</tr>
<tr>
<td></td>
<td>Formworks were 3D printed</td>
</tr>
<tr>
<td></td>
<td>Concreting was done manually</td>
</tr>
<tr>
<td>Slab Roof, ceiling, windows, insulations Plumbing and electrical installation</td>
<td>Precast Conventional method by general contractor</td>
</tr>
<tr>
<td></td>
<td>Conventional method</td>
</tr>
</tbody>
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3.2 Case Study 2: TECLA, Bologna, Italy

Mario Cucinella Architects in Bologna, Italy has teamed with 3D printing specialists WASP to build a low-carbon home prototype that is 3D printed using clay (Figure 5).

Fig. 5. A Tecla house in Bologna, Italy.

The residence was designed by Mario Cucinella Architects and built and developed by Wasp using clay collected from a nearby riverbed. It was named Tecla, a mix of the terms technology and clay [19]. An Italian architecture team was inspired by the potter wasp and utilised 3D printing to create the domed, beehive-like structure of a house as depicted in plan and section, (Figure 6 and Figure 7) out of zero-emissions clay in the hopes of demonstrating the technology's potential for sustainability [20].

Fig. 6. Plan of the Tecla house.
The buildings are created with clay from wherever they are being built, just like the industrious wasps, which means that if they have to be demolished, the only waste is the plumbing, gas, and electrical components. Cucinella co-developed the approach, TECLA, which stands for technology and clay, with the support of another firm called WASP, which specialises in 3D-printing solutions. Their modular design uses two 3D-printing arms at the same time to generate two domed rooms out of 350 layers of undulating clay with rice chaff as insulation, comparable to the traditional Moroccan Kasbah building methods. The goal is to be completely self-sufficient, and the design and durability may be adjusted to meet local climate and environmental challenges. Cucinella missed out on calling the project "circadian cupulas" since one is meant for the day, with a wide circular skylight and door letting in lots of natural light, while the other is designed for the night, with a smaller, warmer, enclosed setting under a smaller window [21]. According to Treehugger, Cucinella Architects plans to build these cupulas as self-sustaining eco-communities for both the fringes of cities and undeveloped countries.

4 Advantages and Disadvantages of 3D Printing in Construction

The curvilinear forms, rather than rectilinear forms, can be used to arrange structures in 3D printed buildings, making them far more robust. Walls of structures are typically hollowed out to allow utility lines to pass through while also reducing the quantity of materials utilised. Less material not only adds to the durability of the product, but it also saves architects and builders money on building costs. While the benefits are limitless, there are still a number of roadblocks in the way of this technology's adoption. Let's look at the benefits and drawbacks of 3D printing construction [22].

4.1 Advantages of 3D Printing in Construction

a) Construction waste is reduced: It is more environmentally favourable to use 3D printed construction for architectural projects. The printed construction will only generate roughly 30% of the garbage that a typical construction project produces while utilising very little energy.

b) Increased the number of design shapes: 3D printing allows for design shapes and customizations that would be impossible or prohibitively expensive to achieve through traditional building. Small amounts of concrete may be precisely placed where needed for complex shapes by printers, considerably improving an architect's design choices.
c) **Reduced Construction Time:** When a building project is completed with a 3D printer, the construction time is drastically reduced.

d) **Construction costs are reduced:** Because of the savings in raw materials and, more crucially, labour, 3D printed buildings are much less expensive to construct than those constructed using traditional methods. By having most of the building performed by 3D printers, an architectural project's labour expenses can be lowered by up to 80%.

### 4.2 Disadvantages of 3D Printing In Construction

a) **Building Regulations:** There are no rules or procedures for obtaining approval for 3D printed structures for home or commercial usage. First, the government would have to establish electrical, plumbing, structural integrity, and public safety rules that must be obeyed.

b) **Types of Materials:** Concrete and polymers are about the only materials that can be delivered from the printing head.

c) **Engineering Compatibility:** 3D printed buildings have piqued the interest of a small number of architects and engineers. During the design process, the additional capabilities that come with the new technology are not utilised. Because traditional plans aren't compatible with 3D printers, the entire design process must be rethought.

d) **3D Printing Technology is Expensive:** The cost of 3D printing equipment and materials makes the technology prohibitively expensive. Industrial 3D printers are still quite expensive, costing hundreds of thousands of dollars, making the technology's initial costs very high. Capital investment for a single machine starts in the tens of thousands of dollars and can reach hundreds of thousands of dollars.

e) **3D Printers aren't that User-friendly:** 3D printers have come across as easy to operate and sound more useful than they really are due to the excitement and possibilities surrounding 3D printing technology.

f) **Unemployment** Because 3D printing just requires one process, it may produce product ideas and prototypes in a couple of hours. It gets rid of a lot of the phases that subtractive manufacturing requires. As a result, it does not necessitate a significant amount of labour. As a result, 3D printing may result in fewer manufacturing jobs. Manufacturing employment losses might have a significant impact on economies in countries that rely heavily on low-wage jobs.

### 5 The 3D Printing Technology in Interior and Product Design

Additive manufacturing, often known as 3D printing, has opened up new options in the design and manufacture of goods across a variety of industries. The worlds of architecture and interior design have begun to explore and diversify into 3D Printing, using this technology to build spatial elements, furniture, decor, and lighting [23]. The materiality of 3D printing is unrestricted, and it has been demonstrated to be sustainable, efficient, and aesthetically pleasing in its application. Designers have envisioned and realised their ideas in 3D Printed shapes all across the world. "A house is more than simply the walls; the visual design and feel of the interior is equally important," says Emerging Objects, a design firm that produced a 3D printed interior for a 3D printed house [24]. "These interiors are massive, beautiful walls or "vessels" within the house that look like enormous sculptures from the outside," they explain. They can quickly manufacture lightweight interior walls to partition interior space using both cement polymer and their unique substance Saltygloo [24].
5.1 Case Study 3: Juice Bar at Loft Flagship Store, Tokyo, Japan

Loft, a Japanese department store, has reopened its flagship building in Tokyo's Ginza district. The exclusive DUS 3D printed furniture is featured in the interior design: A one-of-a-kind look at 3D printing, new materials, and old crafts (Figure 8). The Loft Flagship store's 3306 Sq. M total interior design was handled by Schemata architect Jo Nagasaka. He challenged DUS to create "new 3D printed furniture." Clients Loft recognised the need of constantly finding new ways to distinguish themselves and promote their items as a household name warehouse. DUS responded by creating five custom settings that showcase the best features of each product category [25].

![Fig. 8. Juice bar at Loft Flagship Store.](image)

The Juice Bar Kiosk at the Loft Flagship Store uses 3D printed solutions to produce statement furniture pieces that mix aesthetics and usefulness. To produce recurrent printed patterns that translate into the Form, the company draws inspiration from Japanese folding and drawing techniques. The Juice Bar achieves transparency by printing semi-open screens with the ability to open and close, revealing circular internal patterns. The Juice Bar in the 'healthy cooking' department serves as a showcase for the juicers and kitchen machines on the surrounding shelf. Japanese paper screens inspired the open design (Figure 9). The printed three-dimensional panels are detailed to the point where the bar appears to be a single monolithic structure. The surface appears solid at first glance, but closer inspection reveals detailed patterns that play with light, texture, and colour [25].

![Fig. 9. Recurrent 3D printed patterns closed views at Loft Flagship Store.](image)
5.2 Case Study 4: Stratasys, A 3D Printed Chair by Zaha Hadid Architects

Zaha Hadid Architects (ZHA) began by designing a very lightweight chair that utilised its geometry, details, and manufacturing to highlight and improve its performance (Figure 10). ZHA evaluated the loading situation of a person sitting down when investigating the design potentials of the structural optimisation process, and used the optimisation results to produce a structural pattern that deploys material density and depth where structurally required [26]. The designers were then able to include these structural features into the design using the superior capabilities of Stratasys' Objet1000 Multi-material 3D Printer [27]. Stratasys was able to 3D print the chair with a range of colour and opacity, from transparent to opaque cyan, to indicate the structural performance of each area (Figure 11).

Fig. 10. Stratasys – a 3D printed chair design.

Fig. 11. Plan, section and elevation details of the chair.

The chair has been reproduced in a variety of colours and modifications since the development of the first 3D printed prototype in 2014. The starting point for Zaha Hadid Architects was to develop a relatively lightweight chair that used its geometry, detailing, and construction to highlight and improve its performance (Figure 12).

Fig. 12. Structural form-finding.
5.3 Case Study 5: A 3D Printed Lamp at Paris, France

Paris-based artist duo Linlin and Pierre-Yves Jacques merged interior design and 3D printing in their latest gorgeous creation - a lace-patterned light (Figure 13). When turned on, it creates lovely floral patterns on the walls of your room (Figure 14). For a dazzling impact, its little elements have been enlarged on the walls and ceiling [28].

![Fig. 13. The 3d printed lamp by LP Jacques.](image)

Traditional lace served as inspiration for the designers, who digitally recreated its qualities. They claim that the technology enabled them to bring their grandiose concepts to reality, as well as provide enhanced carved details that would not have been possible without 3D printing. Between the thin white stems are microscopic shapes and textures that imply the look and feel of actual lace [29].

![Fig. 14. Lace patterned light looking pretty decent.](image)

6 Benefits of 3D Printing in Interior and Product Design

Interior design is a highly competitive field, and architects face stiff competition with every project they begin, especially when clients have a wide range of options. To stand out and stay ahead of the competition, interior design firms must strive for success and inventiveness. In the future, they should be able to win more projects.

a) **Showcase complicated design in greater details**

   A 3D printer is an important tool for creating and inspecting complicated features like the façade and the finely textured roof. These intricate and precise features, which would be difficult or impossible to design accurately by hand, may be quickly accomplished using 3D printing online [30]. This will help clients comprehend how
the features would appear in real life and improve their visual perception. To bring the model to life, it might also show how shadows and sunlight would appear during the day.

b) **Experiment with different materials and colors**
A 3D printer is an important tool for creating and inspecting complicated features like the façade and the finely textured roof. These intricate and precise features, which would be difficult or impossible to design accurately by hand, may be quickly accomplished using 3D printing online [30].

c) **Reduce manual labour by a significant amount and save hours of overtime**
Making a construction interior design by hand is a tedious and time-consuming procedure that necessitates perseverance in order to generate high-quality results. Manually creating a conceptual model out of cardboard, foam, or wood might take several days depending on the size and level of detail. Manually building a finished model requires a lengthier timeframe, which can take several weeks. This is a considerable time investment for a single model, and using a 3D printer would drastically reduce the timeframe with economical 3D printing services [30]. The technology eliminates all of the measuring, cutting, bonding, and other human labour required to build a complete model, giving architects more time to focus on their design.

d) **Make multiple copies**
Many different versions of the final model can be easily created, and the 3D print online image can be saved indefinitely for future reference. Given the traditional methods of model construction, the capacity to swiftly manufacture several replicas is extremely unique. This enables the interior designer to give a scale model reproduction of the project to their clients and partners [30].

### 7 Future of 3D Printing in Architectural, Interior and Product Design

Although 3D printing technology (Stereo Lithography, Fusion Deposition Modelling) has been around since the early 1980s, it has been reluctant to catch on. There are many different perspectives on where the technology might go, but it will become more cost efficient in a variety of industries, making research and mass customisation in architecture more possible. Although 3D printing is still in its infancy across all industries, the technology's prospective benefits appear to be propelling it forward. Some predict that 3D printers would mostly be used to manufacture building components and panels in factories or on-site, while others see 3D printing as a transformative technology that will alter the construction sector.

The construction time efficiency may be a crucial role in the introduction of this technology in India, but the type and scale of the structure are also important factors to consider. As a result, it is possible to argue that 3DP technology will be successful in both mass manufacturing projects and massive buildings with restricted floors. It has the potential for speedy production and high quality, which could compensate for the current low quality of work among working people. Furthermore, the adoption of this technology will allow certified architects to reclaim control, resulting in improved internal environmental quality and energy performance in the construction industry across the country. Furthermore, modifying India's current building standards may increase architectural identity and strengthen architects' final responsibilities in the construction business.
8 Challenges and Limitations of 3D Printing

When comparing the cost of bricks (used for ordinary wall construction) to the cost of reinforced concrete (which should be utilised for 3DP), the projected hurdles to the use of this technology is linked with cost [22]. More obstacles include a lack of practical knowledge, a lack of scientific information, and industry/society rejection of norm-changing approaches, as well as a lack of stakeholder interest, a skilled workforce, and the cost of importing. Another factor to consider is modification restrictions, as working with established models limits design flexibility. It's also unable to receive change orders during construction, thus design changes are out of the question. Modifications are also not possible during operation. Other factors to consider include the high costs of durability and maintenance operations. Furthermore, the primary source of worry is that 3DP technology is imported rather than developed locally, resulting in significant cost increases.

9 Conclusions

The 3D printing is a disruptive technology that can be used in the construction industry to gain economic and environmental benefits. It is an automated layer-by-layer production method. In a wide number of architectural research topics, 3D printing technology offers various economic benefits. To begin with, 3D printers can theoretically build most objects that can be redrafted using CAD software rapidly and cheaply. This has a significant practical benefit for daylighting studies as well as many other sorts of empirical architecture studies. Second, compared to traditional manufacturing, it results in less waste of raw materials. Third, unlike traditional manufacturing, which relies on large-scale production to offset costs, 3D printing is very cost-effective for smaller production runs or large-scale customization, including the creation of extremely intricate, difficult, or impossible-to-make products using traditional manufacturing techniques. The industry is pursuing a number of initiatives aimed at lowering the cost of technology.

The findings of this article, particularly the analysis of case studies, show that 3D printing technology has significant architectural, interior design and product design potential. These innovations have the potential to transform the construction industry's future. It is feasible to assert that if development continues at a given rate, it will change the construction process. However, in order for technology to advance at a faster rate, more resources are required. The truth is that none of the 3D construction printing projects that have been completed so far have been competitive. There may have been some cost savings in labour and materials, but it was not competitive with standard construction methods. Much more research is needed on still-unsolved issues such as structural and mechanical stability, material life, and toxic effects of materials, to name a few. The life cycle performance of printed buildings/building components is currently unknown, especially because 3D printing in the construction industry is still in its infancy.

References


