Case Study on 3D Printing Implementation Strategies

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The construction industry is one of the slowest to adapt and utilize new technologies. As a result, the construction industry has remained stagnant while almost all others are improving efficiency. It is becoming incredibly important for the construction industry to adapt to new technologies in order to counter the current worldwide shortage in skilled labor. 3D printing is one of the most advanced technologies that can help increase efficiency and reduce cost across all sectors of the construction industry. This paper will analyze implementation strategies used on three different construction projects using 3D printing and will evaluate what made them successful and what challenges were faced. When analyzing the implementation strategies, this paper will focus on what collaboration between the design and construction team was most effective, and how the use of 3D printing changed the construction process. The purpose of this paper is to provide suggestions regarding which of the strategies are most effective for differing project types.

Key words: 3D Printing in Construction, Implementation Strategies, Best Practices

Introduction

History of 3DP in Construction

3D printing was first invented in 1984 when Charles Hall used stereolithography to create a 3D model layer by layer. Hall completed this process by using a UV laser to melt a photopolymer and applying it to print each individual layer. Architects and contractors used this early technique to create scaled 3D models to help with the design process. However not many advances in 3DP came until early 2000s when the home printer became available. The construction industry first used 3DP to print building materials in 2006. Dr. Behrokh Khoshnevis from The University of Southern California created a 3D printer that printed concrete using a crane’s arm to lay down a building’s structural skeleton.

As the technologies have advanced and become more cost efficient, they have been implemented to build complete buildings. The first of these notable advances was in 2014, when a firm in Amsterdam printed a complete canal house out of plastic using a printer connected to a large crane arm. Second in 2015, a different Dutch firm, MX3D, printed a full-scale steel bridge in downtown Amsterdam that aims to make steel construction faster and more cost efficient. Third in 2016, a Chinese company named HuaShang Tengda began construction on a 3D printed mansion made entirely of structural concrete. This mansion boasts to be earthquake safe and was completed in 45 days. Most recently, a Chinese company named Winsun printed 10 houses in 24 hours. After completing 10 houses in 24 hours, Winsun also printed the first 3D printed commercial office building. (I would sum up this section of the intro somehow, ends a little awkwardly)

Most Recent Advances and Advantages?

The most recent technological advances using in robotics and crane arms has allowed for increased speed and efficiency of 3D printing while also increasing the complexity of possible designs. The increased efficiency throughout construction is one of the greatest advantages of 3D printing over traditional labor. Not only is the 3D printer more efficient than workers, but it also can operate on a 24 hours a day work schedules, greatly reducing the schedule. One of the most overlooked advantages of 3D printing is the increased complexity of design available. The 3D printer is not limited by the constraints of traditional building techniques and has allowed for incredibly complex architecture to be printed at limited additional time compared to simpler designs.
Methodology & Deliverables

The primary method of research I used for this paper was qualitative research on three different construction projects that used 3D printing. I specifically researched the implementation strategies used on these projects and the advantages and disadvantages of all approaches. When analyzing the implementation approaches, I focused on how these projects used 3D printing as an advantage to overcome challenges of construction such as time, cost, design complexity, and material constraints.

The objectives of the case study are as follows:

- Identify what implementation strategies were used for each project
- Analyze the successfulness of these implementation strategies based on cost, time, and quality of work produced
- Provide analysis on what implementation strategies made the greatest benefit and how they can be repeated on future projects.

Case Study

[Project specifics on how they implemented 3DP. What this changed about the process from traditional construction. Describe advances in technology and how it allowed these strategies, and what changed in scheduling etc.]

I analyzed three different construction projects that all successfully implemented 3D printing in different ways and for different scopes of work.

6 Bevis Marks: Complex Parts for Skyscraper

The refurbished 6 Bevis Marks office building in central London was the first project, in 2013, to utilize 3D nylon sintered technology. This technology was used to 3D print incredibly complex pieces and crucial pieces for a cladding system. These eight cladding nodes, were printed by a specialist using “a selective laser sintering machine… to fuse layers of powdered Nylon PA 12 to build up the complex shapes based on a CAD file form the architect” (Construction Index 2013). The architect chose this method over traditional welded or steel spliced plates to meet aesthetic standards.

Although the cladding shroud in not a structural element of the building, the nodes must perform as structural components to ensure the cladding system stays in place. These nodes were tested for 1000 mph winds for 2000 hours and tested for extreme weather conditions before they were approve and installed. These components passed with flying colors and the roof specialist who installed the canopy included these components in their warranty of the system. According to Skanska: “traditional methods, such as case steel nodes, would have been much more expensive and difficult to produce.” Skanska also is aiming to utilize this success on the 6 Bevis Marks to start a 3D printing supply chain to print complex parts for all of their clients.

Figure 1: 6 Bevis Mark Project Photos

HuaShang Tengda: Mansion
In the Tongzhou region near Beijing, China, The Chinese construction company HuaShang Tengda constructed a 400-square-meter mansion using 3D concrete printers to complete this project in just 45 days. This project is especially impressive because the mansion is earthquake proof and can withstand quakes up to magnitudes of 8 on the Richter scale. The walls of the mansion are 250 mm thick and were printed using approximately 20 tons of C30-grade concrete. This grade of concrete is usually used paving roads and provides this mansion with its incredible seismic resistance. The ability to withstand an earthquake is a very important feature due to this project’s location in China, and also provides a new product that can quickly be produced for earthquake prone regions.

This project was the first of its kind to be completely printed on site, rather than shipping preprinted parts from factories. The project first prepared a pre-poured concrete foundation complete with all necessary reinforcement and plumbing installed for the complete 3D printed mansion. Once 3D printing commenced, the mansion was completed using a combination of four different systems: an electronic ingredient formulation system, a concrete mixing system, a transmission system and a 3D printing system. The traditional concrete reinforcement system used does not require any additives in the concrete and allows for locally produced concrete. The use of locally produced concrete greatly reduces the transportation costs and simplifies delivery logistics, however HuaShang Tengda claims that the greatest benefit is the increased speed. HuaShang Tengda estimates that constructing this mansion would have taken three months if conventional techniques were used. The company claimed that this competitive advantage would provide them the extra edge they need to compete internationally when bidding on projects. Once completing the 3D printing process, the crews painted and decorated the interior of the Mansion.

![Figure 2: HuaShang Tengda Project Photos](image)

**MX3D: Steel Bridge**

In Amsterdam, MX3D is constructing a 3D printed stainless steel bridge across one of the oldest and most famous canals, the Oudezijds Achterburgwal. This 4 meter wide pedestrian bridge will span 40 feet across the canal. Although MX3D originally planned for the bridge to be printed in place, during the 18-month design and engineering process, it was constructed offsite in a warehouse due to structural concerns about the stress applied to the canal walls. Additionally printing the bridge offsite helped to mitigate many health, safety, and operational concerns. Welding emits sparks that can cause damage to those looking directly at them, and are a fire hazard to objects below the welding. These safety hazards made it unrealistic to effectively separate the public on the canal from the jobsite. The operational challenge of shielding the robot and welding technologies from weather would also have been incredibly challenging and expensive. According to the chief technology officer from MX3D Tim Geurtjens “It is a MIG welding technique… It is melting the base material and adding a metal wire and that is fusing together. We are basically building with molten metal” (Cunningham 2017). This technology has given tremendous design flexibility and allowed for this project to be incredibly artistic and beautiful.

One of the largest challenges on this project was acquiring the permits for the bridge. Integrity of the bridge is of paramount concern and so MX3D must prove that the bridge is and will continue to be structurally sound. They have used advanced pieces of technology used on this project is the sensors observing how the steel reacts to the pedestrians crossing the bridge. These sensors monitor the number of pedestrians on the bridge and the speed that they walk across at. The sensors will also measure the temperature and the condition of the steel. All of these sensors then are imported into the bridge’s “digital twin” where tests can be done on the live condition of the bridge.
The greatest advantage of utilizing 3D printing to print cladding nodes was the increased complexity and aesthetic look that could be achieved. This increased design complexity was a huge factor for the architect, giving him the product that fit his design without compromising any aspect. 3D printing provides a unique opportunity in construction and design because it does not have any shape constraints. This allows for the nodes to connect 6 different steel supports to the main steel column. Skanska is excited to use this technique as a marketing option for future clients, giving them an advantage when constructing challenging designs.

Another success on the project was the use of 3D nylon sintered technology when printing these nodes. This material choice not only achieved the engineering standards required, but also was a much cheaper alternative to conventional steel welding and splicing. 3D printing has provided a plethora of available materials and the architect showed a perfect example of how to utilize these materials for any use on the project.

The incredibly short schedule was the most impressive advantage gained when printing this mansion in almost one third of the duration of conventional construction techniques. This is one of the most promising advantages of 3D printing and gives an incredible opportunity for savings to both the owner and the contractor. To make this incredibly tight schedule work, HuaShang Tengda used very strategic coordination before starting the 3D printing. The design team first coordinated with the 3D printing company to successfully integrate their CAD model into the correct STL format that the 3D printer can read. This process however is becoming much easier, with new 3D printing technology and increase in soft wares available to help convert file types to necessary precision. The design team then coordinated with the contractor to ensure that the site was prepared for the printer. Due to this challenge, the contractor was forced to provide successful site logistics plans connecting the printer and the concrete being delivered to the site. This thorough preplanning and logistical analysis is what allowed this project to excel and be completed without setbacks of implementing a new technology.
This new technology also provides a great opportunity for disaster relief. The location of this project in China offered an opportunity to capitalize on the earthquake resistance of this design. HuaShang Tengda plans on using this opportunity on future projects to help protect a region so susceptible to seismic activity. This great opportunity can be used all over the world to make 3D printing the top disaster relief option for quick and safe rebuilding. This innovation will provide contractors with a competitive advantage not only in acquiring contracts for disaster relief, but also when procuring current contracts, by providing a cheaper product that is earthquake safe.

**Figure 5: HuaShang Tengda Implementation Method Photos**

**MX3D: Steel Bridge**

The 3D printers used on the MX3D Bridge are some of the most advanced technology to date and have accelerated printing of the bridge. These cutting-edge printers are utilize the latest robots: “While most 3D printers can print in only three directions (i.e. forward-backward, left to right and up-down) the robots of MX3D are able to print in all directions possible. To print an object that protrudes from the middle of a wall, the robots simply turn their welding torches to a side” (Construction Pro’s 2016). This is one of the most successful construction products on utilizing the most up to date and cutting edge advances in technology. This has given MX3D the upper hand and gives them a competitive advantage over other companies, even when producing such large-scale projects. Staying invested and using the most advanced technology is one of the greatest practices a company should take on, giving themselves the advantage over their competitors over and over.

One of the challenges overcome on this project was an unexpected concern about the structural integrity of the existing canal walls. Although this is not surprising due to the age and historic significance of the Oudezijds Achterburgwal canal, it still restricted MX3D from printing the bridge onsite. Although this specific bridge was unable to be printed onsite due to site conditions it had the technology to be printed from both sides of the canal and to meet in the middle. This allows for the bridge to be printed at double the speed than originally expected. By implementing this new technology, MX3D cut their printing time in half, which was significantly faster than conventional steel construction.

**Figure 6: MX3D Printing Lab Photos**

**Implementation Strategies: Challenges**

All three projects faced the same three main challenges when implementing 3D printing into their projects: technology challenges, coordination challenges, and design challenges. All three projects overcame these
challenges differently and so each of the project’s best practices should be utilized on all future 3D printing projects in construction.

**Technology Challenges**

The implementation of new 3D printing technologies can be incredibly challenging throughout all stages of a project. All three of the project schedules were completely revised to allow for increased time to collaborate with 3D printing specialists and successfully employ these new technologies. First, on the 6 Bevis Mark project, they faced challenges choosing which material would provide the desired finish and quality project required by the architect. Second, on the HuaShang Tengda Mansion the technology challenges came when designing the correct concrete mix to use to meet structural requirements to achieve earthquake resistance. Third, on the MX3D Bridge, they faced challenges with getting the desired directional mobility out of their 3D printing welders. To achieve this, they upgraded the robotic arm giving the welder the range of motion it required. MX3D was the most successful implementing the new 3D printing technology and overcoming any questions doubting the ability of the machines to print the desired project.

**Coordination Challenges**

3D printing requires immense amounts of coordination by both the design team and the construction team to learn and successfully implement this new construction method. This coordination flows through all parties including the Contractor, Architect, Engineers, 3D Printing Specialists, and Software Specialists. The coordination between parties when building the MX3D Bridge was most successful, allowing them the smoothest implementation of new technology on the project. MX3D utilized their advantage of being a 3D printing firm to help overcome many of the challenges of changing conventional construction techniques to accommodate 3D printing. However, on the HuaShang Tengda Mansion they showed the opportunity for construction companies to impart their knowledge in site logistics to provide the smoothest operation of large-scale 3D printers on-site. They specifically coordinated this utilizing their four different systems: an electronic ingredient formulation system, a concrete mixing system, a transmission system and a 3D printing system. This coordination on-site allowed for the largest schedule advantage on any of the projects analyzed.

**Design Challenges**

Although 3D printing provides incredible opportunity for complex designs, it also provides challenges for designers who are unfamiliar with 3D printing. These challenges arose when designing the structural components for the HuaShang Tengda Mansion and the MX3D Bridge. When designing the mansion to withstand such harsh seismic conditions as an 8 on the Richter scale, challenges arose of how to shape the wall successfully so that is can be efficiently be printed, and still meet structural requirements. When designing the MX3D Bridge, they also had trouble ensuring the structural integrity of the bridge over time. The initial design called for regular steel, coated to protect from the elements, however MX3D had to revise their design to stainless steel to allow for the 3D printed elements to be visible without a coating. Although these design challenges have caused hiccups for these early 3D printing projects, they were all quickly surpassed and have given the construction industry endless opportunity to design without conventional shape constraints.

**Analysis & Conclusion**

These construction projects that commissioned 3D printing all provided their companies with competitive advantages and provided a future opportunity for similar technologies to be used on all construction projects. The greatest areas for success came with the financial, schedule, design and material advantage that 3D printing provided on these projects. These projects provided insight on how to best choose which benefit of 3D to optimize on a project for the greatest competitive advantage. To fully benefit from 3D printing, contractors must embrace the necessary coordination and seek insight from specialists in all required fields. The most successful of the projects analyzed were the ones that collaborated between all fields of design, technology and construction. The most realistic opportunities for all construction companies to utilize 3D printing is to prefabicate parts, this can be introduced on every construction project and reduces challenges from design complexity for every contractor. Additionally, construction companies need to continue investing in the technology of 3D printing and experimenting with all of 3D printing’s uses to best apply it on projects. All companies can give themselves an advantage by using
3D printing for more than just mock-ups and to use it as an advantageous construction method. In Conclusion, 3D printing will continue to spread throughout the construction industry with many uses, and projects can take advantage of this to enhance the design of their buildings, while improving efficiency and cost.

**References**


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