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Digital Fabrication: How its related to Architecture

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Abstract: Technological developments in architecture continued such as parametric design methods with computational optimization process and digital fabrication to make a scale model. Digital fabrication defined as the process of manipulating objects using CNC router machines, 3D printers, and laser cutters through reduction or addition methods. This technology believed in providing convenience advantages in making an architectural scale model, which gives more precise results with a faster manufacturing process.

Digital fabrication is affecting the architectural design process due to the increasingly important role it has in the fabrication of architectural models. Many design professionals, professors, and students have experienced the benefits and challenges of using digital fabrication in their design processes, but many others in the field are not yet aware of the possibilities and drawbacks afforded by these technologies. The research presented here unveiled key issues on the matter through a series of interviews with different individuals, focusing on digital fabrication in their practices and schools, utilizing eight digital fabrication methods, such as three-dimensional printing, laser cutting, and desktop milling. The interviews and experiments form a basis for suggesting better ways to utilize current digital fabrication methods in design and for proposing future methods better suited for the architectural design process.

Introduction:

Various types of digital fabrication machines are working their way into architecture schools and offices, slowly being integrated into the array of tools architects utilize to create physical representations of their designs. These fabrication technologies were developed for professions other than architecture, such as industrial design and mechanical engineering, so when architects start to use them, they are forced to conform to other ways of working that may not be natural in the architectural design process. These technologies are having positive and negative effects on the design process as more architects and students integrate digital fabrication methods into their model making processes.

Digital fabrication is a design and manufacturing workflow where digital data directly drives manufacturing equipment to form various part geometries. This data most often comes from CAD (computer-aided design), which is then transferred to CAM (computer-aided manufacturing) software. The output of CAM software is data that directs a specific additive and subtractive manufacturing tool, such as a 3D printer or CNC milling machine. A wide variety of digital fabrication tools exist, from hobbyist-level machines to large-scale.

Digital age and transition to Architecture:

Architecture is an effective communication of creative ideas through continuous dialogue of designing and making. Drawing as the core activity of this process, become a more efficient and an easy task by using CAD in Architecture for nearly forty years. But this shift from traditional to digital did not reflect on the design of the buildings (Iwamoto, 2009). Drawing a project by using CAD with a traditional design thinking, can only be seen as a translation of analogue logic into digital realm. This approach is an imitation of manual human design and is called “computerization”, whereas, the real “computation” lets architects to search for “extreme, strange, and occasionally unpredictable situations” by the capacity and use of CAD, in design, form and construction. First attempts for a digital design method were made long before the use of CAD in Architecture. Luigi Moretti, invented the definition for “Parametric Architecture” in 1939 and use the parametric design in his stadium models at the 1960 Twelfth Milan Triennial. According to his explanation for parametric architecture; the parameters become the code of the new architectural language and structure. These parameters and their interrelations must be expressed and supported by computational, logical and mathematical tools and techniques. Another traditional tectonic rejection example is Frei Otto’s researches on form. Otto used physical models such as: soap films which found minimal surfaces, and suspended fabric which found compression-only vaults and branched structures to investigate architectural forms. These searches emerged a new perspective in design thinking. The traditional form making approach of tectonics has shifted into form finding, even without proper CAD & CAM use in architecture. Today, as designers realized that CAD programs could manage complexity beyond human capabilities, form-finding has become an important strategy for shape determination. Now architects can design with a multi-parametric form-finding approach including geometry, dynamic forces, environment, social and any desired data. This new dialogue between form and process has led to new architectural tectonics. Kolarevic (2003a) list these tectonics as; topological, isomorphic animation, metamorphic, parametric, evolutionary, performative architectures and virtual environments. The variety of design processes affected the fabrication of architecture and its components as well. Looking through its history, digital fabrication was first used to make the physical models used in the restorations of Saint John the DivineCathedral and SagradaFamilia (Burry, 2003; Burry, Burry, &Faulí, 2001) for constructive decisions. (Kolarevic, 2003b). Frank Gehry's office began using CAD/ CAM to develop and test the Disney Concert Hall's constructability in 1989. They adapted CATIA (Computer Aided Three-Dimensional Interactive Application) to architecture, to model the exterior facade of the concert hall.

Types of Fabrication:

Physical Representation of Architectural Designs:

Many different forms of representation in the architectural design process exist, ranging from digital to physical, and from two-dimensional to three-dimensional. Sketches, drawings, renderings, animations, and physical models all help to portray the designers' ideas to another person. Whether it is a student conveying an idea to a professor, an architect presenting a design to a client, or an architect providing building instructions to a contractor, representation is a key part of the architectural design and construction process. Among these forms of representation, I focused on physical models, which serve many different purposes in the design process. They help designers generate new ideas, represent their ideas to others, and test the behaviour of full-size building components. In this section, I will present the different types of physical representations that can be found in the field and the different methods for making these models.

Model Types

We should review five different levels of architectural modelling found in schools and offices. In their paper, Rapid Design and Manufacture Tools in Architecture, Ryder, et al. describe three typical levels of modelling drawn from interviews and a literature survey. The three model types they found are: the feasibility model, the planning model, and the final project model. In addition to these three, I found two more levels of modelling through my survey that I would like to add to the list: the abstract model and the full-scale mock-up.

The feasibility model as an object typically used to convey the concept of the building design. Not much detail is added and the size is usually small, yet it is starting to take the general shape of an architectural form.

The planning model is used when a little more detail needs to be conveyed at a slightly higher quality than the feasibility model. The designer can portray a clearer understanding of the building design and its relationship to its context.

The final project model shows what the project will look like once it is completed. In practice, this is the type of model that is shown to clients and the public. In school, this is the model shown at a final design review to portray the final design intent.

The abstract model is commonly used for abstract form or space studies. This type of model is often created to present the "sensibility" of a design in the earliest stages of the design process.

Full-scale mock-ups are occasionally needed in practice to test the fin al behaviours of a certain set of assembled building components. Fabricated at the full scale, these models allow the designer to verify the final form and functionality of the chosen assembly. Students are sometimes required to build small mock-ups in school in order to experience how real, full-sized building materials perform.

The fabrication methods that are used to create architectural models can be split into two groups: handmade model making and digital fabrication. The handmade methods are presented purely as a reference. I will elaborate more on the digital fabrication methods in order to prepare the reader for discussions in subsequent chapters.

Handmade Model Making:

When employing one of the many methods of handmade model making, the designer has immediate control of the tool's manipulation of the material. A wide range of tools can be used to create architectural models by hand and each tool typically has a limited group of materials that can be manipulated by it.

Handheld tools used for making architectural models include scissors, X-Acto knives, utility knives, hacksaws, chisels, files, and sandpaper (fig. 4). Scissors, a tool everyone is familiar with, cut thin sheet materials such as paper, acetate, foil, rubber, and foam. X-Acto and utility knives are used when highly controlled cuts are needed or when the material is thicker or slightly harder. Chipboard, cardboard, foamboard, bass and balsa woods, and thicker foils can be manipulated with these knives. They can also sculpt woods, foams, and clay. Saws are best used when even thicker, harder materials need cutting such as

<u>Advancement in this field to this day:</u>

Digital Fabrication:

When employing digital fabrication methods in the model making process, the user has almost no control of the tool at the moment it is manipulating the material. All digital methods start by the user setting up a file in the computer and end by the user sending the file to the machine. The user has varying amounts of control over the manipulation of the material during set up, but once the file has been sent, the user can do little but watch. There are rare exceptions where some machines allow the user to slow down or speed up the process of manipulation, but never the manipulation itself.

One should keep in mind that all of these processes were originally developed for use in industrial design and manufacturing. Machines designed for use in industrial shops are typically difficult for an architect or student to use because there are too many factors that must be considered for a novice to efficiently operate on his or her own. However, many of these processes have been compacted into smaller, more user-friendly machines that are more suitable for architecture offices and studio environments. This has made it easier for designers to use the machines in architectural model making.

Types Of Digital Fabrication:

1) 3D Printing:

Additive manufacturing is a digital fabrication technology wherein the machine 'adds' layers on layers to create a product. This fabrication process is also known by another name – 3D printing.

Additive manufacturing has been around since the 1980s, used in rapid prototyping to create scale models. However, these products only served as prototypes with no functionality. The advance in additive manufacturing technology nowadays has produced functional objects which can be used in machinery or as furniture. There are so many fabrication materials available now, and we can conveniently manufacture objects in steel, plastics, ceramics, biomaterials and other polymer compounds. Many of these products are designed in parametric modelling software like Rhino 3D.

In a typical 3D printing process, lasers, electron beams or thermal heads are used to melt the material. It is then deposited through a nozzle onto the base platform in layers. The object is ready to be taken out once it has been left to dry. Such a method is also known as Material Extrusion.

Fig 1: 3D Printer – Machine View

2) Direct Energy Deposition:

A more complex process of material extrusion is referred to as Direct Energy Deposition. In material extrusion, the nozzle only lays the material in one direction or axis. On the other hand, direct energy deposition works by using a four- or five-axis arm that deposits the melted material.

Fig 2: Direct Energy Deposition Machine – Imposing Material

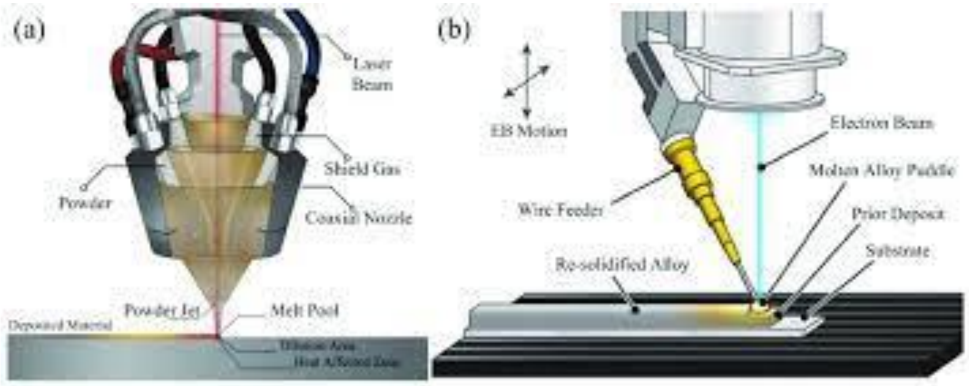

Fig 3: Direct Energy Deposition Machine – Concept

3) CNC Machining:

CNC stands for Computer Numerical Control, a subtractive manufacturing process that makes use of computerised control for operation. CNC milling is a common example of CNC machining processes where the computational system controls the rotary cutting tools to chip away unwanted portions of a material to create a desired shape. The process is feasible with several types of materials including plastics, metals or even 3D printed materials. Many industries, such as industrial design, electronics and automotive, have made use of CNC machining for manufacturing processes as it only requires CAD or CAM drawings.

Fig 4: CNC Machine

4) Laser Cutting:

It is now common to find laser-cut products in the commercial sector ranging from small household items to furniture. Similar to CNC milling, most laser cutting processes require a CAD file which will be placed in the laser cutter software. When the machine starts operating, the high-intensity laser beam falls onto the material.

Cutting a material is not the only function of a laser cutter; we can also engrave at different depths by adjusting the intensity of the laser and the distance between the nozzle and the material. As it is a relatively easy and fast process, many designers, entrepreneurs and even students can create their own products in large quantities in a short time.

Fig 5: Laser Cutting Machine

5) Binder Jetting:

While other 3D printing uses resin of different materials to print, binder jetting uses powder materials and a liquid binding agent to build up layers. The fabrication equipment, with an ink-jet nozzle, deposits the powder onto the base platform in layer by layer based on the CAD file used until the shape is complete. The manufacturers can preset the parameters which essentially automates the fabrication process.

One thing to note is that the type of material used should be taken into account when planning the CAD file as the height of a layer can vary according to the material. The most common materials used in this digital fabrication technology are metals, usually alloys like steel, and ceramics.

Fig 6: Binder Jetting Machine

Digital Creation and Technological advancement:

Computer-aided design (CAD) involves creating computer models defined by geometrical parameters. These models typically appear on a computer monitor as a three-dimensional representation of a part or a system of parts, which can be readily altered by changing relevant parameters. CAD systems enable designers to view objects under a wide variety of representations and to test these objects by simulating real-world conditions.

Computer-aided manufacturing (CAM) uses geometrical design data to control automated machinery. CAM systems are associated with computer numerical control (CNC) or direct numerical control (DNC) systems. These systems differ from older forms of numerical control (NC) in that geometrical data are encoded mechanically. Since both CAD and CAM use computer-based methods for encoding geometrical data, it is possible for the processes of design and manufacture to be highly integrated. Computer-aided design and manufacturing systems are commonly referred to as CAD/CAM.

Case Study Projects Used(Litrature):

Tvasta Manufacturing Solutions:

In 2020, Tvasta Manufacturing Solutions constructed India's first permitted and functional 3D printed house on the IIT Madras Campus (Indian Institute Of Technology), in Chennai, on the east coast of India.

The house is 600 square feet and was constructed by assembling 3D-printed panels, which were 3D printed in Tvasta's facility nearby. Founded by IIT-Madras alumni, Tvasta Construction has developed a 'Made in India' technology focusing on leveraging automation and robotics in 3D printing platforms for faster, economical and sustainable construction, in addition to developing its own material mix, which is an extrudable concrete consisting of cement, sand, geopolymers and fibres. The build was made possible with investment from Habitat for Humanity's ShelterTech. The ShelterTech accelerator — run by Habitat's Terwilliger Centre for Innovation in Shelter and its partners — identifies, nurtures and accelerates start-ups like Tvasta, helping to bring new ideas and technologies to improve low-income housing for families and communities in need of access to decent, affordable homes. Tvasta plans to ramp up operations through partnerships with materials and industrial companies, as well as by licensing their technology to affordable housing developers who they hope can take 3D printed homes to scale across the country.

Tvasta's House:

Tvasta's first structure is a single-storey house, a 600-sq ft unit, created in collaboration with Habitat for Humanity's Terwilliger Centre for Innovation in Shelter at the IIT-Madras campus. The house was built in just five days. Tvasta's official blog states, "A standard 3D printer can produce a 2,000-sq ft home in less than a week, which is 1/8th of the total time spent today in erecting a functioning house. When it comes to waste materials, this technology creates only 1/3rd of the waste generated using conventional building methods."

Fig 7: Real Life Image Of The house

Design and construction process:

The process of building a 3D-printed Tvasta house is not just different but a lot quicker than conventional construction. It is built with focus on reduced build-time, zero-waste construction and optimised production. To start with, the structure was printed using a special concrete mix through which large-scale

3D structures were made. The concrete mix is a base of ordinary cement which has a lower water-cement ratio. While concrete is the primary material for typical construction projects as well, the energy consumed to mix and transport it is way more than in 3D printing.

In one of its company blogs, Tvasta Manufacturing Solutions has mentioned that they have developed their own material mix, which is an extrudable concrete consisting of cement, sand, geopolymers and fibres. The company prepared the final mix by mixing the raw materials in a large hopper. “While 3D printing, the structure was specifically designed hollow, to allow provisions for wiring and plumbing without damaging the wall,” Tvasta said.

Tvasta has also developed an indigenous concrete 3D printer. Tvasta, through the 3D house project, aims to evaluate the ease with which houses can be manufactured through concrete printing technology, and understand the cost on a large scale to address the problems of affordable housing in a country like India.

Tvasta’s house construction process focuses on the use of sustainable materials. Such 3D-printed houses are not just economical but also environment-friendly, as the use of local materials eliminates the need to transport concrete over long distances. “This technology can enable deep personalisation of construction for the ultimate target segment – who is the individual. 3D printing can ensure that affordable, good quality housing is available to all Indians,” said Adithya VS, co-founder, Tvasta Manufacturing Solutions.

Conclusion:

Digital fabrication has emerged as a transformative force in the field of architecture, reshaping the way we conceive, design, and construct buildings. This technological advancement leverages computer-controlled processes to translate intricate digital models into physical structures, offering architects unprecedented precision and efficiency.

One of the key advantages of digital fabrication lies in its ability to seamlessly integrate with parametric design and computational tools. Architects can harness the power of algorithms to generate complex, organic forms that were once challenging to realize using traditional methods. This not only expands the realm of design possibilities but also enables a more nuanced and responsive approach to the surrounding environment and contextual factors.

Furthermore, the efficiency gains in the construction process are noteworthy. With digital fabrication, there is a reduction in material waste, as components can be precisely manufactured to meet the required specifications. The optimization of resources contributes to more sustainable practices, aligning with the growing emphasis on environmentally conscious architecture.

The dynamic interaction between architects and digital fabrication technologies also facilitates a more iterative and experimental design process. Rapid prototyping allows for quick testing and refinement of ideas, fostering a culture of innovation and pushing the boundaries of what is architecturally feasible.

As we look ahead, the future of digital fabrication in architecture appears promising. Continued advancements in materials science, robotics, and artificial intelligence are likely to open new frontiers, enabling even more intricate and sustainable structures. The intersection of technology and architecture is evolving, and the collaborative relationship between human creativity and digital tools is reshaping the built environment in profound ways. In essence, digital fabrication stands as a catalyst for architectural evolution, offering a synthesis of precision, sustainability, and design ingenuity.