Application of Additive Manufacturing on Three Dimensional Printing

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Abstract: ***3D technology utilizes a print head to lay down raw materials in successive layers to fabricate a three dimensional object. Testing of the printed automotive prototypes will be executed using the different technologies offered by Objet 3D printing manufacturers. These case studies include fabrication, a visionary design for a high-rise product of prototype. The original contribution of this research is in the primary field survey of practices and emerging trends within the construction and parallel industries. Original contributions are also made in the synthesis of selected practices identified from literature review and the field surveys to form novel design and construction methodologies. These methodologies have been tested through the design of unique architectural projects focused on fabrication using construction 3D printing.***

Keywords: 3D printing, Additive Manufacturing, Rapid Prototype.

1. Introduction

AM techniques can be used for the manufacture of end-use products as well as prototypes and this provides the opportunity to change the paradigm from mass production to mass customization, this last term refers to the manufacturing of customized products or components on a limited, yet cost-effective, scale [1]. Most recently, Additive Manufacturing of ceramics has benefited from techniques based on extrusion combined with conventional ceramic-forming methods: the “so called” direct casting processes [2]. In these processes, the ceramic slurry is transformed into a solid state without the removal of its water content. This allows the use of a non-porous mould, which has considerable economic advantages as well as an improvement in the homogeneity of the green body. This approach gives improved dimensional control of the fired component and the potential to produce parts with complex geometry. These methods are unique in the way they perform, as they add and bond materials in layers to form objects without the application of traditional forming tools such as dies or moulds. 3D printers use Computer-Aided Design (CAD) software to draw the 3D object digitally. Then, the information is sent to the printer using an STL file format.3The printer then lays down consecutive layers of the raw material to build the object.

2. Rapid Prototyping

Rapid prototyping (RP) is not a new phenomenon in the manufacturing industry, but 3D printing has brought a new way to rapidly prototype objects. Rapid prototyping is vital in concept design in order to finalize the design of a new product. There are several reasons that companies use rapid prototyping. First of all, the new design can be held or seen as it would appear on a shelf. Secondly, the form, function, and appearance of an object can be tested and viewed. Also, if there are any flaws in the CAD file, they can be caught in the rapid-prototyped piece. 3D printers have cartridges that contain spools of ABS (acrylonitrile butadiene styrene) plastic and feature either breakaway supports or soluble supports. RP parts for low-volume end use need to be robust and fit the designed functionality. This makes it essential that the dimensional accuracy of the parts meet the required standard. Previous researchers have mainly devoted their studies to fixing accuracy and the relationships between processing parameters and post-curing accuracy. To the best of our knowledge, there has been no investigation into the consistency and repeatability of different features of the sample part fabricated by a 3D printer. The plastic is heated within 3 degrees of its melting point and is known for its strength properties.

3. Three Dimensional (3-D) Printer

Industrial prototyping and manufacturing process as the technology has become more accessible to small companies and even individuals. Once the domain of huge, multi-national corporations due to the scale and economics of owning a 3D printer, smaller (less capable) 3D printers can now be acquired in minimum price. This has opened up the technology to a much wider audience, and as the exponential adoption rate continues apace on all fronts, more and more systems, materials, applications, services and ancillaries are emerging.

The earliest 3D printing technologies first became visible in the late 1980’s, at which time they were called Rapid Prototyping (RP) technologies. This is because the processes were originally conceived as a fast and more cost-effective method for creating prototypes for product development within industry. Step one of 3D printing is the generation of a 3D printable model. This model is generated using a computer aided design software or via a 3D scanner. A real life object can be set to be 3D printed by scanning it to get a 3D model that is realistically within the bounds of the 3D printer’s capability. Then the STL file is generated by running the design through converting software. Companies have also realized the potential of a consumer market for 3D printers and as such have been aggressively courting enthusiasts with cheaper and better models. There are many communities formed around these enthusiast groups which are active on the internet set up to share projects and ideas and new possibilities. The object may take anywhere from several minutes to several hours to complete depending on the size and complexity of the model and also on the type of machine used.

The main material utilized in the development of 3D objects is plastic, though recently, there has additionally been a slew of innovation toward using alternative materials like metals of various sorts and additionally organic matter like carbon and its varied derivatives. Processes where the part is produced by material removal can be described as subtractive processes and processes where the part is produced by a mold can be described as formative processes. These approaches have significant manufacturing constraints that must be taken into account during the design stage to ensure a feasible design. For example, the need for tool access in the case of machining or the need for part removal from a mold in the case of casting or molding.

- Investigate the suitability of conventional made prototype
- Develop and fine tune a prototype that can be successfully cast in minimum time.
- Develop improved processing conditions for the new material.

4. Techniques

This section focuses on the historical context of both additive fabrication techniques and emerging construction 3D printing techniques. A description of the range of techniques is given and a categorization of them is made. The potentials and limitations of particular techniques are identified, as well as current trends and applications in reference to the focus topics discussed above.

4.1 Rapid Prototyping to Additive Fabrication

As the quality of the output of the Rapid Prototyping machines increased, groups around the world started to use the output of these machines for end use products, hence the adaptation of the term from rapid prototyping to ‘rapid manufacturing’. Organizations such as NASA, Boeing and the FBI began using rapid prototyping devices in the 1990’sfor unique or small orders of parts (Hopkinson and Dickens, 2001, Ayers, 2009), this occurred for a number of reasons; strength of materials and dimensional accuracy/stability increased as rapid prototyping techniques were refined and rapid prototyping of end use products became cost/time competitive with fabrication by other means.

Additional benefits have been realized since the early adaptation of ‘Rapid Prototyping’ techniques that can be considered as value adding significant value for manufacturing. These benefits can be summarized as the following (Wooten, 2006, Hopkinson et al., 2006b):

- **Small fabrication runs** - fabrication runs of one with no penalty, allowing for customization and individualization of products (such as individual form fitting).
- **Highly complex geometries** - including interlocking but physically disconnected assemblies (e.g. textiles)
- **Fabrication for assembly** (prefabrication) – increased ability to incorporate joints for interlocking assemblies (especially where fabrication size constraints exist)
- **Reduction of fabrication constraints** - reduction in design for fabrication items such as draft angles.
- **Part consolidation –** through reduction in fabrication constraints

There are a large variety of techniques used by the different additive fabrication machines; although these techniques can be broadly classified into two groups. Others have made classifications of additive fabrication techniques such as (Bourell and Beaman, 2004) and (Hopkinson and Dickens, 2006).Additive Fabrication techniques build up objects in sequential layers based on a digital three-dimensional model. The categorization by Hopkinson et al. defines categories for emerging additive fabrication systems as: solid, liquid and powder. This categorization is not particularly useful, for discussion within this exegesis, because it focuses on the starting state of the materials rather than active process that create the final objects. As a consequence a new categorization has been made. This classification is made based on listings and descriptions of additive fabrication techniques and description from the State of the industry report by (Wohlers, 2010). The categories and subcategories of techniques are listed in bold type, followed by a brief description as required. Representative companies who produce systems in these categories are listed in brackets.

- **Deposition** of material to build up an object
- **Paste deposition** of premixed materials – (Fabber)
- **Bonding** - Selectively adding a bonding material to a powdered material - Inkjet - jets binder onto powder (Z-corp & Ex One)
- **Selective state change** of materials in a chamber or on a platform (in some cases using catalysis), state change may be temporary (e.g. temporary melting to liquid)or permanent (e.g. solidification).
- **Melting** - Selective sintering using laser, electron beam etc (Metal– MTT, ARCAM & EOS, Stratasys, EOS)
- **Melted Deposition** - Fused Deposition Modeling (Polymer – Stratasys, HP & Makerbot)
- **Inkjet deposition –** Inkjet deposition of photopolymer and light curing **(**objet**)**
- **Light Curing** – Stereo lithography (CMET, 3D systems, & DWS)
- **Chemical reaction** – Selectively adding a material to another to create a chemical transformation - D-Shape.

4.2 Construction 3D Printing

Deriving from the field of Additive Fabrication, Construction 3D Printing techniques have been referred to under a number of terms such as Construction Scale Rapid Manufacturing, Freeform Construction and Construction Additive Fabrication “Large scale automated layer manufacturing systems are not entirely new to the field of construction. In fact, the term layer manufacturing was coined by Shimzu Corporation, one of a number of Japanese companies exploring alternative ways of constructing skyscrapers in the in the late 1980's and 1990s." " Shimizu's SMART system is based on a moveable automated factory formed by robotics systems that is gradually lifted up in the process of erecting a building"(Mengesand Hensel, 2008) p44Construction 3D printing techniques have been in development since the mid1990's with two separate techniques published in that decade, the first was a novel technique based on the deposition of sand and cement with selective curing of this material using steam (Pegna, 1995), the technique was not developed.

- Contour Crafting
- Endless polymer 3D printer

The Loughborough based fabrication technique will be referred to as 'Concrete Printing' for purposes of clarity within this exegesis. The Endless machine is not strictly a construction 3D printing technique as it has only demonstrated fabrication of furniture to date, the technique does however demonstrate how techniques (fused deposition modeling) developed at smaller scales can be scaled up, this is the first such polymer based technique to be scaled up with the potential to fabricate construction scale objects (such as polymer window or panels).In total eight separate construction 3D printing techniques have been conceived, of these techniques: Concrete Printing51, Contour Crafting52 and D-Shape53 have been developed, are focused on construction purposes and are operational today. These techniques are described and discussed in detail below. The Contour Crafting technique has been developed under the principal direction of Dr Behrohk Khoshnevis at the University of Southern California Viterbi School of Engineering in the USA. The technique was unveiled in 1996 and is the oldest technique under development. Although it is claimed that the contour crafting machine has the capacity to extrude a wide range of materials (Raymond, 2008), only two materials types have been demonstrated using the contour crafting machine to date; ceramic pastes during prototyping stage and concrete as the machine has been scaled up. The concrete paste is specially formulated concrete containing Bentonite which" *dramatically decreased water seepage, increased the paste plasticity*" (Hwang,2005). Although the use of Bentonite solved issues with the extrusion of concrete, it does not appear to have completely solved the issue of overhangs. As there is a conspicuous absence of overhangs, such as those which were earlier demonstrated using ceramic pastes at smaller scales; such capacity for creating overhangs has since only been demonstrated on stable geometries (lunar dome) in the modified concrete material at construction scale.

5. Result & Discussions

3D recommends using the highest resolution when printing the models. Although it will take three times as long to print, it produces a much smoother surface. Finally, we learned that tactile models are useful to supplement all types of learning styles. Holding a 3D model and rotating it in our hands is much more instructional than just looking at a 3D sketch on paper. The teleological perspective impacts the thought process of decision making as it relates to aligning and even identifying priorities and affecting criteria. The understanding of information in the system, and its associated importance, is accomplished through engaging teleological perspectives; correspondingly, the perspective also enables information in the system to be challenged. Cost savings because of in-house rapid prototyping as a result of time savings, and overall cost savings must be examined. In several instances, one design flaw found in a prototype prior to mass production can save a company thousands of dollars. Overall, this purchase will be seen as an investment, and recovery costs can occur within the first several months of the purchase. They may enable the ability to rapid prototype in-house items. This may not only speed up concept development, but also enable the manufacture to catch any design flaws. It could allow for testing of parts for fit, form, and function, as well as strength and thermo-mechanical properties.

The benefit of using such robots is that they can be fitted with any number of tools and programmed to perform a wide variety of tasks. The main constraint within this context of these robots is reach, which could on further reflection be extended if the robot were to be hung above the work area rather than being placed to one side.

None of the three construction 3D printing machines have to date demonstrated a capability for fabrication in outdoor environments, it may take years of research and scientific observation to fully understand all of the variables related to particular construction 3D printing fabrication and curing. Before such research is completed, in the interim, control of such variables will be more easily achieved within a factory environment. Material certification and quality control will likely become an important factor as construction 3D printing develops, these requirements can be easily fulfilled within a factory environment. The shell as a prefabricated module is designed for fit-out off-site, which enable the benefits of off-site modular construction to be realized. The Shell is a direct response to the contour crafting technique, which is integrally inclined to create looped shapes, the benefit of this loop is in the creation of a shell which is both structurally robust as well as materially efficient. The modification of the contour crafting technique simply consists of the replacement of the Contour Crafting gantry with Jointed Arm Robots, which have proven efficacy as well as the ability to be swapped between different factory stations.

Freezing Temperature Trials

A total of 30 ceramic samples were prepared from a combination of the two powders (75.47 w %) and the solvent (24.52 w %) that make up the formula (see Table 1). The constituent components were mixed vigorously together by hand and by using a pestle and mortar for 2 minutes. This broke up the soft agglomerates and then air bubbles were eliminated using a vibratory table.

Applied our method to models of varying geometrical complexity and printed model can be shown in Figure 1 and 2, where always show the input model, the model fitted with joints, and the final 3D-printed model. The first model is an arm with shoulder, elbow and wrist joints demonstrating a simple kinematic chain; thus this model contained only joints that are considered limb joints. Band thickness heavily influences the ease of excess material removal and implicitly affects unblocking the joint. As the band size increases, the friction surface also becomes larger requiring much greater force to rotate the joint. A more complex example is the model of a hand, which apart from the limb joint in the wrist and finger articulations, this model contains attachment joints, showing that our system can handle articulating more than cylindrical geometry. Our final example is an elephant model, which has attachment joints at the base of its legs, with the rest of its articulations being classified as limb joints. Depending on the printing process, continued manipulation of a joint can lead to reduced friction due to wear and tear.

Powder	FELDSPAR W%	QUARTZ W%	MOLOCHITE W%
	26	26	48
Solvent	SILICA SOL W%	DISPEX W%	GLYCEROL W%
	93	1	6

Figure 1: Printed model Powder

Figure 2: Printed model Solvent

6. Conclusion

3D printing is capable of mass production, since it fulfils most of its characteristics and those not fulfilled are not needed to fulfill their underlying purposes. 3D printing technology only successfully fulfilled five out of eight characteristics for mass production. However, the underlying purpose of this characteristic to produce standard goods is fulfilled by the 3D printing technology. An approach of fitting printable joints involves mesh segmentation based on joint locations and orientations, while the degrees of freedom of each joint are modeled through the use of computational geometry operations, both in shaping the outer casing of the ball-joints and in sculpting the mesh parts connected by each joint. The current research work is to be extended for making different and complex design to analyze the problem which cannot be solve by observing or analytically. The mechanical strength of interfaces between elastomers and printed parts was measured, and guidelines for the fabrication of these heterogeneous structures will provide.

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