Application of Additive Manufacturing to Fine Art Sculpture

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ABSTRACT

Additive manufacturing (AM) has shown itself to be beneficial in many application areas, including product design and manufacture, medical models and prosthetics, architectural modelling and artistic endeavours. For some of these applications, coupling AM with reverse engineering (RE) enables the utilisation of data from existing 3D shapes. This paper describes the application of AM and RE within sculpture manufacture, in order to optimise the process chain for sculpture reproduction and relic conservation and restoration. This area poses particular problems since the original artefacts can often be fragile and inaccessible, and the finishing required on the AM replicas is both complex and varied. Two on-going projects are presented as case studies: a group of large scale sculptures of horses that will be created and installed in Ordos, Mongolia; and the repair of an antique from the Forbidden City in Beijing. The latter project in particular involves a wide range of artefact shapes and downstream finishing techniques. The combination of digital technologies and traditional art requires interdisciplinary knowledge across engineering and fine art. Also, definitions and requirements (e.g. 'accuracy'), can be applied in both engineering and artistic terms when specifications and trade-offs are being considered. The paper discusses the feasibility for using these technologies across domains, and explores the potential for developing new market opportunities for AM. The paper finishes with conclusions about the feasibility, constraints, pros and cons of adopting AM in this area.

KEYWORDS: Additive Manufacturing, Conservation, Restoration, Finishing Processes, Reproduction, Sculpture

1. INTRODUCTION

Throughout the development of Additive Manufacturing, applications have arisen in many areas. Technology specific to particular applications often benefits from rapid improvements as user take-up accelerates. However, the capability and adoption of AM in finely detailed complex surface creation remains limited, especially in fine art sculpture [1, 2, 3, 4]. This is demonstrated by the relative lack of published work in this area when compared to engineering and medical applications. Although capabilities are theoretically adequate, there is a gap between knowledge and practice. Artists desire an easier and more precise way to produce their art works, in order to leave time for the important creative and conceptual activities. Consequently, engineers are needed to optimise digital technology and process chains to support this market, and provide acceptable solutions to the sculptors. This will result in the simplifying of complicated manufacturing processes and a reduction in reliance upon lengthy, repetitive and tedious manual production work.

1.1. Problems to be addressed

The research context is one where the sculpture industry has yet to benefit significantly from AM, especially when viewed alongside the many success stories in other fields. Theoretically, complex surface creation is one of the strengths of AM [5, 6], and it is clear that complimentary needs and opportunities exist. So what are the problems of applying AM in the world of fine art, and how should AM be optimised for sculpture reproduction?

The general requirements of fine art sculpture in terms of aesthetics, manufacture and artistic integrity need to be understood clearly. Also, the conjunctive areas of 3D digital art and fine art sculpture should be identified. Furthermore, the potential benefits of AM to fine art sculpture and the extent to which 3D technologies might be accepted in the field of fine art are key elements for this research. More practical challenges include the optimal combination of RE and digital data manipulation and optimisation in CADCAM systems. In summary:

- Definitions of fine art sculpture are needed in order to clarify the natural boundaries to and classifications of 3D Digital Art, and to usefully constrain the research.
- The range of materials, tools and manufacturing processes need to be compiled for both conventional sculpture and 3D digital art.
- Dissemination methods common in historical and contemporary sculpture need to be understood.

1.2. Research methods employed – action research

Complimentary research methods have been followed to satisfy these objectives and the collection of information from multiple sources is ongoing. For example, resources are being compiled in other languages and from other disciplines, translated and summarised as appropriate. Besides the literature review, interviews and surveys are being employed alongside action research [7]. However, it is the latter which forms the basis for this paper.

2. MONGOLIAN HORSES CASE STUDY

Ordos city in Mongolia is the location for a government-led urban design project called “a thousand horses galloping ahead”, representing the area’s nomadic ancestry. The project requires at least 100 horse sculptures installed alongside the river, with each horse being 4 metres in height and to be manufactured in either marble or bronze. The sculptures will be designed and manufactured by The Sculpture Workshop in Beijing, and 10 samples are being completed first for the purposes of specifying materials, manufacture, general style and appearance. It is during this stage that the action research case study is being conducted.

2.1. The traditional process

Design and evaluation is carried out by the principal sculptors on the project, lead by Prof Dasheng Zhang. 2% scale clay models (known as ‘sand models’) have been made to show the overall design and layout (Figure 1). 10% scale detailed originals are then made from clay and used to produce plaster moulds for plaster casting (Figure 2). These originals show the general appearance and are used for evaluation and as references for enlarging.

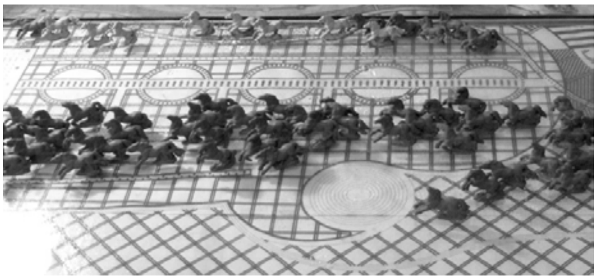

Figure 1: 2% Scale clay model

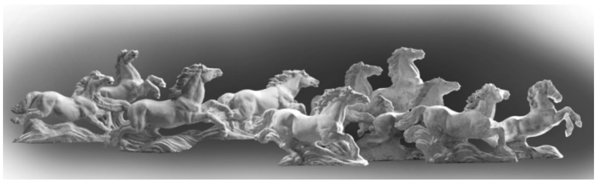

Figure 2: 10% Scale plaster model

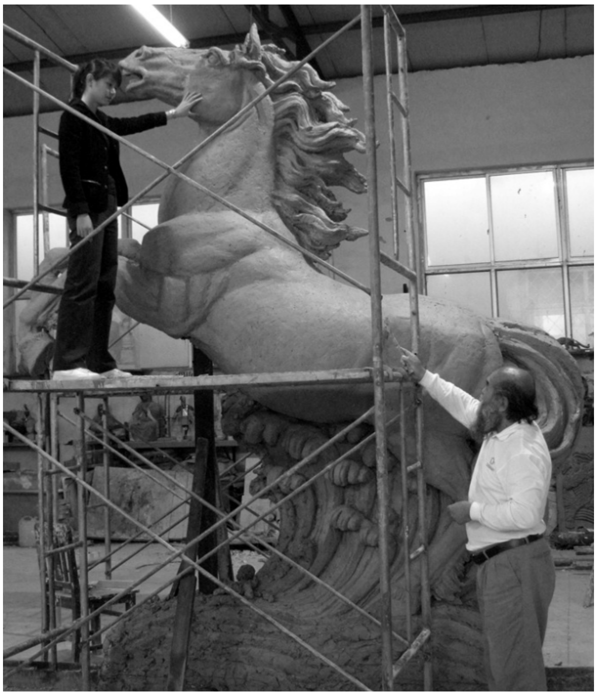

Figure 3: Full scale clay model

Figure 4: Full scale marble sculpture

The enlarging process uses a traditional method [8, 9] where full scale metal and wood frames are used to support the large amount of clay, which is initially built up over 2 days by 2 assistants. Detailed modelling and sculpting processes require 2 higher-skilled assistants to work for a further 2 days. Finally, a principal sculptor would modify the model, emphasising key points and smoothing the surface for around 4 days (Figure 3, also showing the lead author inspecting the horse's head).

Final manufacturing involves the large clay model being used to create a negative mould in reinforced plaster, which in turn is used to produce a fibreglass replica model supported internally on a metal frame (at least 4 days work for 4 people). This is transported to a factory for final production. In the case of marble, the replica model is used as a reference by skilled assistants who carve the final sculpture (Figure 4), which is normally then finished by a principal sculptor, taking around 1 month in all. In the case of bronze, the replica model is used to produce another negative mould in rubber from which a wax casting is produced (enabling final checks by the principal sculptor) before the bronze is cast.

2.2. Layered manufacturing

Design and evaluation this time started with the 10% scale detailed models made from clay and used to produce plaster-cast originals. 3D stereoscopic scanning was used to capture detailed digital data from these originals, and manipulated using the Geomagics RE software. The CAD models were altered by the author (guided by the principle sculptor) in the virtual environment, to produce variations of the horses in different poses. The digital models were scaled down to 2% size and built using an Objet RP machine for the overall layout model.

The enlarging experiments involved slicing up the full-scale CAD model into various thicknesses to create a contour model (Figure 5) which was manufactured in foam board and used as a support structure for the full-scale clay models. The contours of each slice were printed on to paper and used as guides to cut foam boards. The foam board was cut by heated metal wire (Figure 6) and assembled sequentially using reference axes to create the finished contour model (Figure 7).

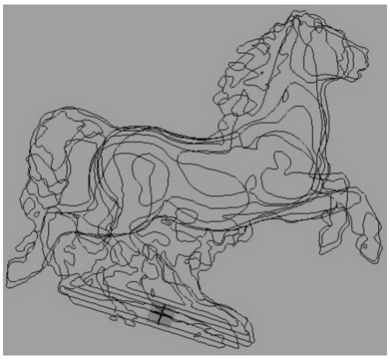

Figure 5: Contour model created in CAD

Figure 6: Cutting foam board

Figure 7: Full scale foam contour model

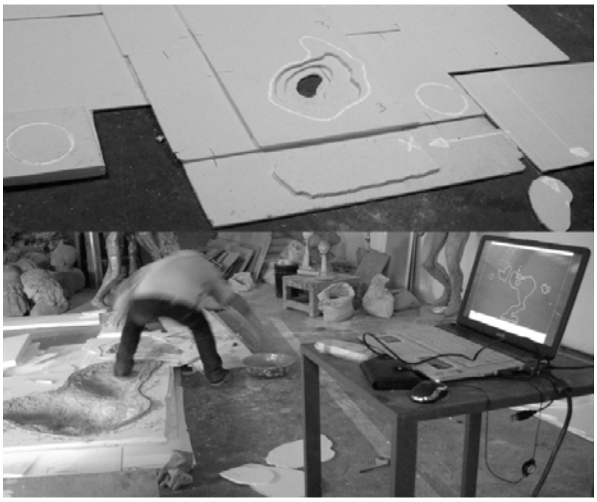

Figure 8: Negtive foam mould before and after addition of fibre-reinforced plaster

Figure 9: Detailed plaster model part

An interesting variation of this technique was used for important parts such as head, bone structure and musculature. Thinner slices were produced, and a projector was fixed on the ceiling to project the outline of each contour onto the foam boards, which were cut by heated wire as before. The main difference was that this time the outer material of each layer was used to built up a foam mould (Figure 8). Plaster mixed with fibre was applied on the inside surface of this mould and the foam was easily removed after the plaster was dry (Figure 9). The two sides of the plaster model were fixed together and sculptor was able to modify the full size final model.

3. FORBIDDEN CITY RENOVATION CASE STUDY

The Forbidden City in central Beijing was built during the 15th Century. It houses the Palace Museum, the location of a renovation project started in 2006 and planned to last 10 years. The project, involving buildings, gardens, furniture, objects, clothes, paintings, etc., entails both extensive restoration and the reproduction of lost or destroyed artefacts. A database of engineering drawings, virtual tours, publication and other media etc. is also being compiled.

This project is managed by the Museum's Ancient Architecture Department, with support from the Technology Department and others. The restoration project members are investigating the use of new technology to improve both quality and efficiency. Several institutions from America, Japan and Britain (e.g. Prince's Charities Foundation) provide their support, and a film about the work premiered at The British Museum in May 2010.

3.1. The traditional process

Archiving involves the antiques being photographed from various angles and the pictures being compiled in order to analyse degradation and defects. Engineering drawings are also produced by hand and annotated for future discussions (Figure 10). The last step is to build digital models via CAD rendering to produce images for publications and virtual tours.

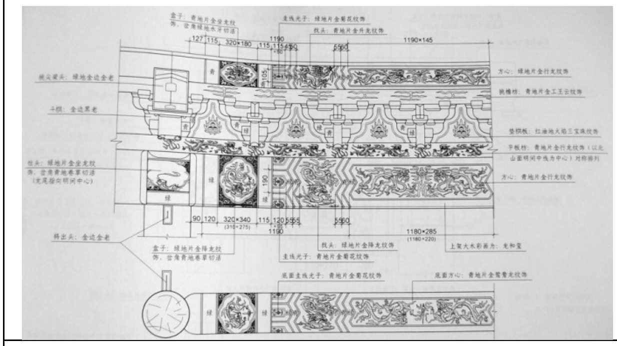

Figure 10: Manual Engineering Drawing

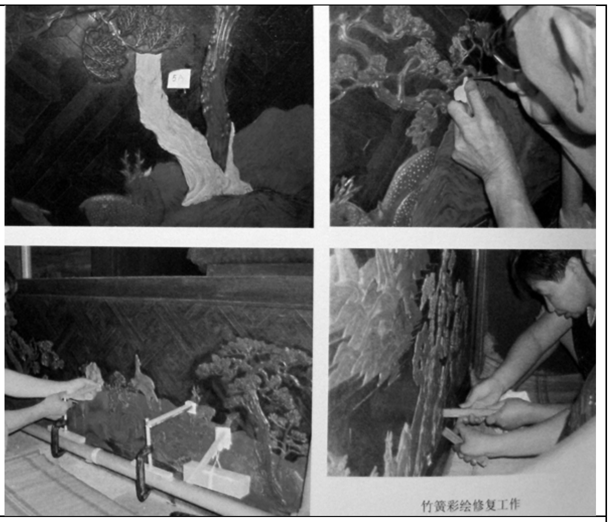

Figure 11: Repairing using Manual Techniques

The repair process starts by marking the defects on the antiques according to the images and engineering drawings. Materials for replacement sections are sourced that are as close to that of the original object as is possible. The dimensions of these replacement sections are specified manually and manufactured using traditional craft skills. The manufactured sections are artificially 'aged' using a variety of finishing techniques (superficial techniques, e.g. painting, and chemical/mechanical aging techniques are used) before being combined with the original antiques (Figure 11).

3.2. AM and finishing techniques

Archiving also involves collecting data via 3D scanning, alongside photography (Figure 12). The 3D scan data is manipulated to produce 3D CAD models, on which defects can be annotated. The 3D models can be used to produce simplified engineering drawings (Figure 13) and also optimised to fulfil a variety of needs such as the creation of virtual tours.

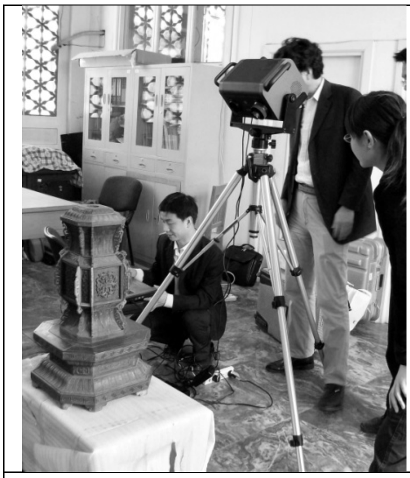

Figure 12: 3D Scanning

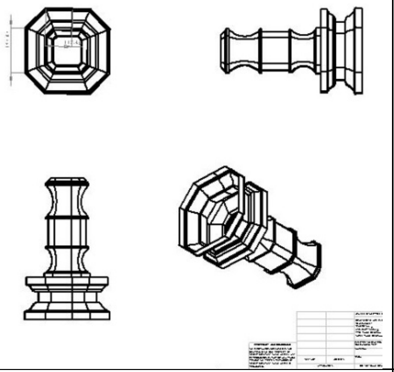

Figure 13: Simplified Engineering Drawing

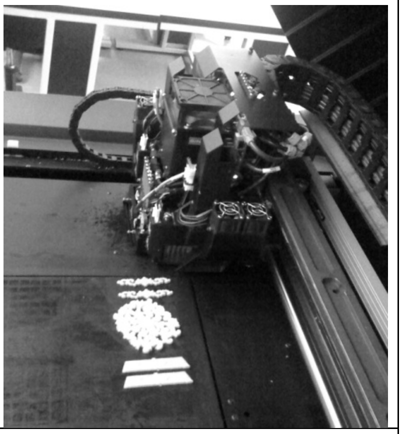

Figure 14: Rapid Prototyping

Figure 15: Turning Rubber Moulds From RP Parts

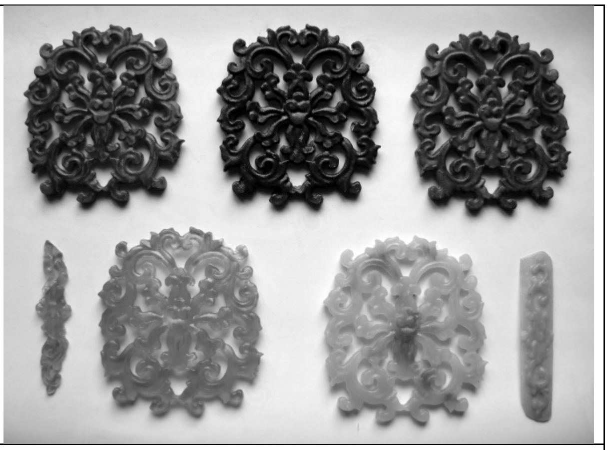

Figure 16: Material Effects by Finishing Techniques

The repair process can be started in much the same way as before, but with analysis of the defects being based on the 3D digital models as well as the photographs. Reproduction of missing parts can be addressed virtually by making changes within the CAD environment with all the advantages that this offers, such as the ability to copy, rotate, mirror and transform similar parts. Parts that are not able to be built via the software can be reproduced by sculptors with clay and imported via 3D scanning. New parts can be produced with RP machines (Figure 14) and different external effects can be created by various finishing techniques (Figures 15 and 16). The new parts are then combined with the original antiques.

4. DISCUSSION

4.1. Mongolian horses project

Using the traditional process, the design and evaluation work is carried out by a highly skilled sculptor on each one of several hundred horses because every individual horse is different. A conservative estimate for the enlarging process is that it needs at least 8 people with different skill levels to work for 12 days. The large clay models are used to create a negative mould in plaster, followed by a positive copy in glass fibre for transporting to the factory. In the layered manufacturing process, the sand model and 10% original for design and evaluation can be obtained within around 4% of the time scale, compared with the traditional process. The models are made with better details using the easier and more flexible working practices of a designer/sculptor.

In the first of two experiments, a full size solid model was made in plastic foam board by 2 workers in 3 days, after which a better method for manufacturing was found. Therefore, in the second experiment, a full size detailed plaster model was be made by 2 workers in 3 days, and they were able to make changes before sending it to the factory, saving time and making it much easier for both the designer/sculptor and the workers in the factory. In addition, it was no longer necessary to create a clay model since it was possible to obtain a full size detailed plaster model directly.

4.2. Forbidden City renovation project

By traditional methods, for archiving purposes, taking photos and hand drawings requires professional skills and takes a long time. Also, any required measurements are not very accurate as they are taken manually. Building 3D digital models from 2D images is a huge project for even a small object, and it needs accurate dimensions, which is also a significant problem. For antique repair, every step of manufacturing requires many hours of input from skilled people of different professions who have been trained for many years. Materials are expensive and are easily wasted if any small mistakes are made. Some special materials and geometric structures are almost impossible to repair.

Using the AM method, the measurements are much more accurate, and engineering drawings and digital models are much easier to obtain for archive purposes. Reproducing parts virtually by copying similar/mirrored parts is much easier and more accurate than hand-making of replicas using just photos and drawings. Producing AM parts can also save much time in avoiding the need to find rare materials for purchasing and also in avoiding the waste of expensive materials. In addition, AM brings greater possibilities for repair.

5. CONCLUSIONS

Art is primarily a vehicle for the expression of the subjective elements of aesthetics, emotion and meaning – although the value of sculptors’ work is often measured in terms of the technical modelling skills employed, as well as the ideas conveyed by their work. However, manufacturing processes play a significant role in the sculpture industry, and often consume significantly more effort overall than the initial artistic creative and design activities. Digital technologies are already proving, though these case studies and beyond, to be useful tools in improving on the traditional approach, by reducing the tedious aspects of the work and allowing greater emphasis on artistic activities.

5.1. Further problems to be solved

At the time of writing, the following problems were still being investigated:

- 3D scanning of translucent objects (e.g. jade and amber) and objects with very high or low reflective surfaces (e.g. gold and hardwood), especially those antiques where contact and the use of powders is prohibited.
- 3D scanning of finely detailed objects in awkward situations (e.g. confined spaces) that prohibit the use of a robot arm and yet require higher resolution than hand-held equipment currently provides.
- Finishing techniques to complement suitable and reasonably priced materials for RP / AM. Currently, time-consuming artistic methods must be used incurring a high cost [10].
- The communication between sculptors, designers and engineers and also the relationships between co-workers involved in the innovative process chains these projects are creating.

5.2. Concluding remarks

The impact of RE and AM on the sculpture industry may bear similarities to that which photography has had on painting over the last 2 centuries, i.e. (digital) technology will not replace artists, but in some way become absorbed from the scientific into the artistic domain. Although at present some concerns exist, and productive communication between artists and engineers is quite isolated, AM can certainly be further optimised as a tool for the manufacturing process chain in the sculpture industry, just as it has developed in other fields.

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