Digital fabrication in the arts: just another technical reproduction advance leap or a new artistic revolution?

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ABSTRACT: The present paper aims at discussing the use of rapid prototyping techniques for the production of artwork. This discussion is based mainly on Walter Benjamin´s (1968) and William Mitchell´s (1992) ideas, respectively about reproduction techniques and the use of digital media. Benjamin points out three aspects of the use of reproduction techniques: for pedagogical purposes, for diffusion of an artist's work, for forgery, and as a new means of expression. The use of rapid prototyping to produce artwork is herein analyzed from these four points of view. In the same way that Benjamin asserts that certain techniques, such as photography and movie-making, resulted in a change in the whole concept of art, Mitchell suggests that digital synthesis techniques can also result in a new artistic revolution. It is possible to extend Mitchell´s ideas to the generation of 3D digital form, which can be output with RP techniques.

1 INTRODUCTION

The present paper aims at discussing the use of rapid prototyping (RP) techniques for the production of art. This discussion is based on the ideas presented by Walter Benjamin in "The Work of Art in the Age of Mechanical Reproduction" (1968), originally published in 1936.

According to Benjamin, traditionally, "replicas were made by pupils in practice of their craft, by masters for diffusing their works, and, finally, by third parties in the pursuit of gain. Mechanical reproduction of a work of art, however, represents something new" (op. cit., p.217). This paper will look at the use of rapid prototyping techniques for these four purposes: education, diffusion, forgery and as a new means of expression.

2 ADVANCE LEAPS

Benjamin asserted that the development of mechanical techniques for the reproduction of works of art had "advanced intermittently and in leaps at long intervals, but with accelerated intensity" (op. cit., p.217). He mentioned the development of different reproduction techniques since the ancient Greeks through the nineteenth century, which are summarized in Table 1:

Table 1. Benjamin´s advance leaps

Time	Technique	Applications in art
Earlier civilizations	Molding	Terracotta
	Founding/casting	Metal statues
	Stamping	Coins
Middle Age	Woodcut	Graphic art, illustrations
	Engraving	Graphic art, illustrations
	Etching	Graphic art, illustrations
XIX Century	Lithography	Pictorial reproduction
	Photography	Pictorial reproduction
	Movie-making	Pictorial reproduction
	Mechanical sound	Sound reproduction

During the XX Century this interval became even shorter, first with industrial techniques that allowed for mass production of identical items, and more recently with post-industrial digital fabrication methods for highly customized production. These new methods include automatically assembling parts in customized arrangements, reshaping materials (such as in metal bending), cutting shapes from laminated materials, and a variety of subtractive and incremental or additive techniques, such as multi-axis milling and rapid prototyping.

Rapid prototyping (RP) is the automated production of physical objects from digital models. Applications of RP range from explorative model making during the product design process to the production of a final product. Most authors consider additive systems the only proper types of RP. In such systems digital models are built by the successive addition of thin layers of fused material (e.g. fused deposition modeling and electron beam melting) or the successive solidification of layers of powder or liquid material (e.g. selective laser sintering, 3D printing, multi jet modeling and stereolithography). RP allows the production of virtually any shape with different materials depending on the machine, such as starch, plaster, wax, nylon, photopolymers, plastic, metal, etc. The size of the objects, however, is limited by the machine's build volume. Most 3D printers can build objects up to 8"x10"x8", but some have larger builds, up to 16"x20"x24". It is also possible to build objects up to 24"x24"x20" with more expensive techniques, such as selective laser sintering and stereolithography. The cost of rapid prototyped objects is still high if compared to large-scale production techniques, and can only be justified in the case of custom objects that require great precision. 3D printing with plaster or starch is presently the most affordable technique.

3 RP AND PEDAGOGY

Traditionally, the reproduction of masterpieces was the most common method for educating an artist (MacDonald, 2004). This was part of the method used, for example, at the *Académie Royale de Peinture et de Sculpture* in Paris, which later became the École Nationale Supérieure des Beaux-Arts. It is still very common to see art students copying paintings in museums such as the Louvre.

In the same way that it is possible to copy a painting with a digital camera or flatbed scanner and a color printer, it is also possible to produce a copy of a sculpture with a 3D scanner and an RP machine, although probably in a smaller scale. The pedagogical value of such operation, however, is highly questionable. Traditional art is literally a "hands-on" process. When copying a masterpiece by hand (either a painting or a sculpture) an art student has the oportunity to practice a specific technique, without having to worry about being creative. By focusing on the technique first, the student can master it and then start doing his or her own compositions, which requires other important skills.

The only pedagogical value of reproducing traditional artwork with an RP technique is that the student can learn the reproduction technique; not the art technique itself. The reproduction of digital art with an RP technique, however, can be interesting from a pedagogical point of view. In this case, the most important step would be to reproduce the computational logic of the composition and then use RP to output the result. The reproduction of the masterpiece´s logic can be done, for example, with the use of the shape grammar formalism defined by Stiny and Gips (1972), and implemented algorithmically in the computer. This method, however, goes beyond the scope of the present paper.

4 RP AND THE DIFFUSION OF ART

The reproduction of traditional or digital 3D art with the process described above is highly justifiable for the diffusion of art. Replicas of famous sculptures can be produced to allow people to see them without having to expose delicate, antique statues to risks. The most well-known case is probably the Digital Michelangelo Project, developed by Stanford University (Levoy et al., 2000). In this project, 23-feet tall David was digitized and then rapid-prototyped in a smaller scale in a thermojet wax printer (Fig. 1). With the specially built, large scale laser-scanner it was not even necessary to touch the delicate, centuries-old statue to reproduce it. Once the digital file was available, the statue could also have been reproduced in stone at full scale, with an automated milling machine anywhere in the world, without the need to transport it there. The rapid prototyped scale model, on the other hand, could be easily transported for a traveling exhibition. More important than that is the fact that David´s digital file is available for download from the Internet, making it possible to any museum or art school that has a 3D printer to produce its own replica at any desired scale, with any available automated technique.

Another important use of RP is to produce "touched-up" replicas of broken or incomplete sculptures, to show people how a masterpiece must have looked years or even centuries ago. According to Mitchell (1992), the possibility of retouching is the most important characteristic of digital imaging, and the same can be said for digital 3d models. As Mitchell points out, when we see a "real" photograph - i.e., printed in photographic paper - we believe it depicts reality. However, when we see a digital image on a computer screen or even in a laser or inkjet print out, our first reaction is to wonder if it has been retouched, if it is really "real". Similarly, when we see a rapid-prototyped copy of Michelangelo's David, even if we are told that the 3D model was acquired by a high-precision 3d laser scanner, we may not be so sure if its imperfections have been retouched and if the sculpture we see corresponds to the "real" David.

Fig. 1: Rapid prototyped version of Michelangelo´s David. Source: http://graphics.stanford.edu/projects/mich/replica/replica.html.

Figure 2: Vase 3d printed in a color ZCorp. Source: http://emsh.calarts.edu/~mathart/sw/Color_3D_Prints.html.

In an extreme situation, it is even possible to 3D-scan small pieces of a broken sculpture, digitally put them together and fill in the gaps, and then rapid prototype the result. This is, however, a very polemic practice - most art critics refuse it, although some educators see great pedagogical potential in it.

Despite the critics´ opinions, it is a fact that the availability of information on the Internet, along with the affordability of output devices have resulted in a new socialization of art. Nowadays it is possible to use relatively cheap - even home kept - equipment such as color laser printers and 3D printers for reproducing paintings and sculptures. Source files for 2D and 3D printing can be downloaded for free in most cases. Sometimes both a painting and a 3D sculpture can be merged in a single printable “work of art”, such as in the vase mapped with a painting by Gustav Klimt shown in Figure 2. The source file for this vase, which can be downloaded from the Internet at no cost, is ready for being rapid-prototyped in a color ZCorp 3D printer.

5 RP AND FORGERY

It is possible to forge a sculpture by using RP techniques. In this case RP would probably not be used to produce the final object, but the mold for casting a metal or terracotta object. The forger, however, would need to have access to the original masterpiece, to be able to film it or take photographs from multiple angles, in order to produce an accurate digital representation of the sculpture. Shlyakhter et al. (2001), for example, describe a technique for generating 3D models from photographs.

However, if technology can help forging a masterpiece, it can also help confirming its age and authenticity, making it much more difficult to cheat nowadays.

6 RP AS A NEW MEANS OF EXPRESSION

The most important approach for understanding the role of RP in the arts is by seeing it not just as a reproduction technique, but also as a new means of expression. According to Benjamin (op. cit.), by 1900 “technical reproduction had reached a standard that not only permitted it to reproduce all transmitted works of art and thus to cause the most profound change in their impact upon the public; it also had captured a place of its own among the artistic processes” (p.217). The author points out that certain reproduction techniques, such as lithography, soon became an artistic mean in itself rather than just a way of massively reproducing paintings and drawings:

> “This much more direct process was distinguished by the tracing of the design on a stone rather than its incision on a block of wood or its etching on a copperplate and permitted graphic art for the first time to put its products on the market, not only in large numbers as hitherto, but also in daily changing forms. Lithography enabled graphic art to illustrate everyday life, and it began to keep pace with printing” (op. cit., p.218).

The same happened to photography, sound recording and other techniques. In regards to movie making, for example, Benjamin (op. cit.) quotes Severin-Mars:

"What art has been granted a dream more poetical and more real at the same time! Approached in this fashion the film might represent an incomparable means of expression. Only the most high-minded persons, in the most perfect and mysterious moments of their lives, should be allowed to enter its ambiance" (p.219).

Photography and movie-making promoted a shift from the traditional use of hands to the use of the artist's eyes:

"For the first time in the process of pictorial reproduction, photography freed the hand of the most important artistic functions which henceforth devolved only upon the eye looking into a lens. Since the eye perceives more swiftly than the hand can draw, the process of pictorial reproduction was accelerated so enormously that it could keep pace with speech" (Benjamin, op. cit., p.217).

According to Mitchell (1992), digital imaging eliminates the traditional differentiation between painting – in which the hand is most important – and photography – in which the eye plays the principal role. With digital imaging it is possible to combine digital – or digitized – photographs, computer-synthesized images, and raster or vector shapes drawn directly on the computer with digital graphic tools:

"...the essential characteristic of digital information is that it can be manipulated easily and very rapidly by computer ... intermediate processing of images plays a central role. Computational tools for transforming, combining, altering and analyzing images are as essential to the digital artist as brushes and pigments are to a painter, and the understanding of them is the foundation of the craft of digital imaging". (p.7)

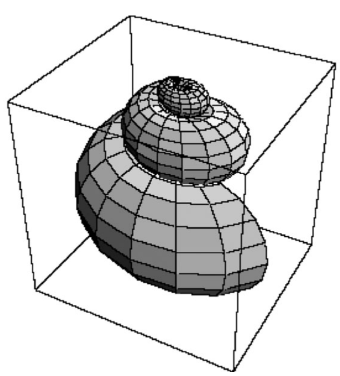

Figure 3: Snail generated in Mathematica. Source: http://emsh.calarts.edu/~mathart/sw/Snail_VRML/Snail.html.

In a similar way, it is possible to generate digital 3D models by digitizing real world objects with 3D scanners, by automatically synthesizing 3D forms in the computer with mathematical equations, and by "manually" modeling 3D forms with CAD software tools. Figure 3 shows a 3D logarithmic spiral form generated in the Mathematica software with the following code:

```
 << Makepolygons.m ;
Needs["Graphics`ThreeScript`"]
rad[u_] := Exp[u/(6 Pi)] - 1 ;
pitch = 2/3 ;
x[u_, v_] := rad[u] * Cos[u] * (1 + Cos[v]) ;
y[u_, v_] := rad [u] * Sin[u] * (1 + Cos[v]) ;
z[u_, v_] := -pitch * (Exp[u/(3 Pi)] - 1) + rad[u] * Sin[v] ;
SnailPolys = MakePolygons[Table[ { x[u, v], y[u, v], z[u, v]},
        {u, 0, 6 Pi, Pi/8.125},
        {v, 0, 2 Pi, Pi/8}]] ;
Show[Graphics3D[SnailPolys], PlotRange -> All] ;
ThreeScript["Snail.3s", Graphics3D[SnailPolys]]
```

Figure 4 shows digitally-generated sculptures by artist Laurita Salles (2003). The forms were developed with CAD software and produced in a selective laser-sintering machine. The artist then post-processed the sculptures, to make them smoother and shinier.

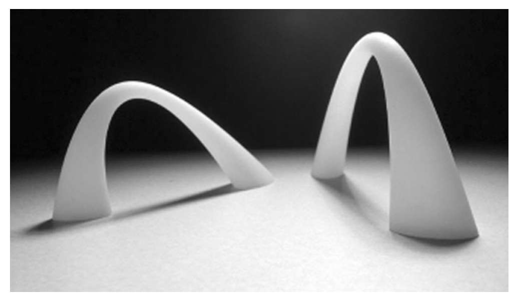

Figure 4: Sculpture by Brazilian artist Laurita Salles. Source: http://www.cimject.ufsc.br/servicos/Cases/02_57USP18JULHO2003.htm

In regards to peripherals for drawing and modeling directly on the computer, 2D shapes can be produced with the help of digitizer boards and pens, and 3D forms can be done with the help of data gloves. It is also possible to combine all these techniques, and even to map 2D raster images on 3D vector models.

Diagram 1 shows some of the possible ways to produce 3D models that can be output with digital fabrication techniques, such as RP:

In the same way that printers allow outputting digital drawings, digital fabrication techniques allow to output digital sculptures. In the first case, if the drawing is based on a raster file, the conversion is straightforward from a pixel matrix to an ink dot grid. If the drawing is based on a vector file, however, the computer first needs to convert the mathematical description of the drawing to a matrix of points. In the case of 3D models, which are always based on vector files, the 3D representation is converted to hundreds - sometimes thousands – of very thin sections of the object, which are then printed layer by layer to physically construct the object in a RP machine.

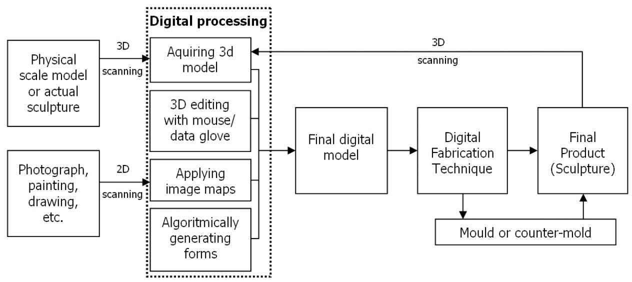

Diagram 1: Acquisition, generation and processing of data for producing a digital 3D model that can be automatically fabricated.

7 DISCUSSION AND CONCLUSIONS

The present paper aimed at proposing an initial discussion on the use of post-industrial techniques in general and RP techniques specifically in the field of art, by critically presenting alternative approaches of the use of RP in the reproduction of existing artwork and in the production of new forms.

In summary, it is possible to say that RP techniques have different applications in art, its most important ones being the diffusion of artwork through the production of replicas and the output of digitally generated sculpture. The latter implies the digital generation of form, which can combine digitation of physical objects, computational synthesis, digital manipulation and the combination of the above. An artist can start, for example, by molding a form with clay, then 3D scan it, digitally change it and rapid prototype it. Alternatively, he or she can define a mathematical equation that generates a 3D shape, digitally alter it, 3d print it and change it manually with traditional tools. In any case, the traditional concept of hand-made art needs to be rethought.

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