COMPLEXITY AND MASS CUSTOMIZATION IN CONTEMPORARY ARCHITECTURE

Prospects in an Emergent Economy

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Abstract. In this paper we demonstrate through examples and an experiment that digital fabrication is viable and it is starting to produce impact in the Brazilian architecture, towards mass customization, not only through some exceptional buildings, but also through small experiences involving ordinary design needs. The examples show that digital fabrication is already contributing to innovative solutions in the Brazilian architecture. The experiment consisted of producing and comparing two models of a column of the National Cathedral of Brasilia, one analogically and other digitally fabricated. The results of this experiment show that digital fabrication technology and mass customization are not only economically viable for the Brazilian construction industry but can also contribute to significant savings.

1. Introduction

Some of the most important applications of computer science in the architecture, engineering and construction (AEC) industry have been in the fields of representation and fabrication.

According to Mitchell (1995), representation is the “creation and manipulation of signs – things that ‘stand for’ or ‘take place of’ something else”. We represent, for example, spoken language through writing, calculations with numbers and artifacts through scaled models and drawings.

Representation plays a double folded role in the AEC industry: firstly, it is an essential part of the design thinking process. It is not possible to fully design without resorting to a concurrent representation system (Merleau-Ponty, 1945). Secondly, representation is a means of design communication to clients and builders (Zevi, 1957).

Computer systems initially represented low level entities such as lines, arcs, polygons and planes. As hardware became more powerful and capable of processing more complex algorithms, new applications were designed for representing higher level entities such as three-dimensional generic solids. As processing power continued to grow, it is now possible to represent specific object-oriented construction components and subassemblies. These computer representations encapsulate not only geometry, but also properties, behavior and inter-relationships in what came to be called Building Information Modeling, BIM.

However, these applications have been often misunderstood by some architects. For instance, the issue of representing architecture through computer systems is frequently regarded as a peripheral practice, with no implications, either in the design process or in its product. This point of view is generally based on the assumption that design thinking and design representation are two distinct and sequential processes. However, as we already pointed out, design cannot take place without a representation system.

In a contradictory statement, those who hold to this view, very often also hold to a kind of 'drawing worship', in which hand drawing is considered an eternal and irreplaceable representation system (Lyn & Dulaney, 2009).

However, the profession of architect, as we know it today, the one who solely designs for others to build, is relatively new in the course of human history (Robbins, 1997). Not much more than five hundred years have elapsed since it came into being replacing the master builder by the end of High Middle Ages. This represents roughly less than 10% of the time elapsed since the invention of phonetic writing, around 4000 BC, which marks the beginning of human history.

In the same way it is with designing by drawing and by drafting, a system which arose together with the profession of architect as we know it today. It was this system that allowed master builders to progressively distance themselves from construction sites and to become solely designers (Robbins, 1997).

Nevertheless, many seem to consider and to act as the profession and its closest counterpart, the drawing/drafting system, had both always existed. Consequently, many professionals and teachers think that drawing and drafting have always had a central role to play in designing and building (Lyn & Dulaney, 2009).

However, the historic evidence does not support these views. Before High Middle Ages, master builders used many different ways to represent their ideas and to have them materialized. Drawing was just one of them and it was not the most important (Robbins, 1997; Coulton, 1977; Kostof, 1977). If drawing and drafting have not always been the prevailing way of designing, there is no need to believe that they should play this role forever. Also, the advent of interactive three dimensional computer modeling seems to be challenging those views. New representational systems can and have been brought to play innovative roles in the design (Kolarevic, 2003a) and in the construction processes (Kolarevic, 2003b).

The construction industry has been based to this point in time in mass standardization. The produced components are generic elements that will be customized later in the life cycle of the product. The mass produced components are classified into specific categories and produced in a limited array of forms and sizes. They are then stored, indexed and catalogued until they eventually, if sold, end up in a combination of elements in a factory or as a part of a building in the construction site (Polette et al, 1995).

Computer resources that allow the computerized manufacturing of artifacts directly from three-dimensional virtual models came to be called digital fabrication (Kolarevic, 2003b). This process allows the production of construction components through computer controlled machines. These components may be produced by order without the need for an indexing system and shipped straight to the construction site. Therefore, substantial savings are made with labor, transportation, storage and cataloging systems.

As a new paradigm, the mass customization provided by digital fabrication allows that construction components may be produced for specific purposes, to become singular elements in unique contexts of specific buildings. The savings obtained in the automation of this process mean that the costs of unique components are hardly above those of the old standardized ones (Silva et al, 2009; Kieran & Timberlake, 2004; Kolarevic, 2003c; Schodek et al, 2005; Franken, 2003).

2. Research Problem

Digital fabrication technology is already available in emergent economies such as Brazil as it was demonstrated in earlier works (Silva et al, 2009). However, has it had any impact towards mass customization in the Brazilian architecture and production of innovative products? If so, did it find application just in exceptional buildings or has it found use in more day-to-day design needs?

3. Hypothesis

We believe that digital fabrication is starting to produce impact in the Brazilian architecture towards mass customization, not only through some exceptional buildings, but also through small experiences involving ordinary design needs.

4. Research Methods and Results

We demonstrate the above hypothesis through surveying and describing a number of examples of art and architectural design works from Brazil which have made used of digital fabrication. We also explore an experiment carried out by one of the authors of this paper in which the results of using digital fabrication were compared to those of traditional production systems in our country. This experiment revealed that digitally fabricated components can even result in a lower cost than those mass standardized ones.

Several examples of digital fabrication were found in the central region of Brazil, the area in which our research has been taking place. Some of them have already been mentioned in previous works (Silva et al, 2009), particularly in the area of arts such as that shown in Figure 1. The so called "sphereoids" by artist Darlan Rosa (http://darlanrosa.com/) were one of the earliest examples of digitally fabricated artifacts in our region. These artifacts have a diameter of 2 meters and were partially produced through digital fabrication. The 2D cutting of the metal sheets were achieved through a Computer Numerically Controlled (CNC) plasma cutter, but forming was still carried out manually. Nevertheless, the "sphereoids" represent a formal and constructive innovation in the area of arts in our country.

Figure 1. "Sphere", by artist Darlan Rosa, DF, Brazil. (Source: authors' photography).

However, the application of digital fabrication is no longer limited to the area of arts, but has already found broader use in the construction industry. Figure 2 shows the entrance of a pedestrian overpass of the Metro System of Brasília, structural design by Márcio Buzar, which was digitally fabricated and assembled by CPC Estruturas, a company based in the Federal District of Brazil (http://www.cpcestruturas.com.br/). The overpass is 210 meters long and 6 meters wide. Its process of designing and constructing was fully integrated involving structural building information modeling system and the digital fabrication of all metal components through CNC 2D cutting and CNC forming. The concrete components were prefabricated but not digitally fabricated. Nevertheless their fabrication was still integrated and controlled by the same company (CPC Estruturas). The innovation of the overpass project was related to the structural and to the sustainability aspects. The innovative structural aspects were expressed through greater precision, faster construction at lower costs. The innovative sustainability aspects were related to a cleaner site due to prefabrication and a much smaller use of timber molds.

Figure 2. Pedestrian overpass – Metro of Brasília, structural design of Márcio Buzar (Source: http://www.cpcestruturas.com.br/).

Figure 3 shows an external view of the same pedestrian overpass which connects a Metro station to a major shopping mall, running over a major high way.

Figure 3. Pedestrian overpass – Metro of Brasília, structural design of Márcio Buzar (Source: http://www.cpcestruturas.com.br/).

We then carried out a particular experiment that consisted of modeling of the 16 columns of Brasilia's Cathedral (Figure 4). The Cathedral was actually built in the early sixties in reinforced concrete, but the shape of each of its columns was remarkably complex for the available technology of the time. Since this shape is also non-uniform, in a NURBS like form, we chose it as the basis of our experiment.

Figure 4. Interior view of Brasilia's Cathedral (Source: http://www.infobrasilia.com.br/).

We then modeled one of those columns in a three-dimensional solid modeler and produced the correspondent blueprints. Their orthographic views (Figure 5) were sent to a standard metal workshop for analogical production of a scaled model.

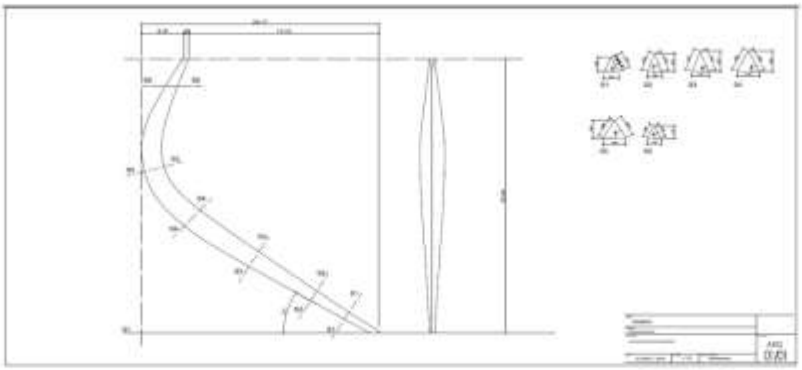

Figure 5. A blueprint of a Brasilia's Cathedral column.

A significant amount of interpretation and some form reduction were necessary to make this undertaking possible, particularly because of the non-uniform shape of the columns curve (Figure 6). The staff of the metal workshop defined a discrete number of straight lines which could represent the curve in a simpler way. This allowed for the non-automated fabrication of the column, particularly the cutting of metal sheets. However, this also resulted in a segmented representation as a replacement of the original smooth curve.

Figure 6. Interpretation and form reduction of a Brasilia's Cathedral column.

On the other hand, the file containing the three-dimensional model was sent to a CNC based metal structures factory in our region for the digital fabrication of a scaled model. No blueprints were sent to this factory.

We compared the results (Figure 7) of the manually and digitally fabricated columns in relation to costs, production time, precision, firmness, and its potential for mass customization. The aspect of durability was not taken into consideration due to time limitations. The aspect of stability was not taken into consideration because this would require the fabrication of a model of the entire Cathedral since in this building the columns are made stable by two sets of rings against which they lean.

Figure 7. Scaled models of a column of Brasilia's Cathedral. The top one was digitally fabricated and the bottom one was analogically produced.

There were no significant differences between the two artifacts regarding firmness. This comparison showed that the benefits of the use of CAD/CAM are promising ones. For example, the differences in precision were visible and favorable to the digitally fabricated artifact. The cost of the analogically produced column was US$210.00 and it took a week to be produced, whereas the digitally fabricated one cost US$40.00 and production time was of just 24 hours. This happened in spite of the Brazilian labor being widely known as very cheap. One could expect that digital technology, in this context, would actually increase the costs rather than reduce them, but this did not happen.

5. Discussion and Conclusion

We believe we have demonstrated that digital fabrication is starting to produce impact in the Brazilian architecture. This process is not limited to exceptional buildings, but is also finding way in experiences involving ordinary needs, such as the case of the pedestrian overpass.

The last example, the comparison between the scaled models of Brasilia Cathedral's columns, shows that digital fabrication technology and mass customization are not only economically viable for the Brazilian construction industry but can also contribute to significant savings.

Cultural obstacles, such as the ingrained belief that a singular artifact is necessarily more expensive than a mass standardized one, may be progressively removed. However, how fast this is going to happen remains to be investigated in the near future**.**

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