How to go from the file to the factory

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File-to-factory / Digital Fabrication / Computer-aided manufacturing

The present paper describes the file-to-factory process of a design object produced through a CNC plasma cut machine as a result of a six-month internship at a steel cutting company called Oxipress. The purpose of this participatory action research was to get a closer contact to the industry in order to find out what architects should know to make file-to-factory process seamless.

1. Introduction

In the past decade there has been an increasing application of computer-numerically-controlled machines in the production of building parts. CNC techniques, originally used in industries such as aerospatial and ship-building, has recently started being incorporated in architecture production. However, for many authors 'digital fabrication technologies will not change building production without fundamental shifts in the social and market structures of design practice' (Moe 2010: 164).

As it has already been pointed out (Silva et al. 2009) Brazil has a significant number of computer-aided-manufacturing companies that remain producing traditional mechanical parts due to a lack of demand from architects and designers. If these professionals had a better understanding of the CAM process they could make use of such sophisticated production techniques.

This method of construction, which has been called "file-to-factory", eliminates the necessity of intermediate representations between the designer and the final building components. Authors such as Kolarevic (2003) have proposed that these new fabrication technologies, along with modeling and evaluation performance software, will challenge the traditional approach to design. However, even though architects have already become familiar to digital software to draw and model their designs, they are not ready for dealing with more specific production issues, such as CNC machine parameters, materials' properties, and so on. As a result, the file-to-factory process is usually not so straightforward as it should be, requiring multiple adjustments and often getting stuck due to issues such as file format incompatibility.

This paper describes an example of a file-to-factory process in the production of a design object using plasma cutting. It consists of a piece of furniture with curved lines and an egg-crate structure, something that a traditional metalworking firm would not be able to produce. The paper is part of a trilogy of conference papers in which three aspects of the process are described: (1) parametric design, (2) prototyping and structural analysis, and (3) fabrication. The work was divided in three parts due to space limitations, but we expect to publish a complete version as a journal paper.

The objective of this part of the study is to show how it was important to get closer to the industry in order to find out which are the most typical difficulties in this type of process, and infer, from this experience, what architects should know to make it seamless. The importance of this approximation has been clearly stated by *Kolarevic:*

> "Knowing the production capabilities and availability of a particular digitally driven fabrication equipment enables designers to design specifically for the capabilities of those machines. The consequence is that designers are becoming much more directly involved in the fabrication process, since they create the information that is translated by fabricators directly into the control data, which drives the digital fabrication equipment." (Kolarevic 2010: 71)

2. Methodology

The method used in the study was participatory action research, through a six-month internship at a local steel cutting company called Oxipress. Although this firm has invested in state of the art steel cutting machines, they are not used for producing complex design objects simply because there is no demand from their clients, its main field being simple mechanical parts (fig. 1).

Figure 1. Parts commonly produced by the company´s CNC plasma cut machines (photo by Wilson Barbosa).

During this time, the authors followed the everyday production process, being able to experience from the early stages of the preparation of CAD files, through cutting steel sheet routines, until the final steps of assembling parts and post-processing. The idea was to learn about the capabilities of the machines and introduce a new scope of production in the factory.

The period of study in the factory was divided into two major steps:

(A) Exploratory Stage, which involved the production of a series of experiments to investigate material properties and to learn about the capabilities of the CNC machines.

(B) Production Stage, which allowed the implementation of the knowledge gathered in the previous stage to complete the file-to-factory process.

The equipment used during this study consists on a Messer Multi Therm 4x14m CNC machine with a Hypertherm HPR 400 plasma source supply capable of cutting up to 60mm stainless steel sheets (fig 2). The CNC machine is basically composed by the following set of parts: (1) a cutting table equipped with a smoke extraction system, (2) a power supply which provides the plasma arc starting circuit; (3) a torch that holds a set of consumables parts enabling an extremely constricted plasma arc and (4) a software that controls the process.

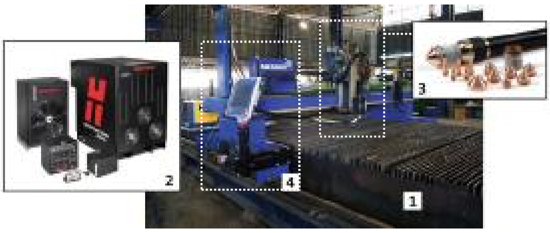


Figure 2. Plasma CNC machine (image by Wilson Barbosa).

According to the manufacturer's 'these system components provide the electrical energy, ionization capability, and process control that is necessary to produce high quality, highly productive cuts on a variety of different materials[1]'.

Exploratory Stage

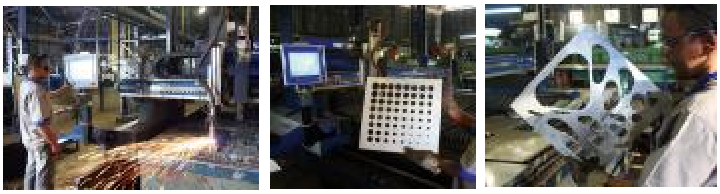
During the development of the Exploratory Stage in the factory, it was necessary to perform a series of experiments related to a range of issues, such as assembly of the parts, thickness of the cuts, and so on. During the fabrication process, many adjustments had to be made in the design to comply with the material's properties. The close contact with the factory's team allowed for a better transition between the original files and the CNC machine files. This experience resulted not just in an original piece of design, but also in an invaluable body of knowledge about the file-to-factory method.

Experiment 1 – Parametric plates

The first experiment was a plasma cut test. The purpose of this excercise was to understand the basic procedures and functionality of the CNC machine, as well as the behavior of three different materials: carbon steel, stainless steel and aluminum. A set of irregular sized shapes was cut in three 400x400x2mm plates to perform the tests.

The designs were generated through a parametric rule using Grasshopper plugin for Rhinoceros CAD software and the 2D information saved as *.dxf* file format in *layer 0*. It is important to note that there was no text or dimensional lines in the drawing. Then the file was e-mailed to the company's engineering department for the following procedures: check the file for drawing or layer mistakes, check the pieces' size and thickness to match material availability and check machine time consumption to inform the production schedule. These procedures are compulsory for any file submission to this particular CNC machine avoiding software malfuncition.

The first material to be cutted was the stainless steel plate (fig.3a-b). This type of steel is popular for its corrosion-resistant properties and its hardness. For this reason it is required that a particular set of consumable parts are placed in the torch to match the material's specifications, in order to perform a good cut. Next, the cutting process was performed on the carbon steel and the aluminum plates (fig.3c).



(a) (b) (c)

Figure 3. CNC plasma cutting process showing different designs (photos by Wilson Barbosa).

Each of these materials was cut with its specific set of consumables (fig.4a). These consumable parts control the size and the shape of the plasma arc and they eventualy wear out and need to be replaced (fig.4b-c). Thus, another important information that arised was the fact that multiple initial piercings, to cut isolated shapes, would cause a higher expenditure of consumables in the torch, shortening its lifetime. This could be a point to be considered at the initial steps of the design process, since the higher the consumables consumption is, the higher will be the final production cost.

(a) (b) (c)

Figure 4. Changing torch consumable parts (photos by Wilson Barbosa).

Moreover, it can be suggested, when suitable to design, that multiple shapes could be arranged to be cutted from a single perforation point, as shown in fig.5.

1 Information available at Hypertherm 'Training and Education': www.hypertherm.com

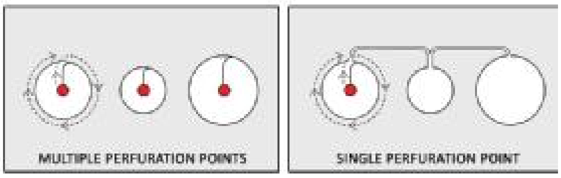


Figure 5. Scheme showing multiple shapes perfuration with a single piercing point (image by Wilson Barbosa).

Experiment 2 – Fitting/Egg-grate sample

To evaluate the best connection between two 2mm-thick transversal pieces of plates, a second test was performed. This type of junction between plates is commonly known as egg-crate fitting, where a notch is cut on both parts (fig.6a).

Firstly a 3D model of a simple structure containing notches with five different widths was developed in Rhino/Grasshopper and 2D vector files were produced to be sent to the machine, as described above. Next, each piece was cut in a 2mm carbon steel plate. Each notch in this drawing had slightly different widths, varying from 2.1mm to 2.6 mm (fig.6b).

When the parts were assembled it was possible to observe some relevant issues. Although in the first option the notch was thicker than the material, the parts did not fit. A closer look revealed that the notches were obstructed by the material waste (fig.6c), due to the cutting process, and had to be removed manually with an orbital sander.

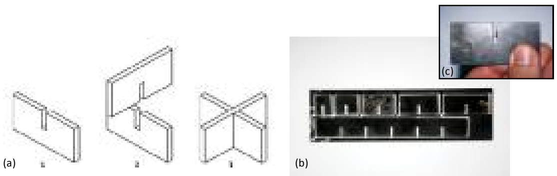


Figure 6. Both virtual model and phisical prototype of fitting sample (images by Wilson Barbosa).

Depending on the part dimensions or the number of parts produced it would be too difficult or take a long time to manually fix each of the notches for best fitting. To improve notch cut, a couple of slightly different egg-crate structures were developed.

At this stage, two 3D parametric models were designed with a more complex shape to further evaluate fittings: (1) a small size curved egg-crate sample and (2) a full size egg-crate chair (fig.8).

Figure 8. Images of both egg-crate experiments virtual models and phisical prototypes (photos by Gabriela Celani).

Both prototypes were made with the same 2mm-thick carbon still sheet used in the previous experiment. However, the notch thickness was set-up as 3mm wide, allowing a correction-free notch and a perfect loose fitting. Then, the parts were assembled and its joints welded together to make a stable structure. Fifteen small size egg-crate samples were made to be submitted to different painting treatments for further finishing analysis.

3. Production Stage

After the completion of the exploratory stage it was possible to transform the gathered information into design principles that would lead to a furniture's quite seamless production process. From now on, the challenge was to design a 3D parametric model that would not only meet the client´s brief but also comply with the automated production capabilities.

The major design object was a curved reception counter made of three parts. The pieces that made up the whole object were generated by the intersection between a *loft extrusion*, which led to the curved shape, and both vertical and horizontal *surface planes* (fig9). The parametric model, built in Rhino/Grasshopper, made it possible to create automatic notches in every part. Thus, if the shape curvature or the material thickness were changed it would simultaneously adjust the information in every single part.

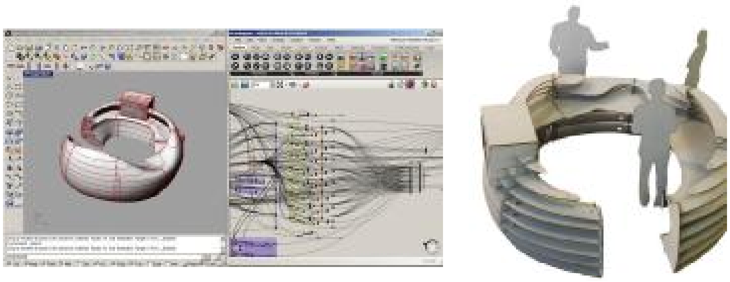


Figure 9. Images showing furniture´s parametric model and 1:20 prototype (images by Wilson Barbosa).

The entire object was made from 33 individual parts. The 2D information of each part was saved in a separately *.dxf* file under *layer 0*. Then, the 33 CAD files were e-mailed as a compressed file format package to the company's engeneering department for 'nesting' set up and other procedures described above. Regarding material consumption efficiency while cutting the parts, the 'nesting' process can be considered the most important step. The word 'nesting' is defined as 'the process of efficiently manufacturing parts from flat raw material[2]'. So, the better the optmization of the parts on the material surface is, less will be its consumption and, consequently, product final cost.

Next, the entire file package was imported in a specific nesting software and its 2D information arranged on 1200x3000x2mm thick carbon steel sheets, which resulted in a material consumption of 16 plates. After that, the nesting files were placed inside

2 Definition from wikipedia.org

the 'job order' folder where they could be accessed by the CNC machine operator. The plasma cutting process took approximatley 7 hours (fig.10).

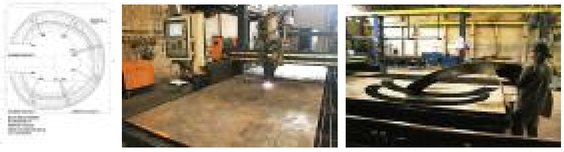


Figure 10. CNC plasma cutting process (images by Wilson Barbosa).

After the parts had been cut they were manually tagged according to design. The pieces were transported to the metalworking shop and then separated by assembling order (fig.11a). Two men were necessary to move the parts and position them for assembling and welding the joints. In order to compensate for the flexion of certain parts of the object, in special the cantilevered parts of the shelves, a metal ribbon was welded underneath them. This part of the production process took 2 days (fig.11b-c).

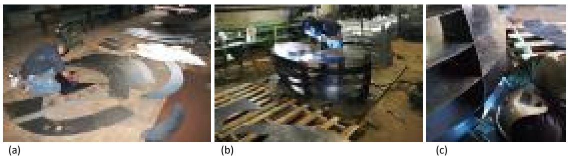


Figure 11. Assembling and welding process (photos by Wilson Barbosa).

4. Discussion

It is possible to conclude that what was learned in the initial experimental stages had an impact the way that the final object was designed, therefore proving that is is important to know well the production methods in order to make better use of the resources and avoid mistakes and imprecisions.

With the description of this process we expect to contribute to the popularization of the use of plasma cutting for the industrial production of custom design objects and building parts.

Acknowledgments

This research would not have been possible without the financial support of Brazilian research agency (CAPES), Laboratory for Automation and Prototyping for Architecture and Construction (LAPAC) and the technology provided by Oxipress Cutting Steel Company.

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