FORM FOLLOWS TOOL: *How the mere existence of a 2D laser cutter does influences architectural design in education?*

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Abstract. The paper is aimed to examine the influence of a digital laser cutter on the design process within the College of Architecture and Planning, University of Utah, Salt Lake City. The tool functions as a peripheral output device within a simple “CAD-CAM” model manufacturing process in the area of architectural model making. It is a 2D laser cutter, accessible to the students since four years. The paper has a critical look at how the machine’s availability, its possibilities, as well as its promising time saving potential has changed the way students develop their design and process their projects. Rapid prototyping is becoming more and more an integral and important part of our design studios. With the adoption of the laser cutter, the model making procedure has changed from a relatively time-consuming, but immediately controllable process, to a procedure where one has to spatially re-think the elements that need to be produced, in order to adapt to the necessary digital workflow or process.

Keywords. 2D Laser Cutter, Digital Design Development, Digital Model Manufacturing Process, Analogue Model Assemblage

1. Introduction

“*What happens when we look beyond” […] the realm of the process that drives a two-dimensional laser cutter “and into those outside processes it effects?”* (CAADRIA call for papers 2007)

An X 660 Laser Platform by Universal Laser Systems was installed as a simple digital output device four years ago at the College of Architecture and Planning at the University of Utah in Salt Lake City. The tool functions as a peripheral output device, similar to a plotter or printer, inside a simple “CAD-CAM” model manufacturing process in the area of architectural model making. With the machine, model making becomes a conglomerate of activities, rather then just a craft limited to the production of miniaturized copies of buildings (Kenzari 2007). Although relatively time consuming in file preparation, the work with the laser cutter is widely incorporated into the student’s work processes, as well as the faculty accepts this method of model making broadly. This paper explains the actual setting of the machine and its typical use in a workflow example, as well as it addresses general questions on the use of the digital tool, raising questions about the work efficiency, and how the machine influences the design process of the students. The author developed a questionnaire, which than was dispersed among the students of the architectural graduate program. Due to the large number of enrolled students in both undergraduate and graduate program, the author limited his survey to the smaller group of graduate students. Although undergraduate students constitute a valuable group to be considered, the group of graduate students includes both experienced architectural students (those who already participated in an architectural undergraduate program) as well as ‘architectural newcomers’ (those who entered the program from a different field of study, therefore being little experienced in architectural design processes).

Beyond the analysis of the questionnaire, the experience of teaching three architectural and urban design studios in which the students had access to the laser cutter, helped to analyze and evaluate the work processes. Within the studio setting, the author was able to discuss process advantages and disadvantages directly with the students. The studio was also the place where new discoveries or deficient production in the process could be directly experienced, observed, and addressed, as well as it enabled the author to look at a possible authority of the machine over the student’s design processes and their final projects.

The questionnaire was handed to 53 graduate students in the program. Within five days, 71,6% or 39 forms were returned to the author. Therefore, the author evaluates the survey as representative. The questionnaire included four main fields: general questions, work efficiency, questions on a possible influence on the design process, and concluding questions. The overall number of questions was 27, of which 10 were to be answered in written format; 17 had to be answered on a scale of 5 points between Yes and No, Less and More, 0% and 100%, etc. The forms were completely answered by the interviewees, with three exceptions; those three did not reply to one to two questions in the questionnaire.

3.1 In the process of creating, developing, and finally assembling your architectural model, do you feel there is any disconnect of your hands, eyes, and brain from the actual manufacturing process of the parts?

Never thought about it ☐

No disconnect ○ ○ ○ ○ ○ strong disconnect

3.2 If there is a disconnect, describe briefly what you do to overcome this handicap:

Figure 1. Sample of a characteristic question in the questionnaire

2. Technology, usage, and workflow of the laser cutter

59% of the respondent students indicated that they have a good to very good understanding how the general technology of the laser cutter works, knowing about the basic principle how material is cut through a concentrated spot of heat, and how the laser head is driven on two axis. 18% pointed out that they don’t know much about the process at all. 5% of the students actually do not use the laser cutter. 95% utilizes the machine regularly, producing an average of 60-70% of their model parts and elements on the machine, crafting the remaining parts with traditional tools and manual labor.

The laser cutter hardware setup is located in the model shop and is maintained and supervised through the shop manager and his employees; the setup consists of a Universal Laser System X-660 Laser Platform, which is connected to a PC that runs on Microsoft’s NT.

The 450 x 812 mm (18" x 32") laser platform uses a 60-watt laser cartridge, a size that is appropriate for its use in the architectural model-making environment. Up to a thickness of 12 mm (”), the laser cuts through acrylic, fiberglass, wood, plywood, MDF, cloth, matte board, corrugated cardboard, paper, etc. The machine can distinguish between general cut lines, inside cuts, and face engravings. Generally, the laser cutter is extremely flexible, since it can be used to produce larger pieces as well as small, detailed and very complex elements.

Users have to sign up for the machine, getting a maximum of two hours of operation time per session. Especially toward mid term and final presentations, the machine is heavily occupied. Different from more dangerous power tools such as the table saws, the laser cutter is accessible at almost any time due to the low risk of getting injured. One major complaint of the students though is the long waiting period for machine time during the peak periods, which is most commonly a result of misuse. Often the laser cutter is used for the production of simple shapes like squares and rectangles, which could be produced faster by using traditional tools and non-digital methods.

To drive the laser cutter, users have to produce two-dimensional model files in a format that can be exported to CorelDraw, which are most commonly dwg-files from AutoCAD, SketchUp, or Vector Works. If those files are adapted from any 3D digital model, the user has to produce sections or plans from the 3D-model and/or flatten the information. Those files have to be produced exclusively for the laser cutting process, since scale, colors, and line weights have to be adjusted to the machine's software. Depending on the applied CAD-software, the information has to be re-edited in CorelDraw; this process can accumulate to quite a bit of work, depending on the complexity of the elements. Double lines, overlapping lines etc. have to be avoided, because the machine would cut or engrave twice or more times. Once the laser cutter files are completed, users have to use the print command to choose their utilized material, its thickness, and the laser's speed, to finally print to the machine. After inserting the appropriate material, the laser head has to be adjusted manually to the material, before the actual cutting process can finally be started.

3. Work efficiency with the laser cutter

The conclusion that can be drawn at this point is that the process of utilizing the laser cutter in architectural model making is not as simple and fast as one would think. Anyhow, compared to traditional model making methods, 76% of the users indicate that they are faster using the machine driven process. The remaining 24% believe it slows them down; in fact some students for this reason don't use the machine at all. One of the biggest potential in the use of the tool though is the possibility to reproduce parts at any time and in any number, based on their digital origin. Furthermore, the laser cutter allows the use of materials that are otherwise hard to handle, such as acrylic.

Those students who pointed out that they actually save time argue that this extra time is spend on the design process, therefore improving their project quality. About 35% of the users specify that they can in fact work less accurate in the model making process, because it is relatively easy to redo parts quickly. On the other hand, this is often contradicted by the fact that machine time is valuable, and access to it is limited due to heavy workload in peak periods. A common result hereof is the use of incorrect parts in models due to those time restraints. Nevertheless, the experience in studio shows that serious mistakes, which influence the whole process and outcome of the project, such as producing an entire model in a wrong scale, naturally happen less with advanced experience of the students.

A frequently observed misuse of the laser cutter is its application to produce parts that would better be produced manually. Valuable machine time is cut down for those who want to produce more complex elements. Any kind of squares and rectangles in most materials can often be produced faster by using saws, sanders, and cutters. It also includes conceptional models in very early design stages, which could be produced more efficient by using simple rip-and-tear methods. By doing so, students would have more time to spend on the conceptional development of their projects, producing a series of first and simple sketch models. The author has experienced some cases in which students were heavily distracted from finding a design solution, simply because they spent too much time on digital file production in early design stages. Some of those students stated that they actually have to force their minds in order to adapt to the process. Especially inexperienced students underestimate the time necessary to develop and transform the digital information into appropriate file formats. Other than the traditional process, where parts get produced one by one, therefore the loss of one or two parts wouldn't have such a severe impact on the overall outcome, the laser cutter process, if it goes wrong, leaves presenting students without models in the worst case.

On the other hand, some users point out that their biggest laser cutter misuse comes from not using it enough. Looking at this aspect neutrally, the author believes that the digital production process demands a certain degree of attention in what is being developed and produced, as well as it demands a high ability of spatial understanding, due to the necessary transformation of 3D information into 2D layers. If this work is not done with the appropriate care, as it is necessary in the field of architecture anyway, users risk to have little mistakes adding up to bigger ones, ending up with an outcome that might not be usable for the purpose it was meant for.

The tendencies in work efficiency also get reflected in the amount of material that is used in the digital production process; about one-third of the students pointed out they would use as much material as in any traditional process; another third indicated to use more material; the remaining 33% said they use less. Specified reasons to use more material were to produce more parts than actually are needed, the amount of leftover material from the cut boards, and miss-production.

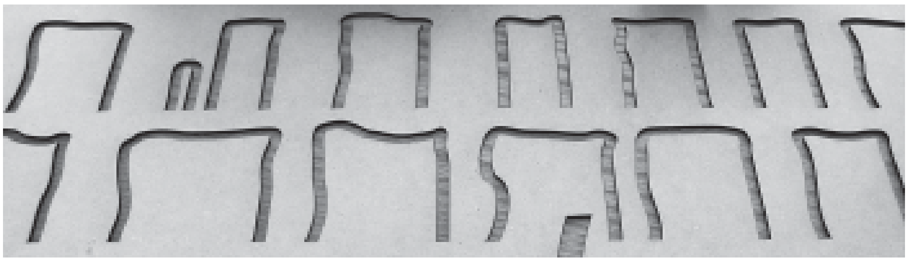

Figure 2. Leftover material in an MDF board

4. Influences on the design process

Traditionally, designers interact with design media by *conversation with materials of a situation* (Schon, 1983). The traditional materials include sketches on tracing paper, design drawings, physical modeling materials, and tangible models, which are used in a conversational process. Using the laser cutter involves a human-to-computer interface for the transformation process. To have a desired conversation with materials of a situation, the user is on the one hand foremost involved in a process of conversation with the computer code [software]. On the other hand, the unique configuration of a specific design problem can be addressed much better in reoccurring cycles by reflecting upon effects of earlier moves in order to make new moves, because the machine allows for fast production of a high number of elements, therefore supporting the conversational process.

By looking at the automated process of fabricating model parts and elements with a digital laser cutter, the question arises if users lose immediate control over the manufactured parts, and if they feel any disconnect between their hands, eyes, and the brain when they produce the necessary, often abstract digital files for their tangible components. 68% of the students stated that they lose no or very little control over their manufactured parts, 56% indicated to feel little or no disconnect between their hands, eyes and the brain in the process. On the other hand, 21% stated to lose immediate control over their work, and 26% of the students felt either a disconnected or strong disconnected of their hands, eyes and brain from the actual manufacturing process.

Those, who felt disconnected and not in full control, have developed different strategies to overcome possible problems. A general method is to couple the digital workflow with traditional hands-on methods of assemblage. Other methods are to build quick models by hand, working with massing and stackable models, leaving out details, which requires more abstractness in the work, and using rip-and-tear model techniques. To a great extend, students produce only specific parts with the machine, trying to keep in direct touch with their work through manually produced pieces. As stated above, mistaken parts are often left in the models, since it is time consuming to redo them. Here the author would suggest manipulation of those parts by hand. This is actually done by few students only; many seem to be anxious about altering those perfectly looking, digitally produced parts. Anyhow, a good way to include the laser cutter at an experimental stage is to produce many variations of a design to find the most appropriate answer. This allows for continuous re-interpretation of statements made in the process, including unexpected results and their possible influence onto the design process.

The mix of laser cut parts with handcrafted elements has established some kind of interesting hybrid aesthetics. Structural elements (especially those that run through a structure in layers) are digitally produced, sometimes altered by power tools or deformed with heat guns. Those kinds of rib structures, covered with a skin, are adopted from airplane and shipyard industries; they already found their way into the building industry, as we can see in buildings like the Guggenheim Museum in Bilbao or others.

Other model types have been developed, where different materials slide into structural elements (e.g. facades), making it easy and fast to change a material, fa ade, and color. In some projects, the idea of layering, which was certainly influenced by the tool, was consequently carried throughout all design stages. Materialwise, the laser cutter has quite an influence onto projects; materials of choice are largely all sorts of acrylic (with a great visual appeal), MDF, and cardboard, all used in thin layers, even for mass models; in earlier times we saw more plywood, solid chunks of Plexiglas and (bass) wood, cardboard, as well as museum board as dominant materials.

About 75% of the respondent students indicated they would rarely use the laser cutter for schematic or pre-schematic design phases. The very expression and rigidity of the cuts, which are highly encoded, demand a confidence and solidity in the design that doesn't necessarily exist in early stages. The traditional process of manually produced rip-and-tear-models with a low degree of encoding is a more fluid and controlled process, as it is also more intuitive, allowing the designer to interpret the work. While a 3D computer model, which reveals itself as a physical manifestation of the digital data much later in the process, still has to be crafted and modeled, the physical act of building a model with your hands is fundamentally and experientially separate.

Toward a more developed stage in the process, when the understanding of the project's tectonics is better, it is much easier to plan out model pieces with a high degree of encoding. 39% of those who utilize the laser cutter in early design work experience problems in combining precisely produced laser cut parts with manually build pieces, and 50% indicate that as a result thereof, they have developed a higher precision in their early study models.

Since the introduction of the laser cutter at the school the threshold between digital and physical realm has been bridged much better. The fact that elements have to be flattened into simple 2D information, which forces planar thinking, comes at the price of enabling students of more organic developments and designs, permitting the creation of more accurate models in a shorter time, without relying on regular shapes and dimensions. Furthermore, the laser cutter is a good tool to create complex curved structures from flat rigid panels through the flexion of 2D panels (Araya 2006). Interestingly enough, the question about a possible influence onto the design process during the necessary transformation from 3D into 2D was answered neutrally by the overall group of participants; all five fields between Yes and No were marked by about the same number of interviewees. Most students refer to traditional methods and means of representation, slicing their digital as well as physical models, extracting sections and plans to produce their 2D files.

In the years since the introduction of the laser cutter, the author has observed generally more precise and communicatable digitally manufactured models, which comes at the cost of an evident loss in the student's ability to produce precise handcrafted architectural models. 66% of the respondents agreed, making the existence of the laser cutter responsible for the lack of craftsmanship. Anyhow, only 30% indicated that they have experienced such a loss themselves. Very rarely students actually think about possible future applications of the digitally advanced process, such as implementations from the model process into real production or the mass-customization for buildings. In order to train students better in material handling and in the use of the laser cutter as an efficient tool, the author generally demands the development of both manual and digital model making skills; this ensures more expressive models as outcomes. An entirely precise and clean presentation model might just look sterile, as it is often the case with purely synthetically produced renderings and images.

This strategy also supports students who have a problem in expressing their ideas through fast sketches and hand-build models. Those students tend to use the digital tools most; anyhow they often have a hard time to recognize what they are creating *spatially*. They tend to spend a lot of time in understanding how to define their models digitally, loosing this time for the design process itself. Controlling their usage of digital production tools toward certain areas in the design process has turned out to be a good support to make them better understand the development of space in architecture.

5. Conclusion

The laser cutter allows for more possibilities in the realm of computer-generated models that use large numbers of intricate parts. Especially students that use the 3D computer model for their design development feel more confident, since they have a tool with which they can transform and communicate their ideas into the physical world, even if it is on a more abstract level. Students indicate that they are not as intimidated by unique shapes and forms, especially those curvilinear; they can be more daring in their design without having to worry so much about model building time constraints. Concepts can mostly be expressed faster, therefore it helps the users to free their design and create more complex ideas. Anyhow, the utilization of the laser cutter requires a lot of pre-planning and fairly specific software knowledge to design fully and freely. Complex shapes can be done, but the user has to be able to think abstract and know the specific process. Some of this required process time is given back through the speed in which pieces and variations are produced; the quality and preciseness of the parts are also hardly reachable through manual work.

On the other hand, interesting model languages emerge from the possibilities given to us by the tool; the process of developing model parts digitally makes students think conceptual and abstract toward the production of their models. They have to constantly visualize the different elements and think about how they will come together. Problems have to be addressed on a more detailed level than in a traditional process. The assemblage of the parts is the most intriguing part, comparable to a mini carpentry. In this phase, when all parts come together in a very precise manner, the projects are often better understood as they are in the digital 3D model. Among the students, some very experienced users have developed quick methods to even substitute elevation, plan, and sectional drawings through a physical model that incorporates all necessary information.

Reservations toward an application of the process in early design phases hint at a subjective perception of the laser cutter as a limiting tool to develop a design; at the same time chances are missed to experience that type of accidental architectural discovery that often opens our eyes toward something unexpected and new.

Figure 3. Different model parts to be assembled

Acknowledgements

My thanks go to the graduate program students for their participation in the survey.

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