CRYSTALLIZING DESIGN INTENTIONS, USING CNC, LASER AND RAPID PROTOYTPING TECHNOLOGIES

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Abstract. The advances made in the Rapid Prototyping and CAD/CAM (including CNC and Laser) Technologies are now offering designers the privilege of building physical realities, at whatever scale, directly and automatically from computer files, with the explicit implications of speed, precision and flexibility.

1. Physical Modelling and New Technologies

From the standpoint of representation, and despite the advent of computer graphics and animation, the architectural model has persisted in being a privileged way of expressing architectural intentions. Architectural firms have indeed continued using this mode of representation because of the irresistible iconic relation between the model and the building on the one hand, and the intimacy witnessed through this association on the other.

Because the physical model has been traditionally made manually (it often takes several hours to interpret, visualize, hand-cut and build the information conveyed by plans and technical drawings), and because of the advent of digital technology and the subsequent connotations of speed, there has been a tendency to equate model-making with slowness, tediousness and inflexibility. The traditional process is time-consuming, indeed, and is generally lacking in precision. This has contributed to the relegation of (physical) model-making to a second position in the debates dealing with architectural representation in the digital age, despite the fact that several international architectural firms, such as the often-quoted Frank Gehry's studio in California, have successfully pushed model making to the forefront of their design strategies and methods.

But the advances made in the *Rapid Prototyping* domain (*Stereo lithography Apparatus* (SLA), *Selective Laser Sintering* (SLS), *Fused deposition modelling* (FDM), *Laminated object manufacturing* (LOM), *3D Printing* (3DP) and in CAD/CAM technologies (including *CNC routing, Laser/Flame/Plasma/Water cutting*) are now offering designers the great privilege of building physical objects directly and automatically from computer files, with the explicit implications of speed, precision and flexibility. The useful translation and conversion of digital data into a setting favourable to the making of artifacts, at whatever scale, and with a minimum manual intervention suggests that digital, CAD/CAM and Rapid Prototyping Technologies are now becoming complementary domains of expertise, all combined to crystallize architectural design intentions in the most efficient fashion. Slowly, the strategies by which we teach and conceptualize architecture at large are becoming complex, efficient, and multi-faced. The gap between the digital and the real is shrinking indeed.

Of course some of these technologies are expensive, others are more affordable. Some could be used for the making of both models and buildings, others are more efficient at the manufacturing of small size objects only. Some could be installed inside office spaces, others on bigger construction sites and factories. Whatever the case, through this web of new technologies, where the digital intermingles with CAD-CAM and Rapid Prototyping, the physical visualization and crystallization of the architectural idea is becoming a smooth process, rather than a single operation as the case used to be in the traditional atelier.

2. Rapid Prototyping

Rapid prototyping (RP) lets designers build physical entities directly and automatically from 3-D computer models. A dozen varieties of rapid-prototyping devices create models by building up thin layers of a particular material. They all require 3-D CAD data translated to the STL format, named after streolithography, the original rapid-prototyping technology. STL files are most easily created from 3-D solids modellers.

Rapid prototyping is common in the design of automobiles and consumer products. Industrial designers in these fields routinely use 3-D solids-modelling systems such as Pro/Engineer and Solid Woks to describe objects that curve in three dimensions. To architects who typically work in 2-D to design buildings 3-D modelling may seem overtly complicated. But 3-D modelling is virtually mandatory for creating good STL files. Architects willing to learn these 3-D modelling systems can take advantage of rapid-prototyping technologies to build physical models with their CAD data.

The oldest and most common systems is *stereo lithography* apparatus (SLA) from 3D systems Inc. There are several SLA models, which vary in size, speed, and cost. With this technology, a laser beam moves through a vat of ultraviolet-sensitive liquid polymer, following the contours of the model’s floor plan. When the beam hits the liquids, a thin layer is solidified. Then the model is lowered slightly within the vat, and the laser produces the next layer. Because the layers are built from the bottom up, the CAD models must provide temporary supports for roof overhangs and similar geometries. Breaking off the supports after construction can potentially damage the model. Toxic fumes from SLA make it unsuitable for an office environment. The process, however, affords great precision and strength even in delicacy shaped objects.

There are similar processes that could be investigated as well, such as: *Selective leaser sintering* (SLS), developed by DTM Corp; *Fused deposition modelling*, or FDM, sold by Stratasys Inc; *Laminated object manufacturing* (LOM), from Helisys Inc; and *3D Printing* (3DP), invented at the Massachusetts Institute of Technology and commercialized by Z-Corp.

Rapid prototyping makes models with complex geometries more affordable than if constructed using traditional means. As a general remark the cost of this technology is no longer a barrier, and most architects don't realize how dramatically prices have dropped; a model that fits in a six-inch cube costs around $100. RP machines have a wide range of options, capabilities and prices. Presently, 15 companies offer more than 50 different systems. With advertised prices of $45,000 to $800,000, the purchase of the equipment does not present a hidden cost; however, support of the machines and long-term requirements can present a few surprises. A more serious barrier is the investment of time and training in conventional software that architects have made. In most cases, a 3-D model developed from 2-D drawings will make a poor STL file. Only time and experience will show the most convenient way to address this hurdle.

3. CNC and Laser Cutting

In its simplest form, CAD-CAM is a way for a machine operator to cause the cutting of a surface. The cutting tool follows a certain path controlled by a computer. The size of the work table limits the size that can be cut. Parts that are cut are later attached, mainly using a chloroform glue.

CNC routing machines work by translating programmed instruction coordinates into precision motion along the path specified. The CNC router uses a tool to machine that path to produce the desired profile. This allows a programmer to write a part program and route many identical parts on a given day, and then resume that same program weeks or months later. *CNC routers* are incredibly fast and have powerful spindles capable of routing and machining very thick sections of solid wood and other materials. CNC routers are even used in manufacturing parts from non-ferrous metals such as aluminum, brass, and copper. There are many other materials that can be cut with a CNC router such as plastic, foam (e.g. Styrofoam), fiberglass, signboard, particleboard, oriented strand board, phenolics, and composites. The cutting process starts with a design drawn in a CAD or other graphics programs (Figure1.) These drawings are generally 2D, but include multiple layers used to separate features of the design or cutting operations (such as a “Cut” layer and an “Engrave” layer).

Figure 1. From AutoCAD to CNC router.

Laser cutting is an excellent method of delivering a very precise controlled spot of heat just where it is needed. Laser produces a significant amount of energy in an extremely small area (as small as .003"). This focused energy leaves its mark by heating, melting, burning or vapourizing away the top layer of the object. Distortion is minimum.

There are other promising technologies such as: *Flame cutting*, *Plasma cutting*, and *water cutting*. In Flame Cutting, also-known as oxy-fuel cutting, flame can penetrate up to 160mmm thick. Fast, cheap, accurate technology, it is used mainly in shipbuilding and automobile factories for cutting steel plates. In Plasma Cutting an electric arc is struck between the cutter head and the work piece, which melts locally, and is then blown away by a powerful stream of inert gas; 50mmm thick materials can be cut. This technology is more accurate than flame cutting. The newest cutting method is water cutting. Water carrying abrasive under extremely high pressure (55, 000 bar) is discharged against the work through a tiny nozzle. A very precise and smooth surface is engendered. It is yet to be seen how these technologies can be appropriated for model-making purposes.

4. Examples from the lab

At the Department of Architectural Engineering, U.A.E. University, we have established the first advanced model-making lab in the Middle East and North Africa academia, at a starting cost of around $200,000. The project comprises 3 phases: Phase (1): purchase and installation of basic modelling tools. Phase (2): purchase of a CNC machine (Figure 2). Phase (3): purchase of laser cutter and a stereo lithography apparatus (SLA). Phases 1 and 2 have been achieved, Phase 3 will hopefully be undertaken in the coming years. The lab is used both for teaching and research purposes. Teaching covers both design courses and model-making courses.

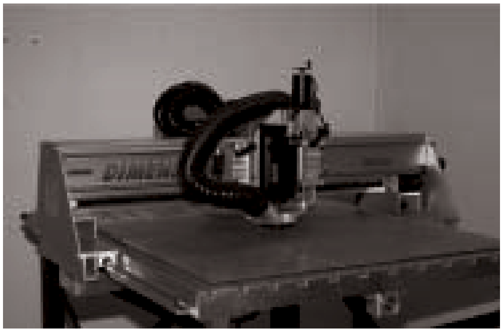


Figure2. Gerber CNC router.

The lab is also used to assist staff conduct research on all sorts of subjects from cladding, to thermal, acoustic, and structural subjects. We have so far produced hundreds of models of buildings that are either designed by students, or selected from the international architectural, repertoire then built in the lab (see Table 1.)

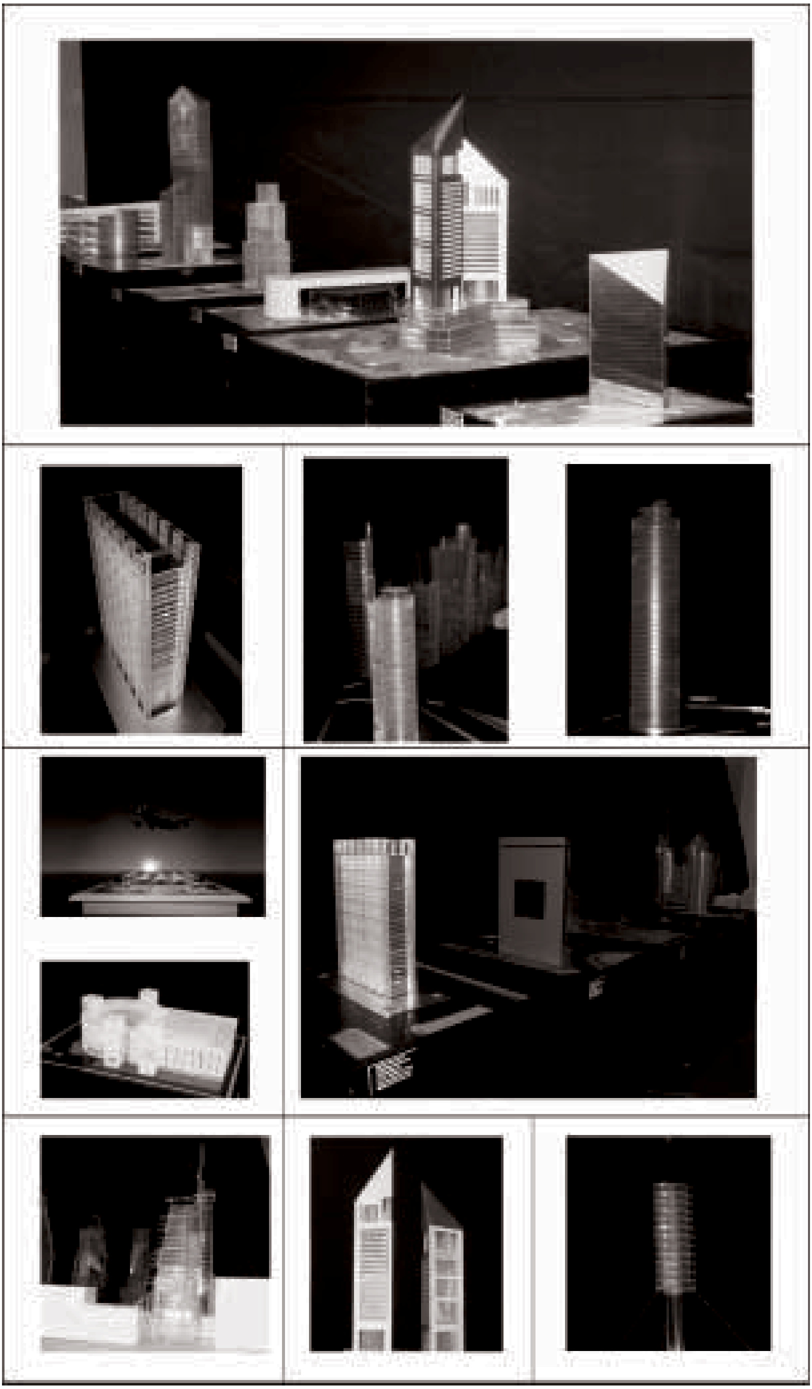
5. Other horizons

So far we have assumed that the design idea itself has been finalized at the design level before it could eventually be built using the new modelling technologies. But if we to take into account the first stage of the design process, namely the conceptual step, another technology will also be included, namely digitizing/3-D scanning. As is clear from Gehry's experience, for example, the most efficient way to move from the early conceptual forms to the final model is to digitize the cluster of quickly-made models (which are generally made manually from torn paper, to balsa, to plastics), then slowly turn them into 3-D digital models (using a FARO digitizer and CATIA solid-modeler). In the case of very complex models, such as the Disney Concert Hall, a CAT scan (computer axial tomography), which is traditionally used to produce detailed cross sectional images of the brain, was exploited.

As the numerous design process models begin to coalesce into a direction that captures the gesture of the original intentions and begins to solve the functional and site relationships, the final model is then built. The general loop will thus include: (i) digitizing the first conceptual models; (ii) turning these digitized forms into 3-D models; (iii) Once a final design decision has been taken, the final model could then be built using CNC/laser/ Rapid Prototyping technologies.

Besides serving to produce the final physical model, the 3-D digital model could also be used by the contractor/manufacturer to shape the final building itself. This move is secured by Rapid Prototyping, the same technology which lets designers build physical models directly and automatically from 3-D computer models. As J. Novitski once speculated, soon architects may be able to put design

TABLE 1. Examples of models cut on a CNC router.



information into a machine that will automatically construct a complete building (Novitski, 1999).

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