FROM THE ADVANCED MODEL-MAKING LAB TO THE CONSTRUCTION SITE

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Abstract. If the building industry wishes to take advantage of the extensive capabilities of CAD-CAM that have been exploited in the aeronautics/aerospace, automotive and shipbuilding industries, then it has to look at what's happening in the advanced model-making lab. The current exploitation of cutting-edge technologies by model-makers points to potential applications on the construction site, both at the constructional and organizational levels.

1. Models and Cutting-edge Technologies

The image of Michelangelo showing Pope Paul IV the model of the Dome of St. Peters, as painted by Domenico Cresti or the photos of the masters of modern architecture standing in front of their highly-detailed finished models are familiar scenes. They are reminders of the role architectural scale models have played in expressing design intentions in a form that the plan and the elevation often fail to convey.

Since there has never been a need to mass produce them, models have always been unique objects. From the standpoint of the model-maker, the changes which printing brought in literature, for example, and the mechanical reproduction of art that was made possible with the inventions of engraving, etching, lithography and photography, as highlighted by Walter Benjamin, have remained alien discoveries (Benjamin, 1969.) And if it is true that few models were once produced from a "mold," then this must have been a rare occurrence (Porter and Neale, 2000.) Setting aside these rare full-size fabrications, it is safe to assert that physical models were not made to be reproduced since, unlike stamps and statues for example, there was no practical need for their duplication.

But for the last fifteen years or so, things have changed. The advances made in CNC routing, laser cutting and rapid prototyping domains, including 3-d printing, have offered model-makers the great privilege of building physical objects directly and automatically from computer files, with the explicit implications of speed, precision, flexibility and *reproducibility*. The useful translation and conversion of digital data into a setting favorable to the making of several prototypes of the same idea, at whatever scale, and with a minim manual intervention suggests that these new cutting-edge technologies are now becoming complementary domains of expertise, all combined to crystallize architectural design intentions in the most efficient and reproducible fashion.

Before examining the entailments of this new orientation, let us first review some of these new technologies. In their simplest form, 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 of the program and route many identical parts on a given day, 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. These routers are used to cut plastic, foam (e.g. styrofoam), fiberglass, signboard, particleboard, oriented strand board, phenolics, as well as non-ferrous metals such as aluminum, brass, and copper. The cutting process starts with a design drawn in a CAD or other graphics programs. The drawings are generally 2-D, but include multiple layers used to separate features of the design or cutting operations (such as a "Cut" layer and an "Engrave" layer). Parts that are cut are later attached, mainly using chloroform glue.

The second major technology used in advanced model-making is laser cutting. Advanced sign and model-making firms today use laser technology in more and more pronounced ways. Laser cutting is an excellent method of delivering a very precise controlled spot of heat just where it is needed. It 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 vaporizing away the top layer of the object. Distortion is minimum. The excellent controllability of the process allows minimal cutting clefts and a repeatability accuracy of ±0,02 mm. The benefits of this technology to the treatment of details at the model-making levels are obvious. Since laser creates a beam of light, there is no part of the laser cutter in contact with the material that one is cutting; gravity can hold the material in place. For thinner materials, most laser systems include an integrated vacuum table to hold down papers, fabrics, and thin plastics as materials are cut through. The cutting operation produces a crisp cut that works well with a multitude of materials. On acrylic, for example, one can achieve a clear, shiny edge, while on fabrics the laser will sear the fabric so that it won't unravel. The thickest materials can also be cut in a single pass, as opposed to the relatively-slow and multiple-pass process that is typical to CNC routers. Although acrylics are commonly used, laser cutters can cut through wood, plastic, cloth, leather, matte board, melamine, paper, mylar, pressboard, rubber, wood veneer, fiberglass, and cork. Alongside the precision and the material processing advantages, laser cutters are also very flexible. Very large contours can in fact be built as well as small and complicated details. Changes can be made quickly and easily via software. The high working speed of laser cutters is to be also stressed. Cutting and engraving speeds are between 1-1000 mm/sec and are improving permanently. There is no-pre and post-processing of the final product, since the cutting has a very good surface finish and the top side is free of scratches.

The third major technology is Rapid Prototyping. Although not as heavily used as CNC and laser cutting, this technology is very promising. 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 stereolithography, the original rapid-prototyping technology. STL files are most easily created from 3-D solid modelers. Industrial designers routinely use 3-D solids-modeling systems such as Pro/Engineer and Solid Woks to describe objects that curve in three dimensions. The oldest and most common system 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. The process affords great precision and strength even in delicately-shaped objects. Rapid prototyping makes models with complex geometries more affordable than if constructed using traditional means.

2. A conglomerate of Activities

Slowly, the strategies by which model-makers operate are becoming efficient, fast, flexible and, above all, multi-faced. The possibilities offered by these new techniques are used in more than one way, with two interesting entailments. First, model-making is becoming a conglomerate of activities, and not just a craft limited to the production of miniaturized copies of buildings. Access to the cutting-edge techniques of routing, laser and rapid prototyping has widened the interests of the model-maker to include: sign making, exhibition stands, display systems, furniture design, and industrial design. This has been mainly facilitated by the fact that the technologies used are multi-functional. The same cutting printers/plotters that are used to print/cut vinyl patterns to simulate parking floors, for examples, are used to produce signs for the advertisement industry. The world of banners, plates, decals, labels, posters, vehicle and floor graphics, apparel decoration and just about any imaginable sign that populates our streets, airports, shopping malls, gymnasia and other public areas now falls within the model-maker's immediate sphere of interests. Likewise, laser engravers and CNC routers which cut/engrave acrylic sheets to make models and modeling accessories (street lights, cars, planes, human figures, boats) are also used to manufacture a host of industrial items made from plastic, wood, paper, rubber, acryl, bullhorn, or fiber products. Last, rapid prototyping machines serve to produce model airplanes as well as scale models of real satellites, full scale models of future cars, scale models of cities, industrial design prototypes, crime scene and accident recreation.

In this sense, model makers are becoming leading artists and designers in their own right. They are even involved in the production of motion pictures. The movie industry has used model makers constantly to build miniature, scale model sets in order to stage action that would be impossible to do full size. The early work by Industrial Light and Magic (ILM), for example, which was set up in 1975 by filmmaker George Lucas in order to create the special effects for the original Star Wars film, was done with miniature models and motion controlled cameras. Ever since, ILM has grown into a visual effects powerhouse that has contributed not just to the entire Star Wars series, but also to films as diverse as Forrest Gump, Jurassic Park, Who Framed Roger Rabbit, Raiders of the Lost Ark, and Terminator 2.

The different ways in which model makers produce their art is one of the most intriguing aspects of the professional sphere today. Although there are no model making schools, the training of model-makers has been secured by the industrial sphere itself and by the implied need to hire people capable of making a prototype of some idea. Footwear model makers often come from the "shoe last" making rooms. Many model makers come from the sign making industry, and there are model makers who have been trained in the fine arts, particularly sculpture. Others come from industrial arts backgrounds. And so on. This development means that well-equipped architectural firms can now stretch their limits beyond the traditional sphere of designing scaled models of buildings. It also means that the very definition of architectural design may be going through some significant changes.

3. The Future of the Building Construction and Automation

The second major revealing remark is the tendency of model-making to anticipate future developments in the building industry. The use of CNC routers and laser cutters inside the model-making lab parallels the use of larger robotic systems that could one day revolutionize the way the built environment will be shaped. By adopting techniques similar to those used in the automobile, aerospace, and shipbuilding industries, advanced model-making could be seen as an appropriate start to steer the construction industry to adopt a more advanced, automated course in its operational process. For if we assume that the building construction industry can take advantage of the extensive technological capabilities that have been exploited in the aeronautics/aerospace, automotive and shipbuilding industries, then it is easy to see the closeness between the current making of an architectural model and the future construction of buildings. All the quasi-automatic routines of cutting, forming, attaching, positioning, templating, erecting and finishing that are present in an advanced model-making session are pointers to similar and wider processes of building, such as manufacturing, casting, erecting, attaching, cladding and polishing. The conditions established by the advanced making of a model are the very attributes, however moderated, of the future building construction arena.

The application of the technologies currently used in model-making may not be exactly mirrored on the real construction site. For the problem of size and the typical nature of modeling and building, with all the empirical requirements embodied, stipulate different modes of constructing 3-D forms. Yet it is possible to argue that more interactions between the two spheres will become evident in the future. A new vocabulary of making could apply to both models and built structures as a consequence. The advanced model-making lab seems to be heading toward becoming the site where real building issues will be simulated and tested before their implementation in reality.

The question of scale remains, of course, a significant issue to be addressed. But the question of scale could only be addressed if we bear in mind what is happening in some leading manufacturing industries. We know, for example, that some firms in the shipbuilding industry use very large cutting tables. Robot laser welders are also used in shipyards where they can crawl inside the double bottoms of ships, and could in principle be adapted to the building construction site. Many strategies adopted by small boatyards are highly applicable to buildings and range from specific layout and forming techniques for curved metal or composite shapes to the development of customizable "product models." At this large scale, a CO2 laser machine is about the size of a small car and delivers its invisible far-infra-red beam along a tube about the size of a drainpipe. Alongside laser, other techniques such as plasma and water cutting are used to tackle cutting at a large scale.

Now, in principle, large-scale volumes with curved facades are as easy to produce as buildings with straight elevations. Of particular interest are the smooth, doubly curved forms seen in automotive and aeronautic design. Semi-monocoque rib-and-skin construction systems today find ready translation from airframes and boat hulls to buildings. And it is conceivable in this sense to construct buildings by successive milling and deposition of hi-tech, lightweight, super strong materials by seven-axis CNC machines like those that produce composite-hulled maxi-yachts and the B-2 bomber. These complex, tailored 3-D structures are relatively easy to build on site, provided a minimum set of technical and organizational requirements is met. The flexibility offered by this change is to be stressed. As André Chaszar pointed out few years ago, one of the more intriguing directions being explored by some architects such as G Lynn, B Cache/Objectile, SHoP, Su-11 and Kol/Mac, is mass-customization for buildings. In these scenarios basic building shells or frames are outfitted –inside, outside, or both – with elements selected by their prospective occupants. These may be along the lines of built-in furniture and fixtures, or larger elements such as additional rooms, alcoves, mezzanines, penthouses and so forth. The basic shell or frame may also be modified within some parameters. This kind of design concept is aided by CAD tools, but even more powerfully by parametric modeling and associative geometry capabilities. When linked to engineering analysis and a construction system that is equally malleable, standardized but tailored buildings may finally be realized after decades of experimentation. Malleable building models would also be able to respond with some sophistication to varying site conditions or other external constraints upon their form such as environmental factors, sightlines and zoning envelopes (Chaszar, 2003.)

With the increased automation of manufacturing processes, therefore, considerable improvements in consistency and quality could be achieved in the sphere of building construction. Automation has reduced the frequency of errors and provided operators with time to perform additional tasks. It has also allowed for more flexibility in the way parts are held in the manufacturing process and the time required to change the machine to produce different components. In a production environment, a series of cutting-edge machines may be combined into one station, or "cell", to progressively machine a part requiring several operations, and so on. Since most of these machines are controlled directly from files created by the CAD/CAM software packages, a part or an assembly can go directly from design to manufacturing without the need to produce a drafted paper drawing of the manufactured component. In a sense, CNC and laser machines represent a special segment of industrial robot systems, as they are programmable to perform many kinds of machining operations (within their designed physical limits, like other robotic systems). CNC machines, for example, can run over night and over weekends without the operator's intervention. Things like tool breakage detection have given the CNC the ability to call the operator's mobile phone if a tool breaks. The ever changing intelligence of CNC controllers has dramatically increased job shop cell production. Some machines might even make 1000 parts on a weekend with no operator, checking each part with lasers and sensors.

The entailment of this scenario is worth highlighting. The fact that the same digital three-dimensional model can now be conceived, modified, refined, and sent to a machine in order to become either a physical model or a building brings a new and radical dimension to the definition of architectural project altogether. Since it is now possible to build several versions of the same architectural idea, and at different scales, the concept of building itself may be heading toward some new definitions. The building, like the model, is revealing itself as one possible manifestation of a digital data which, like an acorn, potentially contains both the building and its several physical prototypes. Within this quasi-Aristotelian context, reminiscent of the notion of *entelechy*, the digital data does not represent, but actively works to become a building itself (Aristotle, 2005.) And until the digital data actualizes itself, the building *qua* building is no more than one single, potential possibility among many others (figure 1.)

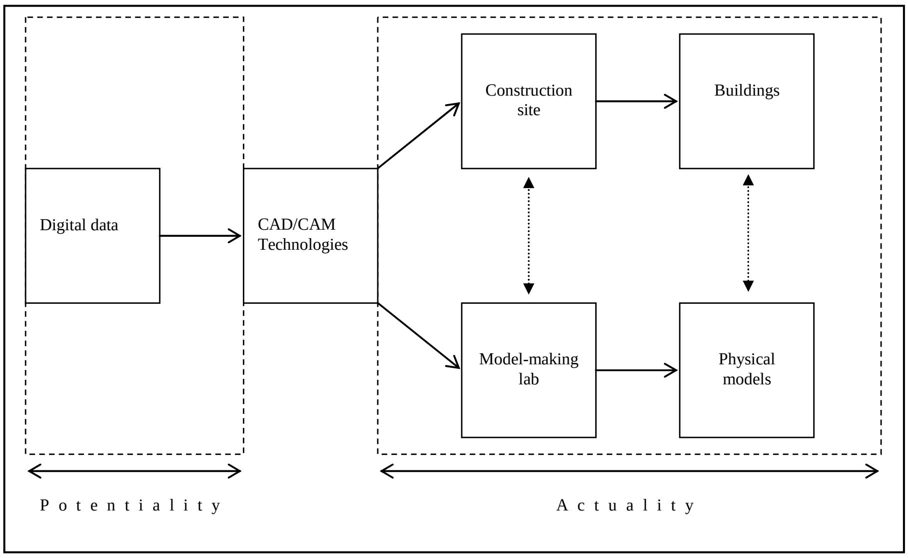

Figure 1. New ontology of the architectural project

This reading seems to be highlighted in the advanced model-making lab, and it may soon reveal itself in a more transparent fashion on the construction site. This is on the one hand. On the other hand, the relation between the model and the building is suggesting a sympathy that connotes some uncanny sensations. This sympathy is not only about the category of likeness but identity. As Foucault once pointed out in his description of different forms of likeness, sympathy is an instance of the “Same”so strong and so insistent that it will not rest content to be merely one of the forms of likeness; it has the power of assimilating, of rendering things identical to one another, of mingling them, and of causing their individuality to disappear (Foucault, 1973.) By virtue of this relation, the model seems to be-coming the building itself. As a corollary, it is conceivable to imagine the construction site as a mere extrapolation of the model-making lab, with all the entailed implications.

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