Practically digital

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Abstract

In the recent article "*Digital Complex*", Stan Allen observes a shift from virtual experiments in continuous surfaces and complex biomorphic forms to a more pragmatic interest in integrating the digital and the analogue, the real and the virtual, or the everyday and the fantastic. This paper presents design processes that utilize computers, small rapid prototyping devices in conjunction with traditional sketch ideation to fabricate realistic and creative form.

This paper posits that the observations made in Allen's article are currently reinforced pedagogically in that digital processes are moving away from the preoccupation with the virtual world and its representations; emphasizing instead the means of practical methods of digital fabrication and assemblage of the real. Undoubtedly, design education shows promise of reinforcing the strategic and operative potentials of the computer.

Similarly, the observations characterize the existing design methodologies of architect Frank Gehry as I experienced during my time working in his office. His process does, in fact, rely as much on the analogue as it does on the digital.

The research currently aims to define and demonstrate the benefits of using a combination of selected digital processes and analogue techniques in use with the design of a single-family, residential project. Again, rather than placing importance on the formal expression that digital design promotes, this paper argues for a new form of creative practice that digital technology enables.
Keywords: digital fabrication, digital design, digital/analogue processes.

1 Introduction

Between the idea and the building there is always a process by which a project is informed, explored and brought to life. Conventionally, this process starts with a series of sketches that evolve into a presentation model and/or hand documents that presumably describe the architecture of the building. As the computer

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became a familiar fixture in every design office, that manual process first lost its position to documentation and representation. The advent of ***C**omputer **A**ided* ***D**esign* or CAD technology emerged as a way to manage (what were thought to be) increasingly more complex projects. CAD did improve accuracy in drawing; increasing the number of "necessary" representations and time involvement in a set of construction documents. The increased time spent planning and managing the documentation created a situation in which technology ultimately diverted the architect's attention from the design process itself. As a result, design exploration of the virtual world remained (for the most part) separated from reality of the architecture and building industries.

The "hand" became even further outdated with the move from a Cartesian geometry to one based on NURBs (short for ***N**on-**U**niform **R**ational **B**-**S**pline*). The digital decade of the 1990s saw in Gilles Deleuze via Lynn [3] a prophet of the morphing, warping, and complicated curvatures of virtual space. This fascination upheld a preoccupation with paperless, un-built plasticity of virtual form and explicit digital design protocols.

Yet, Pfeiffer [2] claims culture is already "post-digital" due to its ubiquity. To concur, architecture practice and pedagogy are showing signs of its move beyond virtual "reality" as its main preoccupation. Indeed, understanding the technical and practical limitations of digital technology trumps the interest in a computer's ability to generate formal innovation and virtual effects. The mystery behind "the digital" has been codified; diminishing such notions as Flusser's [4] "apparitions of computed point elements floating in nothingness".

2 Academia and the acronyms

Pedagogically, an idea can now be informed and explored through the processes of digital fabrication [5]. Architecture schools all over the world are trolling for students with promises of the biggest CNC mill, the greenest CAD/CAM printer or the latest laser cutter. The intention is to make digital design a physical reality; searching for future tangible attributes of abstract thought that were until recently trapped in virtual "reality" image. Coincidentally, the difficulty for young designers is not in how to use these available technologies, but rather which to use and when.

2.1 CAD needs CAM

CAD/CAM abbreviates the overriding relationship of *Computer-Aided Design* to *Computer-Aided Manufacturing*. By integrating CAM with CAD systems, the architect regains control of design AND making. This control means the architect can potentially bypass the builder and talk directly to the machine. The relationship has the ability to produce fast and efficient prototypes, as well as building components straight from a 3D virtual environment. Novitski [10] proclaims this ontological shift to be quite profound, given that these objects of resin, polyester, or other (presumably) full-scale building material are crossovers from another plane of existence—data bits in the virtual world.

Rapid Prototyping (RP) is a term synonymous with CAD/CAM and again automatically constructs physical objects through subtractive or additive methods. Today, architectural explorations have primarily co-opted this technology to visualize during the conceptual stages of design when dimensional accuracy and strength of prototypes are not a primary concern. The word “rapid” is relative: construction of a model with contemporary machines typically takes 3–72 hours, depending on model type and size. In brief, this process takes a virtual design, transforms it into virtual cross sections, and then produces each cross section consecutively in physical space. It is a process where the virtual model and the physical model correspond almost identically.

2.1.1 Additive processes

Three-Dimensional Printing (or 3DP) is a low-end version of additive fabrication technology; optimized primarily for speed and cost efficiency, making it suitable for quick physical models. In additive prototyping, the machine reads data and lays down corresponding successive thin layers of plastic, wax or some other engineered material, and in this way builds up the model from a long series of cross sections. In the end, these layers are fused automatically to create the final shape. The primary advantage to additive construction is its ability to create almost any geometry (excluding trapped negative volumes). One drawback is that these machines make smallish parts, typically smaller than an engine block.

2.1.2 Subtractive processes

CNC or *Computer Numerical Control* refers specifically to the computer control of machine tools for the purpose of manufacturing repeated complex parts in various materials. In this technique, the machine starts out with a block of material (typically foam, wood or plastics) and uses a delicate cutting bit to carve away, layer by layer to match the digital object. It is similar in concept to a sculptor carving away at the surface of a block of marble. Consequently, the subtractive method is older and less efficient. However, curves are as easy to cut as straight lines and are capable of doing large scale projects. Complex 3D structures are relatively easy to produce, and the number of machining steps that require human action has been dramatically reduced. Complex shapes and forms with undercuts are more difficult to accomplish, but are typically made in parts that fit together. Serendipitously, this process can give way to chance as a routing bit receives a glitch in the data and repeats an unintentional part, fig 1.

2.2 3D Mapping

The cartographic process rests on the premise that there is an objective reality and that we can make reliable representations of that reality by levels of abstraction. Digital mapping relies solely on the data and the technological aptitude of its controller.

2.2.1 Laser-cutting

Like rapid prototyping, Laser-cutting takes 2D outlines from virtual designs and “cuts” or etches each line in physical space. Analogue templates can be extracted

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from the physical models, drawn in CAD and then laser-cut back into physical space. Again, it is a process where the virtual content and the physical model correspond identically. When used for topographical sections, laser-cutting maps out 3D space. The laser-cutter can cut a variety of materials, but is best applicable to wood, paper, plastic and acrylic.

Figure 1: CNC fabrication.

Figure 2: LIDAR scan.

2.2.2 LIDAR

Laser Imaging Detection and Ranging technology is used to digitally map physical objects in space. Vertical laser pulses determine complex geometries and gathered unbiased data in the form of a point cloud. A point cloud is a set of three-dimensional dots describing the outlines or surface features of an object. The point cloud is then transferred to a triangulated 3D surface for manipulation and fabrication in a subtractive RP. Alternatively, the triangulated virtual model can then be reduced to interval cross-section profile information to administer to another fabrication process, like laser-cutting, fig. 2.

3 Gehry and “the digital”

Phenomenology as a design philosophy has its basis in the physical and tactile experience of building materials and their sensory properties. Norberg-Schulz [7] relays it as an approach that urges a “‘return to things’ as opposed to abstractions and mental constructions”. Frank Gehry conforms to this philosophy in his digital making; a process that is unique in that it expands on the use of physical models to build digital architecture [8].

This inverted process of creation gives way to chance and the unconscious results of everyday phenomena acting on the design. A coffee cup serendipitously left on a model could easily become part of a project, or accidental breakage of a model could very well give rise to its new shape. The resulting order shows an organic awareness that diverges from the formal logic-sharpened-in-static object concept.

3.1 Analogue methodology

Vidler [8] claims that the design of the Guggenheim Museum in Bilbao was "entirely a product of software". On the contrary, Gehry's design method for that project and every other is embedded in a technique of analogue modelling which allows numerous iterations to be studied quickly and effectively. These models serve as sketches, massing studies, formal studies and ultimately as 3D database. From the earliest sketch stages through to the development of construction documents, the physical model drives the process.

3.1.1 Sketch ideation

The sketch is the starting point for a project's design. It serves as one of the early defining elements to direct the design and is a tool that Gehry returns to throughout the process. Typically, this sketch is almost a child-like, hand-drawn gestural figure of an elevation or plan. The goal of the model-maker is to capture the spontaneity of the first sketch and the human dimension. In this practice, the computer screen is never considered a platform for design. The models are understood as idea diagrams for communication between Gehry and his team.

3.1.2 Scale models

At every stage, scale models are used as a guide to designing and making the full scale architecture. Physical models are where the sketch ideas take form and shape and where accuracy is critical. The more accurate the scale models, the more efficient the final built outcome. The projects start with site and block models that are used to further describe location, program, function and volume. The wood blocks are cut by hand, but the site models employ laser-cutting technology to cut the topography and to etch detail of context information. Once an idea is sketched out volumetrically, the process of shaping takes places with additive paper and glue.

3.1.3 Templating

Rather than using the model as a descriptive tool for final presentations, Gehry has developed a methodology for the "working" model that allows for quick transformations and studies of varying concepts. The models can be easily glued, torn, cut and modified. Every iteration requires a formal "mapping" before any modification takes place. These templates catalogue stationary spatial locations, shape and form; while providing documentation of a ruled surface pattern. A geometrical surface is ruled if through every point on that surface there is a straight line that lies on it. Registration to a Cartesian grid on each site model also prepares the model for transferring the real data into the virtual.

3.2 Digital processing

While the physical models remain the primary place for design exploration, computer models are also utilized to develop the complex forms and provide technical information.

3.2.1 Digitizer

Periodically, the scale model is digitized to create a virtual one in order to extract more precise information about the building. The digitizer, fig. 3, converts the position of a point on a surface into digital coordinate data. The coordinates of the virtual domain allow for analysis and adherence to project limitations such as exterior surface areas.

The physical models test the likely performance of a design and constructability at an early stage without the expense of building a full-scale prototype. Because the characteristics of model making materials (like thickened paper) mimic those of the full-scale building, inherent surface intelligence is being designed in the physical studies. A developable surface is one that can be flattened onto a plane without distortion. All developable surfaces embedded in 3D space are ruled surfaces and thereby allow constructability.

Figure 3.

3.2.2 Parametric modelling

Once a model has been "digitized", it also acquires malleable expediency in the computer by way of parametric modeling: dimension-driven modification of building components, embedded parameters, rules, and constraints. The computer model then develops in a 3D database used for the creation of the construction documents and to aid with required performance analyses such as structural and wind loading.

The ability to simulate whole buildings in the computer-including geometry, materials, lifecycle cost, schedule, and energy use-is thought to be "smart building". Virtual space becomes the testing ground for different potential realities and evaluation for material implementation. Information derived from material constraints to site conditions can be constantly fed into the intelligent computer model to provide an accurate update, which in turn introduces feedback into the overall design, and change can then be registered in the detail. Therefore, simulation becomes a way of assessing the developing performance of the project and the limits of a spatial system through a direct engagement with the underlying geometry of the design.

After the computer model has been adjusted to meet the limitations, information is extracted into 2D CAD documents. These become the floor plates and ruled surfaces for another physical model to check any changes in the computer model and accuracy of the digitization. While there is no definitive conclusion for an idealized form, the process allows for themes of craftsmanship and design overlap through structure, material, pattern, geometry, and parametric control.

4 Single-handed design process

As a solo practitioner now, cultivation of an expedient relationship with laser-cutting and additive rapid-prototyping digital technologies along with analogue processes (learned from working with Gehry) then informs and expedites the current design of a single-family, prefabricated residence in Barbados, West Indies.

In addition, the technological conditions of that country, actually being of high-standard, will allow for full-scale, digital fabrication of the house through parametric modelling. Our overseas collaborator, Preconco, Ltd., [12] has appropriated the use of digital production processes in conjunction with pre-cast, concrete construction methodology. This collaboration will assess their digital methodology by way of a structurally atypical design approach to a detached dwelling.

4.1 Design in process

Due to geographical constraints between the client in Barbados and my self in New Zealand, the design process incorporated transfer of documentation and models through the internet and postal system; necessitating small scale, modelling/prototyping for design update and review. Being a solo practitioner, rapid-prototyping facilitates the making of physical design models.

The design was initiated by a CAD file that 2D showed the terrain to be quite steep; forcing topographical site study models became a first priority. Laser-cutting expedited this act of making through quick production of multiple site model iterations. Vector information from that CAD file, including tree location and drip-line, is etched or cut onto matte or cardboard. The laser-cutter registers information that traditionally gets left behind in the manual model process. Block studies show volume, materiality and coded function, fig. 4.

The design began by adhering to Kepes' [9] visual concept of classical physics, which describes objects existing in three-dimensional space and changing locations in sequence of absolute time. Studies of digital/analogue models developed “lines of force”. These directives capture and produce the sensation of movement even if the spatial position of the house will be stationary and formally static, fig. 5; thus, animating form without the use of NURBS.

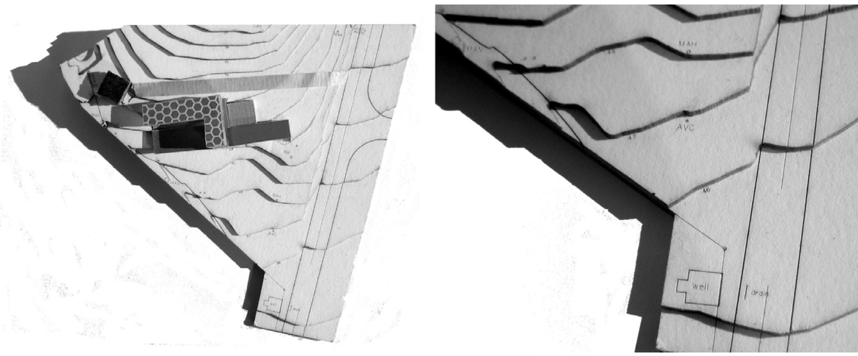

Figure 4: 1" = 500' scale laser-cut study model.

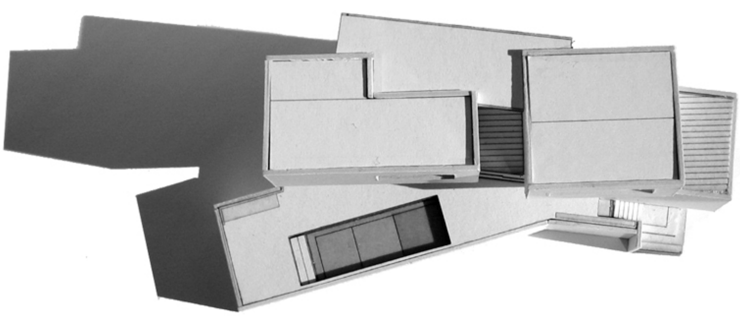

Figure 5: Laser-cut design model.

Furthermore, the site study models locate exact position of form. This position is documented via raster image produced on an everyday flatbed scanner; updating the CAD files with formal information. The massing is developed in virtual 3D to study sun angles digitally. The subtle movement of form also corresponds to this sun angle study developed through physical models and the digital database.

From the same files used to cut the site study models, two additional (larger scaled) site models are laser-cut for schematic design- one to be used by me throughout design and one for the client and local consultants. CAD documents are developed at a schematic level for square footage count and functional placement of rooms. The 2D CAD floor plans then facilitate formal testing patterns for analogue model making via exported files to the laser-cutter.

By exporting the 3D AutoCAD file as a *.stl* file, the 3D virtual model is investigated through *Stereo Lithography* (or STL) - a form of additive rapid-prototyping. This allows the production of a model that fits in a four-inch cube for under US$150. I believe much less time and money is invested than if I had built the models physically myself. The result is an amazingly accurate and sturdy model, with detail that could not be achieved by hand. The physical model becomes the most important design document because it is the information by which the client can "read" and (more importantly), the physical model verifies the design of the 2D CAD documents and solid STL model that are being repeatedly fabricated. These files serve as database into Preconco's BIM modeling package for full-scale fabrication.

4.2 Fabrication

In support of Benjamin's [11] claim, the immaterial of the virtual world must materialize to have any real gravity. Now that the architectural design and construction relationship is enthusiastic about building and/or fabricating digitally, design, representation, analysis, documentation, and production are becoming a relatively seamless collaboration. The intention and challenge for this design process collaboration with Preconco, Ltd. technology is whether the use of *Building Information Model* or BIM can reinvent the ideals of master craftsmanship that CAD seemingly abandoned.

BIM or parametric software is now available to any architect and builder, not just the aeronautical industry and Frank Gehry. Last minute revisions to the intelligent virtual model are acceptable because changes will be automatically populated throughout the digital project. For this practice, introducing the BIM model process to schematic and design-development phases are potentially doing away with the construction document phase as a separate entity. When used in conjunction with technology like the laser-cutting and stereo lithography, the design phase continues up until the moment the information taken from the BIM model gets directly 3D "printed" for construction assembly. For this reason, the adherence to phenomenal "lines of force" can be practical in that the architecture employs prefabricated component pieces as a system of assembly.
Inversely, Preconco's replication of construction in the virtual environment will demonstrate difficulties and allow conflicts to be identified and eliminated before any building begins. Any such necessary adjustments to the design will constitute another STL model for client review. Significant savings in time, money, and materials are amongst the expected economic, social and environmental outcomes.

5 Conclusion

Today, the computer is not a new technology to be celebrated or deconstructed; it is simply a fact, a tool like any other. Realization of the immaterial relies on the creation, reference to and (most importantly) physical distribution of digital "content". After a decade's immersion in the image, the virtual and the "merely" formal, it seems that common sense has returned to the digital process.

A generation of designers that were educated in digital technology are no longer seduced by its formal effects or intimidated by its complexity. Designers from any generation need to know when something is improved through technology, but certainly should be not blind to the fact that technology sometimes is not always the appropriate or practical answer.

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