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Thresholds between Analog and Digital Representations

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The emergence of digital alongside analog design media has created an interest in how the two intersect and differ. A traditional paper drawing can possess qualities of originality, authorship, and continuity of expression that may be lacking in a digitally produced drawing. Audio aficionados hold onto their collection of vinyl records based upon qualities of sound that they perceive. A manually created drawing by a grand master will be valued typically over a digital drawing in which a copy is of equal quality to the original. This paper explores distinctions between analog and digital media, explaining the creative opportunities and critical issues that emerge with the hybrid combinations that have become commonplace within the design studio. Three instructors from separate schools of design survey in-practice uses, and offer a common perspective on a topic that has created uncertainty over the place and use of design media.

Keywords: *Digital Design Media; Analog; Threshold of Perception; Design Process*

Introduction and definition

We assume we experience our environment continuously or analogically, perceiving infinitely smooth gradations of shape and color. Experience of space is a complex multi-sensory event: not only the visual but also the haptic and auditory aspects play an important role. When modeling the spatial condition of architecture and urban space in digital form, the complexity of an environment cannot be completely simulated by modeled polygons. There is grit, irregularity, imperfect construction, the imprint of the human hand, those elements that give a place character. Yet, we can print a 3D physical model from a 3D virtual model and work towards its tangible aspects. We straddle two worlds as designers: we envision in the digital world, we build in the physical world. For this reason, we need to explore in-depth the issue of reality - both analog physical reality and digital virtual reality.

Analog, also spelled "analogue", in this paper refers to those objects or techniques in which a physical quantity is continuously variable. A typical analog device is a clock in which the hands move smoothly around the face without separate increments. Such a clock appears capable of indicating every moment

in a day. In contrast, a "digital" clock appears capable of representing only a finite number of times, such as every second. Yet, though the actual movements of an analog clock are subject to continuous mechanical transformation, they are tied to digital reasoning in the break-up of a minute into seconds, or fractions of a second, and therefore, what appears to be analog is mentally abstracted into discrete increments of time. Therefore, the degree to which we can draw clear distinctions between analog and digital forms lies in the mind of the observer. One can easily devise a digital clock that appears move in the exact same manner as its analog counterpart, where the incremental changes are below the human eye threshold of perception.

We assume that no one mode, digital or analog, has the greater advantage on reflecting a designer's reality. Rather each mode in each its turn, if we transform a model from physical to analog or from analog to digital, effects the end result in qualitatively substantive and complimentary ways. That is, an analog drawing may not be any closer to the physical reality of a built design object than its digital counterpart, depending on how each stands in relationship to series of transformations within a design process.

The following examples will draw upon cases in environmental art, drawing, and physical model making where analog and digital representations phase in and out of a design process. The relationships between these two parallel worlds can be two-way and varied. The final design products can be physical, virtual or some combination of the two. The bridge between digital and physical or analog modeling is a continual transformative act in contemporary design processes, where distinctions are at best fuzzy, and boundaries are often transgressed.

From analog to digital "virtual realities"

What reality are we talking about when we refer to "virtual reality"? What constitutes the virtual aspect or, in other words, what is it about the virtual that we consider to be "not the real thing"?

Analog virtual realities

While many analog real world events can be simulated digitally, some works of design are created with direct perception in mind. The artist James Turrell creates remarkable specimens of the analog experience (for example Exhibition "The Other Horizon" - Turrell, 1999). Could the experience of viewing his work - and particularly the adaptation processes of the human eye - be simulated by means of computer assistance, at all? The answer surely is no. Further, even an ardent digital advocate cannot dismiss Turrell's spatial installations as being only "optical illusions" that might otherwise be disguised by digital equivalents. Turrell's installations have intentionally constructed a time-based ascertainable event, where curiosity dominates upon entry, while the eye pupil adjusts to the situation. The installation wants to be discovered. A seemingly two-dimensional surface "surprisingly" turns into a somewhat graspable color volume on continuous viewing. The viewer reaches out for the light. Even an analog photograph of such a scenario can only act somewhat like a visual memento or an appetizer due to the restrictions of photographic material.

Turrell´s spatial installations deal with sensory perception. His works, which provide an educational experience of receptivity, are almost devoid of objects. In most cases, the viewers only experience a very intricate perception of light. In the absence of everyday objects, which convey scale, weight, haptic quality and density, etc., viewers will rapidly become disoriented. The respective space and its enclosure fade into the background and the spatial structure takes on an utterly dematerialized quality. This seems to open the door for a true "immersion" into that space.

A number of analog '1:1 simulations' (Martens, 1996; Tschuppik, 1999) conducted at the Full Scale Experimental Lab of Vienna University of Technology (Figure 1) during the 1990s generated similar phenomena of perception.

By using artificial lighting, as well as reflective, translucent and semi-translucent materials it was

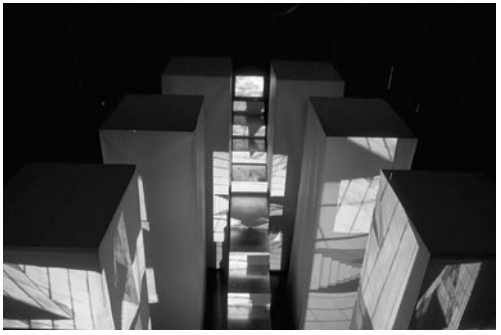

Figure 1
1:1 Experimental stage of the full-scale lab (mobile installations, experimental levels, etc.); different viewing angles can be generated.

Figure 2
Experimental exploration of a three-dimensional depth effect (Full-scale Lab - Vienna).

possible to create under "lab conditions" perception experiences which come near the effects achieved by James Turrell (Figure 2-6). Rotating translucent plastic panels or luminescent objects heightened by projections allow for a suspension - at least in visual terms – of the laws of gravity and place the focus on the question as to what is real and what is virtual.

Digital virtual realities

Although analog simulations would be useful in the traditional architectural process, the poor cost-benefit ratio means that full-scale models are built rather infrequently. Digital models are more cost-effective for architectural representations. From the ubiquity of digital models in architectural competitions, it seems as though only a perfectly visualized building can be translated into a real-world edifice. The computer-generated images have taken on so much reality that we are almost unable to tell whether something is an actual building or a computer simulation.

It is no surprise therefore that the one image which determines the outcome of a competition is of utmost importance. A winning image is called a "killer image" (Figure 7); because it pulls out all the stops, using every psychological trick available to convince the viewer. After all, the objective is to create, in a few seconds, a powerful impression which dwarfs all rivals. Achieving this objective requires not only insights into the psychological impact of an image but also skills to dissimulate certain negative aspects. So digital building simulations are always presented in the best light, look ephemeral and weightless and magically draw the viewer's eyes. The new media allow all sorts of transparent layers and superimpositions to generate unheard-of visual allure. A simulated building is invested with the sort of glamorous appeal that might be impossible to

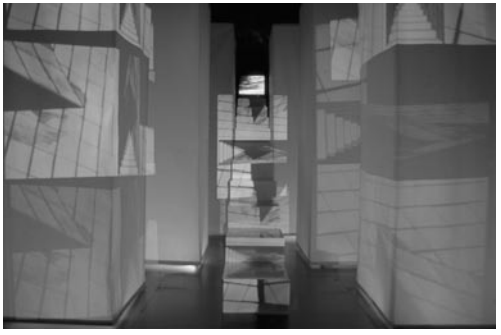

Figure 3
Dematerialization by means of translucency and movement.

Figure 4
Superimposition of real and virtual elements (Full-scale Lab - Vienna).

Figure 5-6.
Translucency and projections lift the limits of reality and lead to an apparent dematerialization of three-dimensional space (Full-scale Lab - Vienna).

achieve in the real world. Digital virtual realities may well be deceptive!

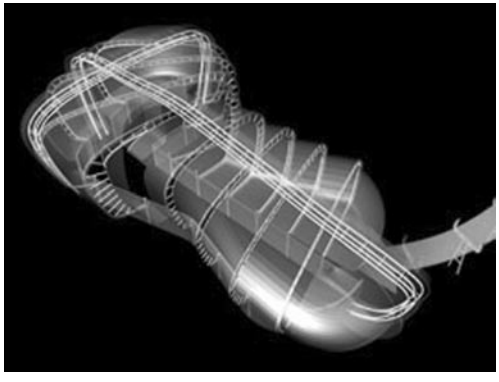

Figure 7
Superimposed images as a leading element in digital architectural representations (Stefan Klein - Vienna University of Technology).

"Real-world" reality?

Over time, with evolving technology, people started to crave a more complex architectural image than familiar ones of adobe and stone. The built environment has been extended to include a number of new "visual ideas", many of them inspired by the new possibilities of superimposition and morphing offered by the computer. Double-curvature surfaces and diaphanous imprinted skins are just two of the innovative architectural effects. Transparency, haptic surface effects, reflecting surfaces and images superimposed on elements can give the viewer the impression of being in an unreal world. To this extent virtual reality has already extended a few feelers into reality.

This is only one side of the issue, however. On the other hand, we often find that the reality once built

Figure 8.
Illusionist projection in the Galerie Lafayette (as portrayed by Jean Nouvel).

is quite different from how it looked in the visual simulation that preceded it. Jean Nouvel´s competition entry for the *Galerie La Fayette* in Berlin (Figure 8) had viewers imagine a giant vortex of light inside the building, a sight that everyone would certainly have been keen to see. In the end, however, the staggering visuals did not materialize – cost probably being one of the reasons. Even the most precise simulations can be deceptive: reality always turns out a little different. Glass, for instance, is transparent only under certain daylight conditions. We could conclude that virtuality may have put a foot in the door of reality, but real-world conditions tend to transform the new "virtual reality".

The experience of analog & digital making

We intermingle analog with digital to enrich not only the final artifact but to enrich the act of making. Weaving between analog and digital processes allows a designer to take advantage of both worlds. What characterizes creating graphics by hand vs. by computer? Designers comfortable with pen, pencil or cardboard are attracted by the immediacy and control of the familiar. Traditional media foregrounds the craft of working with material properties, such as the grain of wood being carved. A pencil allows free exploration of words, calculations, sketches, diagrams, unconstrained by electronic equipment or a programmers' direction.

The computer trades off some of this freedom to offer control and power. Working digitally requires partnering with the program – being in sync with how entities and functions are defined, enjoying how forms can be manipulated. What is easy or difficult to create has already been prioritized. The designer has to learn the application's procedures and categories so that ideas can be structured for development and reuse. Organizing allow selective manipulation and display, enabling different perceptions, creative variations and downstream development.

Digital techniques are not by definition constraining but today's experience of working digitally is typically limited by the keyboard-monitor-mouse interface. Software applications generally offer menus of pre-set choices to non-programmers. These menu choices can open possibilities unattainable with hand-media such as automated walk-throughs, quantitative analysis, and interactive sections. But even when computer applications invite us to customize our workspace, choices are constrained by operating system interface standards which give legibility through consistency. The resulting work is subtly shaped by the fact the world is made of known components and operations.

In contrast, using traditional media offers a more ad hoc environment: from a napkin sketch to a large wall, the designer pulls together a toolkit that is based on personal history and training rather than external guidance.

Designs for new physical interfaces are changing what digital design feels like. Sensors that engage gestures to create lines, colors and forms allow more of the body to be involved. A greater variety of input and output devices engage a wider range of people more comfortably. We have not found the perfect gestural interface in part because the consistent movements that a computer can interpret can be stressful to human bodies: while it is wonderful to occasionally wave the hand across the body, repeating the motion quickly becomes tiresome.

Idiosyncrasies in a pure geometric world

Digital designers seek to create graphics with the traditional expressive characteristic while exploiting computational shortcuts. In hand drawing, the irregularity of a hand-drawn line can be seen as charming. A slight cant to a wall profile can be seen as an opportunity to batter or skew the wall.

Idiosyncrasies are more conspicuous in a digital world defined by pure geometry. In a world where every kind of graphic entity has specific properties, oddball figures that fall outside the norm may cause problems. For example, if shapes are defined in a program as a chain of non-intersecting line segments that meet perfectly at vertices, then a scrawl with several collinear segments falls outside the definition and might function unpredictably. Because mathematical precision is needed for further digital development, the programs help the user conform to its way of working: with grid and endpoint snaps and geometric primitives. In a world where forms are defined either as boxes with perpendicular walls or not boxes, those with near perpendicular walls are forced into a category. The rules that allow the computer to handle great amounts of data with ease tend to guide the graphics into uniformity.

Analog & digital hybrid media to support creativity

The creative act of making lines, shapes and forms is basically the same whether analog and digital. But each medium guides towards particular design explorations and products with specific qualities, so each enables particular kinds of inquiry. By understanding what thinking each medium's process and product enables, a designer can find ways of working that fit different phases of design. In moving from generating possibilities towards refinement, a designer needs tools that stimulate musings, analyze criteria, investigate construction, and explain the project.

Combining the free expression of manual media with the precision and power of digital graphics can enrich a designer toolkit and give a wider range of insight. We can examine how creative processes are enhanced by analog-digital hybrids: drawing, painting, lighting, cutting and forming.

Drawing

In drawing manually or digitally, the designer creates strokes, first on a blank page and then in response to the visual feedback of the preceding strokes. The gesture of making a mark by drawing an instrument across paper gives a tactile satisfaction. A designer can freely move from drawing an edge to filling a shadow to writing notes, extemporaneously changing gears. This type of free working comes with experience in computer: shifting between modes or commands becomes as natural as picking up a different pencil. Expressive freehand drawing can be enriched with digital overlays of controlled color gradients and evocative photographic textures.

The recording nature of digital processes opens up new ways to understand a drawing. By recording strokes with a digital pen, it is possible to rewind the drawing to examine how it was created. Or it can be stopped at an earlier phase so that alternative versions can be made from that point (see Figure 9; http://wired.uoregon.edu/sketching/)

Painting

With watercolor there is an immediacy of moving the pigment across the wet paper, with the results dependent factors such as paper dampness, brush angle, pigment saturation. A smooth wash of color can be completely transformed by a drop of another color that diffuses into the moist surface. The meditative process of pulling a wash and the unpredictable mixing of physical pigments contrasts positively with the rigorous precision of CAD drawings. Architectural renderers often use an underlay of digital rendering with special touches added with Photoshop or by hand to give personality (Leggitt, 2002). Combining photographs, photocopies, digital frameworks with hand-traced overlays enables experimentation in a variety of ways.

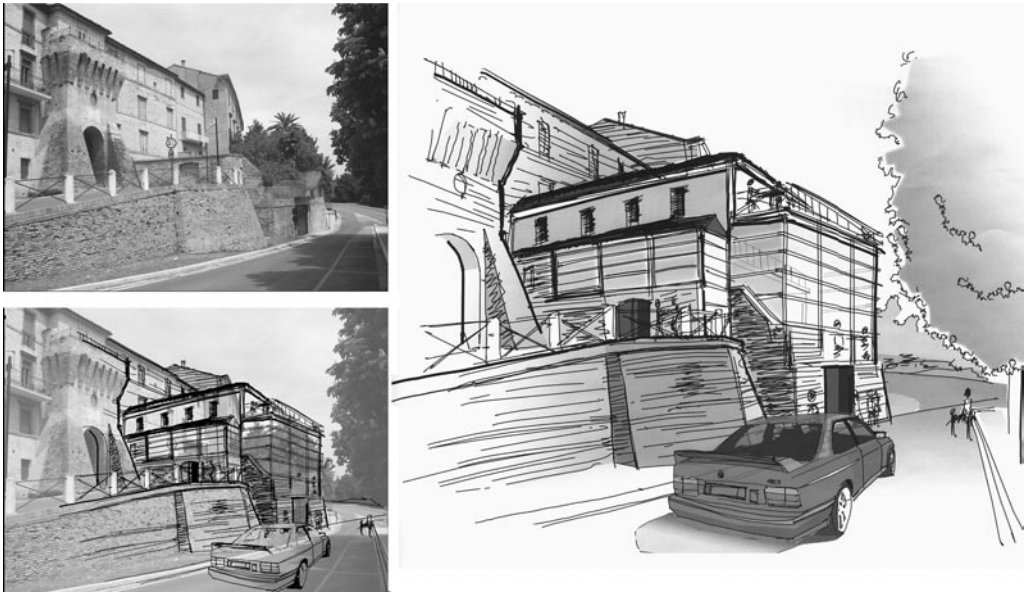

Figure 9
Sketching updated: A renovation drawn with the Logitech Io pen-and-paper system was transferred to Illustrator for stylized rendering. Images by Simon Newton, University of Oregon

As designers move away from pure geometry and color towards more expression, they can use image and processing non-photorealistic rendering to give a painted personality to geometric models. Through careful observation of traditional media, programmers have created applications that help bridge between analog and digital painting. Programs such as *Deep Paint 3D, Zbrush* and *Piranesi* allow designers to select surfaces by material, orientation or layer and apply painting effects or photographic textures. The appearance of watercolor (Cassidy, 1997) and viscous paint (Baxter, 2004), as well as the physical properties of a paintbrush have been simulated so that a Phantom haptic stylus can be used as a virtual brush with force feedback.

Non-photorealistic rendering seeks to bridge the gap by translating artist's strokes into rendering techniques for digital models. The film *A Scanner Darkly* uses a similar kind of image processing to turn traditional cinematography into cartoon graphics so that photographic footage can be seam-

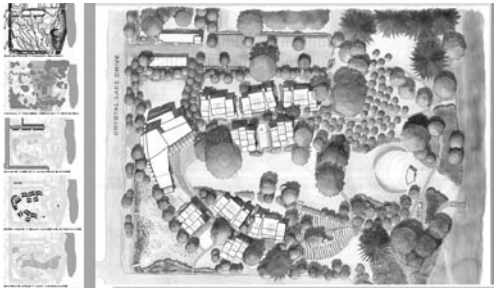

Figure 10.
Site plan uses watercolor to make crisp computer drawings more evocative. Image by Joy Rackley, University of Oregon.

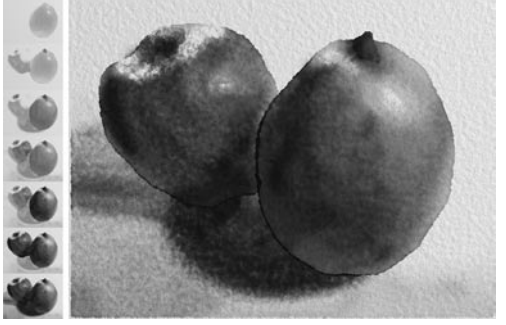

Figure 11
Photo processed to look like a watercolor painting by Cassidy Curtis et. al. (1997).

lessly combined with 3D computer graphics. While photorealistic rendering highlights the tension between the representation and our expectations of photographed reality, stylized graphics provide an opportunity for personalized. The evident human hand masks the need for a photographic illusion and provides emotional appeal.

Lighting: spontaneity vs. control

Because the ephemeral and subtle aspects of natural light can be captured in an authentic way through scaled physical models, these models can be more appropriate for early conceptual design than digital lighting simulations. For lighting design, there is a gradient from crude physical models, through approximate renderers to quantitative analysis with visualization of direct (raytracing) and indirect energy (radiosity). Increasing amounts of time and energy to precisely define the luminous environment is returned with more accurate information.

At the low-end, daylighting model allow designers to see real light and manipulate physical models simply and spontaneously. Photoshop can be used to overlay contextual details while preserving the original contrasts, reflectances, and highlights.

Figure 12.
Daylighting model enriched with photographic textures. Image by Rhonda Mohr supervised by Judy Theodorson, Washington State University.

Cutting: Material resistance

Computer allow us to generate, manipulate and evaluate complex geometry and associated building information, desktop interfaces restrict physical interaction with a project, making physical scale, and textual appeal hard to grasp.

We can find opportunities to bridge from the abstract digital world to the reality of material qualities with automated fabrication techniques. Marrying the digital to analog through cutting, carving and building form can engage the designer into reading how materials work with a design idea. For example, taking manual experiments with scoring cardboard to a lasercutting machine gives precise cutting of curves and allows replicating many lines with little effort. But to find the line where the cardboard natu-

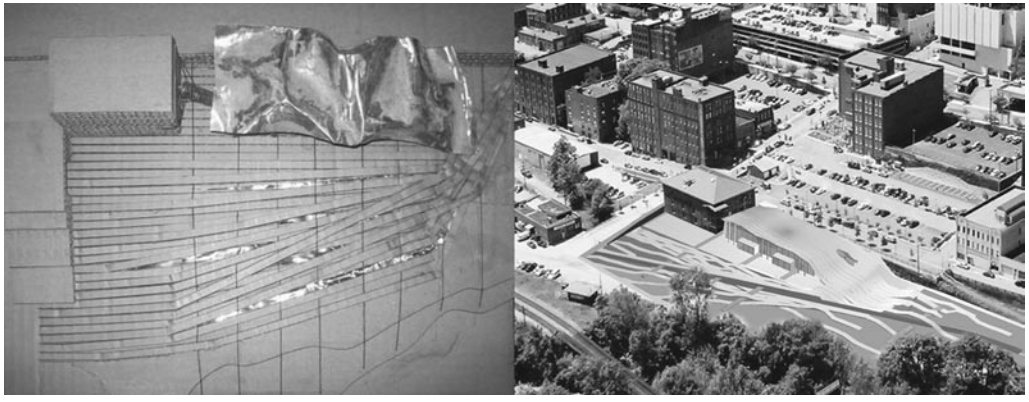

Figure 13
A laser cut model for a skateboard park exploring complex geometrical surfaces with varying curves intended to serve seating and skating. Jessica Tankard, University of Virginia in Earl Mark Arch 402 Design Studio, Spring 06.

rally bends requires careful observation of how the scored edge can be manipulated from 2D to 3D. By compressing the cardboard to crease the arcs, places where the material naturally follows or fights the line can be seen. By adjusting the arc placement, the cardboard forms can more naturally be found.

Three dimensional fabrication and printing

Three-dimensional fabrication allows for the transformation of a digital model into physical form, such as in the use of three-axis milling. The milling production process begins to transform the NURBS or polygon representation of a three-dimensional form on a computer into one determined by the graining of material and the exact cutting movements of a tool-bit. The computer model is an abstraction of the physical realities intended by a certain method of construction. The computer's capacity to abstract and compute form provides a unique framework in which to reckon with geometrical complexity, more difficult if not impossible to conceptually develop by hand. At the same time, the form itself is one that is subject to mechanical processes not fully anticipated in the original digital model. One's experience in working with materials, an understanding of the tolerances and effects of the drill bits, the accumulation of heat and other resistances all contribute to what is produced. Making the tool-bit pathway a part of the design is also a possible option though it requires some CAD programming. Similarly, in working with a laser cutter, the resistance of material to heat, melting and other processes can be anticipated.

In 3D rapid-prototyping, the transformation of virtual to physical model is also subject to the formal effects of a specific physical imprinting process. The device's deposition method, its resolution, its particular processing of plastic polymer or other material, all have bearing on the final output. Therefore, there is but a likeness between the initial virtual model and its physical counterpart: the transformation varies according to the designer's experience. And the 3D printed form is not necessarily the final outcome of the design process, but more typically an interim physical version of the actual product. We can wrestle here with distinctions that may separate out varied states of physical modeling from the production of the final designed object. In doing so, we can make the case that an interim analogue model is no closer to the final design object than is one of its digital counterparts. This is especially true in a

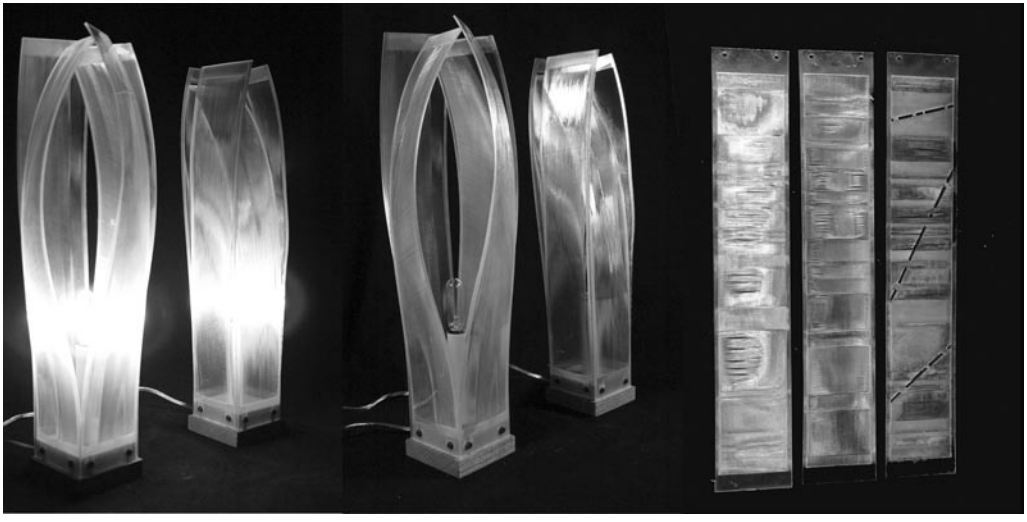

Figure 14
Acrylic Lamps produced using digital moire patterns in vector lines against laser cutter heat. The digital pattern was randomized by the heating / warping process of the laser. Kevin Day, University of Virginia, Eric Field's CNC Fabrication class, Spring 06.

design process where the digital model yields to a prototype which is then modified by hand, scanned, converted into a second digital model for further modification on a computer, preceding printing or fabrication and other forms of post-processing. As the geometrical data travels through a series of incarnations, we can also take note that the physical display on a computer screen may have a series of identities, each having some weight in the mind of the designer working through the possibilities of a particular design. In the emergent methods of the design studio, the varied incarnations of the design can each lend distinct points of insight that contribute to the evolution of a particular design.

In this illustration, the discrete increments of a digital model may be no less continuous in the mind of the designer than the actual analog model that was also engaged in the design process. Andre Bazin (1967), writing on the history of the cinema, suggests that the intentions of the medium were to get at the

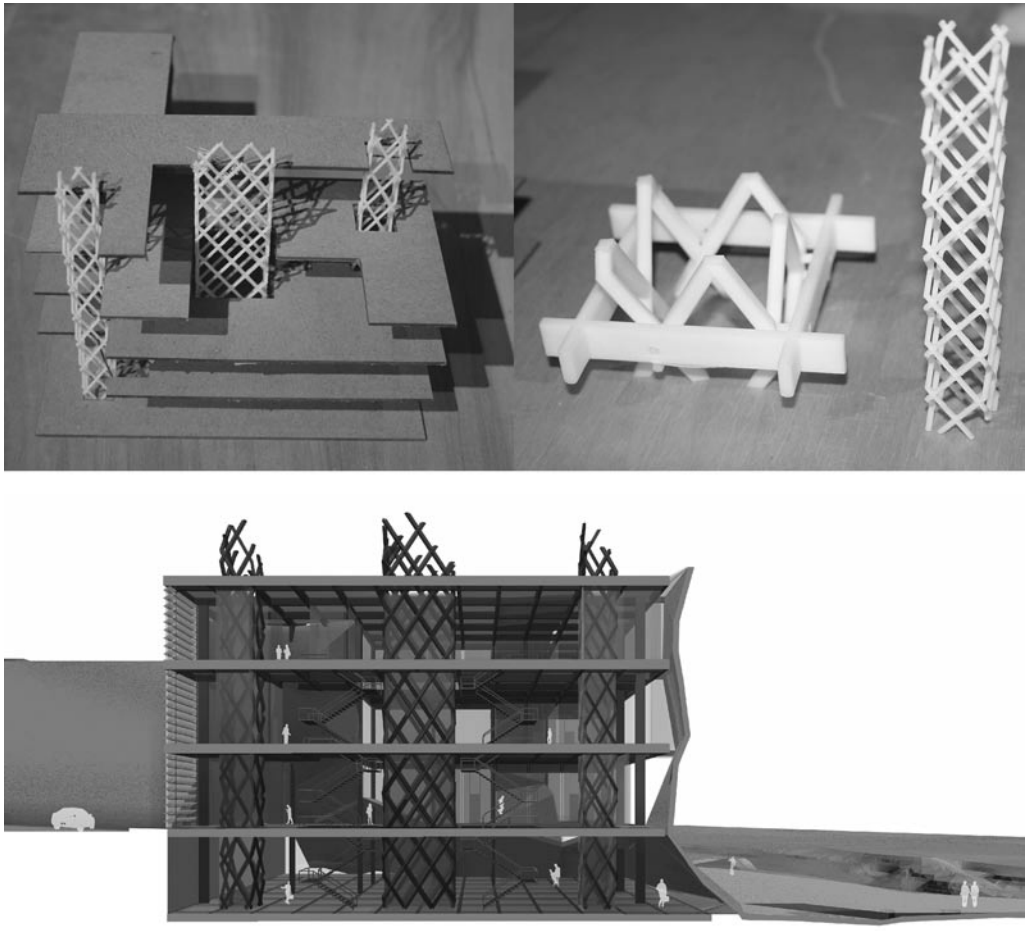

Figure 15
This rapid-prototype 3D model, printed as assembled in different scales, was translated from a structural study associated with a student's design project. It led to further modifications and adjustments to the computer model thus contributing to a design outcome. R. William Mitchell, University of Virginia in Earl Mark402 Design Studio, Spring 06.

magical condition of a continuous reality in which very little human imprint would stand between the physical world and its reflection in celluloid frames. Yet, the frames are in fact a discrete set of images, taking advantage of "persistence of vision" to help create the illusion of continuous motion, and so that direct connection with reality is not so readily established. Our use of virtual technology today similarly engages issues of human perception where perhaps the convergence between the virtual and analog world is difficult to fully establish.

Perceptions of digital/physical distinctions

The integration of digital and analog media in the cases cited above blur the distinction between the types of representations. A digitally reproduced physical model processed through a 3D printer or CNC milling machine may express the same qualities of intention and material representation as a model produced by hand. Today, it is not unusual for a model to be generated on the 3D printer or milling machine, and then further machined by manual means. Within our respective institutions, the free use of analog and digital forms of representation have reached a saturation point where often the naked eye can't discern their specific imprint on various physical and paper based artifacts that result from a long sequence of conversions. As analog and digital media worlds are increasingly amalgamated, such as in the Vienna University of Technology full-scale projects (Figures 1-6) above, we see no basis for arguing that traditional hand drawing is more thoughtful as compared to a computer mediated drawing, or that physical artifact engages more discernable qualities than one which has a more digital form.

The ambiguity of virtual and physical recalls an experiment, the wobbly pen exercise, by Davis Van Bakergem (1990) at Washington University. Design jurists were presented two sets of pen plotted perspective drawings. In the case of the second set of drawings, however, the pens were rigged so as to create random mechanical error. Jurists expressed preferences for the second set that they believed to be produced by hand because they sensed a greater indication of the designer's intentions. Constructing a manual or computer generated perspective may each have separate advantages.. The manual method may force a coming to terms with a design problem one element at a time. The computer method relieves the mechanical drudgery of establishing vanishing points and perhaps allows the architect to see the big picture. Yet, after the drawing is complete, bias shapes the assessment of which method produces more thoughtful work. Today, an experience jurist can be led to believe that a result is machine-made or hand-crafted when the opposite is true.

Conclusions and outlook

As computer-based media becomes more pervasive and multi-faceted, the distinctions between analog and digital are becoming less discernable. Digital media has adopted qualities of work produced manually, physical environments are shaped by digital geometry. In traveling through multiple forms, design products become enigmatic about their path of origin.

Our cases show that in design, the digital and analog divide is an increasingly an artificial one. Paper based drawing may be easier on the eyes than a digital screen, but in today's world, it is but another output vehicle. We may yet acknowledge some preference for the unencumbered spontaneous quality of drawing with lead on paper. Design traditions and biases do not preclude working media together, as in watercolored CAD drawings (Figure 10), or handcrafted and 3D printed models (Figure 15).

Andre Bazin, in his essay "The Evolution of the Language of Cinema" (1967), draws an important connection between film, the stage and painting, suggesting that as film emerged, so did the other media seem to find the find greater license to become more distinct. As filmmaking evolved from stage like settings, so did the stage take on more

experimental form. Photography freed up painting to become less about capturing an everyday visual likeness to what we see and to take on more abstract forms. Yet, painting wasn't merely supplanted by but also anticipated the perspective optics of photography that can be said to mechanically report on the world without the intervention of the human hand. Still, as Bazin notes, photography in its evolution is very much subject to a point of view and to experimental or highly abstract uses. Similarly, the intersections and specializations between analog and digital media occur today through varied input and output devices, each at times taking on distinct qualities, and perhaps at other times becoming indistinguishable. The common qualities between analog and digital media lead to exploiting the creative bridges between them in the highly inventive and eclectic processes of design, where increasingly, distinctions are difficult to establish as such technologies as haptic devices, advances in texture mapping and methods of moving from virtual to physical form lead to a more seamless environment in which to explore a range of design alternatives.

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