Simulating Paradoxes

A political map of the US hangs in most American elementary school classrooms. Today, these teaching aids are illustrated by corporate cartography divisions at Rand McNally and the National Geographic Society. A newly acclaimed version, drawn by David Imus, offers such an improvement of legibility that it won the "Best of Show" award at the 2012 Cartography and Geographic Information Society Convention.[1] The award is considered by many to be Cartography's highest honor.

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On those maps, state capitals are illustrated with a some version of a black star.[2] This convention is used by all[3] three[4] mapmakers mentioned above. For generations, each classroom map has presented a curious feature: *the USA is constituent of fifty states, but no one seems to mind that each US map displays fifty-one state-capital stars.*

This logical inconsistency stems from our conventions of representation. Maps use symbols to efficiently illustrate complex ideas; symbols need legends to inform the viewer's translation.

This logical inconsistency also demonstrates how, "the map is not the territory," or how drawings edit out inconsequential detail, while offering invented information in order to produce effective representations. Effective representations must operate on this symbolic level to skip the obvious and reveal the synthesized. A plan-oriented silhouette of an airplane communicates the intersection of transportation networks on a map. A flick of Louis Kahn's pencil communicates lines of force in his design sketches.

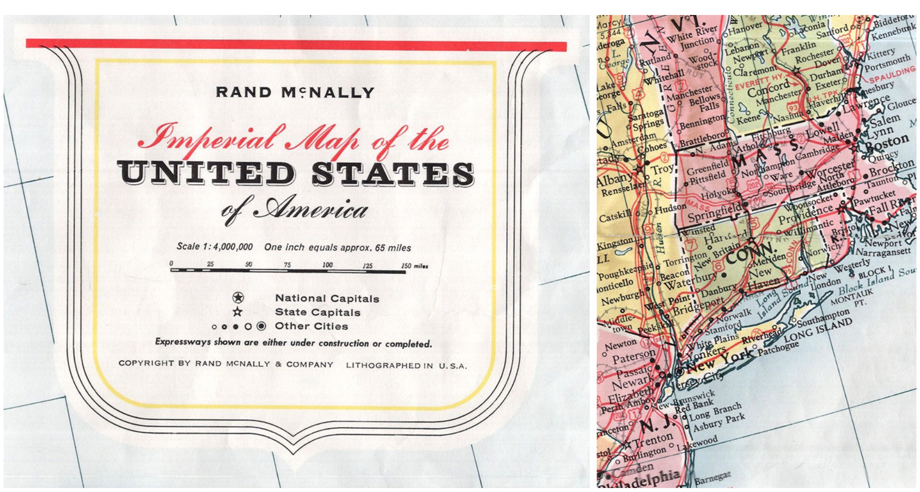

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Figure 1: *Imperial Map of the United States of America*, 1959, Rand McNally & Company.

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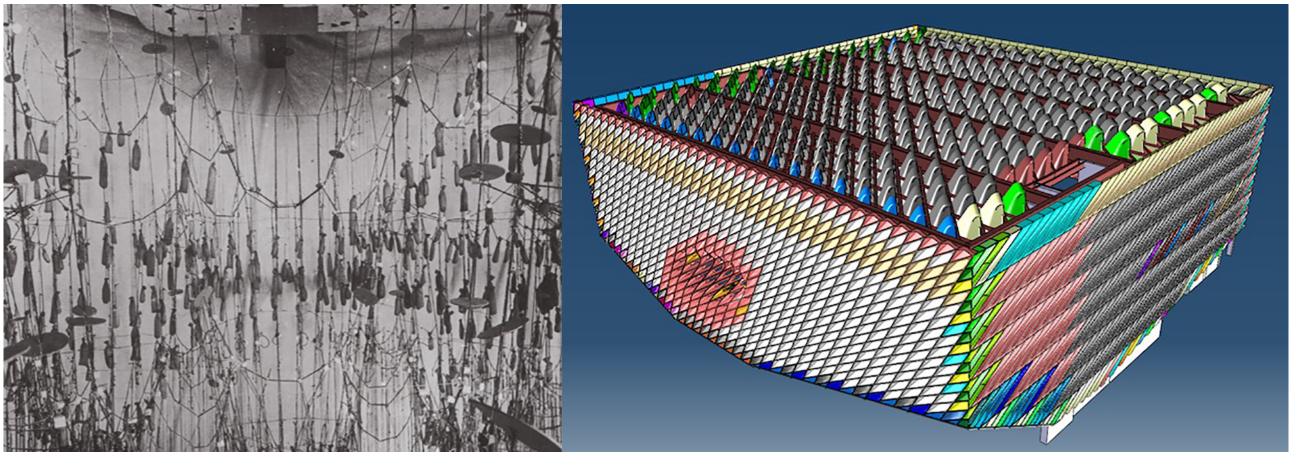

Figure 2: Physical and digital simulation models. Left, *Sagrada Familia Catenary Model*. Barcelona, Spain, 1882–1926, Antoni Gaudi. Right, panel fabrication model for *The Broad* Museum, Los Angeles, 2013, Diller Scofidio + Renfro.

Designers must both think about solutions (calculate), and display solutions (communicate) at this level of synthesis. Considerations of the spatial, material, political, and social are at play. Traditionally, designers toyed with these synthetic ideas in drawings.

COMPOSITION: BOTH CALCULATION AND COMMUNICATION

For the last four hundred years, the architectural design process used drawings and physical models, where calculation and communication were combined, in a paradigm of *Representation*.[5] This paper points to an emerging design process, where architectural ideas—through sketches, drawings, and physical models—are inserted into a digital environment that simulates built-medium phenomena. This paper presents evidence to signal a shift to an adjusted way of thinking about architecture: the paradigm of *Simulation*. This new paradigm features compositional ideas first interogated in simulations, and communicated in representations.

The earlier paradigm of *Representation* began in the Renaissance when master-builders performed design activities. The step towards *Representation* saw Architecture become doubly-mediated as a result of Alberti's project; he positioned the act of designing a building as separate from making the building.[6] As a result, that project situated the act of designing (composing architecture) in concert with the act of making drawings (representations). Alberti created an important cleavage of labor when he separated the designer's locus of work (representations) from their medium (buildings).

Simulation offers architects a design environment that has the internal consistency of building mediums. While not working directly with the building materials, designers enjoy medium-specific feedback for how their elements will perform. *Simulation* unifies architects with their target medium, the future building. It heals the Albertian cleavage.

The ACSA 2015 Fall Conference's debate between "autonomous discipline" and "cultural product" results from a unexplicit conflict between drawings' need to satisfy both roles of communication and calculation. That conflict is a natural consequence of *Representation*, given the doubly-mediated nature of the architect's medium (drawing) from the material reality of the building.

Using models as design tools creates the architectural equivalent of Bonini's Paradox.[7] Like sketches, architectural models (simulations) are only useful to architects as simplified descriptions of a future building. This multi-dimensional reduction creates two problems:

[1] "As a model of a complex system becomes more complete, it becomes less understandable. Alternatively, as a model grows more realistic, it also becomes just as difficult to understand as the real-world processes it represents."[8]

[2] "Essentially, all models are wrong, but some are useful."[9] The more a model of a complex system is trimmed for practicality, the more meaning is left to the viewer's interpretation, which allows for the original misreadings from *Representation*.

These quotes are from scientists, but they inform the architect's position. The spectrum between models and reality reveals what *Representation* never could frame: that *Simulation* offers all representations simultaneously. Indeed, the designer has always selected which representation best communicates process, ideas, poetics, results, and instructions for construction.

The following examples are offered to demonstrate the difference between paradigms. *Representation* communicates a single state from which a viewer could infer larger conditions, but *Simulation* embodies all possible conditions:

[a] A section drawing depicts adjacencies between spaces in a building, but a Virtual Design and Construction (VDC) building model embodies all such adjacencies. *A VDC model can generate all possible section drawings for the building.*

[b] An airflow diagram depicts a building's air movement during one moment, but a Finite Element Model (FEM) can model the total energy of an enclosed system.[10] *An FEM simulation can generate all possible energy transfers for that building.*

[c] An elevation might depict how louvers are spaced on a facade, but a parametric model embodies all attainable louver distributions. *An architect's parametric model can generate all possible orthographic drawings for that building element.*

[d] A physical mock-up may show deformations of s specific material under its own weight. *A simulation can mimic performance for any span, material, and load conditions.*

[e] A physical "light study model" displays illumination characteristics of a selected material in a space. *A lighting simulation model can illustrate light performance of the same composition for any day, month, or year.*

Note the divided role between calculation and communication in each example. One might see how Architecture's "stopping problem"[11] is at some level an acknowledgment that even in *Simulation*, conventions of *Representation* are required to communicate framed qualities of architectural composition.

REPRESENTATION

The evolution of architectural design ideas in the paradigm of *Representation* is well summarized in Robin Evans' book, *The Projective Cast.* In it, Evans posits that projected drawings were the lens through which ideas were generated, and three projective geometries—metrical, projective, and symbolic—influenced the ways architects formed these ideas. Evans' text orients readers to the frontal, planar compositions of late-Renaissance architects as the natural result of the scalar, orthographic drawing (metrical) methods of their day. As counterpoint, Evans positions the roof of Le Corbusier's Notre Dame du Haut as conceived through the lens of a descriptive geometry not accessible to his Renaissance predecessors, but developed through stereotomic and calculus-based advancements.

The reason drawing has proved to be the designer's greatest tool is this: drawings are built in a similar way as buildings. Drawings are more than the sum of steps to arrange construction lines, and then inking presentation elements (communication). Instead, for designers, drawings are a collection of elements, each of which depict a compositional idea. This is what architectural educator Jonathan Friedman calls eidetic vision:

> "The image is not copied directly from life. Rather it is drawn from the mind's understanding and memory of significant elements and relationships between them. This is

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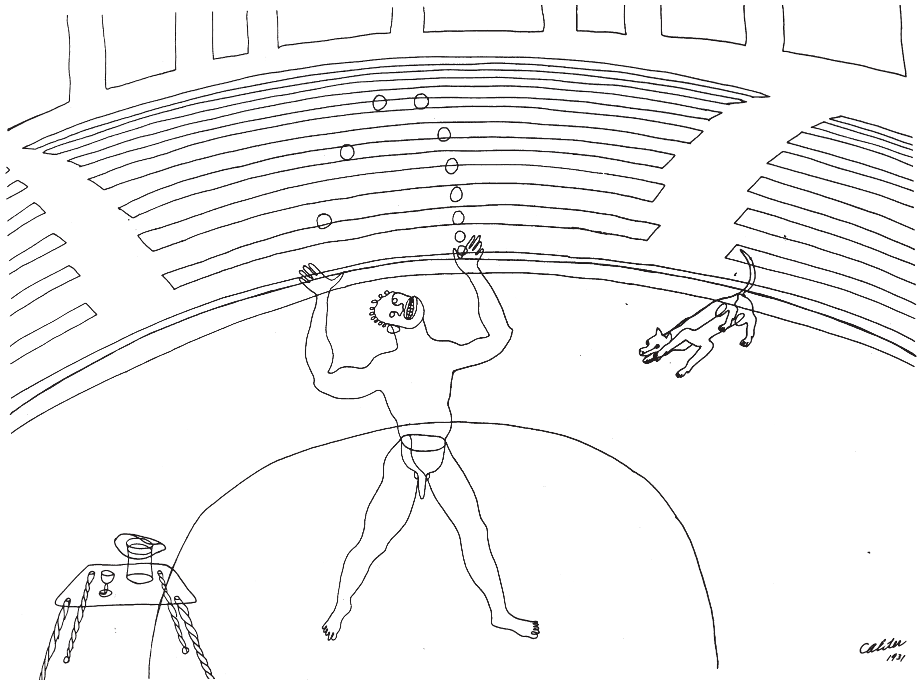


Figure 3: Illustration of eidedic drawing, in Jonathan Friedman, *Creation in Space: Fundamentals of Architecture,* vol. 1, 1988.

> how a five-year-old sees. The primordial union of architectonics and graphics is called eidetic vision."[12]

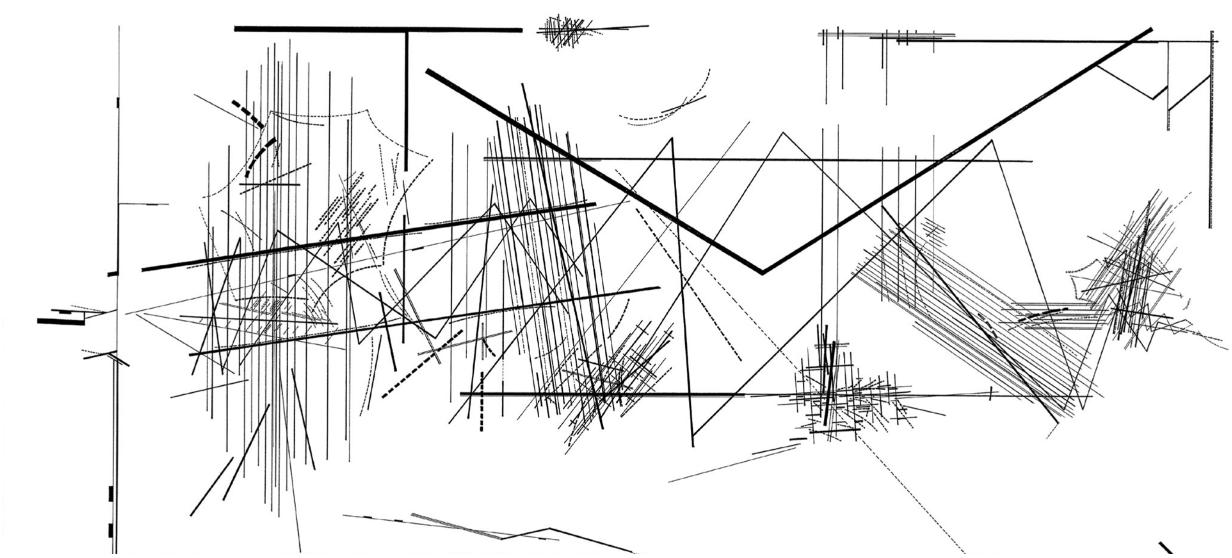
Eidetic vision, and the process of building drawings, has been a profitable analogy to building architecture since Alberti. The eidetic nature of drawing allows sketching to participate in the sequential nature of architects' calculations in *Representation*.

Because of their editorial nature, drawings are ideal tools to communicate curated ideas in *Representation*.[13] For the builder, an architect's drawings communicate design intent, the directions about assembly, and any elemental specification.[14] For the client, drawings communicate effects of their investment.[15] For fellow designers, it is drawings that convey an idealized version of projected work.[16] The 2001 *Perfect Acts of Architecture* exhibition illustrates this last point well. Curator Jeffrey Kipnis frames architectural drawings as the best way to convey design ideals—independent of the referent building—as an alternative artistic act:

> "The history of architectural drawing as an end in itself, as a fully realized, self-sufficient work of architecture rather than a subordinate representation, is well settled. … [T] he architectural drawing as end work can function in any of three ways: as an innovative design tool, as the articulation of a new direction, or as a creation of consummate artistic merit."[17]

For Kipnis, those architectural concepts are better represented in an architect's drawings, since a building is subject to harsh the realities of location, environment, and material, and cannot be ideal.

Herein lies the paradoxal nature of drawings in the paradigm of *Representation*. Drawing's greatest strength (its editorial nature) is the source of its most pointed limitation (reliance on interpretation). By relying on drawings, Alberti fixed Architecture as a doubly-mediated profession: its drawings cannot perform as the built composition will. Architectural drawings are stand-ins for architectural form. They are, by their referent nature, incomplete. They rely on the interpretation of the viewer; anything interpreted is prone to misinterpretation.



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SIMULATION

Simulation offers a new medium for exploring architectural ideas (calculation).

A simulation respects the internal rules of its medium. Architecture is ruled by assemblage, language of form, enclosure, and division of space. Architectural simulations model those rules for medium-specific consistencies:

[1] For *assemblage*, bricks are only modeled at anthropomorphic scales; assemblies are governed by joint conditions; construction must be sequenced.

[2] For *language of form*, simulated assemblies understand hierarchy, dependency, scale, and time.

[3] For *enclosure*, simulated assemblies understand a state of inside, outside, neither, or constituent.

[4] For *division of space*, simulated assemblies understand all geometric consequences inherited from *Representation*.

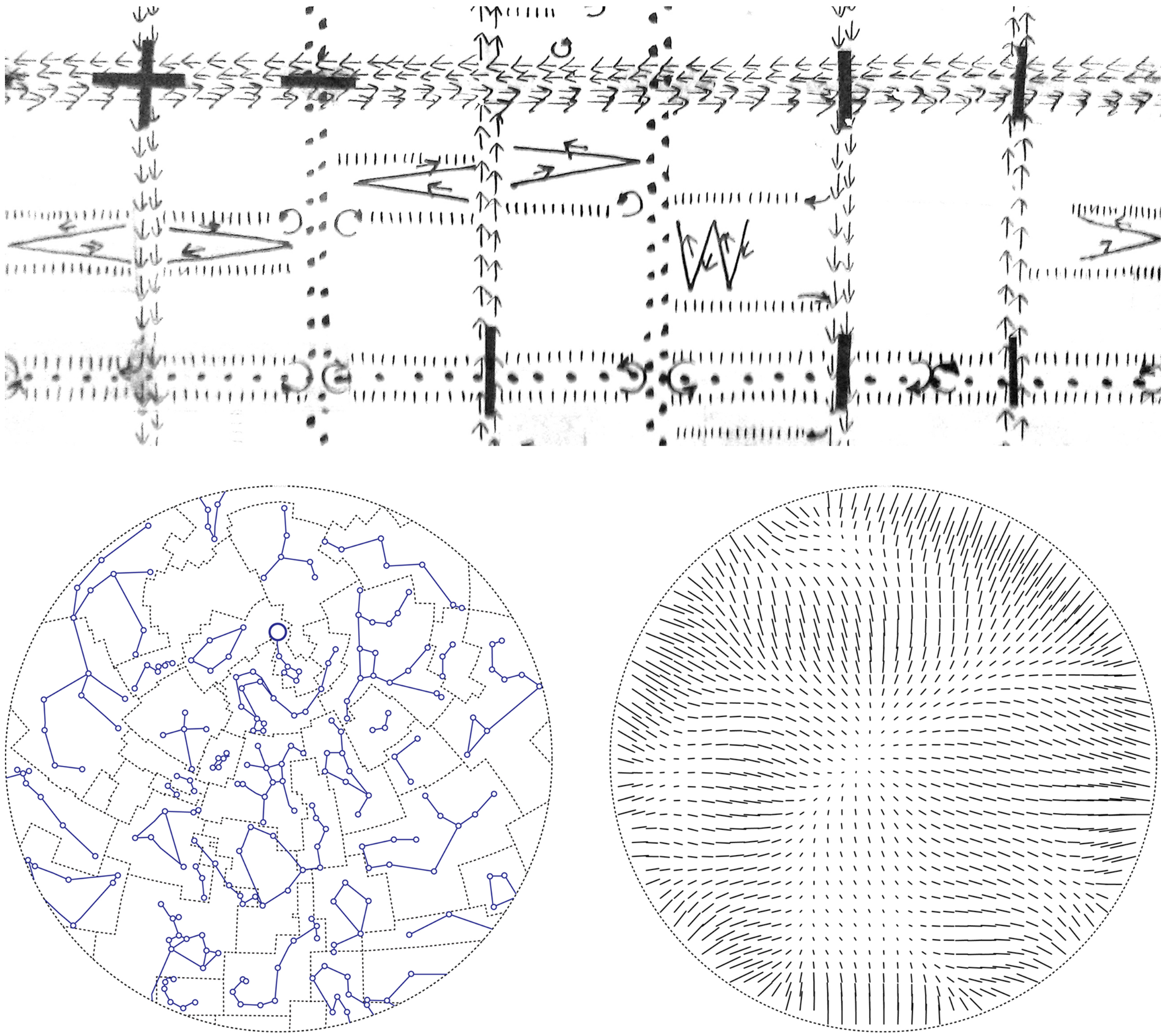
A simulation becomes merely a representation if it loses these essential internal criteria.[18]

A simulation respects the internal operations of its medium. Simulated operations rehearse the changes that occur in the physical environment. For example, when a wall is moved in a simulated environment, not only does the three-dimensional geometry move through space, but the weight of that wall, thermal enclosure, structural resistance, and acoustic performance are moved with it. When one moves a wall in a *Representation* environment, one merely moves a symbol (usually two lines on a page). The viewer must infer the change.

A simulation respects the internal constraints of its medium. Phenomena in Architecture's *Simulation* are constrained by those possible in the built environment. For example, a "door", which is an opening, cannot be created without a host surface to be fenestrated. The nature of enclosures tend to require walls to meet roofs, which simulations favor. When an additional column is added to a simulated assembly, new joints and beams are created consistent with assemblies in the physical built environment.

Some digital surface modelers that architects have been using do not satisfy the medium-specific criteria of *Simulation* above (rules, operations, constraints). Polygonal mesh models (SketchUp, 3ds Max, etc.) and NURBS surface modelers (Rhino, Maya, etc.) represent surfaces with no value beyond geometric qualities. Like lines on a page, they are best

Figure 4: *Chamber Works* (I-H). Daniel Libeskind, 1983, from *Perfect Acts of Architecture*, 2001.



understood in the service of *Representation*, finding significance once interpreted for what they signify.

In contrast, in the last ten years, architects have begun to integrate *Simulation* environments in their design process. VDC and parametric modelers (Bentley Architecture, Grasshopper, CATIA, Processing, etc.) offer a medium-specific simulation of the built physical environment. These environments feature a hierarchy, behavior, and phenomena between spaces and elements. These features signal the arrival of architectural tools, and not just generic geometrical tools.[19]

Simulations offer architects an environment with the rules, operations, and constraints they could only infer previously. *Simulation* thus unifies the architects with their medium. It heals the Albertian cleavage.

Figure 5: Designs with vector fields in *Simulation* and *Representation*. Top, *Traffic Study of Philadelphia*, 1951, Louis I. Kahn. Bottom, study for *Burning Man Light Field*, 2013, Chris Ingram.

Simulations have their limits. Two common limits are described by Eric Winsberg. First, he observes that some simulations simply overwhelm available computational resources, and to be solvable, they must be simplified so severely as to become un-predictive. Second, he notes that some models function by approximating the aggregated behavior of myriad elements, and thus they are over-sensitive to setting initial conditions which undermines their reliability.[20] His caution, reproduced below, rings just as true for architects as it does for his scientific audience:

> "…The data set requires interpretation. It can be visualized, subjected to mathematical analysis, and used in conjunction with other sources of knowledge, including observation, in order to arrive at the final goal of a simulation study—what I call a *model of phenomena*. This, rather than a pile of numbers, is what the simulationist aims to produce." [21]

The quote points to a simulation's larger limitation—the fact that they, too, require selective interpretation and editorializing that architects have relied upon all through the paradigm of *Representation*.

To be clear, calculation through sketching still holds a central role in the architect's design process in *Simulation*. Sketching will always offer primacy between the hand and mind. Historians such as Brian Brace Taylor astutely note that sketching communicates effectively, in that:

> "…a drawing or sketch still stimulates our memory and engages our imagination, and ultimately teaches us something in ways that a camera, the moving image, and techniques of simulation can never do."[22]

Further, that a sketch necessarily focuses and edits, in that it,

> "…does not aim at conveying all the reality perceived by the eye. It ultimately is the outcome of selective simplification."[23]

Sketching offers the immediacy designers need to primarily consider relationships, parameters, and dependencies they aspire to model. Today, few designers can creatively make intuitive design moves in a digital environment; however, designers such as Greg Lynn are attempting to cultivate this ability.[24] In *Simulation*, sketching bears the fruit to study, expand, and refine in simulations. But, it is the simulated environment that becomes the crucible through which one tests whole architectural concepts. Those simulations are then represented in refined drawings. Greg Lynn summarized this style of thinking best in the conclusion of the 2012 "Is Drawing Dead?" symposium at the Yale School of Architecture:

> "…this morning there was an assumption that the precision of digital tools is all about clarification and fixing things and the immediacy of the sketch is all about creating things. For me, it is exactly the reverse.
>
> I find [that] drafting tools give me a volumetric freedom, spatial freedom, and quickness that then gets concretized more in a pen-and-ink drawing. I will use a pen-and-ink drawing to fix the stuff that is being modeled loosely in a CAD software, and then use that information that is in a pen-and-ink drawing to go back and regulate the [modeled] stuff.
>
> That is just the opposite of what we have been told for the last thirty-six hours.
>
> So, if [I use drawn/framed vignettes], it tends to be in the CAD package, because there is one of four windows that is constantly giving me these vignettes, but the clarification and precision actually happens after (in drawings), rather than before."[25]

A simulation offers an improved location for calculations. But a simulation cannot communicate a priori. To create such a simulation creates Bonini's Paradox. To simulate every part of the physical environment, such a composition becomes too detailed to understand.

For architectural ideas to be communicated in *Simulation*, representations still have a role. Representations offer the simplification needed frame individual architectural ideas. The difference is that in *Simulation*, representations are generated from the simulation. That

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which is finally framed and communicated is done by the editing out extraneous simulated information from the model-generated representation.

DISLOCATION OF DESIGN DECISIONS: Simulation and the consolidation of thought (power)

Authors such as Sheer[26] and Bernstein[27] report how architectural production is increasingly employing *Simulation* in addition to *Representation*. With this addition, the (external) tools of cultural influence are immediately recognizable. Daylight analysis, cost estimates, structural load calculation, and others are revealed as accounting data to be harvested in service of profit. In fact, these "plug-in" tools have become commodities; they are wielded by non-architects; they threaten the livelihood of "practicing architects" by giving control (power) to client representatives or construction managers.

To understand how simulations have become a commodity, one must understand how they are the new locus of calculation. A brief history of architectural calculations will show this value.

DESIGN DECISIONS BY INTUITION: Building Reputation with Demonstrated Success

Considerations about how buildings behave have informed architectural design since the beginning of human awakening. Vitruvius' *The Ten Books of Architecture* spent many of its pages documenting building conventions for strength, planning, construction methods, water resistance, and much more. Even in the fifteenth century, the design of the Cathedral of Milan was informed by rules of thumb based on master builders' past experiences. Structural loads, thrusts, and stresses were beyond the conceptual horizon at the time.[28] In the case of Brunelleschi's dome for the Duomo in Florence, his built model convinced the client of his design and methods for constructing the dome.

DESIGN DECISION BY MANUAL CALCULATION: Building Certainty with Mechanical Theory

Gradually, Enlightenment thinking replaced the reliance one's proven-track-record with faith in equations to approximate natural forces. These equations were the awakening of the paradigm of *Simulation*. Instead of relying on specific conditions, observations were systematized into equations that predicted behavior.[29]

With specialization, architects and engineers began to understand these behaviors better. Structural engineering has described the behavior of building materials under loads with great precision for decades. Today, building codes mandate the calculation of structural behavior to protect the public.[30] Similar equations have been created for energy usage, ways of approximating light transmission, acoustic performance, and programmatic usage. These equations and calculations are simulations. Knowledge of them are commodities traded as education. The state governs their use through licensing.

Since the performance of manual calculations is a time consuming service, most design processes are strategic about when to do full calculations to minimize cost.

DESIGN DECISIONS WITH SIMULATIONS (In the Medium of the Physical Environment)

Simulation offers more than an analogy for the medium of the built environment, represented with lines, surfaces, and volumes. Instead, it predicts performance. *Simulation* helps designers manage the legal, financial, and aesthetic risks of their decisions, more so than any collection of drawings ever could.

This predictive quality makes the simulations valuable. These models provide the ability to both complete costly calculations with great speed, and also manage risk with higher accuracy. Bernstein notes that in the paradigm of *Simulation*, the decision-making process has been commodified by non-architects.[31]

More importantly, *Simulation* takes all of the interactions between building elements (what were, mostly, unique calculations up to now), and combines them into an integrated understanding of a building. This integration removes the need for some human inference. The interaction effects of a design change, can be traced through the entirety of a composition with great speed, and are immediately legible (thus controllable).

Herein lies the power of architecture in a contingent setting: *Simulation* offers intuitive, informed, creative feedback to a design process, empowering the simulators to respond with authority to unanticipated challenges.

CONCLUSION: DRAWING IS NOT DEAD

To design is not to make a drawing. To design is to engage in a process that folds in layers of information, to make decisions in response to that information in order to increase the composition's detail. It is a feedback loop.[32] In the design process ideas are tested and edited, first through the calculation of design solutions, then communication of those solutions.

Representation offers a regiment for both testing and display. Calculation work tends to be done in sketch, and sketched section or plan. Communication work tends to be done in drawings. These two-dimensional loci require heavy interpretation on the part of the viewer. This ACSA conference is the result of some misinterpretations.

Simulation offers a another paradigm that tests and evaluates designs, differently, in closer response to our medium. Calculation work tends to be multi-dimensional. Communication work still tends to be done in drawings, and thus benefits from all the conventions established in *Representation*. Those drawings tend to be generated from simulations.

If Alberti's separation of designer from builder created the "architect," this conference risks continuing the overheated examination of criticality, disciplinarity, and specialization that has almost made the "architect" irrelevant.[33] More and more calculation work that carries value is systematized, and done by specialists, engineers, construction managers, owners and software.

Architecture as a profession is starting to harness the artistic merit of simulations. It is also using simulations to buoy the way it addresses the real, physical environment, the context of finance, or other influences of the contingent. Incorporating simulations into the design process reunites the architect with these original media of the built environment.

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