2

RELATIONS: INFORMATION EXCHANGE IN DESIGNING AND MAKING ARCHITECTURE

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2.1.
The *Parthenon* in
Athens, Greece
(5th century BC).

> Architecture depends upon its time. It is the crystallization of its inner structure, the slow unfolding of its form. That is the reason why technology and architecture are so closely related. Our real hope is that they will grow together, that some day the one will be the expression of the other. Only then will we have an architecture worthy of its name: architecture as a true symbol of our time.
> (Mies van der Rohe)[1]

Digital technology has engendered a profound affect on modes of architectural production. While technological change has always been a catalyst for new ideas in architecture, today, digital information technology is the essential agent of innovation in a total process of architecture. The central requirement is clear, reliable, and consistent exchange of information among all parties involved in creating and realizing a given project. Software enables architects to manage complexly articulated designs, while digital models facilitate the exchange of information with collaborative teams, interweaving a diverse range of expertise and feedback into the design process. As a result, analysis, simulation, fabrication, and assembly information are revealed at earlier stages in the process of formulating architecture.

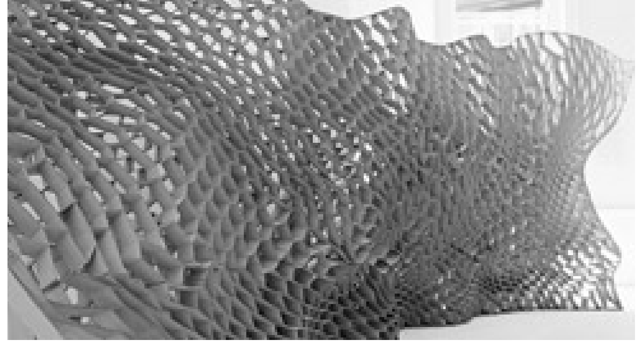
A critical examination of data in a *total process of design through production* sets in motion a well-informed series of architectural intentions. Several factors, which may seem obvious, must be stated as essentials: First, the projects need to be built. Second, *design is central* to the equation, and must be privileged in the development of solutions, augmented by feedback about production realities. Third, *early collaboration* is necessary with a diverse range of expertise. Finally, and most importantly, numerous inputs of information about the project must be *effectively managed* during all stages of realization of a project; while the master model is the central storage mechanism of project information as it evolves toward built form, it is the information that adds value through an iterative process and critical reflection, resulting in useful data stored in the model. Rigorous application of these informed methods leads to abundant solutions that address an array of design and performance concerns. Through a reflective process-oriented crafting of shared information, the effective means of communication and information exchange is vital to the achievement of new methods for design and production for an architecture aligned with the spirit of our age.

ANCIENT HARMONY

The ancient Greeks turned to interrogating nature to reveal its secrets. In a sense, they endeavored to discover the codes of nature and use them with mathematics and geometry as organizing devices, which, if applied judiciously, led to "harmony" in architecture[2] (figure 2.1). (The golden section *is* true; it *does* occur in nature.) Today, we do not talk about "harmony" (let alone "beauty"). Yet, like the ancient Greeks, we are operating at the level of the *code* – whether found in nature or not – by manipulating information that remains largely invisible in the final form.

The ancient Greeks translated codified geometry into fundamental principles that could be applied as universal solutions for design strategies. The analog application of geometry has given way today to the algorithmic definition of complex geometry. This algorithmic, *procedural* geometry, while still governed by a mathematical rigor of an internal logic, has its own inherent nature, resulting in formal strategies that seem to lack the certainty of a universal principle;[3] each solution can be unique depending upon selected input variables (figure 2.2). Yet, it is difficult to critique an algorithmic, generative procedure for its formal implications; we can only evaluate its particular formulaic potentialities. So instead, our focus has shifted mostly to an effective interrogation and revealing of information specific to the formulations of architectural intent; "harmony" remains out with the discussion.

2.2.
Manifold Project:
Andrew Kudless:
Architectural
Association, MA
dissertation,[4]
London (2004).



The ancient Greek temple, elevated high on the hill was dedicated to the gods, but in effect, they were elevating their own understanding of order derived from interpreting the natural realm.[5] If we examine our high places today, such as tops of buildings, mountains, and even the exosphere, we find the signification of ubiquitous information flow: cell towers, dishes, satellites in geosynchronous orbit, all radiating dense waves of invisible bits of information. How do we organize and articulate architecture in this ocean of information? The answer is obvious – by steering in relation to information, and navigating the bits. As such, with a diversity of expertise and fluidity of information exchange, new structural conditions for building can flourish, and we can turn our attention to the fundamental relations of architecture (i.e. the natural world), and its greater affects (i.e. the human realm).

ENCOMPASSING INFORMATION

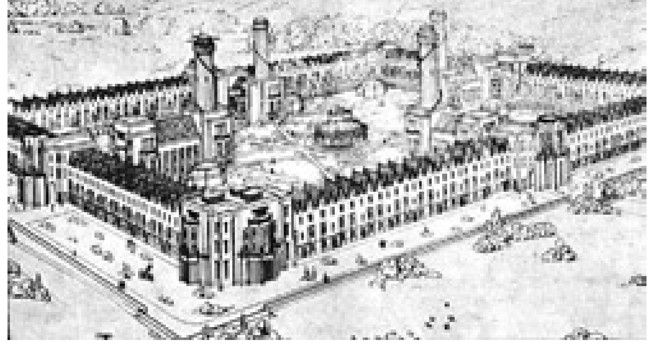
Contemporary methods in architecture promote computational processes, which demand dynamic flows of information. Layers of embedded intelligence are interlaced with formal generative techniques. Parameters take into account behaviors in relation to sun, gravity, environment, or hundreds of other considerations. While algorithms assist in the examination of complex strategies, human reasoning still governs the selection of appropriate input parameters for consideration. Choices are born out of a human capacity, even though we could still envision an architecture that is the result of a direct output of specified inputs and formulaic calculations by computational devices, as envisioned by Nicholas Negroponte in *The Architecture Machine*[6] in the early and radical days of computational speculation of the late 1960s and early 1970s. To set up his argument, Negroponte offers a useful articulation of the human capacity for incorporating information into design:

> What probably distinguishes a talented, competent designer is his ability both to provide and to provide for missing information. Any environmental design task is characterized by an astounding amount of unavailable or indeterminate information. Part of the design process is, in effect, the procurement of this information. Some is gathered by doing research in the preliminary design stages. Some is obtained through experience, overlaying and applying a seasoned wisdom. Other chunks of information are gained through prediction, induction, and guesswork. Finally some information is handled randomly, playfully, whimsically, personally.[7]

At about the same time, however, Buckminster Fuller raised serious questions about the human ability to cope with issues of complexity.[8] Today, the very notion of involving human choice in relation to complexity underscores the necessity for a greater evolution of architectural principles relevant to a *total process of design-through-production* that privileges the exchange of information. This is the hinge. Many new digital design languages import terms and reflect qualities specific to the jargon of the digital tools we use, yet a "clear and critical definition of new principles has yet to materialize."[9] This doesn't mean that the old principles are irrelevant; rather, a broader definition of architectural principles should emerge in relation to the digital age, and in relation to a much more significantly informed understanding of an interconnected world.

DIGITAL EXCHANGE

An effective exchange of information is fundamental in achieving architecture materially, and is increasingly reliant upon close collaboration between architects, manufacturers, fabricators, material suppliers, engineers, and many others in the early, conceptual stages in design. This new structural condition has led to innovative architectural opportunities, well articulated in the resonant call for changing the profession led by Phillip Bernstein[10] and others. Roles of collaborators vary on a per project basis, and in reality, many potential players must retool their operations to more effectively participate in the digital exchange.[11] Ironically, the evidence that the information age has advanced inter- and intra-relations of diverse participants is the ultimate realization of notions proposed during the height of the mechanical age by Walter Gropius[12] and others, who lamented the separation of the trades.



2.3.
This Communitarian town plan was based on a model community at *New Harmony*, Indiana, by Robert Owen (1825).[13] Key elements include functions that elevate the social and human realm: a central conservatory and "Pleasure Grounds" flanked by four major buildings for social gathering, assembly, concerts, libraries, reading rooms, museums, laboratories, artists' rooms, lecture rooms, committee rooms, and places of worship.

More often than not, presentations by those who identify the potentials of new structural conditions for the building industry include some form of diagram that represents a *new* way of organizing the building enterprise. Typically the point of view of the person presenting is what ends up in the center of these diagrams, whether a software developer, regulating institution, developer, contractor, or architect. These diagrams are like so many utopian settlement diagrams, which privilege the central idea of each utopia by placing a building related to that idea in the center of the town plan: communitarian utopia = socializing edifices (figure 2.3); industrial utopia = factory and administration buildings (figure 2.4). To solidify a diagram for operation within a transformed building enterprise may be merely an exercise in affecting control. Yet, the fundamental condition of every diagram is its reliance upon information exchange. Flows are integral, while configurations vary (most likely because each project is unique due to the operative strategies necessary for its completion). As such, diagrams representing changing conditions for the building industry will likely continue to fluctuate, as in some instances, innovative architects will control more of the building process, or clever developers will deploy data exchange mechanisms to exert more influence on the process, while contractors craving more deliverable control and fewer change orders may also formulate new models. The result of this diversity will be a range of different types of projects that can all claim the primacy of information as their driving force. This diversity is desirable.

In light of the necessity for fluid information transfer, contractual arrangements in the building enterprise must evolve more swiftly to facilitate information exchange at *all* stages of the process. Still, we must observe caution in a race to facilitate information flows to avoid instrumentalizing change through rigid systemic control of the enterprise. The capacity for fluid aggregation of diverse input hinges upon the flexibility of arrangements. The opportunity for diverse arrangements is in part what is so exciting about this new structural condition. Exacting, yet flexible arrangements (similar to associative design) will serve to engender innovative new architectural solutions.

Since data files are the chosen medium of exchange (for communication, testing, modeling, prototyping, and manufacturing), all bits must be in order prior to coordinating the atoms. Well-organized information during the design process leads to decidedly *informed form*. As such, the craftworkers have reappeared,[14] only their focus has shifted from direct engagement with the material to creating information for materialization, digital fabrication, and assembly, in relation to material knowledge; encoding information is a form of craft that directs the craft of form.

INPUT PARAMETERS

Selection of input parameters during the design process can be made lightly or in great detail, as a multiplicity of combinatorial possibilities exists. Also, feedback loops can multiply infinitely, thus enabling continuous refinement of a project based on deeper levels of information revealed in subsequent iterations. It is up to the collaborative design group – and ultimately human decision – to determine which parameters are admitted into the process. Critical reflection about appropriate strategies, however, must be articulated at the outset. For example, a range of formal strategies can result from choosing appropriate *scripting* techniques, or operations for producing form (i.e. *sectioning, nesting, unfolding*, etc.).[15] Performative information may be incorporated, revealed by interrogating the digital model via testing, simulation, and analysis (using techniques such as *spatial visibility, daylighting, finite element analysis, acoustic behavior*, to name just a few).[16] Materialization and production parameters can inform the design in many ways, by understanding the operative constraints of the machines, customized detail solutions that replicate through the entire system, tolerance criteria, limits of tooling such as drill bit influence on final fit, as well as complexities involved in shifting from model-scale to full-scale.[17] Assembly factors such as labeling, bar coding, and transportation size limitations are also important; they too reveal information that can affect the final design. Given the diversity of operative techniques, potential parameters that inform the design solution can expand *ad infinitum*.[18] Thus, it is critical to look beyond the operative conditions and ask what the ethical responsibilities for architecture are in relation to natural systems, human behavior, social conditions, etc.

2.4.
The *Ideal City* and *Royal Salt Works* at Chaux, France by Claude Nicolas Ledoux (1775): Industrial city for living and working with central buildings for the director's villa and the industrial evaporation of brine.

INFORMING THE COLLABORATIVE

In light of the fact that design strategies vary dependent upon the team and the project (i.e. levels of complexity, site, scale, materials), some critical topics can be considered in general during the total process of design-through-production:

Consultation: All disciplines have something to input into design thinking, depending on the conditions of the problem. Expertise in fabrication, engineering, scientific analysis, mathematics, systems behavior, environmental performance, construction assemblies, and financial planning are some privileged, obviously beneficial, inputs into design thinking. However, other kinds of knowledge are increasingly relevant to the equation, such as biological sciences, environmental conditions, information management, etc.

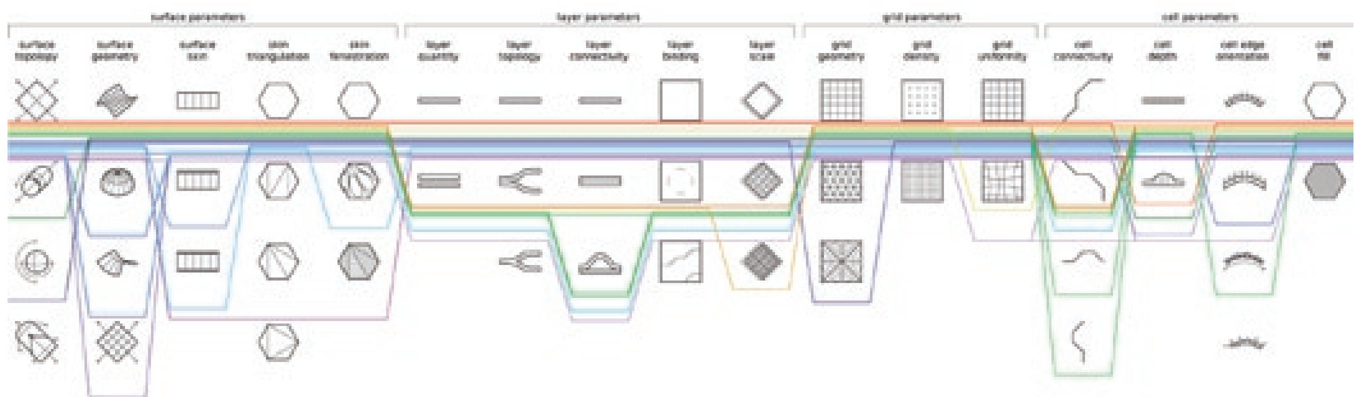
Fabrication: Working with the operative particularities of laser cutters, water jets, joinery machines, etc. can be daunting. Knowledge workers with digital fabrication expertise are more than just automatons of the industrial machine, but rather technical experts skilled at interrogating the machine potentials in light of information inputs derived directly from the master model. As such, well-informed fabrication experts armed with an understanding of design knowledge (at the very least) are essential.

Software and coding: Scripting is a particularly effective strategy for creating necessary design information. It is based on crafting bits of information to achieve certain goals, for a customized solution when software fails to provide a particular operation. Even still, the operative capacity of software has expanded, and further increasing transparency between software facilitates import/export of needed data. Yet, the range of software one needs to adequately inform design and production is still burdensome. Expertise in managing information for modeling can be of fundamental value in translating data and embedding information into useable form to better guide the design and production of building. Perhaps some day, information management experts may even guarantee that all exchanged information is reliable!

Research: Direct research related to problems considered in the design process is essential. As most companies do not have the time or resources to invest heavily in research and development, potential linkages that transgress traditional boundaries between academia and industry are important. Engaging university research centers, as well as collective research and development within particular industries, can address this need. Such an applied form of research can better inform the design process, while potentially leading to innovation. As such, educational programs need to break free from traditional notions of architectural practice by encouraging deeper-connected applied research. Students encouraged to innovate will likely lead in pioneering the necessary changes within the ossified professions that comprise the building industry today.

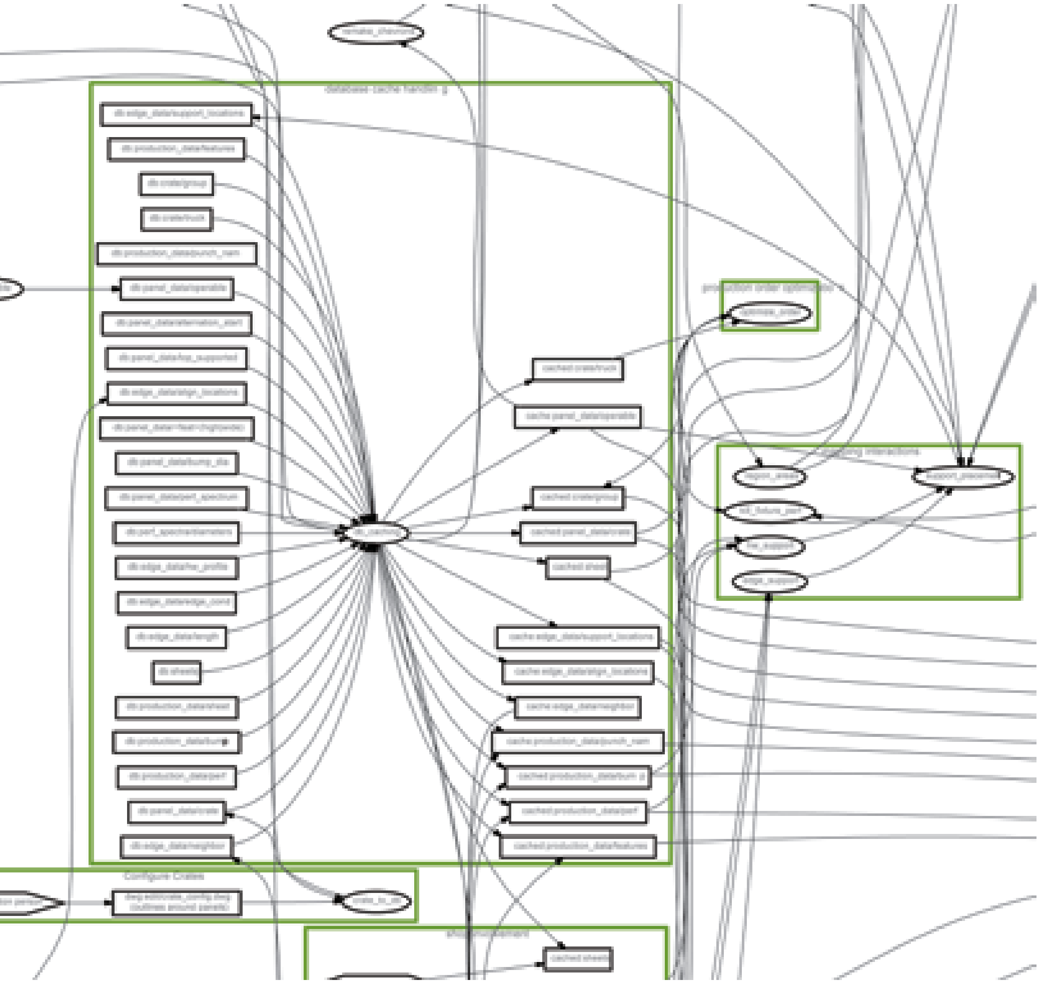
MASTER MODEL

The *master model* (even though it may involve multiple types of models) provides a three-dimensional representation of a project and all of its individual components. Value is added by evolving iterations of the model, as each agent in design and production weighs in with knowledge, expertise, and decision-making. The master model contains important design and production information related to geometry, material properties, simulation, performance, fabrication, and assembly. The model can be used in several interrelated ways: First, the master model encourages systems of associations and constraints that describe relations between formal strategies and components, assemblies, and context. In this way, inevitable design changes are propagated through the entire model, eliminating repetitive elemental modeling tasks and ensuring greater freedom for variety.[19] Second, the master model allows the simulation, analysis, and testing of a project, using digital tools to evaluate performance considerations related to gravity, wind, acoustics, and other simulated influences. Third, prototypes, scale models, and mock-ups can be created without expensive tooling, providing means to inform the master model based on prototyping material production, through "physical-to-digital" feedback loops. Fourth, the master model contains all the geometric information needed to directly fabricate final building components. Fifth, the master model facilitates the assembly



2.5.
Manifold Project by Andrew Kudless (*Architectural Association*): Parametric matrix exploring geometric and topological properties of the honeycomb system.

of complex products and projects by serving as a database of parts and locations by translating data into bar-code scanning, laser positioning, material tracking, and part inventories. Even shipping and delivery can be phased, choreographed, and coordinated through project completion with data obtainable from the master model. The master model is the catalyst for enabling collaborative information exchange, which sets the stage for new structural conditions in the building industry.



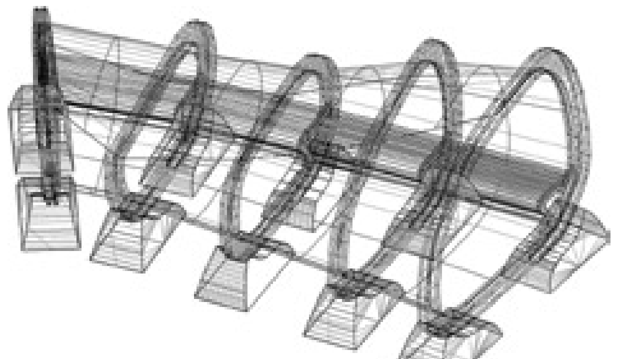
2.6.
Digital information flow relationship tree at the *A. Zahner Company* for the detailing and fabrication of the copper skin panels of the *de Young Museum* in San Francisco.

REPRESENTING RELATIONS

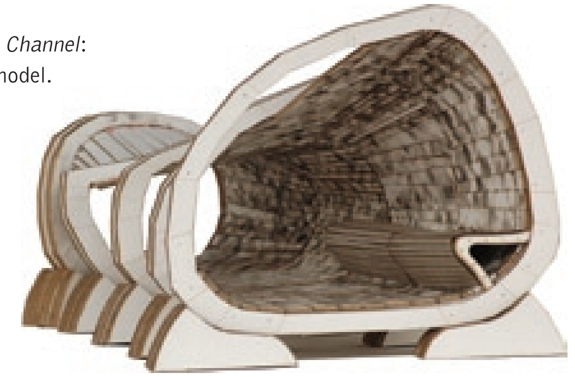
Beyond the master modeling strategies, changing techniques for communicating process information are evolving to facilitate the exchange of information.[20] Plans and sections have given way to nesting diagrams, unfolding operations, surface optimization, material tolerance simulation, and more.[21] New representational techniques emerge from the need to direct machines to cut, bend, and fold precisely the physical shapes and the capacity to guide form. However, some representations also allow envisioning design iterations used to evolve design. *Matrices* and *relationship trees* permit prompt visualization and prioritization of solutions in relation to one another, while providing a capacity to trace a genetic history of design decisions, operations, or even related projects. They are also useful in arranging morphological variants resulting from scripting. As digital tools provide the opportunity for serial differentiation, countless design variants (good and bad) are generated during the design process. Matrices and relationship trees allow the designer to manage and examine this repetitive complexity and direct the next set of decisions for further exploration. For example, the matrices that Andrew Kudless[22] used in the design and making of the *Manifold Project*, produced with the *Architectural Association*'s *Emergent Technologies* (*EmTech*) *Group* (figure 2.5), kept track of the lineage of strategies and parameters used to produce a set of prototypes until the optimal combination was identified using feedback loops and a final path to resolution selected.

A. Zahner Company constructed an operative flow relationship tree (figure 2.6) to manage the complexity of digital information for the fabrication of the *Herzog & de Meuron*-designed copper skin cladding for the *de Young Museum* in San Francisco. Digital model files were charted according to the operations performed (such as shearing, punching, perforating, and dimpling) and the timetable of the fabrication and assembly process.

2.7.
Calibration Channel, Mounds State Park, Anderson, IN (2006).



2.8.
Calibration Channel: digital model.



2.9.
Calibration Channel: prototype model.

2.10a–b.
Calibration Channel: final construction comparison with presentation rendering.

IMMERSIVE EDUCATION: DIGITAL DESIGN AND INDUSTRY PARTNERSHIPS

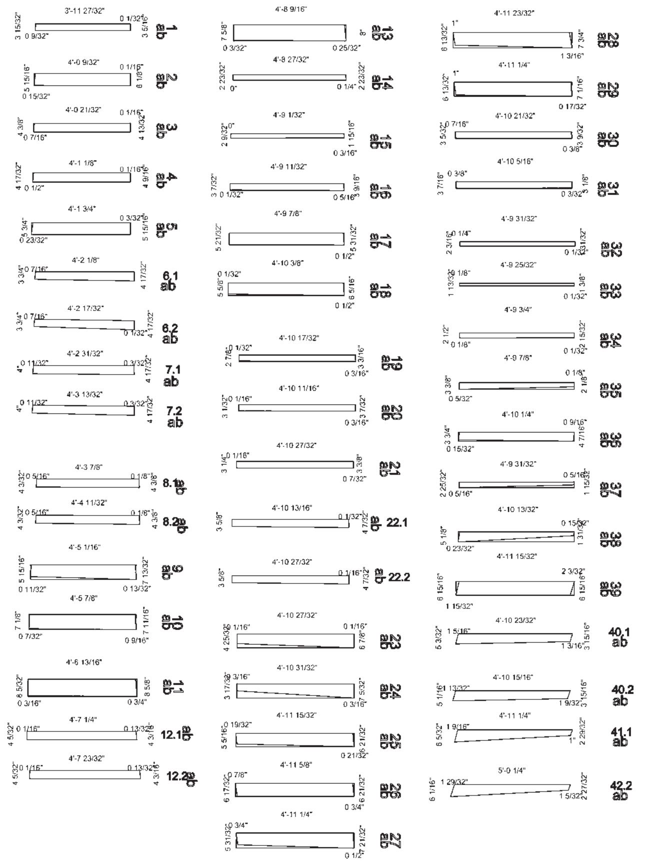
We need a new academic model; one that is not satisfied with architecture as it is typically practiced today. Diverse course offerings are still separated from one another, with little opportunity for integrated techniques and innovative multi-disciplinary collaborations. Within accredited professional degree programs, much attention is paid to satisfying the set of skills students may need for real-world practice, while not deviating from sole author project-driven design investigations. While serving the profession is still necessary, a spirit of innovative partnership between the academia and profession can discover new potentialities. It is critical today to impart to students the imperative for directed research, experimentation, teamwork, and collaboration with industry partners in *design-focused* investigations. There are broad implications about how we train architects for a future that relies upon digital exchange. As such, the educational system needs to be more flexible. Digitally-driven *immersive education* involves students in the application of digital research in real-world projects with industry partners. Through experimentation, academia-and-industry collaborations examine methodologies and a total process of design-through-fabrication at various scales – from furniture to building components.

As the American Midwest has a long tradition of making things through manufacturing and material processing, the *Ball State University* (*BSU*) in Muncie, Indiana, has created a fertile territory by engaging regional industry partners through immersive education in an attempt to test and apply new methodologies for designing and making architecture. In the spring of 2006, students enrolled in a special seminar with the *Virginia Ball Center for Creative Inquiry* at *BSU* in which they developed a number of full-scale installations at strategic locations along Indiana's White River in partnership with key Midwest industry partners.

One particular installation, *The Calibration Channel*, located at Mounds State Park, in Anderson, Indiana, was designed and manufactured in partnership with the *Indiana Limestone* industry and the *Indiana Hardwood* industry (two strong regional material interests within the state). The design was developed in response to the aural presence of the river as it flowed across a ripple zone in the riverbed (figure 2.7). Students generated a design solution with the intention of capturing, channeling, and condensing the sound of rippling water as it traveled up a promontory bluff, thus calibrating the sensory experience. Initial design ideas were modeled, laser cut, and developed with feedback of fabrication realities of hardwood and limestone (figures 2.8, 2.9, and 2.10a–b). Students crafted assembly configurations for the red oak and ash donated by one of the major regional hardwood mills, the

2.11.
Calibration Channel:
rib component nesting/
material matrix.

2.12.
Calibration Channel:
catalog/shop tickets for a portion of the skin panels; each panel was checked off the catalog as fabrication was completed.



Frank Miller Lumber Company, in Union City, IN. Structural decisions were made in accordance with both the limits of the bed size of the in-house 3-axis mill, as well as the variable nominal dimensions of the donated lumber; we received an assortment of board lengths and widths, which were first inventoried into a matrix of available size configurations (figures 2.11 and 2.12). Additionally, a working protocol for the exchange of information was central to the fabrication of the Indiana limestone footers for the structure. Data translated from *Rhino* into *SurfCAM* was exchanged directly between the students and the *Indiana Limestone Fabricators* in Spencer Indiana, who ultimately used the final model information to directly mill the stone using their *Sawing Systems, Inc* 5-axis stone-milling machine. The fabricator had never received information from architects in that format before, which was translated with precision into the final fabrication of the form (figures 2.13 and 2.14). The fabricator now encourages architects to send their information in that particular fashion and format.

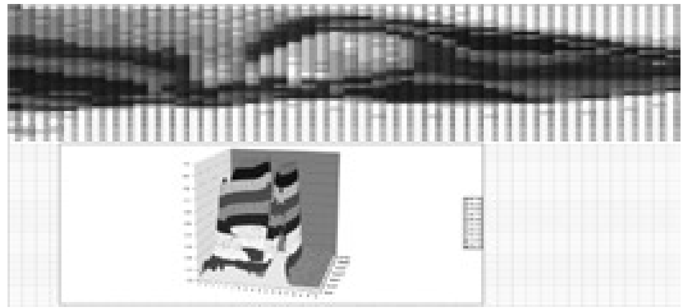
The lesson of the *Calibration Channel* was revealed when, following the seamless translation of design intention into fabricated components, and accurate final assembly procedures, students climbed inside the installation, and it worked precisely as designed, affecting the occupant with a much more amplified sound of the water in the distance (figure 2.15). As such, *Calibration Channel* was both a success as a device for connecting the user to the resonance of the natural surroundings, while demonstrating the potential for managing and sharing information in a total process of design-through-production.

2.13. (below)
Calibration Channel:
precise translation of the model data into the final form.

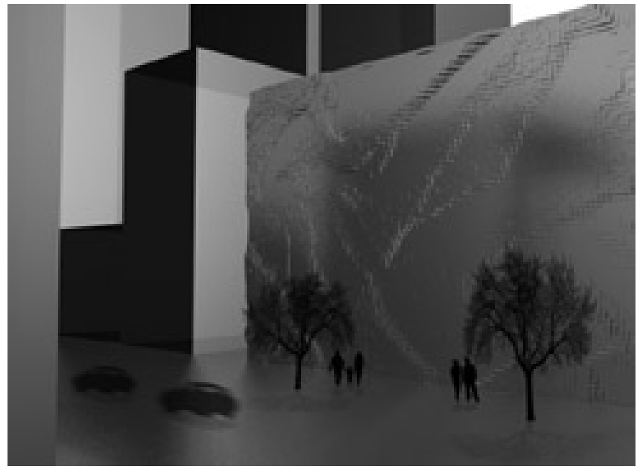
2.14. (right)
Calibration Channel:
final limestone footers.

2.15. (far right)
Calibration Channel:
Virginia Ball Seminar students[23] testing the affect.

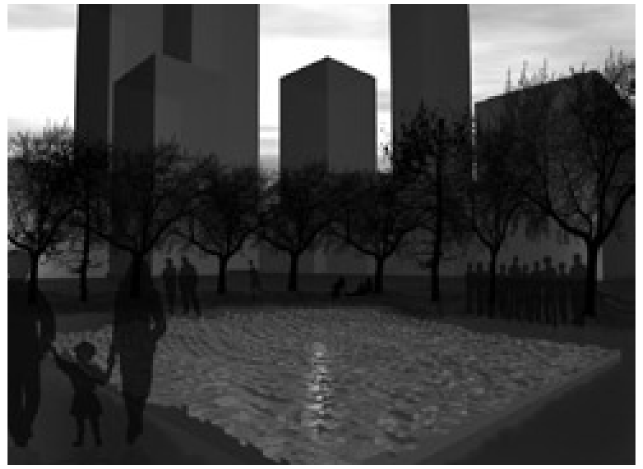
2.18.
SmartScrap project database of available limestone scraps arranged in an overlay configuration of final form.



2.16.
SmartScrap project rendering as wall panel system.



2.17.
SmartScrap project landscape installation.

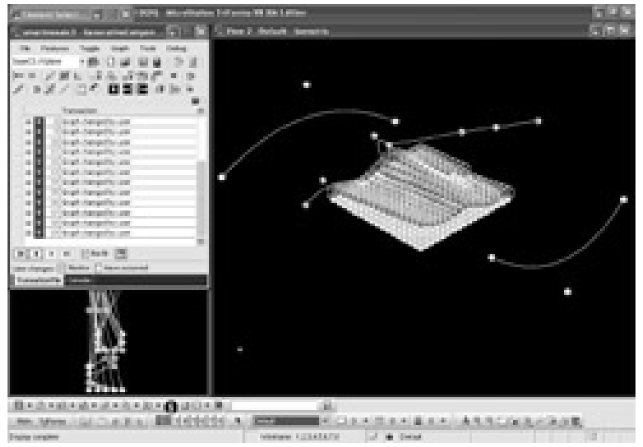


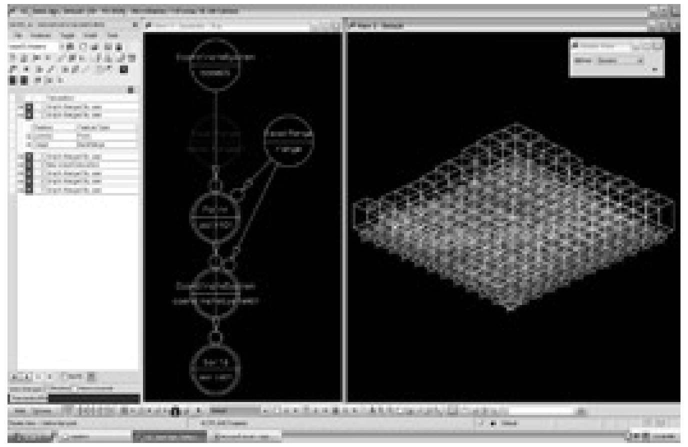
MATERIAL PROCESSING, MINIMIZING WASTE RESEARCH: SMARTSCRAP

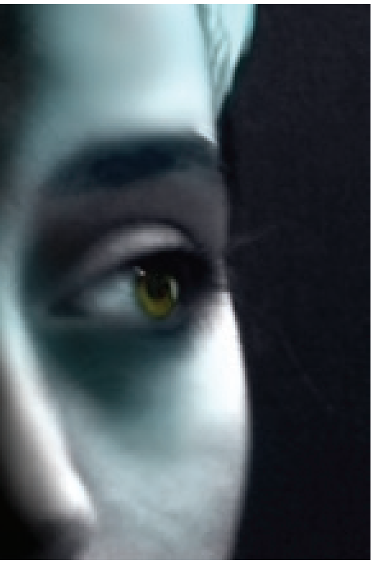
The *SmartScrap* project[24] engages the Indiana limestone industry with direct research and experimentation through the *Institute for Digital Fabrication* at *Ball State University*, by using a digital database of component pieces based on available sizes, shapes, and quantities of leftover/waste stone scrap material. Through a (developing) digital catalog of waste products from the Indiana limestone industry, computational means are deployed to supply the catalog information to parametric design models (figures 2.16 and 2.17) – thus connecting with the broader aim to effectively reuse typically wasted limestone material.

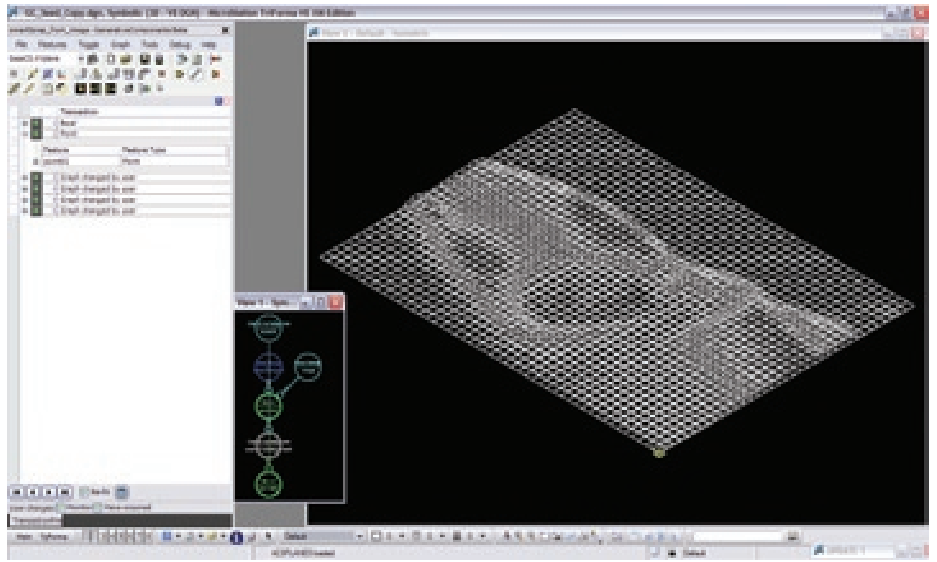
SmartMosaic is a pilot study within the *SmartScrap* project that came into existence by deploying associative modeling and scripting capabilities of *Generative Components* (the completion of the first prototype is scheduled for the summer of 2008). The principal idea behind the *SmartMosaic* is to select typical dimensional scraps with standard X and Y dimensions, but variable Z heights (resulting from standard slicing techniques in the limestone industry), and scan and record the shape and dimensional information about these scraps along with color and texture information into a scrap catalogue. These scrap stone pieces are labeled with a barcode for storage. An *Excel* database catalogue is made available to the parametric modeling system (figure 2.18). The parametric model allows the formal design visualization, where the finish of the façade surface is controlled with a *b-spline surface* (figures 2.19 and 2.20) or an image

2.19 and 2.20.
SmartMosaic:
project parametric façade controls.









2.22.
SmartMosaic:
image translation
into variable
heights.

2.21.
SmartMosaic:
selected image
for translation
and database
query.

data translation of pixel information is used to drive the surface condition (figures 2.21 and 2.22). During the design visualization process, a *VisualBasic* script queries the database for available pieces that could be plugged into the matrix based on the next-best-available technique. Once the finished field conditions with available stone scraps are established, barcoded pieces will be selected in the physical catalog and assembled to produce unique panels in the system.

The most significant outcome of *SmartScrap* project lies in the direct link between the university-based research center and the limestone industry that can lead to mutually beneficial techniques and ultimately an applicable building component, while simultaneously reducing the waste generated in fabrication (figure 2.23). The digital exchange of information is central to the development of this collaboration.

CONCLUSION: DESIGNING AND MAKING RELATIONS IN ARCHITECTURE

As the Machine Age gave way to the Digital Age,[25] key players have started to collaborate at earlier phases of the design process. As a result, considerably more time is devoted to the design phase to incorporate a more diverse range of considerations than was typically the case a mere decade ago. It is instructive to examine in contemporary architectural thinking the discourse – however positive or negative – during the time period when architecture debated the merits of returning to nostalgic notions of the *Arts and Crafts* movement and when *Art Nouveau* flourished, in light of the potentialities of realizing an industrialized architecture. Gropius correctly identified in the late 1940s the slipping role of the architect resulting from the disconnection with building practices:

2.23.
Indiana
Limestone
scrap yards.

> In the great periods of the past the architect was the "master of the crafts" or "master builder" who played a very prominent role within the whole production process of his time. But with the shift from crafts to industry [the architect] is no longer in this governing position.[26]

The implication of this historical position is instructive for our situation today. We must advocate for flexible structural conditions that enable fluid and direct information exchange in architecture, or be destined to repeat the mistakes of the past. We must gravitate towards technologically-driven design through greater attention to research, experimentation, and production considerations. Additionally, we must encourage a *total process of design-through-production* approach that engages all those involved in building design and production in a *collaborative evolution* of each project.

Even though invisible in the final built work, *information* is central to the realization of contemporary projects. Effective communication, sharing, manipulation, formation, decoding, recoding, and association of information are the primary transactions of architecture today. We are charged with the stewardship of this information as we develop a new set of architectural strategies and principles that relate to the spirit of our age.

NOTES

1 Ludwig Mies van der Rohe: "A Speech to IIT (1950)", in Philip Johnson, *Mies van der Rohe*, New York: Museum of Modern Art, 1953,

2 Umberto Eco (ed.), *History of Beauty*, New York: Rizzoli International Publications, 2004, p. 50: "Since in Plato's view the body is a dark cavern that imprisons the soul, the sight of the senses must be overcome by intellectual sight, which requires a knowledge of the dialectical arts, in other words philosophy. And so not everyone is able to grasp true Beauty. By way of compensation, art in the proper sense of the term is a false copy of true Beauty and as such is morally harmful to youth: better therefore to ban it from the schools, and substitute it with the Beauty of geometrical forms, based on proportion and a mathematical concept of the universe."

3 Kevin R. Klinger and Joshua Vermillion state: "Digital technology allowed us to design with different formal strategies, requiring new ways of thinking about architectural principles," in A. Angulo, J.R. Kos, and G. Vasquez de Velasco (eds.) "Visualizing the Operative and Analytic: Representing the Digital Fabrication Feedback Loop and Managing the Digital Exchange," *International Journal of Architecture and Computing*, vol. 4, no, 3, September 2006, pp. 79–97.

4 The directors of the *Emtech* program at the Architectural Association during this dissertation were Michael Weinstock and Michael Hensel, as well as studio master Achim Menges.

5 Lewis Mumford postulates that "By the sixth century, a new god had captured the Acropolis ... This new god was the polis itself; for the people who built these great temples were seized with an ecstasy of collective self-worship; they never noticed, perhaps, that it was their own image of order and beauty and wisdom that they set high upon a hill." (Lewis Mumford, *The City in History: Its Origins, Its Transformations, and Its Prospects*, New York: Harcourt, 1961, p. 146.

6 Negroponte offers: "I therefore propose that we, architects and computer scientists, take advantage of the professional iconoclasms that exist in our day – a day of evolutionary revolution; that we build machines equipped with at least those devices that humans employ to design. Let us build machines that can learn, can grope, and can fumble, machines that will be architectural partners, architecture machines." (Nicholas Negroponte, *The Architecture Machine*, Cambridge, MA: MIT Press, 1970, p. 121).

7 Ibid., p. 119.

8 Buckminster Fuller: "Man has been lacking in comprehensive disciplines and the developed ability to synthesize, essentially because of the bewildering arrays of complex behavior items of natural phenomena. Man shows synergetic re-genius inferior to Nature's regeneration," in "Total Thinking," in J. Meller (ed.), *The Buckminster Fuller Reader*, Worcester, and London: Trinity Press, 1970, p. 298.

9 Further discussion of digital principles can be found in Kevin R. Klinger: "Digital Futures, Defining Digital Discourse," in S. Carmena and R. Utges (eds.), *Digital Culture and Differentiation, Proceedings of the VII Congreso Sociedad Iberoamericana de Gráfica Digital (SIGraDi) 2003 Conference*, Rosario, Argentina, 2003.

10 See the influential essay by Phillip Bernstein entitled: "Integrated Practice: It's Not Just About the Technology," October 2005, available online at http://www.aia.org/aiarchitect/thisweek05/tw0930/tw0930bp_notjusttech.cfm

11 Kevin R. Klinger, "Retooling the Architecture Machine: Innovations of Digitally-Driven Architecture," in *Blueprints: Journal of the National Building Museum*, (published in conjunction with the *Tools of the Imagination* Exhibition, Washington D.C., 2005), vol. XXIII, no. 3, Summer 2005, pp. 8–12.

12 See Walter Gropius, "The Architect Within Our Industrial Society," in *Scope of Total Architecture*, New York: Collier Books, 1962, p. 74. "The architect of the future – if he wants to rise to the top again – will be forced by the trend of events to draw closer once more to the building production." In critique of the AIA 1949 convention addition to the mandatory rules of the Institute, Gropius offers: "I have very great doubts about the wisdom of this rule which would perpetuate the separation of design and construction. Instead we should try to find an organic reunification which would return us to the mastery of the know-how in building."
13 Based on an original plan by Thomas Stedman Whitwell entitled, "Design for a Community of 2000 Persons Founded upon a Principle Commended by Plato, Lord Bacon, and Sir Thomas More."
14 For an in-depth discussion of this issue, see the chapter by Branko Kolarevic in this book.
15 For a concise outline of these strategies, see Branko Kolarevic, "Digital Production," in B. Kolarevic (ed.), *Architecture in the Digital Age: Design and Manufacturing*, London: Spon Press, 2003, pp. 29–54.
16 See B. Kolarevic and A. Malkawi (eds.), *Performative Architecture: Beyond Instrumentality*, London: Spon Press, 2005.
17 The scale issue is fundamentally important; it has resulted in the creation of new firms, such as *designtoproduction* from Zurich, Switzerland, to provide this "scaling" service.
18 However, we run the risk that much of the process-oriented pragmatic problem-solving strategies get all the attention as we critique contemporary architecture – what end will this serve?
19 Makai Smith demonstrates in his chapter in this book the exacting yet flexible use of associative modeling strategies through his work with *Kreysler and Associates* and now more directly with *Bentley Systems*.
20 Kevin R. Klinger, "The ability to move directly from three-dimensional modeling to real three-dimensional output challenges the need for traditional means of representation such as plan, section, etc. ... This subjugation of traditional forms of representation and fabrication has serious implications for architectural design process and production," in H. Penttilä (ed.), "Making Digital Architecture: Historical, Formal, and Structural Implications of Computer Controlled Fabrication and Expressive Form," in *Architectural Information Management Conference, Proceedings of the Education in Computer Aided Architectural Design in Europe (eCAADe) 2001 Conference*, Helsinki, Finland, 2001.
21 For an in-depth examination of these techniques, refer to Kevin R. Klinger and Joshua Vermillion, "Visualizing the Operative and Analytic: Representing the Digital Fabrication Feedback Loop and Managing the Digital Exchange," *International Journal of Architecture and Computing,* vol. 4, no, 3, September 2006, pp. 79–97.
22 For more on these types of projects, visit http://www.materialsystems.org.
23 Student team: Robert Beach, Austin Durbin, Melissa Funkey, Jorie Garcia, Robert Horner (Project Lead), Anne Jeffs, Katie Marinaro, Christopher Peli, Josh Reitz, Jeremy Richmond, and Chelsea Wait.
24 The project is funded in part by the *Graham Foundation for Advanced Studies in the Fine Arts*.
25 The "digital age" used in this context inherently implies information exchange, more open knowledge sharing, and a new global economy.
26 Gropius goes on to suggest: "Today the architect is not the 'master of the building industry.' Deserted by the best craftsmen (who have gone into industry, toolmaking, testing and researching), he has continued thinking in terms of the old craft methods, pathetically unaware of the colossal impact of industrialization. The architect is in a very real danger of losing his grip in competition with the engineer, the scientist and the builder unless he adjusts his attitude and aims to meet the new situation." (Gropius, op. cit., p. 73)