# A Pedagogy of Interdependent Technologies:
## An Experimental Studio for Synthesizing Digital and Mechanical Processes

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Abstract: As computer technology is integrated into design curricula, significant shifts in pedagogy must be developed that acknowledge and incorporate alterations in teaching design process. This paper offers a critical analysis of the effects on design productivity of an experimental design studio that proposed and investigated an interdependent relationship of mechanical and digital technologies. A design studio was developed based on linking digital and physical technologies through systematic transformations of one technology into the other. Transformations were structured as a series of projects to test concepts of "making/building" in the form of abstracting/ making concrete, building/un-building, and un-making/making. Student permutations of the transforming operations revealed that design processes occurred as a mutuality, rather than an opposition, of the virtual and material. Design activity was revealed as a patterned flow of systematic formulations built on previous transformations. Key results of the studio indicated increased early development of conceptualization, increased refinement and integration of design issues throughout the project stages, and greater sensitivity to use of materials in a more holistic realization of concepts. Current curriculum structures that fragment technologies and subjugate ideas of craft, technology, and ideation into separate courses or educational issues, do so at the expense of substantive design refinement. The experimental studio of interdependent technologies offers digital and mechanical technologies as an holistic feature of design processes, thus indicating a greater integration of "support" courses into design studio and implicating an increased role of "hands-on constructing" such as that in wood/metal shops.

The development of design programs entering the 21st century is being challenged by the changes in our culture brought about by the computer and has placed the education of architects and designers at a crossroads. The Bauhaus origins of design studio experience--free exploration of material qualities and mechanical technologies--seems to be supplanted by implementations of "seductive" digitally manipulated pictorial representations. Displacement of the material with the virtual is at the center of many discussions of design process. Discussions about whether the computer represents the physical world as well as traditional methods or whether computation is faster and more economical than traditional processes of design, fragment the understanding of the tools and processes of architectural education. This discourse can place emphasis on irreconcilable oppositions. In light of this, a theoretical model used to link the physical and the digital in the context of architectural design process is needed as a more fundamental component of design education. The model advanced in this paper presupposes that links exist between the mechanical and the digital. Defining these links as processes involved in moving to and from differing poles of duality can serve to build greater understanding of design processes and the resulting products. Building formal relationships between the physical (atoms) and the virtual (bits) can move the design process toward a more inclusive and holistic design experience.

The relationship between digital representations and physical essences is divided. A perceived "non" relationship between the "virtual" and the "material" is defined by many of the educational and professional users of digital and mechanical technologies for design professions. Often in design education, mechanical "shop" technologies and digital "CAD" technologies are marginalized into separate, "specialized" studios with little formal relation being made to holistic design processes. Beyond the obvious differences and/or oppositions between the "real world" and the "virtual world" are relationships that can lead to integrations of digital representations and material essences in architecture. For example, the expanding use of digital forms of representation, dependent as they are on modes of abstraction, necessitates even greater inquiries into the physical essence of space and the subsequent "realness" of material qualities which can be (re)discovered through *acts of making*. Having a basis in making things (whether as material or as mechanical explorations or as models, mock-ups, and prototypes), once a primary form of inquiry in design activity, is increasingly viewed as anathema to digital representation. To the contrary, operations in physical and virtual realms have a mutual basis in "acts of constructing" that are complementary, thus suggesting operation as an integration of processes.

**A Model of Integration**

This inquiry stands on a presupposition that acts of designing involve a dialogue between representations and the intentional manipulation of physical substance. Both physical and digital processes involve a systematic manipulation of solids in space. The geometric / Euclidean mathematics used in computer modeling applications are based on the presentation of order within the physical substances of our environment. Geometries that are imperative in understanding and experiencing the world are implicit in the computer modeling application, thus providing the basis for a link of experience and representation. A digital representation can be characterized as a *synthetic likeness* created from a process using quantified bits of information originating from a presupposed *physical essence*. Digital modeling can be characterized as a movement toward abstraction--a "building" of a virtual construct (the digital image) originating in rules of physical geometry. Mechanical construction is movement toward the concrete--where fabrication acts as a search for formulations of what is possible in the character of material qualities.

The assumed opposition between digital and material can be restated in terms of an operative model of interdependence--where the digital is a transformation of the material and the material a transformation of the digital. Synthetic processes are opposed to mechanical processes. "Bits" are opposed to "atoms." Abstraction is opposed to the concrete. Transformations from digital to material and material to virtual occur as cyclical processes, analogous to the practice of design, where we move repeatedly from the hypothetical or fictive (digital) to the palpable and concrete (material). In design studio education where enlightenment is a goal, our contention is that repeated cycling through processes of digital abstracting and making concrete can enable a basis for design decision-making that provides a material ground for representations.

The proposed model of integrated virtual and physical processes is a dynamic model of transformations, essentially, movement from possibility to probability. Transforming the material to the virtual can be characterized as an abstract process of transforming tangible substance into representations. (See figure 1.)

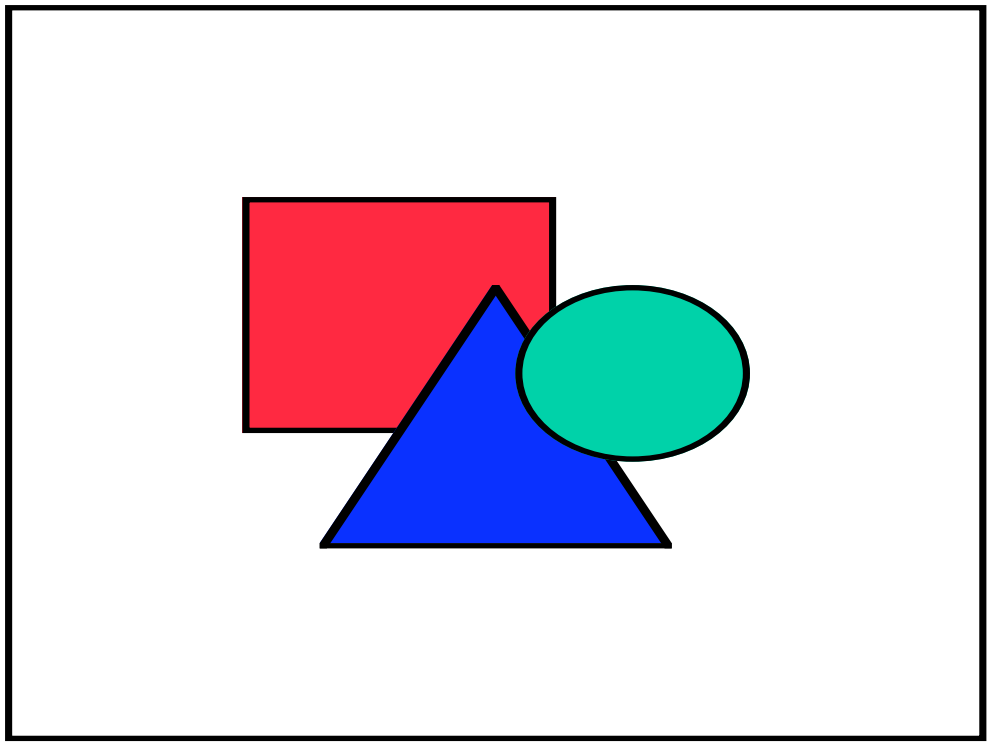

*Figure 1. Model of Integration.*

*Un-building/building* can be characterized as utilizing existing and already structured mechanisms of synthesis to systematically disassemble a physical whole and then build it as a possible digital representation of those systems. Conversely, transformation of the digital to the material can be characterized as movement toward the concrete, substantiating synthetic images in a palpable reality. *Unmaking/making*, as a process, is a mechanism of synthesis that is discovered in an analytic deconstruction of a "synthetic likeness" that is then used to give probable concrete existence to its propositional nature. In practice, the model functions more as a referential structure for dynamic interaction between all parts of the model.

In the context of design experience, systematically linking abstracting and making concrete reveals a continuity in process. Digital production of images as a representation of a designed environment is an abstraction from the concrete. As the tangible, concrete world is the intentional goal of the design process. Representation is impossible without physical substance, and without representation, one cannot develop intentionally in physical substance.

While the representative technologies of the virtual and material may be mutually exclusive, their processes are inherently integrating. Not integrating digital and material technologies can lead to displacement of original presence with a valorization of synthetic likeness. Digital technologies may aid in visualization but the images may appear so complete that any role of making has been reduced as an active part of the design process, creating images that can exist only in a virtual environment. Likewise, processes of design that integrate synthetic operations with the activities necessary to the actual making of the physical environment achieve a consciousness of process enhancing product. Typically, design studio curricula present mechanical and digital technologies as mutually exclusive entities. Placing emphasis on one aspect of the model without relation to the whole can mislead the intention of the design process and disrupt experience of the creation of built environments. Defining these technologies as *concepts of making/building* within the same context can more readily reveal design processes as dynamic mechanisms of transformation.

**Design Studio Utilizing the Model of Transformations**

A design studio was developed as a test of the model. It was a semester experience that provided the students with a structured, yet variable, experience of both the digital and the physical. The studio began with a formal experience of the perceived dualities and advanced to an integrated methodology as represented in the model. The studio involved both third and fourth year students, all of whom had previous foundational experiences with digital modeling and with working materials.

**Phase One**

Design exercises that respectively maximized physical or digital processes were presented separately to two groups of students in small-scale design projects. Both projects contained the same programmatic requirements. Physical investigations included the sequential construction of large-scale models in differing materials, exploring the physical and formal implications of each successive material transformation. Digital design process experiences emphasized the nature of the order of form, space, and light, and the ability to quickly manipulate point of view. After three weeks in either the digital or material mode, students with a digital project were required to transform the digital into the material and those with a material project, the material into the digital. Processes of transformation, abstracting or making concrete, were the central issue of Phase One. The transformation between physical and digital occurred only once. Phase Two emphasized further transformations adding repetition and choice.

**Phase Two**

The second phase developed from the discoveries about modal transformation in design process made in the first phase. The scale of the project was expanded and the systematic context of transformations of digital and physical were expanded into a scenario allowing selection of mode (digital or physical) and the sequence through five separate transformations, each more successively detailed. Each student selected the mode they felt was natural to the design process at each stage. Students completed a minimum of two material and digital explorations. Exercises included options for either physical and/or digital modeling as well as the graphic representation and construction of prototype full-scale details. This phase emphasized the relationship between the digital and physical with more intention to unification and synthesis as the project developed through conceptual, schematic, and detail.

Phase Two was the principle test of the model of transformations in the design studio. Development toward the abstract or to the concrete was the choice of each student. This emphasized independent process and allowed them to decide the flow of transformations as benefiting their own design process. Our discovery was that students reconstructed the model from a circular form to a web--crossing to the process needed at the moment. This is key to how designers work. Any path within the *conceptual framework* of the model is feasible.

**Phase Three**

Emphasis of the studio shifts from a primarily developmental mode in Phase Two, to include the representation of design in Phase Three. The authors acknowledge the idea of repeated shifting from creation to representation is a limited view. Aspects of representation are important in Phase Two and designing will continue in Phase Three. Students began the phase by developing a set of goals for a set of combined digital/physical representations of the

design utilizing results of Phase Two. Students were given complete freedom of choice to use any sets of processes investigated in the previous two phases or add processes not yet investigated in the studio. Phase three allowed transformation of the model with respect to design intentions--suggesting modes of design outside the model of transformations, but still incorporating ideas of the relation between digital and physical modes of operation. This was especially suggestive of forms of representation where an interaction of the digital and physical could enhance the communication of the ideas of their proposal.

**Findings for a Model of Studio Education**

**Advantages**

Students worked better and were more enthusiastic with deadlines where the purpose was to make "only" a single transformation from material to digital or visa versa. What they did not realize was that the transformation caused them to make more decisions than they were otherwise aware of. Transforming from one system to the other involved shifting the process of building the design according to the media - a maneuver which forces rethinking sometimes the entire concept (e.g., could not build out of wire mesh the same way as Bristol board functioned).

Design projects received many more transformations than is typical; the ability to impose an external limit on the inclusive nature of the transformation appealed to the students as a kind of freedom. They did not need (nor was it possible) to solve every aspect of the design with each transformation phase, although emphasis on refinement actually was significantly greater.

Design projects expressed great integration between what the material offers and the digital offers to design decision-making. Students forced transformations between digital and material early in the project but in the latter half of the project they were willingly and frequently shifting between modes as a way of making quick progress or extricating themselves from difficult moments of pause. Integration of design ideas with pragmatic issues and material and lighting decisions seemed more natural to the students when applied within an "outside" methodology of transformation.

Students expressed greater independence of creativity and decision-making; model transformations allowed flexibility in design undertakings and greater growth as a designer on the part of the students through a greater emphasis on an awareness of design processes that may have been implicit. Students expressed more excitement and energy devoted to each successive exercise and there were less feelings of dread for the work due to compartmentalization of phases.

Students can have an either/or mentality to material versus digital media; sometimes they feel both is redundant. No students indicated an attitude that the transformations seemed redundant or repetitive of work as they made transformations from mode to mode, indicating that each phase was progressive. This model explicates the complimentary nature of digital and physical modes as modifiers of the other.

**Limitations**

Some students had a tendency to incorporate expedience as one of the factors in choosing the sequence of digital or physical modes. At times expedience was used to make a transformation instead of diligence, but occurred rarely. The model making experience can also be manipulated as a crutch and the methodology can too easily be manipulated for economizing time rather than optimizing design decision-making. As this studio was used as a test of the application of the model, we were also testing is efficacy with student initiative. Since the process involved giving the students more choice this was unavoidable; however it was only in one instance problematic.

There were limitations of technology. Only computer modeling applications were used, along with image processing applications such as Photoshop. Next time this method is used the authors will include virtual reality and animation applications. The physical/material transformations were primarily model making. The authors need to incorporate more extensive shop activities, especially presenting a greater variety of material alternatives (i.e., actual material mock-ups).

**Conclusions - Speculations**

As this application of the model to a design studio was an initial attempt, its use suggests that a more research outcome-based application will yield data about the specific manner that students used to navigate the choices between modes, and how these choices more specifically inform design decision-making and refinements. Its continued use will undoubtedly lead to amplifications of technique for the use of digital methods modified by material and the reverse. Our students found the potential for modifications provocative but just approached the beginnings of possibility. Figure 2 illustrates the refined model of integration. It is altered to communicate how students jumped between different modes of transformation.

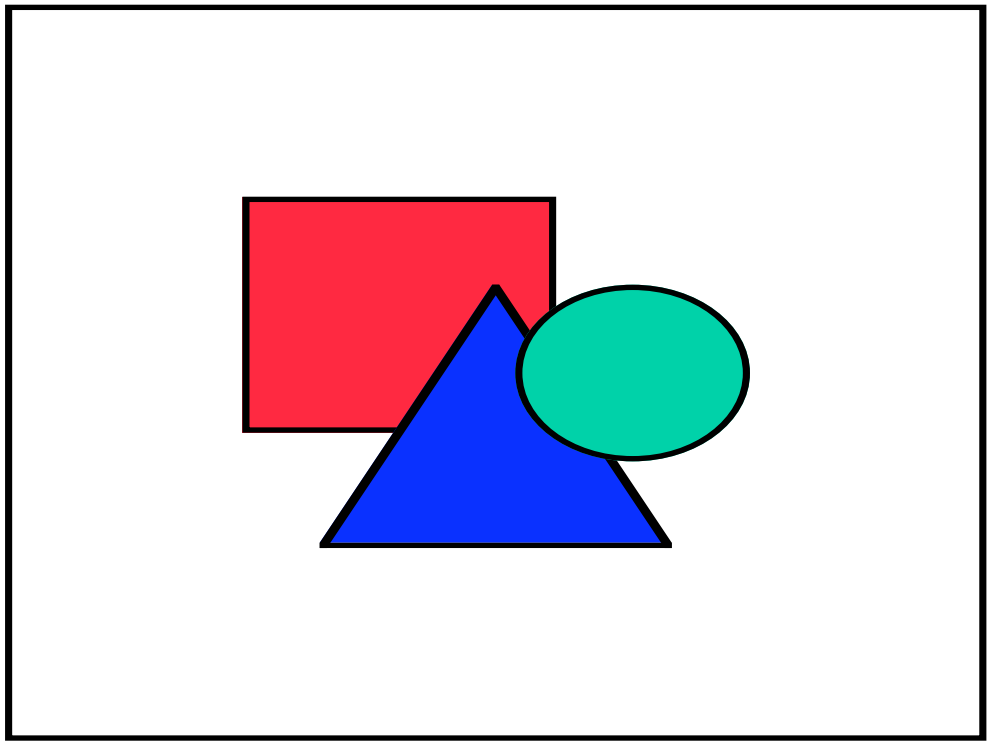

*Figure 2. Refined Model of Integration.*

Digital modeling and rendering applications offer a form and methodology capable of giving designers increased abilities to model, visualize, and communicate their proposals while threatening to reduce connection to methods and techniques necessarily rooted in physical essences. Our model has attempted to demonstrate that this need not be inevitable.

Computerized abstractions offer the opportunity to (re)integrate the actual "stuff" of buildings--materials and light and their perception through occupancy. Using a computer modeling program (such as Form Z) is an act of building directly analogous in method to laying up bricks one by one, depending, as both methods do, on being informed by experience and knowledge of physical qualities. The ability to abstract material qualities into other forms, particularly a mathematical form, is a methodology formed of a natural interconnectedness between digital and material technologies. In appearance, this connection obscures the essential nature of material qualities, but as a holistic process it reveals a deeper refinement of material presence. The perceived opposition between digital and mechanical technologies is a traducement, and recognizing this is a step toward design curricula aimed at (re)unifying designing and making.

Questions are raised for design education and the profession of architecture at large. If digital technologies are replacing and expanding a system of existing abstract representation, how will ideas and experiences of material essences be explored? Will the design processes of the future incorporate material essences as directly as we seem to be currently embracing digital representations? The proposed model links digital and mechanical technologies in such a way that they cannot be separated. The model suggests that the traditional design studio be re-investigated in a manner that acknowledges the relationship between material essences and digital representations. As computers enter the studio and displace the drafting table, how will technologies of material essence be part of the educational experience? The studio that incorporates digital technologies may be most effective in combination with an already existing wood shop, metal shop, and foundry.

To strengthen future educational experiences students in the next integrated studio will be in the second year of design education. The move toward an earlier exploration of the relationship between the material and virtual may provide the student a more holistic understanding of design processes. Students will potentially have less of a fragmented experience between the physical and virtual environments if provided the opportunity to explore the virtual and material in a simultaneous investigation early in design education. More effort will be placed on the critical understanding on the moment of transformation, as well as more shop intensive material investigations. More "realistic" material and detail prototypes will be part of the next studio. It is an objective of the next studio for students to draw less distinctions between the differences of the material and virtual, and to learn to move as needed from one environment to another so they may have more creative freedom. Long term goals include more progressive investigations using rapid prototyping and more effective methods of entering data into computers from three dimensional material models. It is the goal of the studio to make the transformations between the virtual and material as "natural" and eventually transparent as possible.

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