Craft and Digital Consequences

Micro-Hybrid Explorations at (Full) Scale

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This paper presents a comprehensive project-based research investigation that uses both drawing and modeling to challenge conventional design space. Situated at the University of Kentucky-College of Design Applied Computation Center (CoDACC) in Lexington, KY, this independent undergraduate research project reveals an immersive framework that develops, evaluates, and assesses both graphic and three-dimensional information at full scale. This research provides a framework that seamlessly negotiates analog and digital means of communication and prototyping. This paper outlines the micro-hybrid design process to frame topics germane to today's increasingly complex built environment. The paper also includes the micro-hybrid decision-making matrix and discusses the evaluation of the produced artifacts. The research demonstrates how the micro-hybrid process can reveal both the craft and consequences related to design experimentation and construction. Further, the micro-hybrid process has been shown to deepen a student’s understanding of the composition of materials and a student’s awareness of forces and structural loads, which in turn has produced a deeper appreciation for the principles of structures and an improved mastery of manufacturing jointing details.

Keywords: Digital, Pedagogy, Fabrication, Experimentation, Simulation

INTRODUCTION

Today, the infusion of design thinking methodologies in combination with simple tools, sophisticated machinery, and both natural and machine-made materials enable design students to rapidly explore and experiment in ways that just five years ago were not economically possible. This paper presents a strategy for leveraging this enhanced design fluidity by iteratively producing a series of multi-dimensional design artifacts (drawings, models, visualizations, and simulations) that explore phenomenological visual registers through built form.

This research builds upon an established architectural design process, which has typically been used as a platform for integrating new tools, as a way of extending both unexpected and unknown creativity. As Sylvia Lavin states in her interview with the Los Angeles Forum, “Increasingly, larger amounts of
creative resources are being put into producing new tools and concepts that are designed not to make things, but to amplify the creative capacities of others” (Lavin, 2015). Architecture is driven by the synthesis and integration of these new tools. This has led this research to produce an intuitive and inspirational way of thinking and making referred to as the micro-hybrid. The micro-hybrid is characterized as a process-driven resultant that involves both physically and digitally produced volumes in response to operative considerations. These responses expose digital consequences that inform subsequent iterations. The notion of considering digital technology and using computer aided design tools in this way, is viewed as a way of extending the tenets of design thinking into architecture. In his book, *Animate Form*, Greg Lynn argues: “Traditionally, in architecture, the abstract space of design is conceived as an ideal neutral space of Cartesian coordinates. In other design fields, however, design space is conceived as an environment of force and motion rather than as a neutral vacuum” (Lynn, 1999). It is within this creative process that the micro-hybrid aligns with Lynn’s use of different software and hardware platforms to increase a student’s understanding of spline, blob, and movement and ultimately their relationship to construction and design.

**Guiding Questions**

This collaborative research project centers on three core topical areas: process and parametric embodiment, rigorous physical and digital integration, and situated decision-making. From this context, three primary research questions emerge:

- How can the proposed micro-hybrid feedback loop model a workflow that results in a hybridized design research and challenges the traditional conventions of drawing, rapid prototyping and additive/subtractive fabrication methods?
- How can the digital design experience be more connected to the tangible and physical outcomes of the design process?
- Why is the micro-hybrid technique a necessary component of a design process in education and practice today?

**Informal Observations**

This research stems from a current frustration with today’s prescribed and limited design studio curriculum that does not keep pace with industry innovations and focuses on generating details of traditional architecture, rather than using the detail as a formative departure point for design. This research builds upon the current exhibition at Sci-ARC entitled **Close-Up**, that showcased modern methods of designing as a mechanism for advancing architectural knowledge. The intent of this research is to take design methods to another level and to involve the full capacity of opportunities that digital tools currently allow, while also framing design education as an ever-changing pedagogical model. This enhanced capacity involves simulation, computation, rapid-prototyping and iterations using digital fabrication techniques like 3D printers, CNC milling, and robotic assembly to build form.

**Methodology**

This paper presents five case studies that probe two intrinsically linked categories: the methods of making and the means of simulation. With an end goal of advancing building technologies using both theory and hands-on investigation, the micro-hybrid process advances research in the domain of abstracting craft while adding new knowledge to understanding the impact on learning. In design self-efficacy (DSE) research studies conducted by Dr. Gregory Luhan at the University of Kansas, Texas A&M University, and the University of Kentucky, these areas are shown to significantly deepen and positively impact the study and design architecture (Luhan, 2016). As part of a larger typological exploration, this research simultaneously works across three scales of hybridization: the micro-hybrid, the mild-hybrid, and the full-hybrid. While this research focuses specifically on the micro-hybrid, emergent trends revealed through the study point towards scalar implications. The micro-
hybrid reveals simple, intuitive mechanisms that control functions associated with the means of making and the simulation-based tools used to examine form. In this sense, the boundaries between the drawing and the model process narrow, closing the gap between representation and reality.

Neil Spiller when discussing the new generation of architects says, “Those architects featured in the issue agree that the four dimensions of architecture (three spatial dimensions and time) are not enough for a new century; each is grasping for a new fifth dimension in their work, and developing new protocols of drawing to discover it” (Spiller, 2013). On the other hand, while analyzing Neil Denari’s 1989 project for Tokyo International Forum, in his book *Drawing the motive force of architecture*, Peter Cook brings up the comparison between different types of drawing: information drawing and art drawing. “This last, rather loose epithet is often used in architectural circles to describe a drawing that may be used by the author for exhibitions and books, but where the “useful” version has already become part of the working process” (Cook, 2014). After evaluating these two ideas, the search for a fifth dimension in drawing is responded to by the materiality and color used in the representation of micro-hybrid as well as the combination of informative and artist drawings described by Cook. This representation correlates to the actuality of the model material, and the necessity to designate difference between the physical and digital realms of the project. Beyond this fifth dimension, the micro-hybrid looks at the possibilities of “drawing” qualities. As Bryan and Grosman describe the drawing is another layer to hybridize a design medium as a result of the dialogue between digital and physical modeling. “Drawings are explorations of time; models are exploration of space. The digital model as traditionally understood has no advantage over the physical model except for expediency. The digital drawing, on the other hand, creates new opportunities” (Bryan and Grosman, 2016).

The analog methodologies used in this study include: precise measuring, drill pressing, belt sanding, Dremel sanding, chiseling, and oil coating. These methodologies align with the designer’s intuition whereas the digital explorations are situated as structured responses that increase in complexity as the project shifts in scale or are used in simulations of gravity, weight, and material plasticity. These other layers of information seems to be necessary for maintaining the project’s relationship with architecture as Pallasmaa describes, “… in my view, architecture turns into mere formalist visual aesthetics when it departs from its originary motives of domesticating space and time for human occupation through distinct primal encounters, such as the four elements, gravity, verticality and horizontality, as well as the metaphoric representation of the act of construction” (Pallasmaa, 2012).

**Research Design**

The formal process for developing the micro-hybrid is rigorous and reflective. The procedural experiments begins with creating a primitive solid. For the initial iterations, a cube is used.

This was followed by establishing an operative condition assigned to the cube and used to determine the project “cost” - a numeric value or price point for the micro-hybrid. Subsequent gestural drawings were generated to determine the “loose fit” of the project. The impact of this process led to the development of the digital model and machine-made artifact. The digital model was developed from guidelines that emerged from the gestural drawing. The models use geometric primitives in randomized, hybridized or ordered ways. Both digital and physical models are edited in digital space and then reprinted. The digital print was then analyzed, evaluated, and assessed by the design team. The team evaluated each artifact based upon the conceptual elements of each of the operative micro-hybrid conditions. These elements are measured against: initial orientation of the primitive, the relationship to the ground plane, and the apparent recognition of the operative condition. If conceptual purity is determined successful, the artifact is reflected upon. If conceptual fail-
ure is determined, the artifacts were re-edited in real time and corrected by hand. A fitness test verified the machine-made object’s ability to plug into the core of the primitive. This stage revealed issues related to play, tolerance, and looseness of fit. The end result a successfully completed project, includes the possibility for future improvement, but subsequent iterations were beyond the scope of this research study.

**Limitations and Delimitations**

The primary limitation of this study conducted in the spring 2017 semester was the modest number of iterations and students involved in the research. Data collection was limited to students who participated in the study.

The limitations of the study related to the micro-hybrid were:

- Since this was not a controlled experiment, results may have been affected by outside influences.
- Because the student participants self-reported data, the study was limited to the student’s unverified perspectives.

In spite of these limitations, every possible effort was made to design the research in a way that maximizes the potential contribution of the study’s findings about how the micro-hybrid process is registered in architectural design studio education.

The delimitations of the micro-hybrid research design include a focus on both undergraduate and graduate architectural design research. The results of this study could be generalized to teaching methods in courses that involve research-driven, project-based learning such as design studios of all types. In further studies, generalizability will focus on the use of the micro-hybrid decision-making matrix.

**Definition of Terms**

- Operative Conditions - The input which is a relational driver between the individual parts, their orientation and their influence on the architectural composition.
- Digital Consequences - The design method and thought process, including the phenomenological and physically observed tolerances, that inform the resultant product (architectural artifact).
- Micro-hybrid - The scale of the object.
- Mild-hybrid - The scale of the installation.
- Full-hybrid - The scale of the building.
- Primitives Forms - The initial geometric input for the process: cube, sphere, torus, pyramid, cylinder, and cone.
- Subtractive Core - The connection method of the natural and machine made materials (tangential plane, incised plane, and cored plane).
- Gestural Drawing - A digital drawing to visualize the operative conditions as a 2D architectural composition.
- Parasitical Geometrical Relationship: The use of the machine-made form to directly host to the primitive’s cores.
- Randomized Digital Response - Assigning geometric primitives randomly to create a massing.
- Ordered Digital Response - Assigning geometric primitives in order and following a sequence, to create a rhythmic massing.
- Hybridized Digital Response - Assigning geometric primitives both in order and randomized to create a massing flow.
- Purity assessment - Comparing the final tangible outcome with the initial concepts of the Operative condition and Gestural Drawing.
- Fitness test - Checking the tolerance between digital and manual fabrication methods, and how the natural and machine made materials fit together.

**THE MICRO-HYBRID**

The term micro-hybrid has been borrowed from the automotive industry. In the automotive industry, a hybrid car switches between the use of battery and combustion engine. The choice of one energy source or another is based on a variety of factors including the environmental conditions, auto-
motive speed, and necessity for acceleration, etc. In the architectural design context, the micro-hybrid, switches between digital and physical design and fabrication platforms as a way of increasing the intellectual design performance. Rooted in the processes of design-thinking and fabrication, the key drivers of the micro-hybrid design process center on the efficiency and rigor of making at the regional and global scale whereby registering the micro- and macro-factors that influence the decision-making process, including: pragmatic functions of form, aesthetic, a structure’s response to force, and orientation to local context (Figure 1).

The micro-hybrid process is an iterative twelve step process. The micro-hybrid process includes:

1. Manufacturing a primitive geometric form using natural materials;
2. Defining physical subtractive cores as connection methods;
3. Developing a digital model of the primitive geometric form;
4. Establishing an idea-based typological framework that can be modeled;
5. Orienting the digital model to the framework;
6. Generating a 3-dimensional gestural drawing;
7. Initiating the digital design of the typological addition;
8. Adjusting the physical design of the typological addition through the integration of machine-made materials;
9. Conducting an alignment and fitness test;
10. Modifying the tangible outcomes to meet the evaluation requirements (feedback loop);
11. Photo-documenting the final artifacts; and
12. Reflecting on the design process and lessons-learned.

As part of the micro-hybrid research, these twelve steps were tested against five operational conditions ranging from implied adjacencies, direct connections, surface reliefs, balance, and cantilevered projections. The resultant product was a compositional strategy or spatial dialogue that adhered to or responds to the material selection (natural or machine-made) and the corresponding detailed joinery (Figure 3).

Referring to architecture as a spatial “dialogue”, in relation/response to form, forces, and motion, has started a new design thinking about the architectural design process and how it can be driven to maximize the design possibilities. Tom Wiscombe, whose work can be described as a cohesive combination of parts that create an object-oriented architecture, uses the term “worlds” to explain his work, not as an extension of “world” or “nature” but rather, as a new way of thinking about architectural design. Wiscombe contends that architecture must be viewed as an individual object not only in relation to its context, as a field of forces, information, interaction and in a variety of forms and scales, but as an independent “world” (object) that has its own relations, connections inside and out. Wiscombe introduces the idea of “loose-fit” design, as he borrows the theoretical physics vocabulary: “I’m definitely attracted to idea of things existing discreetly but signaling to one another without touching or fusing together - this provides the basis for a new, non-literal coherence of things while also avoiding superposition and collage” (Wiscombe, 2016).
Whether analog or digital, this research continues to examine the impact of gravity, weight, materiality, aperture, and fluidity on the produced artifacts and the means used to assess the fitness of its outcomes. In each case study, the students’ work the designs to failure to iteratively refine the resulting artifacts. This design research drives investigations which act as a result of an innovative and rigorous design methodology and pedagogical structure that tests and calibrates both additive and subtractive processes. In addition to the artifact, the consequences of the selected tool and the digital means used to evaluate each study are viewed as enabling devices that inform the design solution’s construction means and methods. This research produced results that demonstrate the impact of the decision-making process. The consequences of these actions are presented as a rubric-based decision matrix. This matrix enables the design team to evaluate the fitness and the alignment of each design iteration to a given set of criteria. Information obtained through the decision tree is subsequently fed back into the model so that additional investigations can be studied. The analog methodologies used in the study align with the intuitive design process, whereas the digital explorations have demonstrated a more structured response that aligns more with project complexity and material plasticity.

**Micro-hybrid Adjacency**

This prototype examines dead-load as an operative condition for which the relational driver is between the individual parts and parametric inputs. The design process starts in analogue mode with the selection of a cube as a primitive geometric form. As part of the physical design modifications, one core is physically assigned to the form as the first means of design modification. This core allows for the adjacent connection of the natural and machine made objects. The first set of modifications informed the decision process of primitive orientation as a flat relationship to a resting plane.

The starting point for the continued design process centers on digitally collected information that is gathered from the initial primitive and its modification. Based upon this information, a gestural drawing is made and serves as a guide for decision-making. This parasitical geometric relationship also serves as

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<tr>
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<th>Connection</th>
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**Figure 2**

OPERATIVE CONDITION SYNOPSIS, Synopsis of decisions made for each operative condition - relative to the physical, digital, and evaluative properties of the process.
design guidelines for connecting the individual elements (Figure 2).

**Micro-hybrid_Connection**

This prototype examines “connection” by linking two separate primitive forms. The orientation of the two forms were flat on a ground plane, but rotated so that the faces of the forms were not parallel to each other. Considering the connective nature of this operative condition, the gestural drawing produced a bridge-like structure between the two forms. Akin to the previously described adjacency micro-hybrid, the digital response involved randomized geometric forms that maintain a consistent formal language. The digital fabrication failed to produce the desired bridge outcome (Figure 4).

Using the information obtained from the physical modification of the initial primitive and the corresponding gestural drawing, the design combines information from the digital realm with the digitally scanned versions of the initial primitive. As a critical next step, the randomized geometric primitives are added to the digital model. This insertion is in direct response to the orientation of the initial primitive form, its subtracted core and the aforementioned parasitical geometric guidelines. Upon completing the design, the digital fabrication process begins. This process uses machine made materials to produce a 3D printed object. The physical translation of the digital design goes through validation tests that produce results that either completing the process or putting the gathered data back into the feedback loop to produce another iteration. This micro-hybrid considers the medium shift (digital/physical) as a minor digitally fabricated addition that adheres to the tenets of the initial primitive. As a result, it stays connected to the main concept of adjacency. As the last step in the process, the tolerance between the two fabrication methods and scanning are measured. The core of the main primitive is modified to fit the 3D printed part and close the loop of physical, digital and physical design/fabrication process (Figure 3).

The digital fabrication method used for this study is a 3D printer using printed polycaprolactone and a dissolvable plastic for structural supports. Since this printer works by layering, the object’s orientation to the printer bed is imperative as it would maintain contours that were necessary to structure the print. This contouring was unforeseen and unfortunately led to the failure of the aspired fabrication. Upon examination, the attempt to create long spans of digital material not only induces issues related to fabrication, but also results in extensive amounts of structure material that produced cost overruns. While the fabrication failed, the purity assessment demonstrated the possibility of a potential adjustment that could re-instate the connection-based operative condition. An additional study was completed. This new study re-oriented the primitive,
integrating color between the disconnected forms. The subsequent fitness test proved to be acceptable (Figure 5).

**Micro-hybrid_Surface Relief**  
The “surface relief” operative condition explores the use of responsive directionality on digital and physical procedures. Since the cube held no relationship to the operative condition, it was oriented flat. The digital process deployed on this prototype integrated a random response that brought directionality to the micro-hybrid’s planar surfaces (Figure 5).

The gestural drawings engraved on the planar surfaces were etched onto the artifact using a laser engraver. The transition from the digital representation to the final artifact failed to take into account the primitive’s materiality. The engraving was intended to provide a direct response to the gestural drawings, however its visibility was varied due to the perceived direction (Figure 5).

The artifact ailed the purity assessment test. However, the surface relief micro-hybrid passed the fitness test when controlling for object smoothness.

**Micro-hybrid_Balance**  
This operative condition uses balance to drive the iterative conceptual development. The process starts with modifying a cube and uses two nested cores as physical modifiers. This initial concept allows the orientation of the primitive to sit on its corner, thus challenging the idea of equivalency that is apparent through the remaining design process. As the first digital response, the gestural drawing re-balances the composition by illustrating how the existing digital primitive could be modified aesthetically. Drawing reinforces the initial operative concept in a more visible/tangible way and guides the hybridized digital process (Figure 6).

The digital method of fabrication and its contour language was integrated into the decision-making process as a new aesthetic-based parameter. Although the final 3D printed part was characterized as “chunky”, it produced a balanced visual composition (Figure 6). Similar to Micro-hybrid_Adjacency, the physically fabricated primitive was modified to perfectly fit the 3D printed part, thus closing the (digital/analog) fabrication loop.

**Micro-hybrid_Cantilever**  
This operative condition explores “cantilever” by liberating the primitive from the ground plane. The design projects the artifact into the air, thus disallowing a parallel relationship between the ground plane and the faces of the primitive form. This prototype considers the cube’s liberation from the ground as the increased dynamism of the physical primitive (Figure 7).

The response uses iterative simulation-driven digital models and knowledge gained from the previous Micro-hybrids. The considerations taken from all previous primitive iterations and increase in size
compared to the previous micro-hybrids. When these considerations were evaluated, the price point exceeded the original projections of the artifact. What was learned from this form of failure was how the iterative workflow produced the digital consequences that brought about unintended consequences to bear upon the project. For instance, the influence on the set price points for the artifact, became a factor in the editing process. In addition, it challenged the ability to achieve conceptual purity. The resultant did maintain purity of the intended cantilever, but sacrificed formal aesthetics (Figure 7).

Figure 7
CANTILEVER CASE STUDY | DRAWING and MODEL, An axonometric drawing of the artifact shows the dynamic usage of the primitive cube. The model photograph presents the resulting artifact, as it allows for an enhanced visibility of multiple projections within the composition.

RESULTS
This research points towards regenerative, supportive, adaptive, and assistive methodologies that could expand the micro-hybrid research into the mild- and full-hybrid domains. These domains leverage this project’s design decision-tree enabling a deeper alignment with increased design efficiency, operative control, power generation and smart design processes. The micro-hybrid exploration uses the drawing as an operative model. In this particular case, it is simultaneously both the detail and the abstraction in which a process of emergent articulate how drawings become form. Working across scales the metric method of working links the learning process to the crafting process, exposing the consequences of continual translation and embedding them in the process.

The primary findings, implications, and contribution of the study include: a micro-hybrid process informed a workflow that breaks the constraints of modern pedagogy thus allowing the designer to practice more intuitively. The micro-hybrid introduced craft and representation as codependent elements that directly focused on the relationship between making and simulation. This resulted in allowing the architect to inform design through variations in dimension and scale and see firsthand the consequences of dimension, materiality, physicality, virtuality, and scale. This research has produced three results:

- The extension of the design process beyond digital screens and physical paper through the micro-hybrid design process
- The interactive, real-time design evaluation of the built prototype
- The positive impact on student Design Self-Efficacy (DSE)

Knowledge gained by this research presentation could impact design studio curriculum in three ways: extending the pedagogical framework beyond the University of Kentucky-College of Design - Applied Design Computation Laboratory (ADCL); defining the methods and means of evaluating the design artifact as a project score (PS); and providing critical new insights into the analog/digital means utilized to enable the artifact construction. Collectively, these three topics, have also been shown to positively influence student design self-efficacy (DSE) and deepen learning.

CONCLUSIONS
This research discusses an improved design process that integrates fabrication and (physical) simulation in order for students to gain better insights into building design and technology related aspects. In addition, the approach takes into account a decision-making matrix that assists in assessing the effectiveness of the design solutions. This process is intrinsically linked to design thinking processes where ar-
Architecture students are challenged to think creatively and simultaneously about digital technology. In this context, the micro-hybrid is positioned as an emancipator of design that capably expands the possibilities of design. However, the research also revealed the social art form of architecture as being an existing tangible being, that needs to be calibrated with parameters of the outcome medium. Simply put, what can be added to the aforementioned design-thinking, is to not only think about physical translation of the design as part of the test simulation or final construction, but to use prototyping and fabrication as a design tool side-by-side with other digital tools.

What the micro-hybrid research project suggests is the continuation of existing methods coupled with the hybrid use of digital and physical design methods. The research presents an integrated design process that acts as a feedback loop at all stages of architectural design, not just at the earliest stages. This research articulates how the micro-hybrid attempts to fill the gap between the digital design process and the physical world. The information collected before the simulation stage and during the modeling/design phase uses feedback from the physical world, not only in terms of materiality, but in terms of design and aesthetics. The micro-hybrid project is the first step in a larger research initiative to explore simple and intuitive design systems. This project is targeted at controlling functions associated with the methods making and the simulation-based tools used to examine form. As this research continues at larger scales and across other primitive geometric forms, it will expand to include functions such as planning and design that will improve architecture and design education globally.

**FUTURE RESEARCH**
The micro-hybrid research aligns with the advancement, discovery, and understanding of the design process as it relates to the built environment. It also outlines areas of future research beyond this research study and its intellectual merits, leading to broader design impacts. There is direct evidence to support the impact of the rigorous nature of the micro-hybrid specifically the education and training of design students. There is also early evidence to support a range of pedagogical implications where design research can inform the teaching methodologies used in the studio setting or where student-based, self-directed research can inform discovery. To determine the resilience of the process, in addition to the cube, the future micro-hybrid iterations will be tested on all primitive forms (sphere, torus, pyramid, cylinder, and cone) and then analyzed in relation to their core connection method (tangential plane, incised plane, and cored plane) to test this experiment further.

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