Crossing the Digital Divide Through Digital Dexterity

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Skills, desire, and intent tend to relate (McCullough 2005: 160).

It could be argued that if one is not drawing, or speaking, or writing, or hand-crafting, certain thoughts are somehow 'unthinkable' (Groak 1993: 151).

Although the computer is now commonplace at most design schools, there are persistent problems integrating digital media into design culture. Digital media challenges and provides opportunities for the particular ways knowledge is constructed in design education. Skills, tools, and media in the discipline of architectural practice connect to a particular sense of agency. Skills are not isolated techniques to learn but connect to the identity of the architect formed in design education.   Practices and the tools that enable these practices construct values. Developing digital dexterity requires skill-based flexibility and adaptability within the digital medium, while projecting a larger image of practice through the tools.

Developing digital dexterity is not simply frustrated by a generational gap, as I originally thought, but these technologies challenge the underlying conception of what architectural design is and how it is practiced and taught. Through folding in ethnographic methods such as participant-observation in my teaching and through interviews with senior faculty, the concerns and comments from students and faculty alike identify the intellectual split between conception and execution which digital media have had the tendency to amplify. While ethnographic observation is inherently particular and contextual, or "local" in the words of cultural ethnographer Glifford Geertz, the role of ethnography is to create "a continuous dialectical tacking from the most local of local detail and the most global of global structure in such a way to bring them into simultaneous view" (Geertz 1983:69). The particular reflections in this brief essay are selected as they point to much more global issues beyond the particular context they are generated from. Furthermore, the methods of ethnography are well suited to the introduction of new tools and technologies, as the introduction of these tools and technologies challenge the underlying conception of what a practice is (Suchman 1987). Ethnography exposes how particular issues challenge the very identity of a practice. Of course, bringing ethnography into the design studio is well known through the work of Donald Schön and I have emphasized this elsewhere (Schön 1987 Cabrinha 2009). The ethnography in this paper develops through teaching digital integration and fabrication at three design schools each with particular sub-cultures: one that emphasized digital media, another focused on hand drawing, and a third which emphasized physical models. Following the ethics of ethnographic practices, these schools and faculty have not been identified, and students have been identified through pseudonyms.

The relationship between the digital and the physical became the common intersection across these three sub-cultures in which the issue of the digital divide in architectural education is not due to economic, geographic, or generational issues, but in identifying the intellectual split in the discipline between conception and execution. Identifying the digital divide as a problem within the underlying conception of practice offers the opportunity to reconstruct the image of practice through the context

of new tools. Contemporary modes of digital fabrication and the digital dexterity they require enable an opportunity to cross the borders between the digital and the physical and by extension, conception and execution.

DEVELOPING DIGITAL DEXTERITY: PRAGMATIC AND EPISTEMIC ACTIONS

The integration between conception and execution requires a reconsideration of skill-based development as skills, tools, and design media shape design intentions more than is acknowledged.   Skills are associated with what have been termed pragmatic actions, those actions that have a direct consequence or effect in the world, whereas digital dexterity develops from what have been termed epistemic actions, or actions that are performed to uncover information that is hidden or hard to represent internally, and thus have an effect on the agent (Kirsh Maglio 1994). In expert use, the technical capability through skills are paired with the intentional capacity to project a course of action (Sudnow 2001:64). In this way, epistemic actions develop from a broader perception of pragmatic actions in which perception shifts from the tool to positioning one's intentions in a particular course of action. Consequently pragmatic and epistemic actions should not be seen as two separate categories of action, but rather two ends on a spectrum of purposeful action.

A further distinction should be made between skills and the digital dexterity required to operate in a medium. The apologetic response "the computer is just a tool" evades the issue of what is actually at work in digital media. Taken literally, it's not the computer that is the tool, nor is it software, but singular command or icon that is actually the tool. Consequently, any given software package is a set of tools, and the collection of software on a computer is then a set of sets of tools. The ability to fluidly and transparently work across these sets of tools is what is meant by the computer as a medium.

Despite Marshal McLuhan's prophetic optimism that the medium is the message, in my teaching experience it is clear that any single medium is not message enough. In fact, McLuhan emphasized the hybridization of media, the interpretation of one medium by another as a process of transformation that requires insight. McLuhan describes singular media as "make happen" agents whereas the hybridization of media offers an opportunity to expose their structural properties and components as "make aware" agents (McLuhan 1994: 49). This aligns with the spectrum between pragmatic and epistemic actions as pragmatic goal-oriented actions align with "make happen" agents while the insight, discretion, and experience of epistemic actions act as "make aware" agents (Figure 1). That is, they reveal or disclose information to the user rather than simply execute some preconceived goal. Developing digital dexterity is more than the speed of successive skill-based actions, but is an awareness and ability to position oneself within this flow of information.

POSITIONING SKILLS, TOOLS, AND MEDIUM

Malcolm McCullough's *Abstracting Craft: The Practiced Digital Hand,* first published in 1996, is a liminal text bridging an embodied sense of design with the nascent digital media through the interre-

computer as machine   *computer as tool*   *computer as medium*
pragmatic actions   **epistemic actions**
"make happen" agents   "make aware" agents

passive   active   activating

pragmatic and epistemic actions
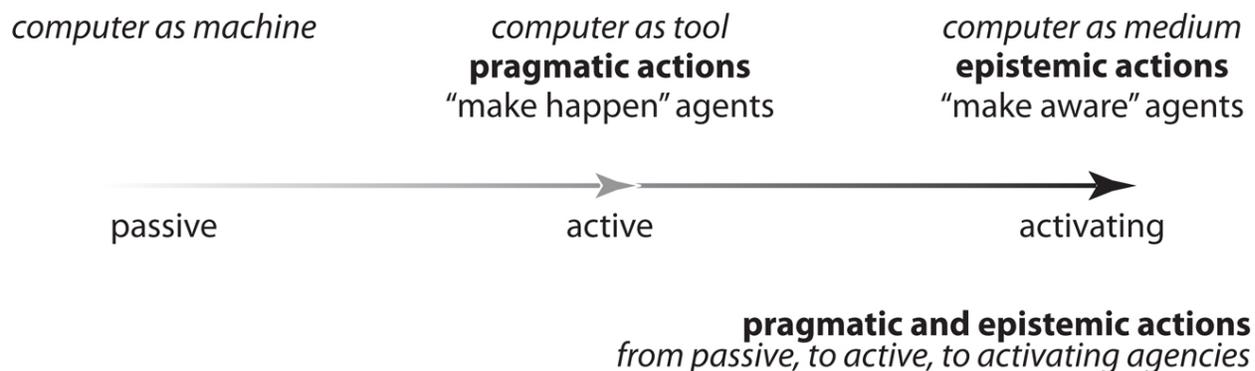*from passive, to active, to activating agencies*

Figure 1: Developing skills exists along a continuum which shifts from a goal oriented pragmatic action to a medium in which one is able to identify issues and position themselves within these issues.

lationship between skills, tools, craft, and medium. Through the "inarticulable skill," or tacit knowledge, abstract craft can be developed. Craft involves interpretation and discretion probing a medium's capacity developing a passion for practice and the value of the medium independent of what is produced (McCullough 1998: 29). While this interpretation and discretion is a desired state combining skill, tool, and craft as a medium, the development of skill curtails this placing focal attention on the tool. Due to the many different software packages an architecture student needs to know, McCullough identified a decade ago a recurrent problem today: "the more we know how to do, the less we know what to do" (McCullough 1998: 67). The development of skills are constructed over time and experience and design curricula should reflect this, rather than isolating skills as a first-year problem or in isolated technique-based seminar course. Digital integration must occur across a curriculum in much the same way that sustainability is not a fringe subject but is present in lectures, seminars, practice courses, and design studios as a fact of architectural pedagogy and practice. A year following the infamous Boyer report of 1996, co-author Lee Mitgang identified four of architectural education's toughest challenges, identifying the computer as the first challenge claiming "it borders on educational malpractice that so many faculty members have yet to master computers well enough to teach it comfortably in the design studio" (Mitgang 1997).

I used the introductory chapters of McCullough's *Abstracting Craft* as a probe to understand the students' perceptions of the digital medium. From the viewpoint of an older generation, it is often assumed that students will simply pick-up the skills as they grew up with the computer. But just because I grew up with the pencil doesn't mean that I was able to draw without the development of that skill through instruction and experience. Why would the computer be any different? The students I taught are the generation that is supposed to have absorbed the computer, and although this student would become the most digitally skilled student in this studio, at first he expressed a strong loss of agency:

> ...we can't say that we use it as a tool and we can't say that we use it to create because we don't create, it creates based on what it could do and not what we want it to do. We are not at the point where the computer becomes transparent in our use of it, I see myself making [the] thing then asking myself what do I do to make this within the computer, what com-

mands, what program, what do I do? And in that sense I am still learning the complex tool/media. Tyler, undergraduate architecture student

He identifies his loss of agency as he says "it creates" which is a particular reflection of a very general attitude as students withdraw a sense of criticality for a general passive acceptance that this is what the computer gave me. Without the development of appropriate skill, design can quickly devolve from an active sense of agency into a passive acceptance. This lack of ability leads to a focal attention on the tool rather than their design intentions. "Break-down" is a phenomenological term that shifts perception from the task-at-hand to making the tool "present-at-hand" when the tool does not perform as intended (Winograd and Flores 1987). In the beginner's hands, the lack of skill and the break-down that follows shifts a student's attention from design to technology. In skilled hands, break-down can be a positive opportunity requiring interpretation and context in which "the designing process is part of this 'dance' in which our structure of possibilities is generated" (Winograd and Flores 1987: 163). Madison's reflections include both the negative and positive aspects of break-down:

> ...sometimes I find myself wanting to do something, but am limited either to the program I'm using, or my knowledge of the program. If it is the latter, I learn how to do it and thereby develop my skill with the computer. If it's the former I'm faced with adapting my intent or representing it in another medium. At other times, I can use the computer to do things that I could never imagine doing on paper or in a physical model... Madison undergraduate architecture student.

Despite the positive opportunities of the digital medium, she also expressed concern about how intentions are shaped by digital media:

> I related this article to design particularly at the end when McCullough wrote, 'A tool is for serving intent, whereas a medium might create intent, and a machine might work on its own.' From the second I got [here] and entered the architecture program, professors have been saying that with the computer we have an amazing tool for design. I've also heard them say the computer is a medium through which we design. And at the end of the day, the computer is defined as a machine...of course when it comes to designing buildings, this is where we aren't sure what to do with them b/c it doesn't really matter if we can do it in the computer if we can't actually develop it in a physical sense b/c at the end of the day buildings are meant to be built. Madison, undergraduate architecture student.

These students frequently reflected the need for physical / digital integration and the need for a tangible connection to their work. The lack of this tangible connection through physical / digital integration can lead to a conflict of values for the student. For Emily, an undergraduate student, this lack of tangible relevance creates a disconnect between academic design and the building industry she desired to become part of:

> Malcolm McCullough's article brings up something that I often think about: the disconnect between the academic world of architecture and the real world construction industry. It seems to me that in many ways it is possible for computers to aggravate this distance between tangible and intangible...I see this as a very serious problem for architects. We are considered by many to be the critical thinkers and the innovators. How are we supposed to think of new construction methods when our understanding of existing ones is so limited? It is too tempting to create fantastical forms on the computer, ones that are not informed by gravity, cost, and construction reality. Perhaps these real world factors should not dictate form, but they should certainly be considered. And it should not be the computer or software's job to think everything through for us either. Technology can be a useful tool for us, but only if we are one step ahead in our thinking. We may have something fantastical on screen but we should be simultaneously brainstorming about how to construct it. Emily, undergraduate student

The loss of agency, phenomenological break-down, and conflict of values can be inverted as a positive pedagogical model through digital / physical integration as an expansion of agency. For this reason I have focused on developing a "materials first" method of teaching digital skills as an interaction between material and geometry enabled by the context of digital fabrication tools.

MATERIALS FIRST

I introduced this materials first approach to developing digital skills to introduce material constraints into the digital design workflow. I conceived of this materials first approach to introduce material constraints and properties to a group of students I presumed was more digitally literate than I was. However, working with materials revealed what little grasp they had with the software. Introducing materials first as the basis for developing digital skills bridges the gap between material constraints and the flexibility of digital tools. This approach has precedence in the 18th Century spline used in shipbuilding, in which the curves drawn with a wood

spline were analogous to the material properties in shipbuilding. The development of NURBS-based software through mathematician engineers such as Pierre Bézier took this material system and abstracted the material constraints out of the equation, and yet now, ironically, the designer must take great effort to put those material constraints back into the way one works with digital software (Bézier 1972 Bézier 1998). Through this materials first approach, a material empathy develops through the interaction between how material takes shape and the precision of digital tools to control and fabricate these shapes. Pedagogically my intent was to allow a simple material feedback at the inception of developing shape rather than post-rationalizing material constraints after a form has already been imposed.

This approach emphasizes a physical-digital-physical cycle beginning with the literal basswood spline discussing its capacity and tendency to take shape (Delanda 2004). The capacity of materials includes its material composition, for example how the higher grain density in basswood is superior to the looser grain structure of balsa. In discussion with my students, many had already experienced how balsa will snap somewhat unpredictably. The tendency of material to bend a certain way has to do with a material's geometric cross section, such as the weak and strong bending axis (bi-axial versus uni-axial) which students identified from their structures courses.

Students were asked to create a simple structure from a minimum of 12 basswood splines developing the most spatial variation with the least number of basswood splines. The structure must past two tests, the fist test and the finger test, which act as a simple heuristic for the student's self assessment. The fist test required that a closed fist should be able to get into the majority of spaces created, emphasizing space over objects. As one student commented, "a thing to look through, not a thing to look at". The finger test tests the behavior when pressing on one stick effects the others, thus requiring the sticks to be assembled in a network-like fashion rather than discrete individual sticks. From this material primitive, a number of principles of NURBS-based geometry can be introduced including degree of curvature, surface development, and surface panelization through ruled surfaces completing the cycle from material primitive, to 3D form, to 2D cut files.

Degree of curvature is introduced through the transcription from the physical to the digital splines. At first students had a raster mentality thinking the more points they transcribe the more accurate their model will be. In fact, the opposite is true. Through understanding degree of curvature, students began to develop a vector mentality understanding that the fewer the points the smoother the curve which supports an economy of information. Dexterity developed not from the speed of their skills but understanding the basis of the system they were working with.

From their digital splines, surface development was introduced. Students selectively built surfaces in their digital model through a range of surface modeling approaches from lofting, railing, from boundary curves etc. The principal point in this approach was to understand the surface as a jig constructing a preliminary surface from which they extracted isocurves to then develop a new surface. Using the surface like a jig developed a flexibility, adaptability, and maneuverability in working and reworking their geometry such that their skills became fluid, not just the form.

From these digital surfaces, surface panelization through ruled surfaces was introduced to come full-circle from physical input, digital development, to physical fabrication. Ruled surfaces are required to "unroll" three-dimensional surfaces into two-dimensional shapes to be fabricated from flat sheet material. Rationalizing these surfaces through curvature degree reduction required a judgment call on the amount of surface subdivision - the more subdivisions the more accurate the surface but the complexity and time in fabrication increased as well. Although rudimentary, the real world material and time constraints of fabricating complex shapes balanced their idealized non-material digital surfaces. Students also quickly realized that at each surface seam a back-up structure was required from which the surface normal was introduced to develop structural ribs from the surface panels. Through this process, the entire three dimensional digital model was developed as two dimensional fabrication files.

The students were then required to fabricate an accurate physical model from this digital model, closing the loop from a loose intuitive physical model, to a rigorous if analytical digital model, to a more

Figure 2: Model developed from physical spline model, to 3d digital model to 2d cut files to 3d physical model in digital media seminar.
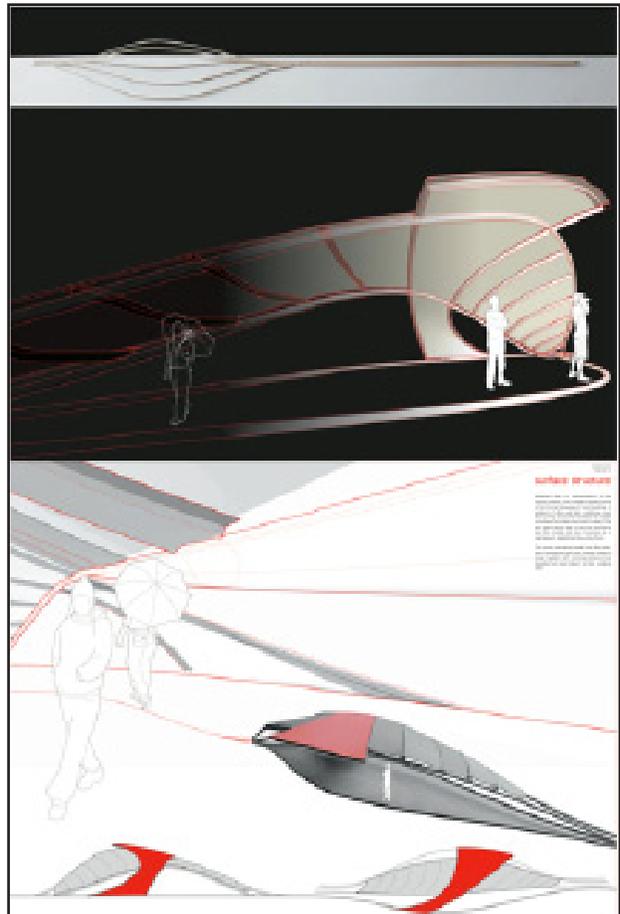

Figure 3: Graphic representation and immersive perspectives from physical basswood splines, to digital design development to physical model in 4-week seminar process.

structured physical model (Figure Two) and a graphic layout describing the process (Figure Three). In a few weeks, students moved between the intuitive to the analytical; from very loose to highly structured thinking. Along the way, they learned the software very well. Beginning with materials first, the development of digital skills became tangible.

MATERIALS FIRST: ASSESSMENT

Reflections on design culture emerged through these exercises. In my exit interviews, students confirmed the intersection between the physical and the digital required them to further hone their digital skills. One student noted that the "negotiation between the physical and the digital" helped her to learn through this transition. The most colorful example came from a Japanese student who thought this experience was unique in how it balanced "two extremes" between the material and the computational. Growing up in Japan, she saw craftsman on TV making joints which made her think it was easy, but she had never done it before until some of the very simple joints she was making in this class. She acknowledged the dominant digital culture saying "we are so into one thing," but now recognized the need to balance between the digital model and physical material constraints:

> The material is not superman. You can't just say 'I want you to do this.' We always overlook material. Material is limiting what we do a lot more than expected. Brook undergraduate

Developing this strategy at multiple schools also revealed that this physical-digital integration works both ways. At one school with a strong digital culture the constraints of materials challenged their preconceptions of what was possible and refined their digital skills, while at another school with a hand-drawing tradition the materials first approach gave the students a comfort level as an entryway into developing their digital skills. In a recorded class discussion at the end of the seminar, their comments confirm the role material play had in informing how they learned the software:

> When I went into the class, I thought we were just going to learn 3D software, doing rendering whatever. I think it was really cool to bridge the gap between design and actually physically building. I realized there was going to be a cross there, but I didn't realize how much I would learn from actually crossing that gap. There is like exponentially as much as you want to learn there. Sean, graduate student

Or another student admits how the physical digital physical cylce enables a feedback loop relative to her sense of scale:

> I think it was really good to take that digital file and make it physical. I learned a lot about proportions - in the computer you kind of get lost in the infinite scaleness - scale gets lost a little bit - so it is good to always go back and check yourself. Nicole, undergraduate student

The tacit knowledge developed through manipulating material in this materials first process became an effective pedagogical opportunity to bridge the gap between the digital and the physical. In the end, digital fabrication requires not only digital dexterity, but a robust material sensibility that precedes digital mediation.

IDENTIFYING THE INTELLECTUAL SPLIT IN THE DIGITAL DIVIDE

As the computer is no longer something other but something students' take with them, the debate around the computer is over and instead of endless debates for and against the computer questions of fit can be made. Some students will be quicker than others, more interested than others, better skilled than others, which is no different than traditional forms of media. However, the central argument here is not that one replaces the other or that we need to compare analog media versus digital media, but rather the direct link to physical fabrication is exactly what was missing from the endless debates about the pencil and the mouse. As early as 2001, Dana Cuff at UCLA identified the opportunities inherent in digital physical integration (Cuff 2001). She noted the "undeniable, alluring energy" at particular schools that were pushing the forefront of digital design while she was well aware of the faculty divide between digital and hand media, suggesting that there should be "knowledgeable experimentation on the part of faculty, many of whom are caught instead of supporting or resisting digitization." Her focus on pedagogy was not simply on how to teach digital media, but on how computers and software direct a student's thinking - "the computer's cognitive implications." Furthermore, Cuff highlighted the "visualization versus production" divide, noting not only different issues explored, but how particular software amplified this divide. Visualization programs such as Maya and production-oriented programs such as AutoCAD reified the separation between design and execu-

tion. This can amplify the split between the academy and practice as she forewarned in 2001, "the academy may be further removed from practice and from buildings than ever."   She highlighted the central problem: moving between digital and material design. The pedagogical opportunity is the translation between these two modes of thinking, and for this, she closes the essay noting the opportunity that CAM offered to translate between the shop, research lab, and the design studio.

Although it has taken over a decade, and while digital fabrication is now ubiquitous, questions of the analog and digital continue to resurface as they have in this session topic. For a longer view, I had the opportunity to speak with a senior faculty who was initially hesitant to digital media, though now he finds it "a little weird" if a graduating student insists on hand-drawing. More than as if it were simply a choice between the pencil or the mouse, he identifies that the fundamental issue is the intellectual split in the discipline between design and construction. In one continued thought, he contrasts the culture clash from introducing digital tools in design education in the early 1990's to the new possibilities in connecting conception and execution through digital fabrication:

> We were in this struggle with regard to computers [in the early 1990's]. This absolute mess. Some people didn't want it at all, and some people did, and these people couldn't talk to each other. I think this same thing was going on in a lot of different schools. The stuff that I saw coming out of computer-based studios here was much more awkward, much more clumsy, you just couldn't see why people were doing it. What I saw at other places was stuff that was totally arbitrary and formally based, just playing with the machine because it could be played with. So I wasn't making the connection. At least from looking at schools, I wasn't seeing the value of it. At the same time, I was familiar with Frank Gehry and I was always more interested not in the forms, but the way the buildings were put together. I was fascinated with that because it connected to the stuff that I had actually been working on. It actually connected with this idea of a direct connection between conception and making. And that seems to me to be really important, because…all of this crap with the general contractor and working drawings and all that stuff just gets in the way. If you think about traditional architecture, there is a direct connection between conception and making... And that seems to me to be a pretty healthy thing. So then, I look at Gehry, and ok, I don't like those buildings very much, but there is something there. So this business with institutions, and contractors and architects it's all the same ball of twine. I feel now, and the way that people are talking about it, that we are on the verge of something

that is - at least something that is more interesting to me…the architect being able to have control over the product in a very different way than the architect has had in the last 100 years. If you start to add that with a healthy relationship with clients, then you potentially have the beginnings of something that is really great.

This senior faculty crystallizes the disconnect between conception and execution which the early emphasis on digital form making amplified. This intellectual split creates a conflict of values in the developing design student that is likely to be far more pernicious in stopping design development than any particular skill. Conversely, the opportunity to bridge conception and execution through the integration between the physical and digital can be a motivation for developing digital dexterity as an expansion of agency. In the end, the digital divide is not the result of a generational gap, but the intellectual split in the discipline between conception and execution. Positioning digital skills as an extension of material agency through contemporary modes of fabrication bridges the gap between conception and execution, and in so doing shifts the conversation from technology to how tools, technology, and media construct an image of practice.

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