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Cultivating the critical imagination: post-disciplinary pedagogy in a computational design laboratory

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ABSTRACT

This article documents and reflects upon a pedagogical project aimed at fostering critical engagements with technology in the context of a graduate research and learning laboratory at the nexus of computer science, design, engineering, and architecture. With the notions of critical technical practice and reflective practice as touchstones, the project links a specific tradition of twentieth century design pedagogy to critical sensibilities drawn from the field of science and technology studies (STS) in a space we call the ‘research studio.’ The methods and examples presented illustrate how this hybrid pedagogical model can cultivate the critical imagination of learners – their ability to place critical and sociohistorical reflection at the centre of creative technology design – and show that the fields of design and STS offer distinct but mutually enriching traditions of learning and research. The article offers insight to educators and researchers across STEM and humanities fields interested in engaging with technologies not merely as subjects but also as vehicles of scholarly and creative inquiry.

KEYWORDS

Computational design; design pedagogy; science and technology studies; architecture; critical technical practice; interdisciplinarity

Introduction

This article documents and reflects upon ongoing efforts to cultivate critical engagements with technology in a post-disciplinary graduate programme and research laboratory at Carnegie Mellon University. With the notions of critical technical practice (Agre 1997a) and reflective practice (Schon 1983) as touchstones, it discusses a hybrid pedagogy that fosters the convergence of material, technical, and critical perspectives in a physical and social space we call the ‘research studio.’ Re-directing the design-studio model towards reconciling creative and critical engagements with technology we seek to enrich traditional, case and problem-based, approaches to technical education

with imaginative and reflexive attitudes that recognize technologies’ sociohistorical dimension. The article starts by situating our pedagogical approach in relation to a specific pedagogical tradition rooted in early twentieth century models of design education, and by linking it to critical sensibilities drawn from the field of science and technology studies (STS). In describing this linkage, we develop the notion that the fields of design and STS offer distinct but mutually enriching traditions of learning and research. The second section describes the site of this pedagogical intervention: an interdisciplinary programme located at the nexus of design and STEM, combining methods and concerns from the fields of

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computer science and engineering with those from architecture and design. The third section articulates the programme's renewed proposition, emphasizing design itself as a subject of both creative and sociotechnical inquiry. Drawing from the first author's piloting of this programme since 2016, the article offers a detailed picture of the curricular, pedagogical, and conceptual methods implemented, with a focus on the sequence of 'research studios' that structure it. Discussing a series of outcomes, including research projects and students' theses, the following section illustrates some results. Of interest here is the scale, methodological, and thematic diversity across the examples presented. From haptics to bodies in virtual and urban spaces; from archival research to visual ethnography; and from interrogative technology design to data intensive computation, the examples presented illustrate how a hybrid pedagogical model can cultivate students' critical imagination – their ability to make critical and sociohistorical reflection a key axis of creative technology design.

The conclusions section offers an overview of the challenges encountered, including points of tension between design and critical scholarship. Important among these is the difficulty of de-centering technological innovation as the key goal of research and learning in the context of a research university. Finally, the key insight of this research is articulated: that enriched with a sociotechnical perspective design can be construed as a form of critical reflection which can help a community of learners to situate technologies in specific historical and socio-material contexts, critically consider the implications of their design, deployment, and use, and reflexively harness these understandings in processes of creative design.

The article's main contribution is a detailed case study of a hybrid pedagogy that reinterprets the design studio tradition in order to put technical and critical abilities in productive conversation. A secondary contribution is to identify specific alignments between the

intellectual and pedagogical traditions of design and STS, offering an overview of some related challenges. The article will be useful for researchers and educators across a range of fields. For example, educators in STEM fields may find in the experiences documented here useful insights to adopt design studios as sites of creative sociotechnical exploration. Similarly, educators in the humanities and interpretive fields such as STS may find clues for engaging with technologies not only as subjects but also as vehicles of scholarly and creative inquiry.

Background

Visual and tactile pedagogies

American philosopher and educator John Dewey advocated for artistic creativity as a mode of intelligence, and for hands-on artistic production as a key component of an effective (and affective) pedagogy (1958). Along with ideas advanced by the contemporary Arts and Crafts movement, Dewey's pedagogical philosophy helped configure a distinctly modern notion of the creative individual. With both intuition and intellect, this individual understands and takes critical distance from their creative acts, acts methodically and reflexively, and translates ideas across different contexts. Dewey further argued for these industrious and reflexive capacities to be essential characteristics of individuals in a democratic society (1944). His pedagogical philosophy – often termed 'learning by doing' and closely associated with constructivism – posits that learning processes based on hands-on experiences are richer than those based on verbalized and textual accounts. Its roots can be traced further back to the nineteenth century kindergarten where drawing, making, building, and play formed the basis of children's learning (1990 [1902]). Sensory engagement with objects and situations is here a source of discovery of new and surprising relations between things allowing learners to acquire a practiced, situated,

and personalized understanding of the subjects of their learning.

Central to the pedagogical philosophy of ‘learning by doing’ is training learners’ sensibility and judgement through tangible engagements with material, technical, and cultural practices. As important is nurturing a reflective mindset that enables learners to actively explore these practices while articulating, and critically engaging with, their impacts on their social contexts (Dewey 1903). This pedagogical tradition recognizes that visual and tactile engagements with real materials and situations can elicit the discovery of new and surprising relations between the elements of a design and their context. From a constructivist perspective, this spirit of discovery is heightened by pedagogies that rely on visual and tactile exploration, rather than on abstract and standardized problems with prescribed solutions. This pedagogical tradition makes its way into the fields of design through the academic lineage of the Bauhaus (Bredendieck 1962), and is also recognized in psychology (James 1983). Important for our analysis, this tradition inflects computational approaches to design which forefront sensory human experience (Knight and Stiny 2001) and sociality (Habraken and Gross 1988) over blind automation. Here ‘doing’ is not only a specific type of design training, but also a worldview that takes effect as a situated engagement with the world. Accordingly, ‘design’ here is not merely the capacity to organize things but the ability to critically assess relations, explore, and reflect on reconfigurations of the world (Ozkar 2017). A growing body of scholarship recognizes that this approach to learning enables critical reflection and a deeper understanding of design’s social contexts and implications (Lucas 2012; Gardner 2009). The studio is the space where these pedagogical and intellectual vectors have historically converged (Salama and Wilkinson 2007).

The pedagogical and artistic tradition described above is located in the physical and social environment of the studio. Studios

facilitate learning by doing by structuring opportunities for hands-on, context-sensitive experimentation, peer to peer communication, critical thinking, and legitimate peripheral participation (Lave and Wenger 1991), which are essential to cultivate tacit knowledge (Schank 1995), and reflective attitudes which contribute to practitioner’s critical understanding of the material and social dimensions of the work (Schon 1990). In addition, less hierarchical than conventional classrooms, studios facilitate interdisciplinary research and learning as they are, by design, open to multiple experts and participants’ viewpoints, and facilitate interdisciplinary and peer-to-peer mentorship, conversations, and collaborations.

Creative and critical technical practices

The pedagogical project outlined in this article aims at reconciling technically-grounded practices with imaginative and reflexive attitudes that recognize technology’s sociotechnical and historical dimensions and impacts. Important here is the notion of ‘critical technical practice.’ Reflecting upon his personal and professional transit from artificial intelligence (AI) into the social sciences, Phil Agre argues for the importance, within technical disciplines, of critical engagements with the discipline’s own methods and concepts. Reflexive, critical thinking is key to technical projects because it creates space for moral and ethical discussions, and for the enrichment of disciplines’ own evaluative and methodological toolkits (Agre 1997a). This approach reflects the critical and interpretive sensibilities towards technology cultivated in the field of studies of science and technology (STS), highlighting how technological systems are not autonomous from but rather are deeply entwined in social, material, and political milieus. For example, scholars working in this field have shown how artifacts, including at the urban scale, can enact a politics through their very design (Winner 1980); how large-scale technical systems configure infrastructures

comprising multiple interrelated social, material, and technical vectors (Star and Ruhleder 1996); and how practices of technology design are shaped, often unconsciously and sometimes problematically, by cultural imaginaries defining users and the extent to which their actions can be technically inscribed (Suchman 2006; Agre 1997b).

Attempts to engage with design through a sociotechnical lens often enact historical and ethnographic sensibilities, and an aspiration to enable new understandings of – or modes of operation within – the practices of design. These include a variety of approaches (Vertesi et al. 2017) ranging from critical engagements with corporate design cultures (Suchman 1987; boyd and Crawford 2012), to studies of socio-technical system and infrastructure design (Ribes and Baker 2007), reflective and critical technology design (Irani and Silberman 2015), as well as participatory and speculative modes of design production (DiSalvo 2015). Additionally, related scholarship from fields including design, computation, architecture, and human–computer interaction has sought to employ a sociotechnical lens to examine the collective nature of design practices, challenge narratives of ‘heroic’ individual inventors, and investigate contemporary ecologies of design production (Tonkinwise 2012; Loukissas 2012; Cardoso Llach 2015; Yaneva 2016; Cardoso Llach 2019).

In university settings, a number of laboratories and programmes navigate similar questions.¹ These all vary in terms of disciplinary composition, institutional context, outputs, and intellectual aspirations, and are in fact key sources of inspiration for this project. However, the potential of a design-based pedagogy to nurture critical engagements with technologies’ sociohistorical dimension remains relatively unexplored. In what follows we document our ongoing efforts to develop a pedagogical proposition that uses design as a pedagogical framework for cultivating the critical imagination of technically-engaged practitioners.

The computational design laboratory

Our site is a research and learning laboratory housed within the School of Architecture at Carnegie Mellon University rooted in an interdisciplinary tradition combining methods and concerns from the fields of computer science and engineering with those from architecture and design. The lab is an interdisciplinary community with members from fields including design, architecture, computer science, engineering, and art. In the Spring of 2019 this community comprised 40 members including MS and PhD students, undergraduate researchers, visiting scholars, and affiliated faculty. The laboratory is closely tied to the master of science (MS) and PhD programme in Computational Design.

A brief history

Research into computational design at Carnegie Mellon has its origins in the late 1960s with faculty collaborations across the School of Architecture, the School of Computer Science, and what was then called the School for Urban and Public Affairs (SUPA). Architecture faculty, prominently Charles E. Eastman (who also held a position in the School of Computer Science), sought to apply computational ideas and methods to questions of design and the built environment and spearheaded a new, research-based, graduate programme in architecture and computation. Along with graduate students in the programme, he sought to apply AI research to architecture (Eastman 1969), developed problem-oriented languages premised on the alignment of data and building structures (Eastman 1975; Yessios 1973), and created systems for design automation and layout generation (Eastman 1981). These early efforts produced important examples of geometric modelling and design interfaces (Woodbury 1984); performance analysis software (Fenves, Flemming, and Hendrickson 1994); as well as theoretical developments in

generative expert systems; design cognition (Akin 1987); and shape grammars (Krishnamurti 1979). In the early 2000s the Computational Design Laboratory (Code Lab) was established with the arrival of architecture faculty members Mark Gross and Ellen Do. The lab sought to enrich the programme's historical strengths with perspectives informed by a concern with embodied cognition, constructivist learning, and experimental modes of human-machine interaction. Crucially, the new laboratory sought to take distance from representation as the chief site of architectural and design research – often with a clear orientation towards industrial and product design. Additionally, the laboratory set out to explore design opportunities linked to the growing ubiquity of computational and networked systems. This new environment reflected concerns from faculty and students in, for example, human-machine collaboration in design; architectural robotics; virtual and mixed reality; and tangible media. This new conceptual and technical repertoire formed the basis of a new masters concentration on tangible interaction design which evolved in conjunction with (and sometimes in tension with) the original concentration in computational design.

As the history briefly outlined above suggests, the field of computational design evolved from the recognition that symbolic systems could be used to represent and encode aspects of design and manufacturing. Whether through abstract structures in computer code, or through algebras made of shapes or physical forms, design-related processes such as drawing, modelling or manufacturing could be represented as a series of declarative statements and thus imagined away from the long-standing traditions of practice they were meant to replace. This approach has yielded many promising questions and applications. Crucially, it helped give design research the standing it enjoys today in universities as a field of rigorous inquiry and research – sometimes as an independent department, and sometimes as an

area of focus within architecture, art, or engineering schools. Today, however, we know something that we didn't know in the 1960s and 1970s: that computing and digital technologies are not neutral artifacts that simply replace what exists, but are instead intentional, discursive ones, which are incorporated (often messily and in unexpected ways) into existing traditions of practice, yielding new forms of craftsmanship, the demand for new skills, often de-stabilizing sociotechnical worlds. In addition, we know that the image of the designer as a solitary figure – a legacy of Schön and the design inquiry tradition – is inadequate to approach the much richer practices of design, which invariably involve collective, sociotechnical work. These raise new questions that the initial focus on design automation and representation fails to address. How to re-direct the lab's, and the field's, energies to address them?

A renewed proposition

The programme's renewed proposition, informed by the design and STS traditions outlined in the previous sections, is to shift our view of design as a process to represent formally and optimize, into a view of design as a phenomenon to *understand* and a sociotechnical ecology to thoughtfully *re-imagine*, *intervene*, and *explore*. The work of the laboratory and its associated programme is thus premised on the recognition that, first, technical systems are always already situated in material and social contexts, and that their design, implementation, and operation is always already shaped by political and sociomaterial practices. Second, that plans and representations, a historical focus of the field's research, are never fully prescriptive and are themselves artifacts enmeshed with their material, socio-technical, and institutional milieus. Finally, that computational technologies never fully replace but rather co-exist, sometimes in unexpected ways, with enduring cultural, material,

and technical practices. Through these distinctively STS lenses the separations between the ‘computational’ and the ‘tangible’; between ‘representation’ and ‘artifact’; and between the ‘digital’ and the ‘material’ are no longer useful, desirable, nor tenable. The recent re-orientation of the programme has thus sought to cultivate a broader outlook where technical systems are understood as discursive artifacts, like texts, that may be analyzed and constructed with inquisitive or interpretive intents – as, following Suchman, ‘propositions for a geography where relevant subjects may take their place’ (2011).

The laboratory and its associated programme thus aspire to offer a space for mobilizing computational ideas and methods critically towards questions of design – broadly understood to encompass a diversity of conceptual and practical approaches to the production of human-made environments. This means, on the one hand, to create the conditions for (design) technologies to be formulated inquisitively in order to interrogate or renegotiate social and socio-technical relations. On the other, to cultivate an interpretive attitude construing digital environments and human-machine entanglements in processes of designing and making as new and exciting sites of sociotechnical inquiry. With this new framing, projects in the laboratory aspire to occupy a place in a spectrum between *technologically informed design scholarship*, and *scholarly-informed design technology*. As will be discussed in detail below, recent projects combine methods and explore themes from design and STS and include experimental software reconstructions, tangible interfaces for design exploration, urban data ethnographies, exhibitions, and international symposia.

A design-centric post-disciplinary ‘knowledge-space’

The programme’s diverse disciplinary composition is fundamental to its pedagogy. Its members come from fields including design, architecture, computer science, engineering,

and art – or combinations thereof. In recent cohorts students coming from a design background make for roughly half of students, and the other half come from other disciplines including engineering, art, media studies, and the social sciences. This configures a design-centric yet disciplinarily diverse ‘knowledge-space’ where the specificity of each discipline is recognized, but understood tactically: research projects are inquiry-driven rather than shaped by disciplinary inclinations, industry imperatives, or methodological comfort zones. The decision to configure disciplinarily diverse cohorts also aims at creating opportunities for peer to peer learning, and at enriching the intellectual atmosphere of the laboratory. Similarly, cohorts are configured with the ambition of achieving cultural and gender diversity. In the Spring of 2019 the cohort was 70% female, an auspicious sign for a technical field. The composition of the faculty body is similarly diverse with affiliates from architecture, art, design, and HCII. While the bulk of the advising and core teaching falls on the shoulders of a few faculty members, faculty affiliates and visiting scholars, including the second author, participate in students’ committees as advisors and contribute to the programme through thesis reviews, lectures, seminars, and events. External guests and lectures supplement the interdisciplinary atmosphere of the programme.

The lab’s spatial configuration shapes the programme’s social and intellectual atmosphere. CodeLab occupies a two-story space of approximately 1,700 sqft adjacent but independent from other studios and classrooms in the School of Architecture. Aside from individual workspaces for 20 students, it provides an area for collaborative work, meetings, and presentations; an electronics workbench; a traditional fabrication workstation and rapid prototyping equipment including a 3D printer, and a laser cutter; several VR and AR development workstations, and a motion capture rig. These resources, and the spatial conditions of this laboratory, support this project’s pedagogical

model of ‘learning by doing.’ In addition, the university offers a lively backdrop for the post-disciplinary atmosphere of the programme, with digital fabrication, robotics, and prototyping facilities nearby. The unusual positioning of the lab within a school of architecture, within a college of fine arts – and within one of the world’s foremost engineering research institutions – has the effect of creating an eclectic intellectual atmosphere where different disciplinary and intellectual sensibilities enter in contact, sometimes in unexpected ways. Students in the programme typically take courses in computer science, design, art, human computer interaction, among others. Faculty in these departments often serve as co-advisors or committee members in students’ masters and doctoral work. The vibrancy of the university’s intellectual environment also entails a challenge, as the gravitational pull of other departments can sometimes overwhelm students and make critical engagements with technology difficult, as will be discussed later.

The laboratory and programme’s singular mission to cultivate creative and critical technical practitioners, its institutional context, post-disciplinary character, and prior history offer a unique context to prototype hybrid pedagogies that put STS and design perspectives in conversation. The following section offers details about how this vision is currently being implemented.

Elements of the programme

Outline: a flexible ‘knowledge-space’

The curricular backbone of the programme is a sequence of ‘research studios’ introducing students to the literature, history, and contemporary manifestations of computation in design, and creating space for hands-on explorations. Aside from this sequence the programme’s curriculum is intentionally flexible in order to encourage students to compose their path through the university with electives as well as extra-departmental courses. Elective courses

and special topics seminars delve deeper into related critical and technical domains. Students flexibly combine these with courses from across campus tailored to their evolving research interests and questions. Through the sequence of research studios students develop a thesis that systematically explores the intersection of computation and design through the iterative definition, prototyping, and/or critical interrogation of technological artifacts. A combination of interdisciplinary mentorship, vertical collaborations, and expert guest reviewers supplement the programme’s curricular activities. The key elements of the programme are described in more detail below.

Research studios: contextualizing technical systems and materializing knowledge

A cornerstone of the programme is a sequence of three ‘research studios’ designed to provide the physical and social space to combine hands-on exploration with critical understandings of historical and social aspects of technology. Through crits, discussions, and hands-on explorations, this sequence of seeks to ensure that research projects are inquiry-driven rather than simply shaped by disciplinary inclinations, industry imperatives, or methodological comfort zones. An additional benefit is that the sequence creates a strong sense of community within the programme, which supports peer to peer mentoring and learning.

The first, introductory studio, ‘Inquiry into Computational Design,’ focuses on ‘the emergence of computation as a pivotal concept in contemporary architecture and other design fields.’² Through readings, writing, and hands-on projects, it explores design theories and practices responding to the so-called ‘computer revolution,’ cybernetics, artificial intelligence, and the linked transformations on our conceptions of design, creativity, nature, body, and place. This studio is collaboratively taught by the programme’s faculty, each conducting a

2-week module exploring topics linked to their own research. Topics include visual and material computation, tangible interaction design, artificial intelligence and machine learning, architectural robotics, and technologies for sustainable design, among others. This introductory studio is followed by a sequence of two pre-thesis studios. While conventional design studios are based on the idea of a pre-defined 'brief,' these two studios guide students through the process of developing their own briefs by identifying an area of research interest, formulating a research question, situating it within a wider scholarly conversation, stating its relevance, and defining an approach to method. Studios offer the intellectual infrastructure for this process by orchestrating assignments, crits, and presentations where participants share research progress and open early research ideas or prototypes to scrutiny by faculty and peers. Questions of method are addressed through presentations by faculty and guests, and through writing assignments. The first of these two studios ends with the definition of a specific area of inquiry and its relevance, supported by a preliminary literature review. The second culminates with a thesis proposal presentation accompanied by early results such as a prototype or a preliminary analysis. Both presentations are announced widely, and are attended by the programme's faculty, students' advisory committee, as well

as guest critics. The final semester is a 'thesis' which culminates on a thesis defense where creative and critical technical practices should converge. Its development typically involves defining, prototyping, and/or critically interrogating a technological system. Students typically work closely with advisory committees within the collaborative atmosphere of the laboratory. (Figure 1).

Independent studies and research groups: focused exploration

Central to the project of bringing together design and sociotechnical perspectives are special topics courses, some of which work as reading seminars, and some of which work as faculty led research groups where students work with faculty members on specific research projects. Illustrating the first category, special topics, is a reading seminar on 'Computational Design: Critical Technologies and Perspectives' conducted in the Spring and Fall of 2018, which covered literature in STS and critical HCI. Readings were organized around three concepts or themes: Critical Practices, Materialities of Computing, and Cybercultures of Design. The second category, research groups, fosters the creation of small teams focusing on specific projects aligned with faculty research while cultivating conceptual and practical competencies. For example, the 'Experimental Archaeology



Figure 1. Students present ongoing thesis work to peers, faculty, and guest critics.

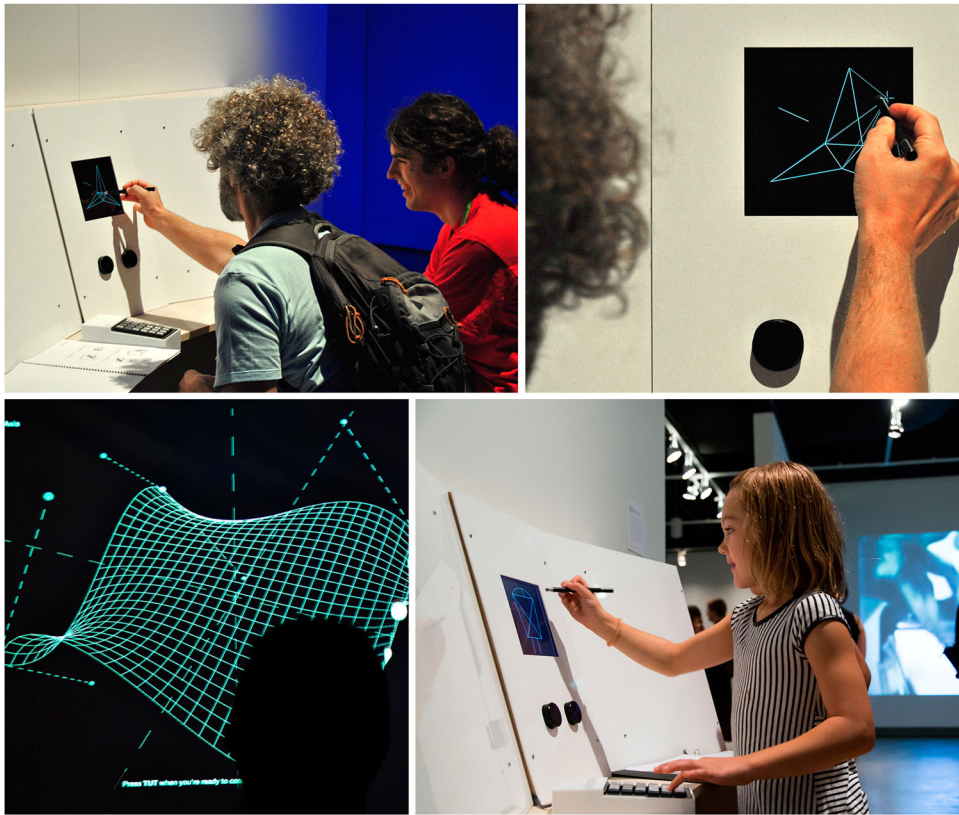


Figure 2. Interactive software reconstructions of Ivan Sutherland's 'Sketchpad' and Steven A. Coons's 'Coons Patch' approximate these systems' visual, tactile, and ergonomic dimensions, configuring an 'experimental archaeology of CAD' (Cardoso Llach 2018; Cardoso Llach and Donaldson 2019). Images by the first author except bottom right by Tom Little, 2017.

of CAD' project explored the early history of computer-aided design technologies through both archival materials and technology prototyping (Fig. 2). Extending frameworks from media archaeology and the history of science and technology, this group creates interactive software reconstructions of early CAD systems that approximate their material, ergonomic, and interactive signatures (Cardoso Llach 2018; Cardoso Llach and Donaldson 2019). Aside from making these technologies' gestural and material dimensions accessible as subjects of historical and design inquiry, this project exposes students to the rudiments of archival research and to basic principles of interactive technology design.

Another illustration of the laboratory's historical sensibility is the research group formed to assist the development of the exhibition 'Designing the Computational Image, Imagining Computational Design' (Fig. 3) and its accompanying symposium 'Computational Design: Practices, Histories, Infrastructures.' The faculty-led 2017 exhibition 'showcased rare photographs, films, high-quality reproductions, and interactive software reconstructions examining the formative period of numerical control and computer-aided design technologies, along with a selection of experimental work by present-day computational designers' (Cardoso Llach 2017). The symposium, on the other hand, brought together scholars and



Figure 3. The Designing the Computational Image, Imagining Computational Design at the Miller Gallery at Carnegie Mellon University, curated by the first author. Photo by Tom Little, 2017.

practitioners in computational design, history of science, media studies, and architecture, to examine computation as a subject of both scholarly and creative inquiry. These two related projects and events were aimed at making visible computational design practices' multidisciplinary roots in postwar technology projects, and to examine their political, material, and aesthetic specificity. Tracing new methods and tactics to incorporate computation as a subject of both critical and creative inquiry in design and architecture, they are indicative of the programme's new direction. Students participated in these in different capacities, for example as curatorial or research assistants, software developers, and designers.

Results

As a post-professional master of science research programme, student theses can be seen as illustrations of the programme's pedagogical approach and intellectual ecology. Accordingly, this section focuses on four recent

theses, highlighting their links to the aspirations and instruments described above. These students' work was selected because it represents different scales of intervention, different modes of critical engagement with technology, and different sociotechnical understandings of design.

Camille: linking feminist theory and VR experimentalism

Camille expertly brought together different strands of CMU research into her own research and thinking process. She first began to investigate work by artists challenging conventional uses of technologies. Drawing inspiration from female artists and academics such as Annina Rüst and Angela Washko – who use technology critically to challenge preconceptions of gender and to highlight different forms of inequality – Camille began to build her own critical perspective questioning the role of online platforms and digital interfaces in subverting or supporting gender dynamics in the United

States. This was the main subject of her paper in the Inquiry seminar ‘The Spatial Future is Female and We’re All Vulnerable Because of It,’ where she observed that as technology becomes more ubiquitous and integrated into the domestic experience, online vindictive behaviour becomes more surreal and charged with sexist intent. After her first semester, Camille focused her research on online harassment, specifically in how it manifests in Virtual Reality (VR) environments. She explored these concerns in the pre-thesis seminars during her second and third semesters, and through courses in the schools of art and computer science educated herself on the intersection between film, game design, computational, and gender studies.

Her thesis ‘Designing for the Hybrid Body: Presence, Representation, and Self in Virtual Reality’ employed a rich methodological repertoire to examine the issue of online harassment, specifically in how it manifests in VR (Baumann Jaegger 2018). Its aim was not only to understand how artistic developments for virtual reality (especially video games) have been designed in ways that reinforce – or shield from scrutiny – vindictive behaviour towards women, but also to re-imagine how bodies are represented in VR. Through a digital ethnography of the multiuser virtual reality game *VRChat*, and a series of VR prototypes she designed, implemented, and tested she probed how different representations of the body elicit distinct social engagements in these emerging virtual worlds (Fig. 4). Her analysis was informed by recent media, STS, and feminist scholarship, which was central to her thesis’ conceptual framework.

Wei Wei: translating between the tactile and the visual

Wei Wei’s research focused on exploring new methods for sampling, codifying, and sensually reconstructing texture information. Prototyping

methods for sampling and simulating real-world textures through haptic devices, Wei Wei’s thesis investigated tactile interfaces that enhance our interactions with computers (Chi 2019). The thrust of his research is a concern with how the experiences offered by present-day interfaces are overwhelmingly visual and two-dimensional, and a desire to develop multi-modal technologies that incorporate other, non-visual, forms of sensory feedback and response.

During his time in the programme Wei Wei combined courses and research engagements in design, computation, and HCI, letting perspectives and methods from these fields shaped his research. For example, in computer science courses he developed strong proficiencies in computer vision and machine learning, which helped him formulate a technically sophisticated research question. Perhaps more importantly for our analysis, Wei Wei developed an interest in how tacit knowledge could be susceptible to haptic augmentation. This question was informed by recent literature in STS and critical HCI interrogating the materiality of digital information, which he explored in the programme’s inquiry and reading seminars. Also crucial were conversations with his advisory committee which, along with the first author, included Prof. Dr. Daragh Byrne and, as an external advisor, psychology professor Dr. Roberta Klatsky.

Wei Wei’s thesis ‘Cultivating Material Knowledge for the Practiced Digital Hand’ documented his efforts to develop a new kind of hardware-software prototype able to capture microscopic textures from materials, making it available for visualization, digital manipulation, and haptic simulation for design purposes (Fig. 5). In comparison with Camille’s work, which made an interpretive use of VR technologies, Wei Wei’s placed a greater focus on technical development. While Camille used technology as a language to formulate and address new questions about inhabiting in and designing computational environments, Wei

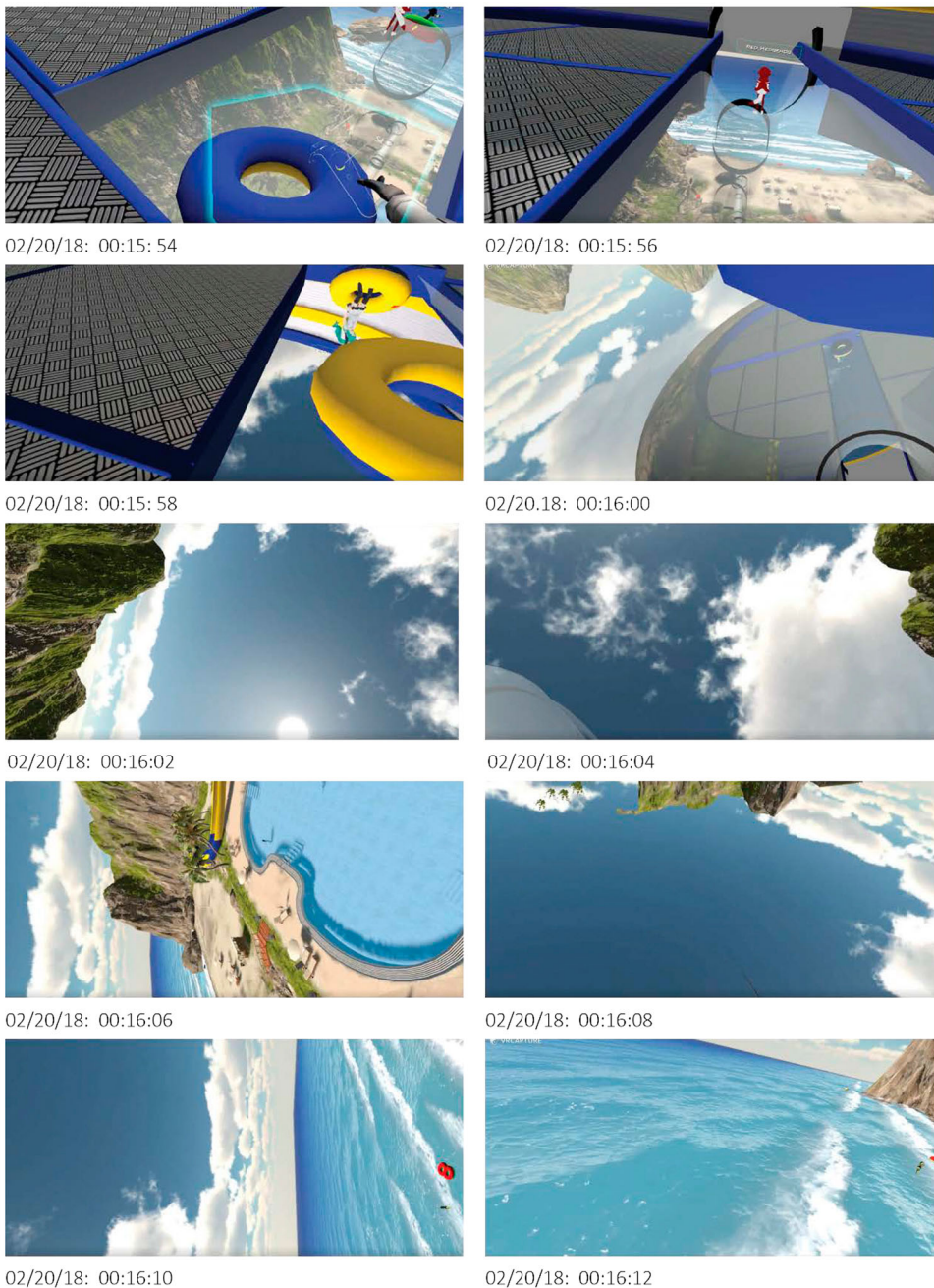


Figure 4. Camille investigated how the level of abstraction of body representations in VR affected user's experience. Image credit: Camille Baumann-Jaegger.

Wei developed a new computational technology in order to enable a new kind of design process, incorporating information about materials' tactility.

Javier: imagining urban data ethnographies

Javier sought to develop new ways to understand how urban space is used by combining spatial

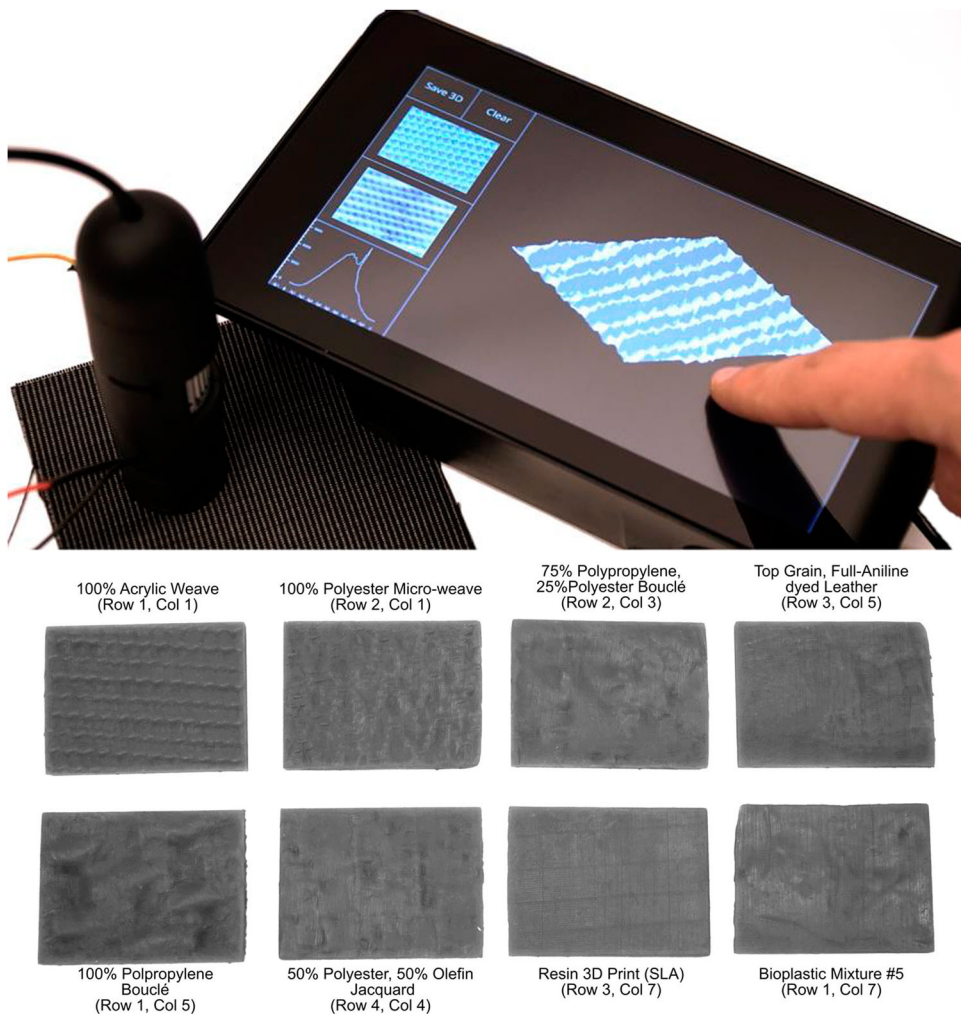


Figure 5. Through a novel kind of software and hardware prototype, Wei Wei investigated how to capture and design with microscopic textures. Image credit: Wei Wei Chi, 2018.

analysis methods from architectural and urban planning with recent developments in data science, machine learning, and computer vision. Essential to his project was the development of new descriptive vocabularies to think about how the interaction between physical environments and urban flows of people, resources, and goods. Building on his prior experience as a researcher and entrepreneur in Spain, Javier explored across the university and acquired considerable technical skills in computer vision, machine learning, network, and spatial analysis techniques. With these, he developed a

framework to document and analyze study the micro-locations of multiple anonymous city actors – people, vehicles, furniture – in urban settings (Fig. 6). The resulting thesis ‘What you See Is What You Get: A Data-Informed Workflow for Architecture and Urbanism’ (Argota Sanchez-Vaquerizo 2018) demonstrates that in combination with algorithmics, and an ethnographic sensibility, micro-location technologies can challenge current revenue-centered applications. The portraits of city life offered by his research point at ways for us to re-imagine how urban space is designed and inhabited.

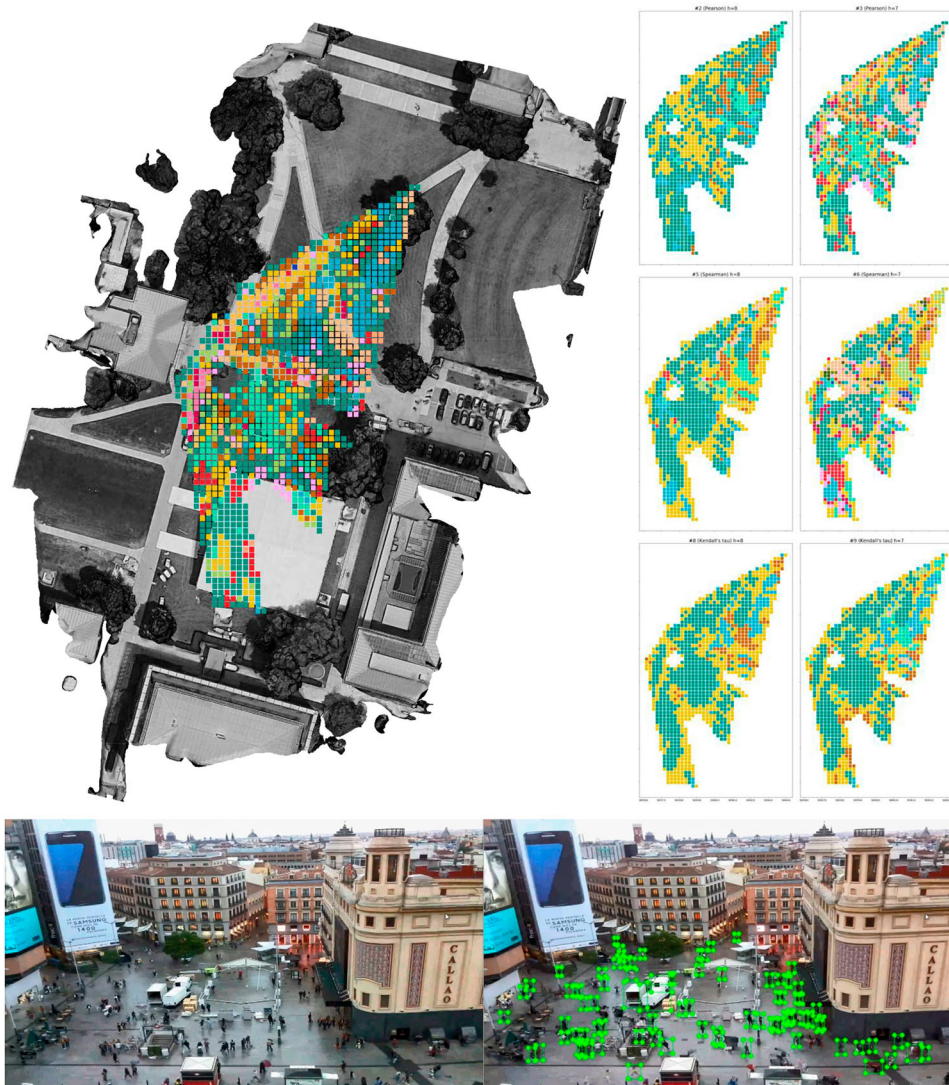


Figure 6. Javier used computer vision and machine learning methods to create detailed portraits of human activity in urban public spaces. Images by: Javier Argota Sánchez-Vaquerizo, 2018.

Importantly, Javier's research required additional support including the involvement of city agencies. After finishing his MS thesis in the Spring of 2018 he stayed as a visiting scholar at the laboratory for one semester. There, he collaborated with CMU's Smart Cities Metro 21 Institute, which supported the project through the Heinz Endowment, and with the city of Pittsburgh through the Pittsburgh Downtown Partnership, which lent additional material support. With

these, Javier refined his technology and conducted a new study of Pittsburgh's Market Square, which resulted in a new type of urban data ethnography of this emblematic public space.

Jinmo: understanding cities through algorithms, and walks

Jinmo's research focuses on applications of artificial intelligence and machine learning in

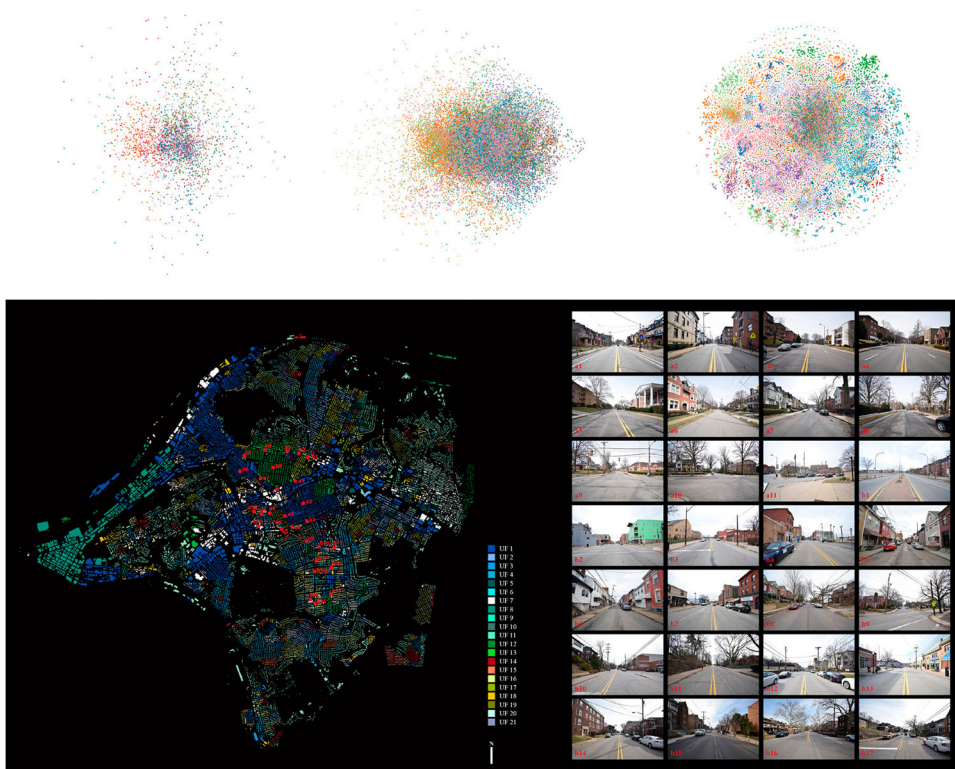


Figure 7. Jinmo combined archival research, visual ethnography, and data intensive computational methods to analyze Pittsburgh's urban fabric. Image credit: Jinmo Rhee, 2018.

urban analysis and design. He developed a computational framework for analyzing urban morphology using deep learning, a subset of machine learning methods that leverages data representations and neural networks. For his thesis Jinmo curated and analyzed large ‘urban datasets’ comprising urban data from Pittsburgh and Seoul (Rhee 2019). His objectives were, on the one hand, to characterize these cities’ urban and spatial features and, on the other, explore the possibility of adaptively synthesizing urban fabric based on their specific morphology. Updating a long tradition of urban research with present-day computational techniques, Jinmo’s toolkit highlighted new opportunities for urban analysis. For example, his study of Pittsburgh’s urban fabric yielded a fine-grain understanding of the city’s different urban fabrics, making visible unexpected

commonalities and contrasts across different neighbourhoods. One of the outputs of this analysis was an urban plan that identified the city’s morphological gradients – a sort of high-resolution ‘heat map’ that varies according to how public and private spaces, heights, and density are configured at every point in the city. Facilitating morphological comparisons within a city and between different cities, this was already a valuable contribution to urban analysis toolkits.

Sociotechnical perspectives played an important role in two aspects of Jinmo’s work. First, in his decision to adopt an analytical and interpretive stance. Rather than imagining his system as an ‘automatic architect’ or surrogate urban planner – as countless computational design projects have attempted to do – he framed his system as a resource in the service

of urban and spatial questions. Avoiding ‘perfect slave’ tropes is not merely a matter of scholarly modesty, or rhetorical sophistication, but rather a feature of any serious argument concerning design and computation – and an important condition of work developed in the programme. Second, Jinmo sought to corroborate and expand the insights offered by his computational analysis *on the ground* through qualitative visual evaluation and through archival research in the city’s historical archives. Thus, in Jinmo’s research, computational methods did not work as substitutes but rather in conjunction with qualitative forms of observation and analysis. (Figure 7).

Conclusions

The experiences documented above offer educators across a range of fields a detailed case study of a hybrid pedagogy that draws from a tradition of design education to put technical and critical abilities in a productive dialogue. Educators in STEM fields such as engineering, information and computer sciences, and human–computer interaction, for example, may find in this article useful insights to make design studios the site of sociotechnical and creative explorations. Conversely, educators in fields closer to interpretive traditions such as STS, information studies, and the humanities may find useful insights to explore technological artifacts not only as subjects but also as vehicles of scholarly and creative inquiry. A secondary contribution is to identify points of convergence between the intellectual and pedagogical traditions of design and studies of science and technology.

The results show that a pedagogy combining design and sociotechnical perspectives has the potential to cultivate a community of creative and critical technical practitioners and learners. Adapting the design studio tradition to reconcile technical and critical engagements with design increases learners’ awareness of technologies’ social and material contexts; highlights

situated understandings and responses to local contexts (rather than abstract solutions to pre-defined problems); and cultivates speculative, exploratory, and critical approaches which can unlock opportunities for reflection and creativity – we summarize these reflective qualities with the term ‘critical imagination.’

Important here is the methodological and thematic plurality achieved. Methods range from historical and archival research to digital and visual ethnography, and from interpretive technology design to data intensive computation. Computational strategies for observation, analysis, and design converge with qualitative engagements with research questions and subjects. Similarly, the projects show a variety of themes and scales of intervention – from haptics to bodies in virtual and urban spaces. As Jinmo’s and Javier’s theses show, technologies can offer valuable materials with which to ask new questions about design, and to generate new insights about the built environment. Through the development of algorithmic methods to explore urban pasts and presents, their research highlights cities’ hybrid digital and sociomaterial construction. As Camille’s and Wei Wei’s theses show, digital infrastructures pose important questions about how we perceive, are perceived, and design digitally – and what this might mean for different design publics. Their research opens up avenues for tactile engagements with design, and for an enriched understanding of bodily representations in VR. The methodological plurality – or promiscuity – represented in these approaches is enabled by the programme’s flexible curricular structure and by its hybrid pedagogy emphasizing critical and creative engagements with technical practice. These works were produced in a flexible knowledge ecosystem structured by both curricular and non-curricular elements. Research projects, special topics seminars, and reading groups, such as the ‘Experimental Archaeology of CAD’ project and ‘Designing the Computational Image, Imagining Computational

Design' exhibition made visible the multidisciplinary histories of computational design as well as broader political, material, and aesthetic contexts of computing. Along with reading and special topics seminars, these helped nurture sociohistorical sensibilities. Aside from offering opportunities for technical and research training, they helped shape students' projects as well as their learning and research aspirations.

While the results are generally encouraging, it is equally important to overview some key challenges and limitations. For example, the programme's ambition to incorporate critical perspectives demands that technological innovation is de-centered as the chief purpose of research and learning. This constitutes a significant challenge at a research university such as Carnegie Mellon – an institution conceptually adjacent to what Suchman has evocatively termed 'the future of everywhere' (2011). The programme's proximity to the technological state of the art inscribes a privilege, but can also make it difficult to adopt a critical distance from a dominant image of technology as neutral and inherently positive. In the reading seminars, for example, it was sometimes difficult to engage with literature that did not construe technologies as *solutions* but which sought instead to investigate them critically. Interestingly, the multidisciplinary composition of the programme and its somewhat eclectic positioning inside a school of architecture and college of fine arts are useful buffers which helped create this distance. In this institutional context the post-disciplinary stance of the lab is a strength, but it is worth noting that the same stance can be a hindrance in its most immediate, disciplinarily specific (and professional-leaning), context of an architectural school. Secondly, while over the last few years the programme has become the centre of a vibrant community of masters and PhD students, affiliated faculty, visiting scholars, and critics, one important challenge is to consolidate a larger full-time faculty group to increase the programme's capacity to advise growing numbers of students

while delivering a critically-engaged curriculum. Currently only one tenure track faculty member, the first author of this paper, has the programme as their focus. While other architecture faculty members and visiting scholars – including the second author – make essential contributions to the life of the programme and laboratory, continuing to nurture this unusual 'knowledge-space' will require an expanded effort involving new faculty and teaching fellows, as well as new alliances with communities inside and outside the university. Finally, this pedagogical project's partial reliance on re-interpreting theoretical and pedagogical frameworks drawn from twentieth century art and design traditions risks importing modernist blindspots and epistemic biases. Identifying and addressing them are critical next steps.

Notes

1. For example, laboratories linking design and critically-engaged technical practice include Concept Lab in Emily Carr, Vancouver (Hertz 2015), Johanna Drucker's SpecLab: Digital Aesthetics and Speculative Computing at the University of Virginia (Drucker 2009), Semaphore at University of Toronto (Ratto 2011), Culturally Embedded Computing Group at Cornell University (Khovanskaya et al. 2017), Center for Interdisciplinary Methodologies at University of Warwick (Marres 2016), and TAT Lab at University of Washington (Rosner, Friedman, and Stolterman 2018). (References cited immediately above are indicative of the specific lab's broader production, or that of their directors or principals).
2. 'Design inquiry' was the name of an academic concentration started at the MIT Department of Architecture in the 1990s which sought to investigate design through a constructionist lens. Aspects of this approach remain to this day in the conceptual DNA of this school's Design and Computation discipline group – in no small part through the seminar 'Inquiry into Design and Computation,' initially formulated by William J. Porter as 'Design Inquiry' and further developed by Terry Knight into its current shape. The 'inquiry'

described here is indebted to and extends this academic tradition.

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