# Prototype Driven Learning and Inquiry: A case study of architectural design and conceptualization

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**Abstract** This chapter provides a situated analysis of an architectural research team engaging in prototype driven experimentation. These experiments are meant to both expand the researcher's own understandings of design as well as contribute to ongoing debates in the field of architectural research and education. The chapter draws on video analysis of prototyping exchanges and discussions in which the researchers explore and reflect on varying digital design prototypes. The analysis highlights different communicative strategies that are used by the architects to explore both digital and non-digital aspects. It is argued that by entertaining these experimental modes of reasoning a number of new possibilities for theorizing architectural practices arise. This includes opening up a conceptual space that allows the architects to indulge in the open-ended questioning of core ideas and techniques that permeate their embodied understanding of the field of architecture.

Across the Social Sciences and Humanities there is a surge of interest in digital technologies and their social impact on both cultural production and capitalistic consumption. Scholars have discussed these effects in relation to a wide array of phenomena and domains, ranging from the influence of social media tools on local political movements to analyses of how DIY technologies are being used by non-scientists to monitor environmental conditions (Ochigame and Holston, 2016; Gabry, 2016). Yet, in architecture, digital technologies are not a new trend. In the mid-nineties prominent design schools and studios, led by the School of Architecture at Columbia, began to eliminate traditional design processes that relied on hand-drawn designs and instead developed a strong dependency on high-end software adopted from the movie industry (Andia, 2002). This rendering software offered more than mere visualisation tools. The software also began to inform and transform the aesthetics of the designs themselves (Cramer & Guiney, 2000). As a result, the topic of algorithmic design has now become so prevalent that a number of design scholars, who earlier on in their careers had adopted this software, have begun to grow weary of the formal languages associated with it. One example is the American architect Mark Foster Gage who has raised a critical eye towards the profession's current dependence on computational software. He sees the widespread prevalence of the design software as somewhat credulous and has called for a deepened discussion about the influence of digital technology since, as he argues, it "dramatically continues to alter how the products of the architectural profession are designed, produced, documented, transmitted, approved, tested, and recorded." (2011, p. 109). In this spirit, some architectural researchers are now actively searching for new ways of using digital software to produce alternative design methodologies by arranging and working through experiments in prototyping (Runberger, 2012).

This chapter examines digital research practices by focusing on a series of experimental moves carried out by ARCH5, a small group of architectural researchers, who are attempting to breach the boundaries of current thinking in architectural design and planning. The research group, which include principals Mary and Petra and their associate, Daniel, employ methodological practices that rely on both the use of non-digital and digital modeling techniques. In the examples explored in this chapter, non-digital modeling techniques range from references of another architect's work to the impromptu use of a garlic bulb to model a design idea. From the digital realm, this includes the use of computer software, like Grasshopper or Maya, which are used by designers to create parametric 3D models. This technology is integral to the design process because it enables architects to create algorithmically generated renderings of architectural designs that are exceedingly more precise than hand drawn models. Moreover, modern architecture is organized around the use of a vast network of digital services and operating systems (Ivarsson, 2010). This is why learning how to design with 3D modeling software is an important part of a novice architect's training. Yet, even after years of professional practice, architects can find themselves working on projects where they have to learn new methods for employing this software. This includes when architects, like the members of ARCH5, engage in experimental research, which involve both the use of digital and non-digital design methods.

The following sections of this chapter examine how prototyping is used by the members of the ARCH5 research team to engage in professional learning and inquiry through prototype driven experimentation. Specifically, we focus on the investigative work that went into the initial conceptualization of a design project that was originally commissioned for a gallery exhibition on sustainable design at an architectural school. In taking this approach, we seek to highlight how the conceptual stage of the design process relies heavily on the use of both digital and non-digital modeling practices. In doing so we argue that digital design and learning are co-productive of one another.

In unpacking this argument, we will first describe the research goals of ARCH5 and the analytical frameworks that we are using to analyze the embodied practices and forms of reasoning that inform ARCH5's research practices. Next, we will examine three examples that were selected from 14 hours of audio-video footage that was recorded over a three-day period in 2011 when the ARCH5 researchers gathered together to work on the initial conceptualization of a design project. Finally, in the last section we build on this analysis through what we will describe as *prototype driven learning and inquiry*. This phrase is meant to highlight how the iterative and conceptual work of these architects, in turn inspires them to rework their epistemological understandings of design by embodying new sensibilities and approaches for digitally creating prototypes that they can analyze and discuss as a group. In doing so the researchers learn to speculate about how their design will be received by their peers and its relationship to the work of other architects and peers who are working on related projects.

## Context: Prototype driven learning in professional architecture

Prototyping as both a method for generating design ideas and means for testing those ideas, has gained increased interest in the social sciences (e.g. Akama et al, 2017; Halse and Boffi, 2016; Jiménez, 2013; Nicewonger, 2018). Analytical work on the social aspects of prototyping is in part motivated by the ways in which design experiments open up opportunities for social scientists to analyze the iterative nature through which design knowledge comes into being and exacts an effect on the material-social world (Ingold 2013). In attending to these processes researchers are not only able to question how design methods influence design trends and movements, but are also able to raise questions about the broader implications of prototyping on learning and inquiry. As a result, a growing body of literature has emerged that examines the roles that design tools, methodological practices, and institutional theories play in the cultural production of design goods and services. In this literature insights are illuminated about how design forms are socially created, while also generating theories about knowledge production, more generally. This case study contributes to both of these perspectives by examining how digital learning and design knowledge in architectural research are transformed through experiments in prototyping.

Research conducted by architects on the methodological effects of design practices is important to the field of architecture because it questions the normalization of professional practices and opens up analytical spaces for rethinking architectural possibilities (Nilsson, 2013; Chapter 5 this volume). As the architectural scholar Jonas Runberger argues: "Throughout history, representational modes of architecture enabled or restricted architectural design" (2012, p. 21).

In a similar vein, ARCH5's research over the past decade has sought to disrupt digital design methodologies as part of the group's wider interests in identifying alternative approaches for generating sustainable design innovations. In the process, this work has allowed them to engage in debates about the relationship between the aesthetic and methodological effects of digital technologies on architectural practice and emergent sustainable design movements. This includes two recent projects carried out by the principals of ARCH5, Mary and Petra, where they explored fabricating techniques for designing rooftop landscapes (i.e., roofscapes). This research was inspired in part by the organic processes through which plants and naturally occurring materials break down. Influenced by the architectural theory of entropy that Japanese architect Kisho Kurokawa originated, Mary and Petra worked to integrate entropic processes, both literally and analogically, into their design work. This included designing fabrication techniques that allow for certain segments of a roofscape to safely degenerate. But it has also involved designing prototyping methods that break away from highly controlled machine processes, such as by algorithmically programming a CNC mill so that it cuts an irregular and in part unpredictable series of grooves into the surfaces of wooden planks.

This was possible because the instructions embedded in the algorithm only contained information about the vector-shaped incisions. As a result, the physical properties of the wooden material and the dimensions of the CNC drill-bit would also control the shape of the end product. The purpose for making, what they described as vector-infused planks, was to identify fabrication methods that they could use to strategically line certain sections of a building's external roofing structure. In doing so, Mary and Petra sought to identify a method for including design elements that would slowly deteriorate and create habitats for plants and insects on the roofscape.

While ARCH5 has yet to use this method in the design of an actual building, the prototypes that emerged from this research have circulated widely among their peers via architectural exhibitions, online curatorial sites, and in published articles. Thus, they represent one of the central means by which these architectural researchers engage in professional learning and inquiry. More importantly, the prototypes provide Mary and Petra with a means for intervening in knowledge making processes by illustrating how improvisational activities, like hacking a CNC mill, can generate alternative "architectural languages" and design styles. It also provides a jumping off point for exploring new methods, like the creation of prototypes examined in this case study. Consequently, unlike the example just described, the work being analyzed in this chapter focuses on a particular phase of the design process, which Mary and Petra call: "investigations."

Investigations, as they explained, begin at a point in the design process where deadlines are less of a concern (cf. Ochs and Jacoby, 1997). This means that the group is purposely allocating time to the exploration of design methodologies that may reveal sources of inspiration. Thus, unlike the example described above where a prototype is circulated among experts to gather further insights for the development of their design, in the phase analyzed here, the aim of the architects is to take a design technique that they find promising (but which they know very little about) and find a way to digitally conceptualize it as a sustainable design model. Subsequently, the following analysis draws on a series of interactions where ARCH5's principals, Mary and Petra, along with their colleague Daniel who they invited to work on this project, begin to "investigate" their design ideas. Integral to the analysis of these architect's design practice is the study of the embodied interactions.

**Embodied interaction as an analytical framework**
Embodied interaction is an analytical framework for examining how recognizable and exchangeable actions are co-produced through multimodal activities (e.g. Murphy, 2012; Keating and Jarvenpaa, 2011; Goodwin, 2000). This framework is used to understand how certain processes are organized; the consequence of those practices; and the kinds of labor required to carry out certain activities. Analyzing embodied processes requires attending to both the verbal interactions between actors as well as how actors employ a wide range of conceptual, material, and interactional resources. As Jurgen Streeck, Charles Goodwin and Curtis LeBaron write:

> These embodied orientational frameworks create local environments where participants can treat each other as attending to, and working together within, a shared world of perception and action, something crucial to the way in which… [actors] are building action together by attending to how each other is interpreting and operating…. (2011, p. 2)

Drawing on this analytical framework, two central ideas are important to keep in mind when analyzing digital learning in contexts where architects are conducting design research. First, "face-to-face interaction is a central place where language emerges in the natural world" (Streek, Goodwin, and LeBaron, 2011, p. 3). This means that the conceptual discourses, descriptive gestures, and narratives through which design forms are given semiotic-material qualities manifest out of

designers' interactions with not just each other, but also the semiotic-material tools of their profession (Murphy, Ivarsson, and Lymer, 2012). Second, contexts where designers are engaging in digital modeling with their peers are productive sites for examining these processes, because it is in the act of both working with digital software and tools, as well as reflecting on these practices (often through talk) that particular ways of communicating and perceptually evaluating design practices become observable for social analysis (Ivarsson, 2009; Murphy, 2012). In the interactions examined here, this includes qualitative assessments made by the architectural researcher as well as references to the work of other experts and the use of cultural idioms and references. It also includes a host of non-verbal actions, such as the improvisational use of an object to express a design idea (see examples below).

These multimodal actions aid actors in speculating about the value and meanings they want to express through a particular design as it is being created. This means that digital modelling involves more than just representing or translating an idea that has been preemptively crafted in the secreted recesses of a designer's thoughts (Hallam & Ingold, 2007). Rather digital design is considered in this chapter as an active, emergent outcome of the embodied actions through which digital design models are iteratively created to carry out architectural research (Nilsson, 2013). Another way of talking about this process is to say that the embodied work of digitally rendering a design is distributed across multimodal activities; a perspective that design anthropologist Keith Murphy expounds upon when he writes:

> With few exceptions… [design] studies tend to emphasize individuated embodied skill and action while passing over—or treating as "context"—the dynamic interactional and indeed conversational frameworks in which much creative work is embedded. But I take very seriously the contention that the details of making things, in the moments of making them, matter; that "in the act of production, the artisan couples his own movements and gestures—indeed, his very life—with the becoming of his materials, joining with and following the forces and flows that bring his work to fruition" …. (2015, p. 27)

Building on this analytical approach, in this chapter we want to emphasize how digital model-making is made sensible to the architects being analyzed here through both their engagement with the modeling software and the reflexive discussions they have with one another about this work. These embodied and technologically mediated practices thus reflect a productive site where design actions are being mediated as well as contribute to knowledge production in architecture design research.

One way to do this is to distinguish between different phases of the design process that invite particular kinds of analytical reflection and experimentation by the designers in ways that may be less evident in other phases of the design process. Specifically, we want to draw attention to the investigative work that goes into the design of a prototype versus the use of prototypes to gather feedback from peers and other specialists whose insights about building processes can further advance an architect's ability to imagine the implications of their design on the built environment. The investigations we are adhering to here can tell us about how the researchers explore their design ideas by developing new sensibilities and how they probe into the inner qualities of materials, as well as conceptualize those materials, in search for unexpected discoveries and new forms of material resistance/biases. This dual mode of conceptually inquiry and more open-ended sensitive exploration—alternating between *shaping* and *sensing* the phenomenon at stake—is what we call *prototype driven learning and inquiry.*

**Example 1: Searching for design expressions through "investigative work"**

Mary is sitting in front of a laptop computer where she is searching for a design on her computer screen. Suddenly she exclaims: "There it is! There it is!" Instantly, Petra and Daniel look up from their own laptops and begin to study her digital design.

A few seconds later, Petra offers her evaluation of what Mary is displaying: "But could they have some other shape? They don't have to be so circular," she asks as her eyes look over at a garlic bulb that had been left on the table where the architects were working. Reaching for the bulb and then holding it up in the air (see Figure 1.), Petra continues her thoughts:

> "I mean couldn't you have more of anoth– almost like the [Isamu] Noguchi. They don't have to have a symmetrical form or shape. If you didn't know this was a garlic bulb, if you wouldn't have all the tectonic features of a garlic, you would really read it as something else. So, to start to deform it then the garlic is just a point of departure [for our design]. But the symmetry of the garlic, [is something that] we [can] go away from."

In this short interaction, the digital and improvisational acts that inform the architectural design of a prototype for a sustainable roofscape are made evident through a series of interactions involving three architects, the digital technology they are using to design a 3D rendering of a prototype, and a garlic bulb. The work illustrated in this interaction is not geared towards producing plans for buildings in any immediate sense, and, the primary audience is neither contractors nor builders. Rather Mary, Petra and Daniel's primary audience are the other architectural scholars and students that they imagine will participate in an exhibition that will include prototypes that are inspired by the experimental investigations they are working on in this interaction. This means that the intended outcome of this work is dual in character: the architects were both making some form of an object or physical prototype, while also working to produce a narrative or explanation that



Figure 1: The upper image provides a contextual illustration of how Petra, Mary and Daniel collaborated when they were digitally carrying out what they referred to as "investigations." This includes using modeling software to create digital prototypes as well as non-digital resources to critique and reflect on their digital design work (see also Figure 2). The latter activity is depicted by Petra, in the front of the image, who is holding an object up to the others. In doing so she makes a curved gesture with her finger and thumb, which helps her communicate a relationship between the garlic bulb held in her left hand and the expression she is attempting to gesture with her right hand. As illustrated in the examples below, both a garlic bulb and shallot played important roles in communicating design ideas in multiple interactions between the three architects.

could accompany the prototypes (in both written and verbal forms) when the they are eventually exhibited. As a result, during this work session Mary, Petra and Daniel were simultaneously engaged in both material and conceptual investigations. That is, on the one hand, they were working towards completing "physical manifestations" of their design, which they sought to represent through a series of material objects. On the other hand, they were striving to develop and articulate some "central ideas" that they could draw on to speculate about how their peers will interact and interpret the physical manifestation of their design ideas/theories.

Consequently, these investigations produce interactions that inspire conversations about the affordances of their digitally produced design models. These interactions, we argue, are an example of how these architects search for "a new language" for expressing their design ideas. In this case this includes the use of a non-digital form (i.e. garlic bulb), which the architects use to rethink and expand the design ideas they had initially created using digital modeling software. Therefore, while there is a dual orientation underlining this interaction and the design work it produces, in both cases it can be argued that the researchers are engaging in embodied, iterative practices through which they explore their design ideas via digital modeling and communicative analysis. Through these investigations they learn to embody and generate new understandings about the digital software they are using and more generally, their thinking about sustainable design.

**Example 2: "Swooshy": Past architectural work and the search for "newness"**
This exchange begins as Mary shares a digital design that she has been working on with Petra and Daniel. As she turns her laptop screen towards the others so that they can see the display, a series of digital objects that were created with a modeling software called Maya come into view. As Petra and Daniel study the screen they begin to recognize the objects as belonging to a past project that Mary and Petra had worked on several years before. This design, Mary reminds them, worked with a series of "nested layers."

While still studying the objects on the screen, Petra and Daniel begin to affirm Mary's recollection of the design by jointly uttering, "yeah, yeah." In turn Mary continues to deconstruct the digital model further by describing the layers as having a "flat surface."

Seemingly encouraged by Petra's appreciation for the layered processes that were used to create this model, Mary then suggests that they draw on a similar technique in their current work, to which Petra interjects: "Yeah the only thing [is] I like the [name of the project] …. I think the "logic of working [out] of a surface, with [name of the project] was very good."

In response Mary agrees with Petra's observation, while also adding that the "layer" effect of the model allowed them to achieve "a nest" like quality in that work. But as Mary describes the nested nature of the models, Petra suddenly, begins to argue: "But this, these parts, get really; a little bit Zaha Hadid-ish." In making this reference, Petra cites the work of a renowned architect. Expanding on this point further, Petra relates the model's pointy edges to the work of the famous architect in order to argue that the "tip of them [i.e. the model] become…very swooshy."

In addition to making these references, Petra also engages in gestural work as she talks about the digital design (see Figure 1). This includes incorporating a physical object from the surrounding environment to elaborate on her idea. Specifically, Petra picks up a shallot that is lying on the table. As she does so she utters: "the tip of them", while she simultaneously uses her thumb and index finger to outline the top-end of the shallot. The words "the tip of them" are made in reference to the digital design and together the gesture, talk, and objects under inspections allow her to

describe the affordances she is suggesting they incorporate into their digital design. In other words, by using gestures and talk to show relations between the digital design and non-digital objects under discussion, Petra is able to use the physical properties of the shallot as an aid in articulating the so-called "swooshy" feature of the digital design that she and her colleagues are assessing.



Figure 2: These images represent different stages of ARCH5's investigations. The first image is of a simple 3D printed prototype brought to the meeting as an inspirational resource that the researchers could draw on as they carried out their prototype driven experiments. The middle image is of a shallot and a garlic bulb. As we describe in Example 1 and 2 the garlic bulb and the shallot become important non-digital resources that the architects improvisationally incorporated into their modeling practices. Finally, the last image is of a preliminary version of the sustainable roofscape prototype that was informed by the "investigations" analyzed in this chapter. The expressive forms of these prototypes were originally created using digital software (e.g. Maya and Rhino). This prototype, however, reflects only part of a more intricate set of prototypes that made up the work that was eventually exhibited by ARCH5 at an architectural school gallery.

Building on these interactions, we want to draw attention to how Petra points to the screen and says: "these parts." This indexical expression and its accompanying gestures make clear that the object under scrutiny is not the entire model presented by Mary but some selected aspects of the model. When the referential ground has been established Petra offers a characterization of the "parts" as "a little bit Zaha Hadidish." What has happened here is that the proper name, Zaha Hadid, has been inflected with the added suffix "–ish" and is now meant to be heard as if it were an adjective. That is, the name is used as a stand-in on behalf of the architectural style associated with that name. This in turn implies that the detail pointed to by Petra is to be seen as a form of design that one could find in the catalogue of Zaha Hadid, a celebrated architect whose work is well known in academic design circles. The use of the shallot to further illustrate these qualities underscores the associative and analogous forms of reasoning that that these designers use to fluently move observations and experiential qualities between different media. For a moment, and only for the practical purposes of communicating this specific idea, the shallot becomes a physical manifestation of their previous design work, which they see as exhibiting Hadid-like qualities. As soon as it is returned to the table it resumes its previous status as a mere vegetable which may or may not be invoked in further exchanges.

**Example 3: Speculating about water and their design's contributions**
In this final example, we explore how the investigations that the three architects carried out on this project exhibited a constant inspiration for moving back and forth between material and conceptual considerations. Because of the open-ended nature of what was to be produced, the discussion could move in any direction between the two modes of investigation, neither was primary. This meant that a discussion about a particular material investigation could touch off questions about what kind of *idea* the design form would be an exemplar of. Or it could produce reasoning that worked the opposite direction, as in discussions about how to realize materially an investigation of a certain concept. Recurrently these two aspects and their interrelationship were addressed throughout the prototyping work sessions. A case in point is the following interaction, where Mary, Petra and Daniel gather to reflect on their work after conducting several hours of digital

modeling investigations. Central to this discussion was how the concept of water, which they viewed as a central part of their design, should figure into the next set of explorations they wanted to conduct later in their investigations.

Turning to Daniel and Petra, Mary begins to share her ideas by talking about her thoughts for exploring ways of relating concepts to sustainable techniques for reclaiming water, by saying:

> "I still think it's really important [that the design addresses] the notion that it is part of the roof and that it does in some way channel water—not literally in[side] the gallery but that it is designed to show its involvement with water…. I think that is kind of important."

In agreement Daniel nods, while saying "Yeah." Petra in turn utters her agreement, which encourages Mary to expand on her point further by saying:

> "Otherwise it is a different [project]. More like a Romero project, where it is about a certain investigation, a line moving through space. But I think that the investigation we have had on the table has been this kind of hydrophobic and hydrophilic performance and how the form and the material collaborate to do a certain performance. …."

In turn Mary expands on this point by referring to a certain aspect of the digital design, saying:

> "So maybe water sits in there… and at a certain point when it fills it starts to trickle over… and it is somehow designed in terms of the macro porosity to channel. I mean that is what I think is crucial, that when you look at these material treatments and formal logic, [if they] are both going to work [we have] to do something with water."

Reflecting on Mary's analysis, Petra intercedes with a question: "But I thought… that is what is on the table… which is something we would continue with. And I totally agree that is extremely important and we have already invested time."

Mary in turn responds by bringing the conversation back to the subject of water. She argues: "when we talk about the cascade of catastrophic change … it is still important that we think how this will engage with water."

"But" Daniel asserts, "before [today] the answer to that was kind of clear because [our earlier design] had a continuous surface that [collected and engaged] with water. And if we don't have that, then I don't know what it is."

"Maybe it's more like the Francoise Roche thing where you have these sort of drip situations," suggests Mary.

In this exchange, the future qualities of the exhibited design are discussed and reflected upon as part of a conversation that questions the supposed shared understandings of their design investigation up until this point. Petra is pointing to the importance that the object, which would later be characterized as a "prototype for a hydrodynamic green roof tile", retains its connection to water on a conceptual level. So, while actual water will never be present, the object should nevertheless be perceivable as being "about" water. In other words, discourse about water must be fitted to the design as a relevant component of the work as a whole. In this way, the communicative work

that will go into the design exhibition's display and write-up are seen as emerging from the co-productive work that informed their initial design investigations. In this case this includes both the design of forms that will allow water to interact with the physical forms of the roofscape as well as techniques for talking about its relation to water. Together this reasoning will affect how the design is understood as an example of sustainable architecture.

An additional aspect of the work analyzed here is how it is socially situated in a professional landscape of other projects. Later in the researcher's discussion about their work to a certain point, Petra expressed this concern along the lines of "I was just trying to think through the problem like in terms of, ehm methodologically how, what is the discussion that we want to engage with?"

This formulation not only points to the conceptual and methodological development that is seen as a requirement of their own work, but it also highlights its social relations. Within the scene of contemporary architectural research and design, exhibited projects are assessed on their original-ity and contribution in terms of conceptual innovations. To be successful a project must not be conceived of as copying ideas from others. This is a primary concern for the studied group and some of the ways that they keep track of current developments is by updating each other on other designers and by describing details of prior projects. At the same time, there is a risk in straying too far from the current scene. To establish relevance their own work has to be situated in relation to some on-going discussion happening within their group of peers. In these terms, one goal of the project was that it should be understood as, first, *engaging* with some discussion, and second, as significantly contributing to that discussion. *Which* discussion however or what kind of issue or problem they were to tackle, was an open question.

**Prototype Driven Learning and Inquiry**
As illustrated above, digitally produced prototypes are used to destabilize the processes by which representational forms in architecture are generated and understood as interventions for reworking knowledge epistemologies in architecture. In the process of carrying out these experiments, the ARCH5 researchers are able to open up spaces for experimenting with techniques that require them to embody new sensibilities for digitally exploring their design ideas using modeling soft-ware. Thus, each example illustrates the role that digital and improvisational activities jointly play in ARCH5's efforts in designing a prototype for an exhibition on sustainable architecture.

Learning in this context occurs on two levels. The first level arises via the insights about architec-tural design that the architects gain as they conduct their experiments and work on their proto-types. Learning in this context is shaped by the iterative processes of design (Schön, 1984). The second level occurs through the speculative exchanges and discussions that the architects have about how the forms will eventually be perceived by their colleagues and students at the gal-lery exhibition. Learning in this way is illustrative of how professional inquiry and development is organized in architectural research communities and thus must be understood as a particular kind of knowledge production, one that is circulated and debated through the speculative work of design experimentation. Together, these two processes generate contexts for engaging in *prototype driven learning and inquiry*—a phrase that brings together important insights for understanding how digital design and learning are transformative of one another.

The philosopher of technology, Marx Wartofsky, argued some fifty years ago, that the "model pro-duces more than it contains" (1968, p. 144). There is, in other words, social and technical insights embedded in the aesthetic and material make up of a design model that exceed the intentions that

go into its initial development. This excess is not just tied to the technical aspects of the prototype, such as the expertise needed to digitally create a particular form or shape. Rather this excess also points to the model or prototype's ability to inspire embodied material-aesthetic insights and new modes of reasoning.

These insights and new realities are gained through the practice of creating a digital model or when a designer uses a prototype to critically question an architectural design trend or style (i.e. as it is understood by makers of said prototype). This point is evidenced in ARCH5's exploration of curved shapes as a way of identifying a new architectural language. In this way, the shape of the garlic bulb and a shallot are introduced into the design process at different points as a way to generate feedback loops across digital and non-digital social worlds and design methodologies.

Why does this matter? It matters because it points to the embedded assumption that something can be learned and brought into the world through experimentation and inquiry as a socially meaningful design investigation that has the potential to inspire insight and knowledge about sustainable architecture. In this particular case study, the architects' concern for the aesthetic effects of a curve, are rooted in their commitment to promoting environmental thinking and theory in architectural design. To breach the contemporary paradigms of architectural practice, they draw on the garlic bulb and shallot as an intervention for reframing their conceptual practices. In this way, we can also understand the reference to "swooshy" as an attempt by Petra to capture an aesthetic feeling that she believes might inspire the group's ability to imagine/speculate about their design in new ways. In doing so she uses swooshy to link the conceptualization of their prototype (i.e. of a roofscape) to the expertise needed to model it and vice versa. In this case, this included the work of a famous architect, who the researchers' had to develop a reason for why or why not their design would be in conversation with that designer's well-known work. Hence, references to particular languages of forms and shapes inspire embodied actions that are grounded in social ideologies and imaginaries associated with known designs. These embodied actions feed back into the digital design work that inform Mary, Petra, and Daniel's investigations.

Thus, the examples drawn on in this chapter point to the educative work that is generated through the conceptualization of prototypes; a perspective that is heightened by the highly conceptual context in which the examples drawn on in this chapter belong. This context is dedicated to professional development and inquiry in architectural research, and thus represents a purposely created praxis or analytical space for objectifying design practices into conceptual spaces that inspire the designers to extend, rework, and at times invent technical and embodied methods for achieving new environmental relationships through their prototypes' design. In the process, designers learn to attend to certain possibilities for achieving a social good through their design work, i.e. a design prototype that can be exhibited as a method for designing sustainable roofscapes.

As our analysis has shown, the prototype driven work of engaging in professional learning and inquiry cannot be separated from representational tools for rendering architectural models, which in this case involves both digital and non-technical techniques. These two sites of communicative and representational practice are co-productive of one another. In this way, we can see how the forms of excess that Wartofsky refers to is reflective of interior and exterior forces that manifest through embodied practices. These practices are both influencing and are influenced by the embodied processes of conceptualizing prototypes.

**Conclusion**

This chapter probes the learning and research processes that emerged out of the initial conceptualization of a sustainable design prototype that was being created for a gallery exhibition at an architectural school. In doing so the analysis presented here focuses on the initial work that went into the conceptualization of this design project, which the architects refer to as a period of *investigation*. This phase within the design process is characterized by iterative experimentations and is thus packed with multiple examples of how the inter-relationship between the embodied techniques used to digitally generate models of the architect's design ideas are critically reflected upon through communicative interactions among the three architects that made up the research team. Specifically, this chapter highlights three different communicative examples that are used by the architects to explore both the digital and non-digital modes of reasoning that informs their experimental work. This includes the importation of objects to represent material affordances that are then used to reinterpret the shape and "feel" of a digital model. It also includes drawing attention to the work of other architects by using affective descriptions, like the word "swooshy" to illustrate overlapping styles. Finally, in the last section we saw the emphasis on their design having to retain conceptual links to the core ideas of the investigation when the prototype is to move out into the world and has to stand on its own. Taken together, this chapter highlights three different ways in which the architectural researchers informed or shaped their design so that it would elicit certain responses and readings by a targeted social group of design scholars.

In conclusion, by entertaining the experimental mode of reasoning a number of new possibilities for theorizing architectural practices arise. This includes opening up a conceptual space that allows the architects to divulge in the open- ended questioning of core ideas and techniques that permeate their embodied understanding of the field of architecture. In turn, this practice points to one the primary venues for professional development among architectural researchers, like ARCH5, in that it is central to their ability to carry their understandings of design further, and thus learn about new forms of reasoning and designing sustainable architecture.

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