Constructing Information
Towards a Feedback Ecology in Digital Design and Fabrication

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As strategies evolve using digital means to navigate design in architecture, critical process-based approaches are essential to the discourse. The often complex integration of design, analysis, and fabrication through digital technologies is wholly reliant upon a process-based necessitating the use of a design feedback loop, which reinforces critical decision-making and challenges the notions of how we produce, visualize, and analyze information in the service of production and assembly. Central to this process-based approach is the effective and innovative integration of information and the interrogation of material-based explorations in the making of architecture. This fabrication ‘ecology’ forces designers to engage complexity and accept the unpredictability of emergent systems. It also exposes the process of working to critique and refine feedback loops in light of complex tools, methods, materials, site, and performance considerations. In total, strategies for engaging this ‘ecology’ are essential to accentuate our present understanding of environmental design and theory in relation to digital processes for design and fabrication.

This paper recounts a design/fabrication seminar entitled “Constructing Information” in which architecture students examined an environmental design problem by way of the design feedback loop, where their efforts in applying digital design and fabrication methods were driven explicitly by material and site realities and where their work was executed, installed, and critically explored in situ. These projections raise important questions about how information, complexity, and context overlay and merge, and underscore the critical potential of visual, spatial, and material effects as part of a fabrication-oriented design process.
1 Introduction

Digitally driven technologies and methods have expanded the discourse in architecture relative to ‘fabrication.’ Digital fabrication is both material and immaterial, pushing the limits of experimentation while working with the imperatives of manufacturing and computational design. The process has been fundamentally characterized by the term “feedback loop” (SHoP 2005), where formerly discreet digital methods are part of fluid decision-making design process, which plays out in the service of production, assembly, construction, translation, perception, and design iteration. In contrast with notions of ‘universal space’ and ‘universal design’ established in modernist discourse, the approach of the feedback loop is highly mutable: design here is a process rather than a singular, fixed objective, and design’s decision-making threads are freely informed by conditions from code, material, context, and fabrication. Michael Hensel and Achim Menges write of this transition from ‘universal space’ to new models of process and practice:

A remedy may be found in an understanding of architecture as ecology, involving dynamic and varied relations and mutual modulation between material systems, macro- and micro-environmental conditions, and individual and collective inhabitation. The proposed approach to architectural design is based on the deliberate differentiation of material systems and assemblies beyond the established catalogue of types, on making them dissimilar or distinct in degree and across ranges HENSHEL AND MENGES, 2006

Projects emerging from the feedback loop are ‘organisms,’ in that they are products of the relations of circumstances by which they are conceived and interrogated. In this sense, the digital design to fabrication feedback loop is, itself, an ‘ecology’: a system of relationships involving projects and their circumstances. The familiar paradigm of environmental design is evident here: the environment being the circumstance of the thing, rather than solely things. Thus, it may be argued that the exercise and discourse of the feedback loop branches from environmental design, rather than from experimentation solely in form and technique. For example, the work of sculptor Richard Serra is more than just ‘thing’ or artifact, and also more than the process of contriving geometry: Serra’s work is intended to be seen and interacted with, thus its importance is not as an artifact, but an artifact existing in the dimension of the environment.

In contrast, the technological methods of making (logical parameters, scripts, coding, production factors) and the tools of execution dominate the discourse of many digitally-designed and fabricated projects, rather than their circumstances; nonetheless, they may qualify as ‘environmental’ projects by way of their unique contexts and locations (building facades, interiors, landscapes, ceiling installations, furnishings, and so on), in spite of a direct intention to incorporate environmental factors in the genesis of the projection. Chris Abel, in reference to the work of Norman Foster, dismisses the use of technology solely
“for abstract or static form making” in favor of technology as “an instrument of integration across the entire range of environmental design, production in use” (Abel 2003, 9). Abel, consequently, refers to the integrated work of Norman Foster as an ‘electronic ecology.’

While the generic fabrication project aims at form and technique alone, the design to fabrication feedback loop as ecology promises to inform an environmental approach in a twofold manner: through information, operating between representation, simulation, and effects; and through construction, operating between assemblies, production, and materials. Here, the environmental-technological entanglement is strikingly similar to the conditions of the 19th century following the implementation of descriptive geometry. Descriptive geometry’s methods supplied new tools for representation and documentation via projection and perspective, while concurrently introducing new tools for the precise construction of artifacts and implements (Perez-Gomez 1983). The duality of representation and construction via descriptive geometry established, as its own ‘feedback ecology,’ a push for both contemplating geometry in design and perception, and for enhancing industrial effectiveness. Today’s digital tools for designing and making imply a comparatively influential feedback ecology while working simultaneously with information and construction.

This paper asserts that the feedback process between digital design and fabrication is an ecology, not simply ‘looped,’ but an exercise of recursive design and decision making informed both by technology and environmental theory, rather than technology alone. Pedagogical instruments illustrate the argument, both in technological and environmental dimensions. In the spring of 2008, Ball State University architecture students examined an environmental design problem by way of the design feedback loop, where their efforts in applying digital design and fabrication methods were driven explicitly by material and site realities, and the work was executed, installed, and critically explored in situ (Figure 1). The student projections raised important questions about how information and context overlay and merge, and raised the critical potential of visual, spatial, and material effects as part of...
a fabrication-oriented design process, while elevating the discussion towards the implication of fabrication as ecology.

2 Feedback Ecologies of a Fabrication Project

In the context of a semester-long design project, students engaged a design problem involving an environmental construct emphasizing the digital feedback loop. The construct, at the schematic level, was charged to address an internally directed, computational logical response to a specific environmental condition and function.

Preliminary exercises to create a particular environmental construct were selected from the following list: wall cladding, curtain wall interior shading, suspended ceiling, privacy partition, interior passage point, skylight interior shading, overhead light diffusing screen, interior furnishing. Students were asked to define the conditions of the design problem in terms of environmental effect; that is, clearly defining combinations of conditions from which objects could respond (sunlight, artificial lighting, acoustics, ergonomics, experience, media, movement, touch, or climate). Computational design methods were introduced in a set of workshops, followed by a workshop presenting methods for environmental simulation related to the set of criteria mentioned above. Sites for the projects remained intentionally abstract, to allow students to narrow their conceptual focus on particular effects and relationships. Following individual inquiry on stages of the feedback loop (Figure 2), students assembled into two teams assigned to select a site, within or around the college’s building, in which to interrogate and install their designs. Issues related to each conceptual stage were as follows:

1. Design and Visualization: Setting up design problem, environmental conditions, and ‘project image’
2. Informed Form: Structural rationalization, integrating information through scripting and parametric modeling, and creating causal results.
3. Design and Analysis: Development of an integrated approach to environmental, structural, and material conditions of design and linkages to simulation and fabrication methods.
4. Concept to Fabrication: Final design development, with students proposing project scope, site, and fabrication prototypes in two teams.

The feedback ecologies of the project were manifest at multiple levels. First, in the development of the individual projects, various methodologies introduced to students were adopted not as hermetic exercises, but as part of looser process inquiries where intentions, computational technique, and environmental conditions became interrelated in the conceptual scope of each project. The strongest individual projects were identified by this scope of relationships—a feedback ecology. A second order of the feedback loop emerged in the final stages of development, when the individual projects merged first into two project hybrids, and then into a single ‘super project’ where all students collaborated. In addition to contributing their own expertise and influence, there was an observable pattern of influence that the individual projects had on the final project, independent of original authorship. In this case, several feedback loops became a larger ecology—a collaborative exercise that linked the intentions, computational technique, and environmental conditions of each project (Figure 3). This merging strategy underscored the emphasis of the course towards an environment-critical process over a premeditated ‘object’; by way of the feedback loop, the focus on iterative development over end product encouraged integrative, and collaborative problem solving over homogenized, individual expression.

The final project occupies a small section of curtain wall windows in an elevated but public section of the architecture building. The students were drawn towards the site location at the end of a short transition hall to a frequently used stair, as it offers opportunities for people to see the project while moving—both in parallel with the windows as they pass by the main hallway, and in line with the installation when moving towards the stair. This area also faces a large common area, which is advantageous at nighttime as the aperture, as a result of interior lighting and its position in the building, frames a unique view to the interior from the outside. The curtain wall itself opens up to the south, flanked by two brick-
surfaced walls, providing the site with well-defined sunlight geometry (Figure 4). Beyond the curtain wall lies an exterior entry terrace, sunken one full level below. Here the exterior terrain presents the opportunity to view the installation in a level orientation in relation to the landscape beyond, and from below approaching the entry of the building at the terrace level. (Figure 5).

The students elected to pursue the design problem of light-diffusing screen that would be attached to the interior of the curtain wall of the site. It was assumed that the project should, as a basic function, diffuse both sunlight and daylight for the improvement of lighting conditions on the interior of the building (i.e. reduction of glare, diffusion of light to the ceiling, etc.).

Beyond this simple functional objective, the students intended to create distortion of light and transparency and thus a particular spatial effect. Their design aimed to interact with multiple light sources: direct sunlight, the ambient light from the sky and exterior surroundings, and a projected light source that was proposed for the interior. With shifting sun position and light conditions, solar geometry and daylighting could relate to project geometry as perceived during the daytime, while a projection system could illuminate the project after dusk. Studying the site carefully, the students realized that the shifting position of occupants in the space could further multiply the effect of distortion and transparency. Overall, the site and its geometry inform the project significantly, from inside, outside, through the movement of viewers through the space, and through the changing light conditions during the day (Figure 6).

3 Design to Fabrication: Hypotheses Towards a Feedback Ecology

The theoretical model of environmental design opposes the simple duality of a ‘virtual to real’ process, or perhaps a ‘representational to material’ process. Instead, environmental theory implies ‘ecologies’ at two levels. The first ecology is rather humanistic—the idea that the environment is not simply objects by themselves, but objects relating to objects, and objects experienced by humans through effect and phenomena. Secondly, the environment is proposed as a range of classifications among interrelated objects and their parts, rather than plastic, singular objects (Rapoport 1987).

Thus we may hypothesize a feedback ecology of information and construction. The ecology emerging from the interrelationships of information reflects the project ‘in an en-
environment’ and implies representation, simulation, and effect. The ecology emerging from the interrelationships of construction reflect the project ‘as an environment,’ implying systemization, materiality and assembly. In this context, neither information nor constructions are purely virtual or real—instead, these two ecologies are emerging conceptual systems, perhaps even theses, at the scale of the project. Robert Romanyshyn refers to technology, specifically perspective drawings, as a “psychological reality” rather than a “series of events” (Romanyshyn 1989, 10). It may be argued that digital ecologies present a similar ‘psychological reality’ defying the limited definitions of ‘method’ and ‘technique.’ The idea of a ‘psychological reality’ suggests a new way to examine projects emerging from a process ecology—in place of a rational set of steps, the project is borne from the fluid interaction between informational and constructional circumstances. This process of feedback is more than a loop-like symbiosis, it is a sum of influences working in multiple directions, more integral as a whole than any of its independent influences.

3.1 FIRST HYPOTHESIS: THE FEEDBACK LOOP IS AN ECOSYSTEM OF INFORMATION

For most of the students involved in the fabrication project, it was their first time using scripting and parametric design techniques. The idea of explicitly recording their design intentions—focusing on design intent and procedures, rather than design outcome—was also new to the students. As the students learned to control information and perceive its causal effects, they were forced to confront losing direct control of the outcomes. Eventually students began to recognize a balance between intention and accident throughout the process of designing and learning to opportunistically embrace certain unintended outcomes. Simultaneously, emphasis was placed on not accepting results without critical and thoughtful evaluation. From this complex web of inputs and outputs, the students became engaged in the interrogation of their design process, rather than just the data. The scripts from the strongest individual projects evolved in this way; results were not simply assessed, they were critically ‘seen’ in relationship to design and environmental intentions.

The use of media in this manner works beyond the simple input-output application of computational design, and it similarly drives deeper than the deployment of digital tools towards graphic production alone. In fact, the demand to represent the process of scripting and environmental design became a rich exercise that drew students into the abstract implications of their projects—offering a curious curve to what Stan Allen refers to as “the distance interposed between the thing and its representation (Allen 2000, 149).” In this distance, the relationship between data, computation, and result are hugely expanded. In the case of this fabrication project, by linking constantly to effect and experience (Figure 7), visualizations were a device used to understand the exchange of feedback loop information and design decision-making (Klinger and Vermillion 2006).

At the most explicit level, the script was related to the individual extruded and trimmed polygons that established the project geometry. The operation of the script worked with the input of a simple volumetric boundary, first dividing it into variegated cells, then extruding and tapering the cells according to supplied vectors. Early versions of the script adopted a method of randomizing each cell as it was divided from the larger boundary—yet this first script, developed in a student’s individual project, only produced randomly shaped, flat tiles, while addressing the distortion of space through the layering of transparent figures. After a series of iterations, this scripting strategy evolved into a useful application for the final installation relative to specific environmental influences.

The project also evolved through an increased understanding of the relationships between scripting, effect, and human perception within the actual environment. The project was able to realize distortion as both surface geometry and transparency: approaching each unit as a shifting ‘tube’ which lent the project the ability to work as both a screen of facets and a pattern of openings whose total geometries could be controlled. Understanding these tubes as a schematic objective provided the students with a new objective for their generative methods, and the students were able to identify meaningful inputs to integrate with their computation.

Scripting and parametric design were useful vehicles to manage complexity—framed in the course as the measure of a prototype’s dependency on a diverse set of constraints.
and interactions—as design was negotiated and resolved through rules and associations. Sufficient complexities were achieved as specific environmental constraints and parameters (in the form of information) were collected and effectively integrated within a design recipe to activate local behaviors and properties to generate site-informed differentiation.

Using site and material constraints as the basis for generative design rules, performative, material, and fabrication logics were integrated within the design generation framework, rather than post-rationalized. Of course, this integration did not occur in a singular “genius-moment,” but rather within an iterative and non-linear ecology. Additionally, the students’ work with simulation and analysis provided a basis for design with environmental factors in mind. The final project, while not explicitly analyzed for performance, benefited from the students’ individual experience with light simulation: students were able to retrieve detailed solar geometry and make informed decisions about the interrelationship between geometry, material, and effect. Overall, the ecology of information was characterized not by discreet stages, but by fluidly navigating computer modeling methods, scripting strategies, and parametric design. This design feedback loop process forced the students to see beyond immediate ‘results,’ and encouraged them to craft a creative vision where these tools would critically serve design intentions.

3.2 SECOND HYPOTHESIS: THE FEEDBACK LOOP IS AN ECOSYSTEM OF CONSTRUCTION

Interestingly, the project had no distinction or boundaries between ‘designers’ and ‘makers,’ even though typically in practice these two groups are separated professionally and legally. The importance of this method to the problems of context, place, and environment is that issues working between ‘construction’ in a conceptual sense are inseparably linked to ‘construction’ in a practical sense. While this is certainly a result of the convenience of computer modeling, it is more importantly a result of the ability to define, solve, and redefine construction within the digital environment, and to create prototypes directly from this environment. In other words, the ecology of construction in digital design transcends the boundary of the material and immaterial, and thus designers can make decisions in both ‘worlds.’

This unified ecology is suggested by Katie Lloyd Thomas as “an alternative philosophical approach which does not split the world into form and matter but instead considers it in terms of force, setting up equivalence between persons, objects, words, solar systems, and so on, which all act on each other.” She goes on to say that “in such a view the real and the virtual, or the material and the idea, are part of a continuum of potentiality and actualization (Lloyd Thomas 2007, 5).” More than a pragmatic activity, construction as an ecology addresses the role of geometry, form, materials, and assembly as thesis as well as solution.

Construction as a thesis requires a theoretical basis, a way of understanding the implication of fabrication decisions on multiple levels. Through simulation—the students had already been primed on material physics in setting up digital approximations for their individual projects—they were aware of how specific lighting effects related to material properties and form. Consequently, the students understood that their construct would have to support a particular set of effects, and that the use of material and its application to form needed to concretize their intended system of effects.

A critical moment for the project’s concretization occurred when the students gained access to a sizable volume of translucent acrylic scraps remaining from a previous project of the Institute for Digital Fabrication. The laser cutter allowed the students to produce a series of quickly fabricated prototypes with which they could experiment at full scale and study in situ. While working with these prototypes, the properties of the ‘milky’ acrylic in light became further apparent. The students discovered that it was highly reactive in light, diffusing light and allowing it to escape the surface with startling effects. In certain conditions in daylight and projected light, this material became luminous in contrast to the surrounding atmosphere (Figures 8, 9). Continued experimentation with the material revealed that light reacted differently with the geometry the formed material, particularly at corners, edges, and shifts of orientation when the incident angle of illumination changed relative to the observer. Consequently, the constructional nature of the project moved quickly away
from a more plastic scheme of apertures (proposed at one time to be milled from foam) to an array of individual tube-cells, created from folded surfaces with open apertures at each end.

Scripting the cells enabled the students to engage the entire array of cells at once, studying cell size, depth, and orientation pattern quickly, while observing its impact on the overall field of cells. In randomizing the orientation of each cell to a degree, the cells were able to disintegrate the amount of incident surface towards the viewer—rather than regular appearances of tube-cell surfaces, the viewer would see a composition of various edges and surfaces. Students working on the script had developed earlier a method of controlling the orientation of the tube-cells with the interest of controlling view. However, the possibilities to work with both view and sun geometry became apparent from site observation. In the end, the orienting inputs for the script were based on sun geometry, but were also positioned to respond to the datum of ‘eye level’ for an observer on the interior. As the tube-cells rose beyond eye level, they shifted to relate to the terrace on the exterior below.

Production methods are important to any design feedback loop. Working carefully to estimate the potential of their scrap material, the students determined cell sizes and quantities that the volume of scraps could support, and restrained the size of the cells to the limits of the in-house laser cutting beds. The production method for each cell involved unfolding from the model, nesting in cut sheets, and labeling. Finished parts were organized and bent using printed templates and a single-element plastic heater (Figure 10). In order to ensure the accuracy of each cell, the students were required to study the method of scoring and bending joints in the acrylic. Scores on the outer surface of a bend would be visible and detract from the effect, thus scores needed to be made internally. A single score created too much dimensional distortion, and a series of scores created ‘wobbly’ folds and a different sort of dimensional distortion. The final solution involved creating a rasterized gradient at each seam, which was processed by the laser cutter as a pattern of pulses which, in turn, would cut a groove in the acrylic (Figure 11).

In detailing the project, the students elected to pursue a method for attaching the components to glass, rather than anchor to the curtain wall mullions. The initial approach involved bending flanges around each cell, but this system added time and complexity with extra bends, and proved too difficult to control. A second attempt involved a branching frame working between each cell—this too was a difficult system to control and greatly complicated assembly. The successful detail used silicon rubber suction cups and clear acrylic tabs which snapped into each cell: a system manufactured using the laser cutters, easily optimized with slight modifications to snap ‘teeth,’ and allowing a loose fit when attached to glass to absorb remaining geometric discrepancies. Working with real prototypes, understanding the capabilities for forming the material and assembly tolerances, and organizing the project around site conditions enabled these realizations in the design process—a direct manifestation of the feedback ecology from design to fabrication (Figures 12, 13).

The design process shift from a plastic approach to folded tube-cells was an important juncture that made fabrication by folding possible, fitting the available acrylic material and fabrication means. More importantly, the folded tube-cells allowed the properties of the acrylic to more fully inform the performance and experience of the final installation.
In this configuration, sun and skylight could move through and around the tube-cells, but also diffuse visibly through large amount of surfaces and react with a larger amount of corners and geometric shifts. Offsetting each tube-cell allowed light to pass around it, and the transparancy of the acrylic taps and suction cups support this effect. Through an ecology of construction the project emerged as a synthesis of computation, material intent, and experiential design.

The total result is arresting, not only as a crafted object, but also an object performing in the context of its environment. The phenomenological aspect of this project working within its environment through its materiality is clear, as decisions towards construction, while pragmatic, respond directly to the senses and to experience. Similarly, Norberg-Shulz recounts the Medieval stone-builders, who were tasked with ‘building light’—a “function of dematerialization” related in parallel to a system of building (Norberg-Shulz 1984, 54). In this case, the ecology of construction exhibited in the students’ work fulfills a similar ‘dematerialization’ through luminous experience, which carefully situated digital design, fabrication, and environment (Figures 14, 15).

4 Conclusion: Feedback Ecology—Critical Environmentalism

It may be hypothesized that the computer-based methods and the conditions of these design problems as feedback ecologies may overcome the segregation apparent in media (representation vs. material and virtual vs. real). Ecology, according to the theoretical model of environmental design, implies not only integration across the conceptual process (the means of designing and making) but also concurrent integration in the project as a construct (in context, across environmental conditions). Information, in this context, is both computation and experiential effect. Construction is both digital geometry and actualized materiality. Here, the familiar dialectic of material and effect emerge, not as discreet design objectives, but points of engagement for an incorporated feedback ecology. Moreover, the feedback ecology of the digitally designed and fabricated project offers the same duality as the use of descriptive geometry in the 19th century; a duality of information and construction which impacted the way things were designed, produced, and projected.

The digital process as ecology offers an opportunity to examine and organize the decision-making systems of design through environmental circumstances, working both in the real space of site and the virtual space of data and information. And further, there is the more abstract implication that the feedback loop may inform perception—within the conceptual perimeter of the project, and in the way the project itself is experienced. Thus fabrication ecology is both a model for the iterative process of feedback, and an approach for defining environmental factors within and beyond the project. Thus this ecology is two-fold, both a process and a projection within environmentalism.

Robert Romanyshyn writes that the technology of perspective drawing and calculation marked “the transformation of the eye into technology and a redefinition of the world to suit the eye (Romanyshyn 1989, 33).” Technology, and computational technology, may contribute more to lead architectural discourse beyond the novelty project: technology can augment and inform human imagination and experience, and thus impact our perception. The critical hinge in this argument lies in training technology towards environmentalism.
This is a call for the fabrication project to move towards a design notion of a total ecology. From Ernst Bloch’s critique of modernism emerged the idea of “homo faber and homo fabricatus,” that “not only do [hu]mans make [their] world, but the world makes the [hu]man (Bloch 1979, 45).” Have we not arrived at a similar juncture with our technology? Through the theory of environmentalism, people and projects are equivalent: thus it can be argued through Bloch’s language that not only does the project make the world, but the world makes the project.

Addressing digital tools in a humanistic way will foster dialogue about how the computer-aided process can respond more directly to people, places, and environmental systems. The paradox in reconfiguring the design process and its imperatives toward a new ‘ecology’ affecting relationships and participants will push designers and design projections beyond what is easily predicted or expected. Rather than eliminate environmentalism from design, new projects may be characterized by more direct translations of information towards form, materials, components, and systems. These projections need not be interpreted as monsters, but rather as specific productive works within an ecology resulting from new processes and methods; each new project reveals new territory. Each digital fabrication project, charted with the intention of environmental design, will be effective guides for future critical experiments. As noted by Tafuri, a critical tool must work from within the context of its field (Tafuri 1974, 149)—thus the feedback loop must be addressed as ecology in order to realize its influence in the built world. Feedback ecology, more than fabrication and design alone, proves to be an important vehicle for reinterpreting the environment critically, bringing digital discourse towards the recalibration of environmental issues and human relations through design in our digital age.

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6 References