Performative Architecture

by

Sergio Araya

Dip.A. Universidad Catolica de Chile
M.A. Universidad Catolica de Chile
M.S. Massachusetts Institute of Technology

Submitted to the Department of Architecture
in Partial Fullfilment of the Requirements for the Degree of

Doctor of Philosophy in Architecture: Design and Computation

Massachusetts Institute of Technology

September 2011

Signature Author...

Department of Architecture

August 5, 2011

Certified by..

George Stiny

Professor of Design and Computation

Thesis Advisor

Accepted by..

Takehiko Nagakura

Chair of the Department Committee in Graduate Students

Examining Committee

George Stiny, Professor of Design and Computation, Massachusetts Institute of Technology

Edith Ackerman, Professor of Psychology, University Aix-Maseille, Visiting Scientist Massachusetts Institute of Technology

Ann Pendleton, Walter H. Kidd Professor of Architecture
The Ohio State University

Performative Architecture

by

Sergio Araya Goldberg

Submitted to the Department of Architecture
on August 5, 2011
in Partial Fulfillment of the Requirements for the Degree of

Doctor of Philosophy in Architecture

Abstract.

The following thesis explores two central hypotheses. On the one hand it introduces the idea of performative architecture (performance in design), and has done so with the desire to contribute directly to the expansion of design education and practice. It proposes stretch the boundaries of the discipline by challenging current paradigms on architectural theory and practice by conveying an axiom of active engagement between artifacts and their environments with human users/inhabitants forming part of such an environment. Performance is here proposed as the action that mediates the two forces of artifice and environment. The second hypothesis of this thesis has been to offer a distinct point of view regarding analogue relations—as asserted by this work—between the design process—as it relates to pedagogy and practice—and the performance of design (considered through that which is built, materialized and produced) as it engages with its surroundings. Designing requires fundamental ambiguity, imposing both theoretically and empirically, a methodological systematization of two recurrent and consequent processes: mergence and emergence. I will describe how both, explained by Shape Grammars design theory, are complimentary and interdependent processes, mergence in order to produce the essential ambiguity required and emergence in order to embed and operate, and that this processes are present both during the design process (designing) and during the experience of design (inhabiting/using). These two hypotheses temporarily blur the distinction between environment and design artifact, or between natural and artificial, and propose a displacement of these distinctions towards the performance of the interfaces between such conditions, independent of their "natural" or "artificial" transient connotations. I will describe how this manifold notion of performance can be used to understand this displacement in architectural discourse, and its practical implications towards a performative architecture.

Thesis Supervisor:

George Stiny
Professor of Design and Computation

I dedicate this work to my children, Nicolas, Sergio, Santiago, Cazu and Sebastian, for they have always all the questions in the world but also the patience and love to accompany me in this journey of inquiry.

And to Marcela,

for ever.

Table of Contents

Acknowledgement

This book would not exist and I would not be here if it wasn't for a number of crucial characters that I have been fortunate enough in getting to know well and share experiences with, and I feel the least I can do is to use this space and thank them for helping and supporting me during all these years at MIT. My journey at MIT started in 2003, when in a 10 minutes interview at his office in the Media Lab, William J. Mitchell saw my work, (he was already late for a meeting but nonetheless took the time to receive this young architect coming all the way from Chile) he listened to my two minutes pitch, and told me I was at the right place, and that those kinds of questions were precisely what MIT was about. He was right. It is because of his drive and support during the years, our always fascinating conversations and the hours of research work together with the Smart Cities Group and at the Design Lab, that I came here and stayed here, but most importantly, that I am now about to leave MIT, transformed and eager to continue working in the fundamental questions that moved us both all this years. I owe Bill so much and I will miss him very much. But his drive and energy lives in all of us who had the privilege to know him.

But any journey needs a pilot, and that pilot has been George Stiny, who during all these years has tolerated me for much, much longer than I would have expected, even for him, to do so. I will always proudly remember that is has been the only class I have taken, voluntarily, more than 5 consecutive times in my life, and now that I am about to leave MIT, I will surely miss those mornings of discussion and enlightenment. The work in this thesis is as much about the things I agree with George about design and Shape Grammars, and seeing and doing, as it is about the things we disagree on. And I am satisfied to know that he might have also enjoyed some of those disagreements himself. He has been and will continue to be my mentor and a dear friend, and I am looking forward to have many more conversations and discussions, perhaps some of them in Chile while enjoying local beverages and food, as we did here in Cambridge at every end of the class.

But as I have said so many times, I've learned both from my professors as I've learned from my peers and my students. I feel privileged to have shared lifetime experiences with these friends at MIT, who coming from all places of the world, shared their hearts and brilliant minds with me. I feel grateful and nostalgic as many of them are now as well about to leave Cambridge, to continue their careers in the most prestigious institutions in the world, or leading promising initiatives that I am sure will make an important impact in the world. Alex Tsamis, Orkan Telhan, Duks Koschitz, Onur Gun, Hector Ouilhet, Daniel Rosenberg, Ayah Bdeir, Andres Zahler, and many more, have been behind me and my family every time they were needed, unconditionally. Some of them I will continue to see soon as we will continue working together, but I am sure than in some way we will all continue to be close and to discuss, as we did so many times, about some abstract and ungraspable concept or the practical implications of a technology yet to be developed, in some hidden corner of the Infinite Corridor.
Finally, I would like to express my gratitude to my parents and my parents-in-law, whom have missed us for many years, but have supported us unconditionally for all this time. We are now going back, but we know that wherever we call ourselves home, we can count on your love and support.

From my heart, thank you to all of you.

Preface

In order to facilitate the reading and comprehension of the subsequent chapters I would like to make explicit what may be obvious to me—after five years work with this subject—but that may not be so evident for the reader: the structure of this book and the part-to-whole relationship concerning the different fragments that comprise it. First of all, I would like to clarify that although it may seem (based on the case studies) that the work is presented chronologically, this is only a partial truth.

The arguments pertaining to the three main parts of the text are each illustrated by a case study, and while these cases are presented in the order in which they were developed, it should be noted that observations and concepts I developed several years ago are connected within this work to that which I have done most recently, and some new ideas have been retrofitted into previous cases in order to explain certain aspects of them. These concepts are often revised and re-discussed under the light of new ideas, or with the changing conditions of the case studies in question. If I insist, as I do, on the notion of design[ing] as an unstable, yet full-of-potential "state of action", it is also correct to understand that this thesis may include different, sometimes even necessarily contradictory notions regarding certain concepts and relationships about design methods and design practices, and that this is a fine and accepted aspect of the writing of such a book and about design. For to write about design is to write about an ongoing process, one that redefines permanently the way in which we engage—whether it be through abstraction (to extract) or concretization (to return, to put back)—with the world around us. This in turn opens up the door for the idea of design (and the complex relationship to the environment it entails) to become the subject of redefinition—to become, as it were, a problem of design.

About the structure

The structure of the thesis is divided in four main parts: Part I constructs a theoretical and historical framework in order to discuss the idea of artifice and environment within the realm of design, and how the relationships between them has changed and developed over time, permeating design practices and design education. Part II first presents an introduction to the discussion surrounding modern design, of design as a response to either function or form, and lays the groundwork for the introduction of performance as a third tenet of this function-form relationship, presenting it as a new term that defies or, at the very least, blurs the dichotomy between the two former concepts. In doing so, *design as performance* changes the nature of the relationship that design (as a practice and discipline) has with the environment, the world in which and by which it occurs.

Part III describes a paradigm shift, and outlines the new relationship formed by design and the environment, showing how the adoption of this new relationship turns both the notion of design and that of environment into temporal definitions, definitions that could be seen in overlapping or even replaceable terms. This last argument clearly expands on ideas originating in the first two parts of the text but goes further still by attempting to suggest some of the possible ways of understanding the role of design in the future. Finally, some closing remarks will highlight the principal questions that, despite remaining unanswered ,contribute through their presence alone to the expansion of design as a discipline, in helping reshape the boundaries and methods that are relevant to its practice. This last part attempts to retrieve the notion of *problem worrying* forged by S. Anderson in the '70s in response to the engineering notion of design as *problem solving*. This it does by frontloading some of the issues apparent in contemporary design discourse, and offering a few perspectives which, I believe, open up this conversation to the possibility of new discourse and practice.

As a necessary step for discussing the concepts raised in each of these three sections of the text, I have written, at the beginning of each section, a type of introduction in which I present a brief background of the subject and the topics to be discussed. This provides a space for presenting fundamental questions and pertinent theoretical ideas as well as introducing a number of cases—not intended to exemplify the "best" principles or practices—but to encourage discussion based on concrete designs and their processes. These cases were chosen, not due to their design qualities or manifestation of specific concepts, but rather because of their importance as a springboard for the sorts of questions important to the text, in particular questions regarding the performative relationship between design, the artifice and the environment. With regards to this, I should note that the first two cases were begun well before I began the writing of this book, and that one dates to even before I moved to the United States and MIT, coming out of my professional practice in Chile. Some of the cases presented in this book, or parts thereof, have been presented in other publications or as part of conference lectures.

However, the particular aspects I highlight from each are specific to this work, and are particularly relevant to the understanding of how design concepts (and relationships between the same) are subject to constant revision. This work also asks the question of why this would be the case, and discusses the implications of this sort of change has for the pedagogy and practice of design.

Standing on the shoulders of giants

There are a few authors who have inspired my work and deserve recognition beyond that of an in-text citation or mention in the *Notes*. As scholars, we often discover passages or excerpts that are exceptional and inspiring or highly controversial and that motivate our immediate reaction. But only rarely does the work of an author transcend that initial moment of empathic connection and become one of those driving concepts that we carry with us—even if at times inadvertently. For me this occurs with two specific authors, and I would like to make explicit how I understand their influence and its effect on this text.

The first is George Stiny, whose theory of design Shape Grammars, elucidated in his book *Shape*, has greatly influenced my perspective on both design pedagogy and practice. In a very peculiar fashion, some of the aspects of *Shape Grammars* have molded my own view and opinions regarding design theory, yet other aspects of Stiny's work have triggered long term inquiries on how design happens, how design operates is perceived. In many ways, this thesis is both a reflection on *Shape Grammars* and its applications—both theoretical and empirical—in the design process; yet it is also the documentation of an ongoing conversation with Stiny's theory of design. The reader may expect to see some concurring perspectives at times, but also some contradictory interpretations. I hope I am sufficiently explicit in stating once more, that these contradictions are welcomed, and at sometimes even sought. For it is at those moments of friction, of divergence, that I believe true creativity occurs, and due to this fact that my book is also a celebration of the contradictions and discrepancies in thought that emerged from my conversations with George.

The second figure to whom I owe a debt of gratitude is Jon McKenzie, an author I haven't had the pleasure of meeting, but whose work has also deeply influenced my writings. McKenzie is a professor at University of Wisconsin, a prolific writer, author of numerous essays and of two important books on performance research. His first book "Perform or Else," was a text that influenced my thoughts on design precisely at a time when I was making the transition from practicing architect to a return to academia. His theory of performance, or as he puts it *rehearsal for a general theory of performance*, resonated deeply with my own ideas on design research. In some ways, the title of this thesis is about performance as a mediating factor in the relationship between design and the environment. In this sense, it owes inspiration to these two authors, despite whatever deviations from their line of thought may have emerged from my own critical position as it concerns their ideas. But, as Stiny always says, *design is what happens in a conversation with friends in a bar*. Design is both a personal endeavor, one that involves *my* particular way of seeing and experiencing the world around me; yet at the same time design requires that I establish a dialogue with that which is outside of me. It requires a personal connection (what he would call a "conversation"), and more often than not design tends to happen precisely at the moment in which, during a dialogue, my views collide with those of another person. It is through this sort of friction, one produced by conflicting perspectives, that opportunities emerge, and this occurence, I would argue, is the source of design's multi-, trans-, cross- or even post-disciplinary nature. The friction is one produced when boundaries (conceptual, pragmatic, epistemological or ideological) come together or overlap and gaps are found through that juxtaposition. It is with this in mind that I would like to take a moment to acknowledge the many conversations—both long and short—that I have had during the past seven years I have spent at MIT, walking down the seemingly endless corridors of MIT and meeting people who would prove to impact me, not just as bright and intelligent students, colleagues and professors, but sensible and compassionate people as well. It is a bit of a commonplace, yet a truth nonetheless, to say that I have learned as much from my peers and my students as I have learned from my professors and mentors. I would like acknowledge this debt of gratitude by mentioning a few names, and by doing so I may hopefully strike a balance, making sure to note the influence of both professors and authors with that of peers and colleagues. Both of these groups have been influential to my thinking, and this fact is reflected strongly in my thesis. I met Onur Gun during a time when we were both earning our Master of Science degrees at MIT, and through collaborative work and engaging conversation he helped me to form ideas regarding the sensible use of technological frameworks, that space where experience and tech meet. Alexandros Tsamis and Orkan Telhan are two extraordinarily bright minds I had the honor of sharing time with, and it was through tough discussions (made lighter by their always sought-after humor and sarcasm) and long late-hours collaboration that they have contributed to the development of the ideas present in this book. Some of the ideas I have developed concern performativity in design, programmable matter and responsive systems—these were a large portion of the menu of ideas we would have on the table and under constant discussion. Sitting with this pair, enlightening one another in turn while sharing a beer somewhere in Cambridge are some of the fondest memories I have of my time here. I am optimistic about the future conversations to be had with them, and with the many other people I had the pleasure of meeting while at MIT. This conversational and non-specific nature of design is also presented in this book in the way in which the case studies and the theoretical discussions "talk" to each other. Sometimes a case provided the spark that would set off some of the ideas under discussion; however, in other instances the conceptual conflict itself—a burning question that arose while drafting, or some other exercise—sowed the seeds of the projects described. As I have stated before, in neither case is process linear or chronological. Some of the inquires raised by early projects and design proposals in this text could fit in with or respond to hypotheses made, but could still be developed further, or in novel ways. This is something about the nature of design itself, *it is never finished.* So a thesis such as this may only attempt to present a cross section of a moment in time and a cumulative body of research work, but could not and should not attempt to be conclusive regarding absolutes or endeavor to "have the last word." Not if it wishes to stay true to its design nature.

Intro

"Architecture is situated" (Wren Strabucchi)

Architecture happens. Specifically, it happens when it comes to occupy space and qualify a place. Its occurrence establishes a connection between these two, space and place, that did not exist before. When W. Strabucchi[1] said these words, he had several things in mind. First that the act of architecture was directed linked to a specific site, that it connected design and place. Architecture is *situated* in the sense that it establishes a connection to a place; it becomes (a) place, it transforms (the) place. Strabucchi also meant that architecture provokes a situation by envisioning a site where bodies and space interact. In this sense architecture is connected to actions in time, qualifying temporal conditions and affecting our own perception of the passage of time itself.

I would add to that architecture *is* situated because it has to renew these relations to place and time repeatedly. In fact, it can't but renew such relations as both time and place are in a state of constant flux. Architecture is not something that occurred *ex post facto*, but rather an *act that occurs*. I have struggled with this particular question for decades, and now, as I write this thesis, I remember just how omnipresent it has been: a consistent source of inquiry since my first steps into architecture. And yet it is a question that is always changing, mutating, transforming. Design *is* a verb, a verb with a question mark afterwards.

The question of design is always a question of context.

Establishing the relationship between that which is designed and that which preexisted design (those factors with which design must coinhabit, in both space and time) upon the installation of any sort of architecture brings us to the notion of context. Context is not simply that which preceded the installation of an artifice, but the relationships established between the artifice and its environment, environment being understood here as that which is external to the artifice itself[2]. The definition of a context is an operation of situation. It is that which allows those relations to be situated. On the one hand this understanding aids us by putting things in perspective so that we might understand the implications of (an) invention, its connection to preexistences and the resultant consequences and implications of such a combination. Yet that which we call context also helps us frame these aspects, in that it allows us to set temporal descriptions based on that artifice and its context. This framing selects and depicts a certain and discrete number of features from both sets of conditions, namely, those preexistent (such as place and time) and those created (situated design).

This contextualizing frame is an operation that temporarily fixes the perceived and understood notions of the environment/design pairing in order to establish the connections and relationships between them (environment and design). An example of this being the form and materiality of a design as it relates to the physical reality of the space in which it is deployed and used. Context then is the temporal set of constraints created in order to be able to observe and operate. And because the manner in which we apply this contextualizing frame is always biased by historical and cultural values, by disciplinary views and ideologies, I will endeavor in the following pages to delineate and characterize the historical evolution of this notion of context, tracing its development up to the present day.

Beginnings and Endings: the binary mode of cultural change.

Despite the many death knells architecture has received throughout its history as a discipline and practice, it has somehow always managed to evade own extinction. This it has done, I would argue, by adapting and mutating. I would go on to say that, ironically, many of these sorts of salvatory mutations are brought about by those very forces affirming architecture's imminent end. Every cultural revolution has—to a certain extent—laid waste to those methods and theories which preceded it; something due in part no doubt to the sense that there is a need for an ending of such now-archaic (in the eyes of the revolutionary) practices and the creation and implementation of new models. The ability of architecture as a discipline to deal with its own mortality seems to be one of its essential virtues, its survival dependent on its being able to change and adapt to varying historical conditions. Outside social, political, economical and cultural conditions, all components of any dynamic society, have very different notions of what they will design—and how they will design it—within their environment. Two conditions have deeply influenced the last two decades of human history: technological development, a product of man's own ingenuity and creativity and something that has radically transformed our culture and will continue to do so along an exponential curve; and, on the other side, the changing environment we live in, both natural and artificial. As the latter changes it alters, in a fundamental manner, our understanding of our place in the world. This will prove, no doubt, to be a continuous force in shaping our experience and vision of what is possible within human society.

The radical and global effects of these two developments have affected and transformed our culture to an extent we have yet to discover. Yet their influence has not come painted with broad strokes, but rather through the subtle transformations of modes, practices and beliefs we already rely upon and apply in our daily lives. And just as the advent of new technology and the various changes in our physical environment transform how we understand our own situation, they also affect—through design—how these conditions manifest themselves through their direct effect on the materialization and production of both our built and natural environment. Though many years have passed since the last dogmatic, inflammatory manifesto emerged from under the surface, proclaiming the dawn of a new era and the fall of previous values, historians and critics have persisted in their attempts to find hints of the next big revolution.

While some are skeptical as to the importance and potential implications of each of these fundamental transformations, the eruption of the digital revolution[3] and the advent of the environmental crisis[4], have both had a major impact on contemporary society, and extend directly to design practices and disciplines. Yet neither of these two "revolutions" have been understood in a dialectical fashion. Both will no doubt shape the way will envision our world and how we will exist within it, but, for the most part, any discourse regarding either technological advancements in design practice or the changing values of architecture with respect to the environment are presented in an antagonistic fashion; it is a classic dichotomist approach to cultural change: technology versus nature, cutting edge versus archaic, abstract versus concrete, virtual versus real, etc. But it is a fact that the two share some common ground—that they have affected one another increasingly as they have evolved from utopian, scattered visions and subliminal criticism and have grown into mainstream discourses. They have been and are still two of the principal sources of change affecting and shaping our environment. I will argue that this term environment, a term that will be used expansively and intensely in this work, serves in its rich usage to convey conditions present and influential across a multitude of disciplines, disciplines ranging from art to architecture, from urban design to landscape architecture. Environment comes both from outside the epistemological framework of each of these comparative spectrums, referring to an external environment, as well as from within, describing the internal environment defined and prescribed by those epistemologies as their internal operational space and ideological scaffolding.

Part One

Architecture and Environment in Context

The history of design and architecture has always been intertwined with the prevailing interpretation of environment or context. Since the time of classical antiquity, from which the first major documents regarding design (i.e. architecture/ engineering) are dated, every design, every completed edifice has been radically dependant, in its conception and construction, with respect to those conditions regarded as the predominant mode of understanding the environment in which it was built.

The notion of environment as it relates to architecture has been thus molded and informed by cultural transformations and scientific development. Ancient notions of environment as a given, the result of a higher power, a constant and stabilizing condition have created the idea of the environment as a the mediator of a sensitive equilibrium, the outcome of complex interactions in a dynamic process. Environment, from this point of view, was seen as synonymous with nature; this would change with the development of the idea of both a natural and constructed environment. Because of this fact, environment as an external circumstance has become part of a complex relationship; one in which external and internal conditions are variable and exchangeable. If we devised architecture to protect us from the environment in the past, today architecture is reinventing itself to protect nature from us. If nature was the model to imitate, its own survival is now in part the result of careful design and engineering. How the actual ground figures in the relationship between what we do and where we do it is changing.

Given/Created

"In the assembly, therefore, which thus brought them first together, they were led to the consideration of sheltering themselves from the seasons, some by making arbours with the boughs of trees, some by excavating caves in the mountains, and others in imitation of the nests and habitations of swallows, by making dwellings of twigs interwoven and covered with mud or clay. From observation of and improvement on each others' expedients for sheltering

Laugier's depiction of Architecture and its origins in Nature.
Frontispiece to 2nd ed. of Essai sur l'Architecture, 1753

themselves, they soon began to provide a better species of huts." (Vitruvius, Book II)

From Antiquity to Modernity, nature has always been the essential source of inspiration for Architecture. It has been this way since the time of Vitruvius, who recounted the early origins of architecture and set up the founding principles of the art over two thousand years ago. It was confirmed by many and sustained through centuries of cultural and technological development by architectural treatises of influential characters like Alberti[5] and Palladio[6]. For Alberti environment was a matter of geographical position—of locality; it was one of "(...)the elements of which the whole matter of building is composed"[7]. Even though, for Alberti's locality, the notion of environment included climate as well as local topographic considerations, these atmospheric conditions were still bound and confined to geographic location – climate was a quality of location. This philosophy of environment underscores the idea of nature as a *given* condition, one in which a man's *ingenuity* would enable him to survive its inclemencies by *understanding* its rules and *obeying* them[8]. It also emphasizes nature as a model from which to learn, extract or derive those principles, later adopting and adapting them in order to cope with the unforeseen difficulties of nature itself. For Vitruvius, the notion of *given* natural environment (a vision that influenced architecture for over fifteen centuries) the act of *choosing* a right place to locate a city was of paramount importance since the health, safety, and well-being of its inhabitants depended on site-specific circumstances. A proper site selection, aided by architecture-savvy thinking and engineering constructions would be the fulcrum that allowed a city to prosper, or not.[9] This notion of given nature enabled architects, through their combined knowledge of sciences and of design, to be able to distinguish and therefore *choose* among different conditions, hence to select and designate a better site, orientation and materials with which to build. Environment, in this time period, could be understood as those formal conditions necessary for the construction of a successful settlement. This would be the established and universal conception of architecture in western world for centuries. Only by the turn of the 18th century did the idea of nature (environment) as a static, finite, conditional space in which humanity created dwelling by imitating it, start to change into a dynamic, infinite, constantly-evolving understanding of nature and architecture as something distinct from one another. Important forerunners in this type of modern thought, such as Perrault[10] and Boulleé[11], began by proposing that architecture should *not* follow a path in which the imitation of nature -and the veneration of classicism as part of that- was considered the apex of architecture. (It should be noted, however, that these ideas were not without their own contradictions and ambiguities.) Perrault and Boulleé also attributed independence and autonomy to the design process, regarding it as the result of a purely human artistic invention. For Perrault, this innovative thought process, straying from the original Vitruvian principles, may be seen to stem from the fact that he was trained, not as an architect, but as a physician. He was one of the first to critique the Vitruvian principles, and was adamant about the fact that there were other factors that played a key role in the foundational tenets of the profession.[12]

As the 19th century ended and the 20th began, the first voices of the modern movement with

Architecture's quality

might rightly be judged,

not by the problems it solves,

but by the problems

it creates.

Lebbeus Woods. Of a Human Nature (fragment)

Lebbeus Woods, Of a Human Nature

Le Corbusier in the lead, worked above all to transform and replace what they saw as the traditionalist paradigms of architecture, historical assumptions and preconceptions they considered patently outdated. They envisioned the relationship between architecture as an emulation of the natural environment as nothing more than a reminder of previous conservative and reactionary values. Modernists in the first decades of the 1900's declared that the connection with the past, with history and—by extension—the model they embraced and represented, was in direct need of replacement . Le Corbusier himself used the *clean tablecloth* metaphor[13], as did many others, to introduce the concept of the modern *Tabula Rasa*, by way of which a new "mankind would be reborn", as Le Corbusier proclaimed. One of the major—though indirect— impacts of Modernism on the 20th and 21st centuries was that of the replacement of nature and the *natural environment* as the center of *design theory*; modernism replaced this with *human creativity*. To the modernists, environment too was something to be designed. The environment, natural or built, is a canvas onto which modernity deployed its new project for humanity.

Since a major part of this vision concerned the *erasure* the of all traces of tradition, the canvas had been, conceptually and concretely, rendered a blank surface—an empty space. Such an idea was materially manifested in Corbusier's plan, *Voisin*[14], which suggested that this sort of erasing operation may have required, at times, the flattening of entire neighborhoods. These types of radical, visionary agendas of the modernist spirit, though at times strongly criticized, still proved a major influence on both late and postmodernism. Decades of architectural and urban design followed Heideggerian principles, maintaining and reinforcing both the distinctive relationship between *man* and *things,* and the common, linking factor they have in the human *being in the world*[15]. This may be better defined as the proclamation that the human act of *inhabiting* is one that prizes instrumentality over the environment. Norbelg-Schulz, one of the most influential thinkers of late modernism, argued expansively in favor of this distinction[16] proposing an architecture that "takes place", where place is defined as a phenomenological description of the environment.[17] This sort of "taking place" may be read both from the standpoint of *taking* as *appropriating*, but also in terms of *taking* as *occupying*. Place is thus an operational condition—when architecture *takes place* it is both an action and a condition. Departing from this, more philosophical perspective, a conception of the relationship between the environment and artifice revolves around the instrumentation of the first through operations performed by the latter, operations mediated or regulated by human action.

With an optimistic eye towards the future, the 1972 UN conference on "Human Environment" gathered both industrial and developing nations in order to come to a agreement regarding the common and universal rights of the human family to a "healthy and productive environment"[18]. For the first time a new subject was broached: the notion that although developing nations could flourish, "being blessed with natural resources"[19], it was to become essential for their future development that equalitarian access to these resources be guaranteed—hence the need to regulate and legislate. In 1987 the UN's Brundtland commission's report, "Our Common

Future," concluded that steps needed taking, first to ameliorate and then to progressively remediate declining environmental conditions, conditions that had endangered the "sustainable development" of human nations[20]. With this, the idea of an environment which was not guaranteed to be perennial began to take hold around the world. For the first time, scientists and politicians began to change the way the thought about the environment.

This notion of a rapidly decaying planet transformed the concept of man's relationship with the environment. Since, as far as anyone can tell, human action seems to have played a major role in destabilizing the environment, this new agenda of sustainability, proposed by the Brundland Commision at the '87 conference, attempted to reconcile the apparently divergent paths of nature and human development, terms interchangeable with environment and architecture, or (in a larger, more global sense) environment and urbanism. Since the "project of urbanism"[21] as Mostafavi refers to seems antagonistic or at least in contradiction to the "project of ecology,"[22] the idea that architecture could be "sustainable," and urbanism "ecological," seem almost oxymoronic in nature. However, as this idea developed, the ideology of Sustainability emerged as a consequence. This rethinking of the man/environment relationship—though it has yet to fully be developed—has nevertheless radically influenced the last two decades of architectural academia; some thinkers even point at this new ideology as a potential successor to modernism, or at least as comparable to it in terms of impact on contemporary culture[23]. A kind of *green dogma*, a Green Movement and a new emergent ideology, recovers nature and the environment and returns them to the center of scholarly discourse. But this time it has returned with a very different connotation.

Mimic/Model

The role of the environment in *shaping* and *informing* the architectural artifice is in no way novel, but has been present for centuries. The environment, considered not simply as a location but as an inspirational muse, this marked the origin and early development of architecture as a discipline. For Vitruvius, buildings and structures were designed to mimic nature: nature was not only the ideal model but was also the given, universal condition, something accepted unquestioningly. The role of the architect, as understood from the ancient treatises, was to observe and interpret, to imitate those behaviors observed in nature and then codify them in the building canon. These sorts of observed rules, described from "natural laws," were slowly built up into a tradition, creating the first set of rules regarding successful design and construction. Nature, at this time, was always a location but also a model—a model to be imitated.

Centuries passed and this assumption was maintained. Alberti in the mid 15th Century reinvigorated this connection by professing in a treatise this, the same conviction coined 16 centuries earlier. Later Palladio would also reconfirm this notion, saying "architecture imitates nature (as all the other arts), it cannot endure anything that alienates and distances it from what nature herself permits"[24].

The Vitruvian influence defined centuries of architectural production, all practicing a design based on ideas of the discipline as a tribute to natural laws. In this way the canon was considered irrefutable as it was something that had emerged from a higher power. The influence of Classicism excepted human experience, development and progress, always drawing designers back to these same, strict norms. Since it was human beings who" (...) were of an imitative and teachable nature"[25] but also "proud of their own inventions, gaining daily experience also by what had been previously executed, vied with each other in their progress towards perfection in building"[26].

This type of progress, a working dedicated towards perfecting rules and orders, was conceived as the epitome of achievement as it produced reinterpretations of the original principles.

The emergence of new cultural movements due to the Industrial Revolution at the end of the 18th century, as well as changing social norms brought about with the end of World War I promoted and encouraged new models of design, ones focused on human creativity and with an eye towards the mythologizing of technology.

The modernist claim to the aesthetics of machinery as model for future design is as much a fetishization of the new modes of production—

modes brought about by the art and design community—as it is a symptom of the culture's adoption of the technology-driven images associated with military power, especially for developing nations. Independence, in this sense, was as political as it was environmental. The centerpiece role technology and human creativity would play allowed modernism and other cultural movements to free themselves from the past and historical conservativism, while at the same time freeing themselves from the binding aspects of nature. This hard-won autonomy remained in place for the majority of the 20th century.

But in the last two or three decades, the environment seems to be responding back. One of the major causes for this has been, of course, the movement towards Sustainability. However, we should bear in mind the progresses made in life sciences, notably genomics, which have also had a profound influence on the general public's perception of the artifice-environment relationship. Numerous authors from different spheres, including architecture,have addressed these topics in recent years, each basing their interpretation on a different aspect of the environment/architecture relationship.

The idea that the environment is just one of many unstable conditions in precarious equilibrium has emerged, due in part, no doubt, to the conviction that this new environment is the product of a human/nature relationship. These ideas have a direct effect on our conception of architecture itself. Other critics maintain that the relationship should be rethought and redefined. Leatherbarrow, for example, gives a description of a dynamic and fluctuating environment, one which is both given and produced, and claims it is or should be reciprocated by a distinctly animated architecture.

> *"If a 'form' is to 'flower into perfection', it will be on a daily basis, never the same as it was before, and repeatedly, like the manifestations of the land or earth of which it is a part. While the adjustment of the building's parts give it a quasi-animation, it itself is not animate but animated, not temporal but temporalized."27*

Leatherbarrow's view , more simply put, is the following: that the environment can now cover, not simply nature, but the urban landscape as well. And although here its limiting factor is that *site* always appear as *given*, it carries within it the memory of how it developed, how it has been molded and processed, and how it will only progressed further in the future. This novel way of understanding of environment, as a type of flow or process, is remarkably different from that of the environment as a constant, universal condition, one which is given and within which we are able to situate and embed ourselves.

On the one hand, bioengineers and synthetic biologists today ask themselves the question, given the power of genetic design, how should we design nature? Yet, on the other hand, designers faced with the public's urging—almost to the point of its being an imposition—to apply and implement *sustainable* design; this is in order to palliate or at least ameliorate the effects of industrialized exploitation and material production in the name of human progress, an effect that traverses centuries. The fact is however, that although the urbanization of the environment is being held as one of the most prominent factors responsible for the environmental crisis, Sustainability in environmental architecture and technology is being regarded as its potential solution, something which is, it seems, paradoxical. Sustainable urbanism claims to want to attempt to reconstruct the relationship between architecture and the environment, reestablishing a rapport not only with the natural environment, but with the urban environment as well. Some scientists, however, would attempt to go even further, claiming that they can create a new, better natural environment using its own foundational building blocks (DNA).

Regardless of who has the right answer, this much is obvious: a new type of environment is in its gestation period. The discourse of environmentalism has permeated all design disciplines and has become a central issue in contemporary scholarly debate.This time, however, the terms "environment" and "artifice" have very different meanings. The distinctions are now not so clear-cut, and at times seem to have been purposefully erased. In an era in which a man-made environment is *the* environment, it seems that artificial *is* the *new model*. While in 2008 for the first time in history, the world population that lives in urban areas surpassed the one living in rural conditions, and anticipating that that number will increase to 70% by 2050[28], the broadcasted assessment is that more than more than half of the inhabited space on the planet is today urban spreads—somehow this carries with it the connotation that everything here is *environment*; this is because what is left of natural environment is already subject to its manipulation if it desires being preserved. Nature is artificial, Sustainability scientists seem to say, and the more human influence plays a part, the more *natural* it will become.

The ability to distinguish environment from artifice lies, it seems, in the eye of the beholder, or perhaps the hand of the designer.[29] And according to Sustainability accolytes, it seems also to be our last and only hope. Hope sells, and this makes sustainability a great business market and marketing strategy, something which in turn, makes the Sustainable Project very sustainable indeed as it becomes a large revenue generator. Its idealism seems to be the driving force behind it, but this also gives its detractors significant room for skepticism, as they see it as another incarnation of capitalist dogma. All creeds aside, the global perception of environment has changed, and this is changing design practices radically.

Design Discourse/Design Practice

While the design process has always required a conscious taking into account of the "background" or *abstract environment* of the canvas upon which it occurs (even in 3D space), the relationship between environment an and that which is being designed has remained more or less unchanged, despite radical transformations such as the irruption of the digital revolution. What has changed is how we codify environment in terms of its representation and instrumentalization, which become driving factors for design or even material for the design process itself.

But at what point in time did these notions of the environment and design artifice change, it is worth asking; one believes that the design process itself should reflect those conditions suitable for a change, conditions in which the environment and design are—for the most part—interchangeable, or the line between them at least ambiguously blurred.

The notion of *embedding*, borrowed from the Shape Grammars design theory, contributes two processes or operations that may be seen as working within these conditions: finding (embedding) and forgetting . As understood in the terms of Shape Grammars, embedding consists in the detection of emergence through seeing (although seeing may here be understood widely in terms of any means of sensory perception, such as hearing, taste, touch, etc), which enables the *embedded shape* to operate through meta-rules of transformation. Embedding then is that basic operation which *extracts* a condition from its *environment* in order that it might become *operational*.

Forgetting, on the other hand, is the capacity to—at any point—release a particular definition, allowing us to extract or detect (i.e. embed) any other conditions (shapes) from the current temporal situation. Shape Grammars focuses extensively on the embedding aspect of the design process, on how a condition is *seen*. Yet *Forgetting* should not be overlooked, as it is equally relevant to the design process since it "flattens" or "re-homogenizes" everything back to a "pure environment". After *Forgetting*, everything is, at the same time, figure and ground.

After *Forgetting* takes place *Everything* is (or can be) a potential ground for design (or something operable through design processes) and *yet, at the same time, everything is also environment. Forgetting* flattens everything back to a *continuum*, back to *pure environment*. It becomes even more complex to grasp, when these ideas of Shape Grammars have to negotiate with conditions outside those of the controlled, differentiated and highly abstracted world of shapes.

This isn't to say that Shape Grammars does not operate outside of shapes, but rather that the definition of conditions is more directly communicable in those spaces where the distinction between figure and ground, between design and environment, is more evident, such as it is in the world of drawing, a world of two dimensional figures on a canvas and three dimensional geometries in Euclidian space. But the ideas in Shape Grammars, although being less explicit and less evident, become more pertinent than ever when they are forced to deal with intensive conditions (as opposed to extensive conditions, which are more patent and straightforward and hence more easily grasped). Focus on the *Forgetting* capacity of Shape Grammars, instead of on the seeing aspect, may shed light on how we may better understand how design operates when boundaries cannot be clearly defined and where conditions are variable and blurry.. While actual and abstract environments seem to be undergoing profound changes, it should be noted that architectural discourse and practice still struggles to reconcile itself with these new, emergent notions, accustomed as it is to relying on more fixed and reliable definitions. When artifice and environment become intertwined in dynamically changing relationship, one based on reciprocity and exchange, a radical transformations takes place—one that requires a rethinking and reconfiguration concerning the relationship between what which designers do and when, how and where they do it.

Case Study Part One

The case presented and discussed here describes a design process that emphasizes a formalistic approach to design, and I wish to stress how the materialization of the project was strongly influenced by those ideological precepts concerning the built and the natural environment from modern architectural theory. The project is founded based on the premise that architectural design operates by giving form to matter, and by doing so it *shapes* and *qualifies* the space in and around it. By doing so, architecture recognizes a basic distinction from the beginning, namely, that the operational mode of the design process acts upon matter, a matter which had been previously inactive before the start of this process. The only action recognized by this mode of thinking is the temporality of the situation created by the act of the architectural design. While this particular case embodies the previously mentioned discussion concerning the relationship between architectural artifact and the environment, it is also offers tentative, forward-looking perspectives on how other modes of engagement between the artifact and the environment could be pursued, focusing on the moment when this type of engagement stretches past the most canonical aspects of the conventional architectural formalism. By attempting to deal with these intangible, variable, physical (but not specifically concrete) conditions, conditions which differ greatly from the traditional geometrical and material considerations usually addressed in architecture design, this project became a vehicle for the exploration of other modes of engaging with the more general, spatial properties of architecture. The notion of an ecosystem as a variable and continuous condition appears and is manifested both in the study of the continuity of the folding formalism, as well as in the study of the light and shading of the space's interiors. In some ways this case summarizes a number of beliefs and ideologies that were particularly resonant with me at the time, notably contemporary building and infrastructural designs such as the Yokohama port by Foreign Office Architects, the entry project for that same competition by Reisser and Umemoto, the West 8 project for the Swiss Expo in 2002 and others. But this case also embodies a number of lessons gained through a traditional architectural education, at the School I was formed, Catholic University of Chile. A theoretical approach inherited from the Beaux Arts school but influenced as well by regionalist movements and local ideologies, such as *Amereida*[30]. This last current of thought was a particularly influential one for a generation of architects in Chile, a school of which most of my professors at the Cahtolic University of Chile would likely have claimed to have been a part or at least to have important intellectual affinity with. Its foundational tenet was that observation was a distinctly *poetic* action, and that architecture was designed and created out of this creative observational act. Many young architects of the time were influenced by this model, which gave the *poetic word* a power equivalent to that of the sketch coming out of the drafter's hand. This conception of architecture as a poetic act was the fundamental basis of the ideological position behind the *Amereida* school of thought, necessarily implied a radical separation of the observer and that which is observed; according to this school of thought that which was contemplated always assumed a given condition. The poet interprets the world, and by doing so effectively creates new worlds. Yet there is always a given world at the origin, a world which can be observed. This almost subconscious train of thought is most visible in the work of the generation of architects working in Chile[31] during the '80s and '90s. Despite my skepticism and reluctantance to adhere to the declarations of any particular school, I would be remiss if I did not say that the *Amereida* school—even if only though its influence on my work in reaction *to it*, rather than with it—left a mark on my work, one which I believe I can now discern at a distance.

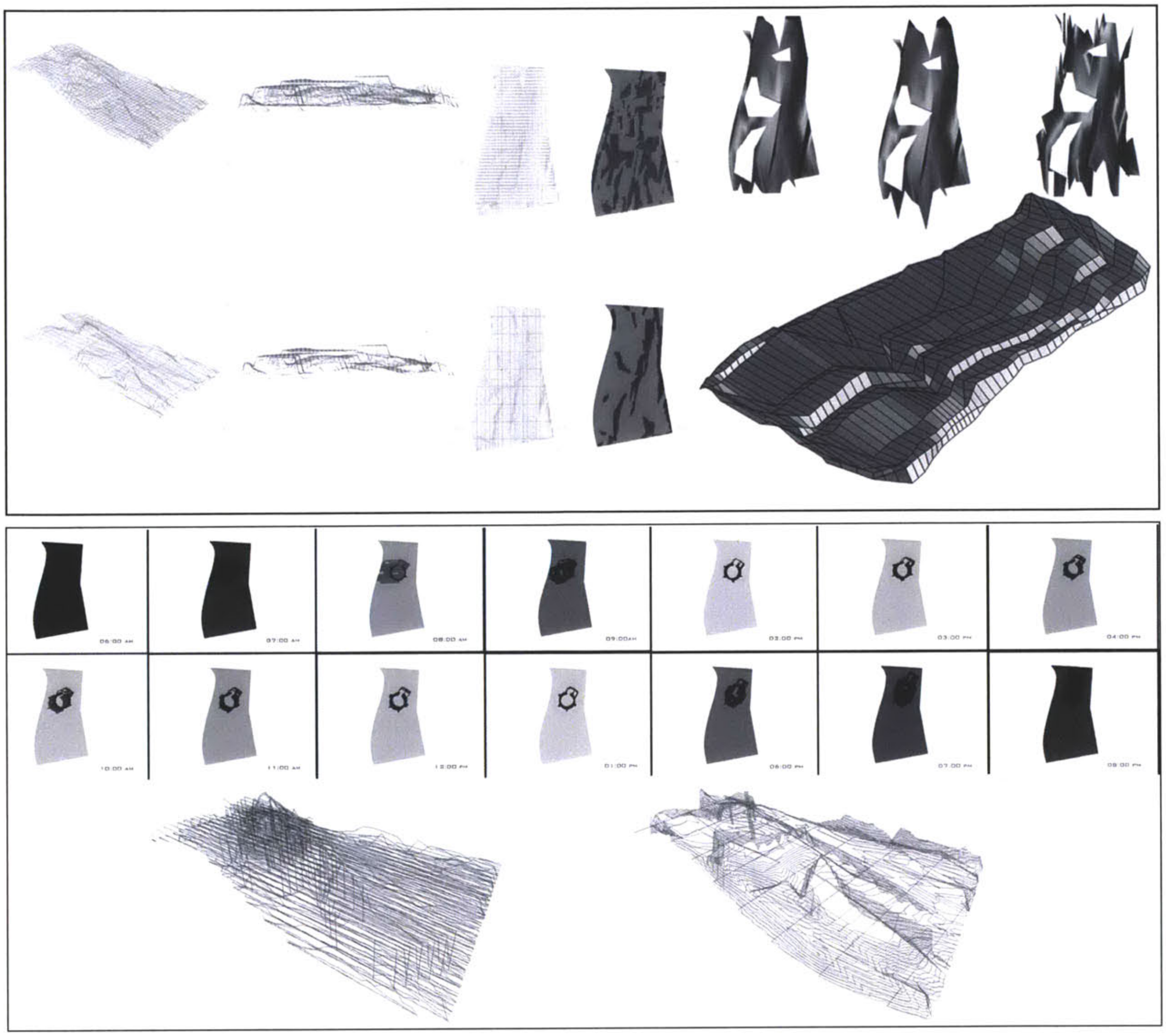
Both of these influences, a growing interest in territorial metaphors and topological design operations and an ideology of poetic observation (one in which this type of creative thought acts as a type a architectural intervention) affected not just the work that is presented here in this case study, but was an influence on my early years of practice and teaching as well. In this particular case, phenomenological observation and its operational role in the design process is particularly evident and will be discussed as the product of an inherited historical paradigm. Specifically, a paradigm that presented a clear distinction between man, nature and the artificial.

Downhill perspective of d_shop project and artificial landscape.

D-Shop

Case

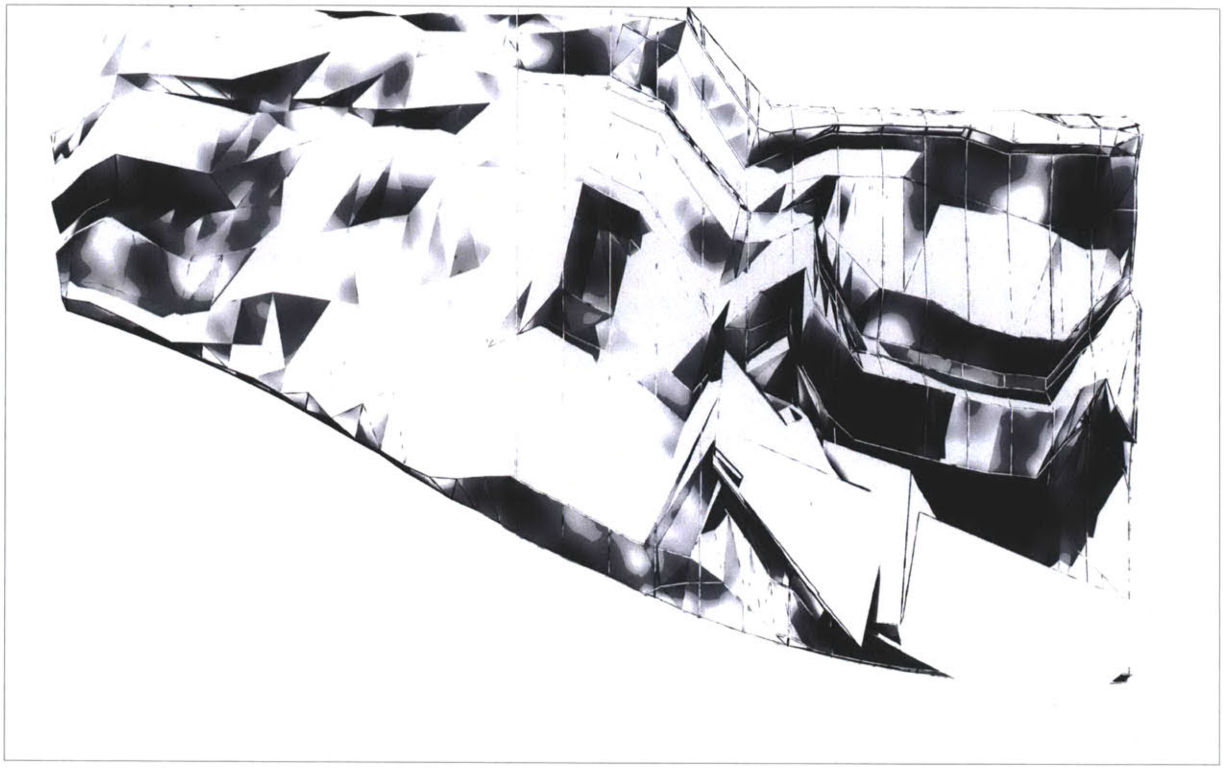
This project explores the notion of integration and differentiation in the context of both building and landscape by integrating a common formalism and also developing a type of formalism such as that of the (new) morphology of the site. The interpretation of such (pre-existent) morphology through formalisms became the subject matter of subsequent transformation and reconfiguration operations of the site. The commission consisted of a shop for a jewelry designer, to be located on a site with a slope in the rural area of Cajón del Maipo Canyon, near the small town of San Alfonso on the outskirts of Santiago, Chile. The Jeweler planned on using the shop both as a teaching space and as a workshop. The criteria for the building proposed included a work/teaching space for the designer, but required a (somewhat minimal) accommodation space for the occasional guest or guest instructor as well, given its remote location. This accommodation space was to consist of a small dormitory and bathroom. The Canyon in which the commission was to be built was one framed by the rocky formations of the



Top: topological study derived from existing topography of the site. Center: Solar study and shading evolution including existing buildings on site that will inform final morphological parameters. Bottom: Morphological parameters from topology, solar (light and shade) orientation and principal framed views of the landscape .

mountains, which showcased changing hues of pink and orange at dawn and dusk. The site, with an impressive mountain rock wall in the background, could even have been called a "hardscape."

The design strategy we proposed consisted of a volumetric design set at multiple scales. Imitating the rocks and other topographical features of the site we created both the interior and exterior spaces, with the resulted in a type of architecture that had been individually treated, *augmented* or *amplified* to fit particular programmatic conditions. The project aimed at reconfiguring the whole site into a new landscape, transforming the geography into a *topographical artifice*

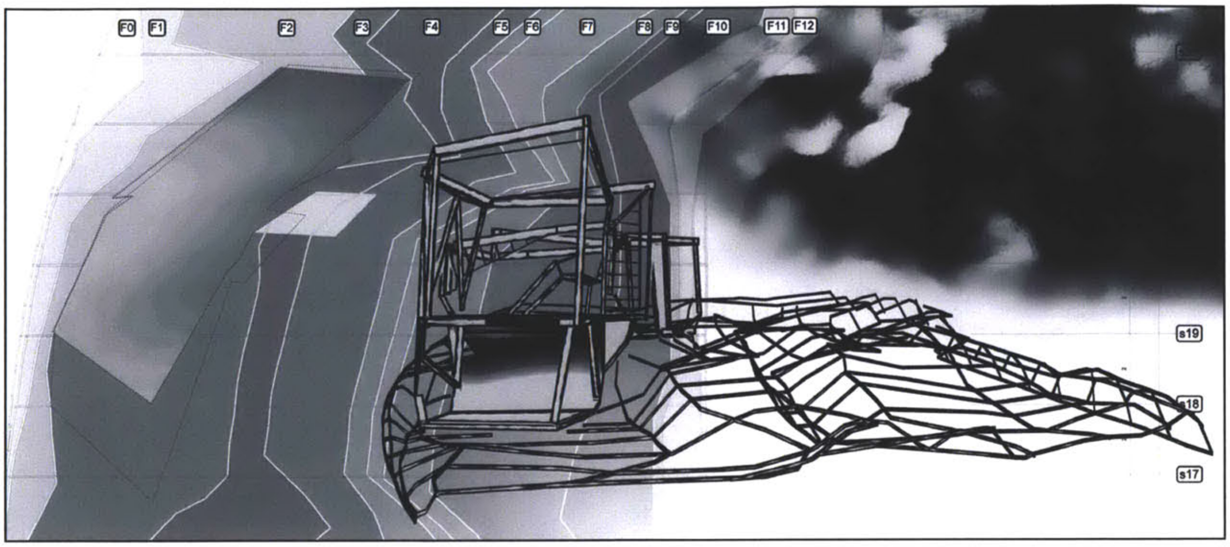


Plan view of final topography, including proposed building.

from which the silhouette of the building would emerge. The new topography for the site is one characterized by folds and reliefs, which in turn become functional elements, ranging in scale from pavement changes and furniture choice to entire walls and enclosed spaces.

Methods

This concept of "folding" went from being a general geometrical principle to factual construct. As far as engineering, fabrication and construction went, this sort of intricate geometry was deconstructed in order to bring out each aspect or facet of the project. The project was *unfolded*, treated as if it were a singular flat component that could be assembled *on site* and *folded* to the precise configuration that was required. This was the logic behind the creation of a template and the molding for the project, but carried over into the actual construction as well: this thought was utilized to completely reconfigure the landscape. In some cases the folded elements would remain, notably in the walls, slabs and roof, but in other cases the folding would only serve as a sort of mold in the shaping of the landscape, and in these instances the folds would be removed. It was a

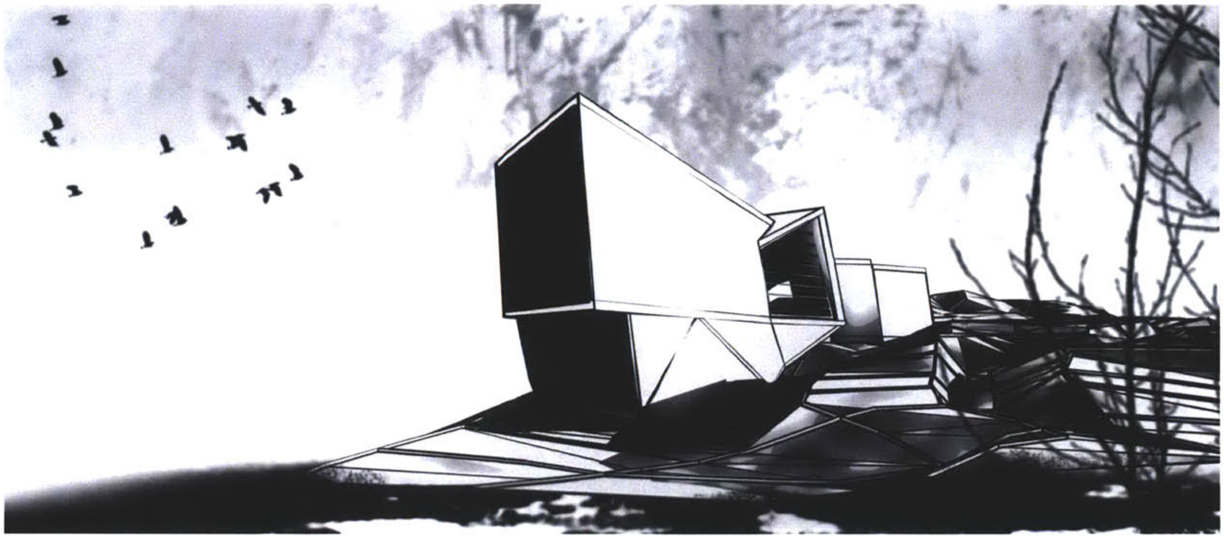


Structural framework of proposed building and landscape architecture, derived from a continuous folding morphology that will receive differentiated infill treatments regarding local conditions.

folded scape, one in which the folding elements sometimes remained and, in other cases, these folds (molds) were removed. Regardless of whether or not a fold was removed, however, the folding informed the matter through leaving its trace in form.

Questions about the artifice.

The project exhibits clearly an inherent controversy regarding its natural and/or artificial qualities, with the emphasis resting the question of *and/or*. On one hand, this project attempted to establish a dialogue between the natural characteristics of the site and those which, although preexisting before the commission of the building had been proposed, were not natural to the site itself, but rather created by unintentional animal, human and mechanical contact. This included things such as paths created from erosion or by the continual passage of humans or animals. Also included in this list would have been those things created through intentional acts, such as the rerouting of a small stream that carried water down from the mountain. Yet the project also worked by presenting a transfigured version of the terrain and surrounding characteristics as *artificial topography*, where material and formal characteristics play dual roles, partially diverging from pre-existent morphological types yet also in

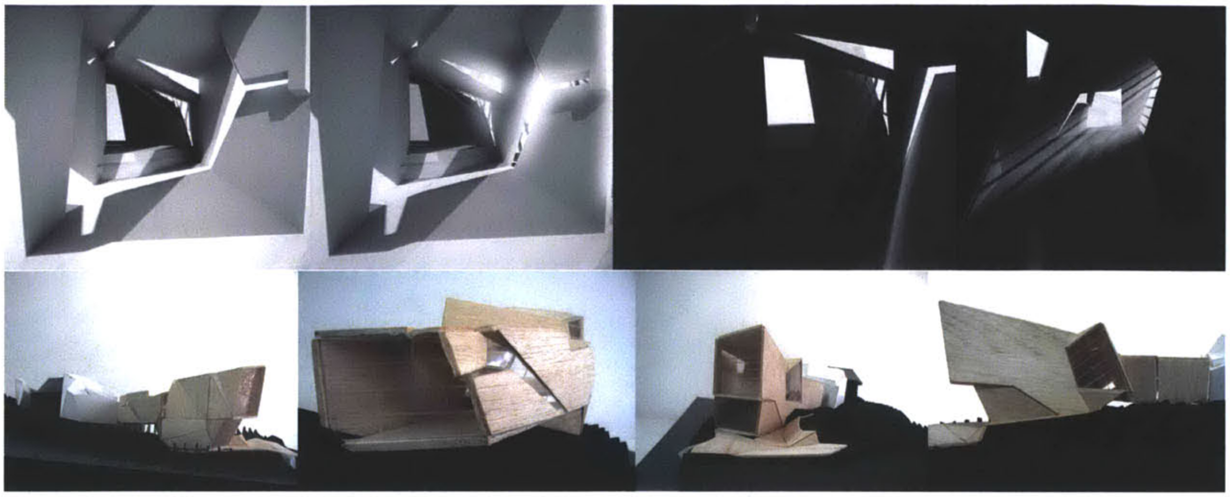


Uphill perspective of d_shop building and landscape.

conversation with the local material attributes and spatial features. The ambition of the proposal, to be omnipresent at all times at the site, contributes to the disintegration of the distinction between original and intervened, while at the same time contrasting deeply with the background landscape and neighboring conditions.

Questions concerning the environment.

The environment was treated or rather folded into the project in what I believe to be a novel way, especially when one regards the design of the interior spaces. The cloistered and secluded nature of project's locale, a canyon with contorted geography, producing late dawns and early dusks (depending on which side of the canyon you find yourself) became one of the driving forces behind the project. The conditions of the surrounding area—its light and shade—were reinforced and heightened as we designed a precisely oriented and focused series of fenestrations on the envelope of the building, targeting time-specific light conditions (solar lighting study). The light ambient (distinct from the ambient light) properties were designed with regard to how the light would enter the building. This is also demonstrated by the selective use of light colored matte surfaces and dark colored, highly reflective surfaces. The end result was that, during the daylight working hours,



Digital and physical models to perform light-shading studies that inform morphological variation and iteration in the design process.

a diffused, high level of illumination is provided via the major fenestrations—those oriented towards the opposite side of the canyon—through which indirect light is bounced into the building and reflected and further diffused by the matte walls. At the artificial[32] dawn and dusk times during which the canyon light is low but the intensity of the solar light is high (given its elevation), direct lighting is introduced into the building at specific places: places where maximum contrast is achieved. This was done in order to magnify the atmospheric light conditions, illuminating the interior of the building. The light that appears under these circumstances will appear have a material quality to it, will appear to exist beyond its mere visual status. At this intensity, even its thermal qualities are enhanced by this contrast.

Discussion

The design of this project attempts to expose how tangible and intangible interfaces shape the architectural experience. It achieves this by accentuating the moments when such an experience would take place. Geometry is as much a factor in the computation of design variables as it is an output of the non-


East Elevation of d-shop building and landscape

material processes at play in the "performance" given by the building and the landscape. It is a defined and precise geometry that captures the specific inflections of the terrain, or accentuates a particular time and light condition at the site; both of these things affect the ensemble of materials and forms at play in a way that it produces a different, slightly augmented and intensified temporal and environmental experience. The sharp, precise shapes of the building's envelope attempt to produce a fuzzy, blurry and fading ambience, something which in turn transforms and dissolves the sharp shapes themselves into undefined light and material conditions that will remain in constant flux. What we can conclude from this is that there is a gap between the observed phenomena and the capacity to design within conditions able to affect material and spatial situations. The fact is that either the results are partially known in advance (and hence it is not an actual design operation but rather an implementation of a known strategy or rule) or there is no precedent for such a condition and it is something based on a trial-and-error experience, something accomplished through speculation and post-rationalization of results after their materialization. An experimental methodology while expecting certain consistencies but always accepting and maintaining a certain (high) level of uncertainty. There was no system in place then that would allow us to design things that could not be described in terms of their specific and set material characteristics or geometric boundaries.

Part Two

A Paradigm (Of) Change

"It is not the strongest of the species that survives, nor the most intelligent, but rather the one most adaptable to change "

The above quote is attributed both to Clarence Darrow and to Charles Darwin. Some authors cite the famous civil libertarian American lawyer, who used such expression during a hearing defending the rights of elderly black people in 1987. The same phrase, or even a slight variation ("...rather the one most responsive to change") have also been attributed to the British naturalist, in several sources, since at least 1997, but it has never been cited from any original source. Despite the controversy, or the truth behind its claims, change, and most importantly the capacity to adapt to it, is perceived as an essential and positive characteristic. Change is inherent to nature's evolutionary process and as part of nature; human activities are constantly subjected to changing conditions. But it is not change on its own what characterizes this decade but rather the urgency to respond to evermore pressing and imminent challenges, challenges originated in increasingly greater technological and cultural developments which keep happening progressively faster. Phrases like "(blank) for a Changing World" (you may fill in the blank with Engineering, Political Leadership, Energy, Health Education, or Urbanism), have covered printed and electronic press highlights, book titles and scholarly papers for several many years now, but with a marked increase since the late 90's. Either because of a false urge catalyzed by the millennium shift, or based on real data, this demanding challenges are, allegedly, compelling us to change, or to adapt to ongoing processes of change. So caught somewhere in between acknowledging the changing and transient nature of the world we inhabit and yet still being critical about the paranoid fear (for what are seem as apocalyptic) changes to come and that propel many of the current political, economical and technological campaigns for an "urgent change", this work tries to hypothesize about what can architecture say or do. And it aims at doing so, precisely (and ironically) as from a disciplinary perspective, architecture has traditionally claimed permanency, consistency and stability.

Artifice through assemblage

The architectural artifice is achieved through a perceptual, conceptual and material synthesis. Through synthesis, as in *putting things together to create something anew*, the design process encompasses observation and analysis of both natural and artificial phenomena, their convergence through design concepts and methods and the development of new design artifacts and principles through successive materialization and iterative refinement.

In the process described above, design is both a noun and a verb, and the following thesis uses extensively this ambiguous definition; far from trying to clarify each of their particular scopes or attempting to establish the demarcations of each of their connotations, these writings exploit this ambiguity as a field where creative processes (as ongoing) and instances (as fixed instantiations, even if only momentarily) happen.

Architecture is understood from this perspective as a craft, of synthesis through assemblage, putting things together to achieve an effect, whether that objective regards environmental conditions, structural properties, human use or cultural demands.

From Stasis to Allostasis

Our ever changing natural environment, the world we inhabit, imposes demands which require the development of strategies from organisms to survive and strive. To cope with the variable conditions of the environment they inhabit, they have to develop mechanisms to adjust their organism's internal environment, in order to compensate and sustain living conditions. Scientists have observed and described phenomena regarding these mechanisms, which range from short-term, reflex-like, reactions and responses, to long-term adaptive transformations. All living organisms are affected by the surrounding environment in which they live. Homeostasis or responding to a changing environment (or outer environment[1]) in order to achieve internal equilibrium, is a mechanism that allows organisms to counter-effect the changes of the medium they operate in and the influence this medium exerts on them. The term was coined in 1929 by Walter Cannon, the prestigious American physiologist, developed from Claude Bernard's earlier idea of *milieu interieur*. Homeostatic behavior in animals and humans works as a corrective procedure, seeking the reestablishment of the internal balance, in order to maintain and guarantee the optimal internal conditions for the organism, and its organs, to function. Physiologists have determined that for homeostasis to occur, a sensing capacity has to exist and operate, and a feedback mechanism has to be in place and implemented. This feedback can either be positive feedback or negative feedback, and generally, homeostatic behavior implies a negative feedback response, acting against and correcting the sensed anomaly. Homeostatic behavior is responsible, in mammals for example, for regulating internal body temperature, providing them with the ability to function in diverse environments with varying temperature conditions. Cold blooded animals in contrast, require external temperature conditions for their bodies to function adequately; therefore their range of adaptation to diverse environmental conditions is narrower than that of mammals. Other scientist following Bernard and Cannon became interested on this regulatory phenomena, as did G. Chrousus in 1998 when he presented evidence of observed adaptive behavior in animals that would be originated from physiological adjustments performed to achieve homeostasis. For example when particular environmental changes are sensed by the subject, a physiological reaction triggers both the release of higher doses of substances into the bloodstream and the stressing of the vascular system to increase the blood flow, promoting those substances to reach the affected body parts and the central neural system in charge of the regulatory process, faster in order to accelerate the sensing and feedback process. Such physical reaction translates into an increased state of alert by the subject, a behavioral adaptation.

> *"Bernard and Cannon understood that stability is the key, both in short and long term, with regard to both low and high taxation of the body's resources. For Cannon homeostatic regulation reflected 'a condition, which may vary but which is relatively constant'* [2]*."*

Homeostatic behavior is generally associated with short-term physiological regulation, whereas long-term regulation, which biologists would call adaptation, cannot be fully explained by homeostasis.

Behavioral adaptation	**Physical adaptation**
Increased arousal and alertness	**Oxygen and nutrients directed to the CNS and stressed body site(s) Altered cardiovascular tone, increased blood pressure and heart rate**
Increased cognition, vigilance, and focused attention	**Increased respiratory rate; increased glucogenesis and lipolysis**
Euphoria and dysphoria	**Detoxification from endogenous or exogenous toxic products**
Suppresion of appetite and feeding behavior	**Inhibition of digestion, stimulation of colonic motility**
Suppresion of reproductive behavior	**Inhibition of growth and reproductive systems**
Containment of stress response	**Containment of the inflammatory/ immune response**

Behavioral and physical adaptations following an acute challenge (Chrousos, 1998)

Short-term adaptation	Long-term adaptation
Inhibition of sexual motivation	**Inhibition of reproduction**
Regulate immune system	**Suppress immune system**
Increase glucogenesis	**Promote protein loss**
Increase foraging behavior	**Suppress growth**
Incresed activation of the brain	**Neuronal loss**

Short-term and long-term consequences of glucoconticoid hormones (Wingfield and Romero, 2001)

In 1988, Sterling and Eyer after observing homeostatic behavior on animals, proposed that in certain cases, where external conditions are variable, homeostasis could not fully describe the physiological changes and adjustments taking place. While searching for a new concept, beyond homeostasis, Hans Selye stating that "when faced with unusually heavy demands, however, ordinary homeostasis is not enough" coined the term *heterotasis.* When the homeostat is raised beyond its functioning capacity levels, it *breaks down,* and as Jay Schulkin explained, a *resetting*[3] of the homeostatic condition is required to assure long term survival. *Rheostasis*[4] and *Predictive*

Homeostasis[5], were concepts that attempting to further explain the "wide variation in systemic physiological systems" were defined by studying the role of time and clocks on animal behavior, specifically regarding behavioral and physiological regulation performed *in anticipation* to future needs and demands.

Sterling and Eyer published the paper entitled "Allostasis, a new paradigm to explain Arousal Pathology"[6], stating that *allostasis*, as opposed to homeostasis, "involves whole brain and body rather than simply local feedback", and that this explanation was "a far more complex form of regulation than homeostasis"[7]. According to Schulkin[8], the concept of *allostasis* was introduced to "take account of regulatory systems in which (1) the set point is variable; (2) there are individual differences in expression; (3) the behavioral and physiological responses can be anticipatory, although they not need to be; and (4) there is a vulnerability to physiological overload and the breakdown of regulatory capacities".[9]

In the process of describing how these behaviors were explained by the notion of allostasis, Sterling and Eyer shifted the homeostatic notion of *balance*, or *equilibrium*, to the notion of *viability*, as there is *no equilibrium* in allostasis. And as noted by investigators, this predictive response replaces the negative/positive feedback mechanism of homeostasis by a *feedforward* anticipatory mechanism in allostasis.

> *"Allostasis reflects longer-term regulatory and organismic viability in diverse contexts with varying points of bodily needs and competing motivations"*[10]

Between biologists, homeostasis is still accepted as a valid general model to explain physiological regulatory behavior, and despite the fact that although there have been numerous attempts to establish alternative models to take into account variability and flexibility in such behaviors, most of them are still considered as variation or deviations from homeostasis. Nevertheless there is a growing consent about the need to further develop the original concept of homeostasis, and the notion of allostasis is one of the latest concepts to discuss how change as oppose to equilibrium, should be the underlying condition behind any explanatory model.

On a slightly different field, psychologist Gordon W. Allport[11], when describing the relationship between (psychological) imbalance and growth, used the notion of *transistasis*, which was oddly coined from the Latin etymology *trans*, meaning beyond, across, over, and the Greek *stasis* meaning stability. Allport realizing that psychologists were becoming more and more critical of the concepts of "adjustment and, correspondingly to the concepts of *tension reduction, restoration of equilibrium* and *homeostasis*"[12], stated as early as 1960, that "growth, we know, is not due to homeostasis, but to a kind of transistasis".

> *"Cohesion is a matter of keeping our human relationships moving, not in mere state of equilibrium. Stability cannot be a criterion of normality, for stability brings evolution to a standstill, negating both growth and cohesion".*[13]

Since then, transistasis is a term used widely to refer to regulatory behavior that requires multiple dynamic equilibrium adjustments, in order to achieve viability.

From firmitas to mobilitas

Architecture has been historically conceived as the construction and basis for societal life and its transcendence for future generations as one of its founding pillars. Anthropologically utilized as a conquering mechanism, establishes itself as a disruptive act, constructed by men and different from natural order. Architecture as a symbol of power, of territorial control, of political influence, and of organizational prominence, has been thought of, built for, and used as the cornerstone of the values, traditions and culture of its time, and as a way of perpetuating those values and culture into posterity.

As early as 25 B.C. roman architect Vitruvius declared that *firmitas* was one of the three fundamental principles of architecture, along with *utilitas* and *venustas*. Vitruvius's *firmitas* standing both for strength and durability, has had an enormous and incalculable influence in both the profession and the discipline, in particular because it implies a combination of both these attributes, material resistance and building permanency. This thesis proposes shift towards an understanding of the conditions in which architecture operates through the notion of *mobilitas* -instead of the Vitruvian *firmitas*- which can better explain the dynamic nature of the world as we know it today. This thesis will explore the reasons and the implications for such paradigm shift, introducing the notion of performance to mediate and propagate such change.

Architecture and Performance

Over the course of the last ten years the word Performance has become a regular expression in design disciplines. With its adoption, a new and complex set of issues and perspectives have also been introduced. However, discerning what an exact definition of performance *is* within the field of design is no easy task. Two things become evident from the start: that there is no general understanding of what performance is, and there is also no unified history of the concept. What we do have are a number of differing interpretations and uses of the notion across different fields and disciplines—each of them seem to see performance from a different point of view. Simply put, Performance is always an ambiguous concept; the only thing we may say for sure is that it can, at the very least, always be interpreted simultaneously as "experimentation and normativity."[33]

Why Performance?

"Perform or Else initiates a challenge, one that links the performances of artists and activists with those of workers and executives, as well as computers and missile systems." J. Mckenzie[34]

Establishing a coherent network of relations between design discourses and the different notions of performance presents several challenges identical to those that concerned McKenzie in the quote above. In order to respond to these challenges, an idea regarding the relationship between the question of architecture as a discipline (designing) and architecture as an artifact (building) will have to be assembled.[35]

This first idea, of architecture as a discipline begins by shifting the assumption of what architecture is, nominally, from a noun to a verb; it shifts from a definition of the discipline itself to an act of epistemological inquiry. If and when architecture can be made into a verb, then a secondary meaning can be construed as we now deal with a different challenge: shifting the conception of architecture as *inert* to architecture as *active*[36]. I propose that the operation which produces these two shifts or dislocations brought about by these notions is (through) Performance.

While performance is not a new term in architectural discourse—it has already been present in the architectural vernacular for a few decades now (in different contexts)—it still suffers from the same deficiency that McKenzie denounced years ago. Mckenzie's point was that, although performance is all around us, "work, play, sex, and even resistance—it's all performance to us,"[37] it still has yet to enable the confluence of these different visions into a general theory of performance.

> *"Because performance assembles such a vast network of discourses and practices, because it brings together such diverse forces. Anyone trying to map its passages must navigate a long twisting path"*[38]

On the one hand, the question "how relevant is it for us to even ask about the role of performance in architecture?" seems to seek to validate the introduction of the term itself (note: why perform?). On the other hand, however, the question seems to be inherently rhetorical as performing seems inevitable (i.e. how is it not possible to perform?). To attempt to illuminate a bit of a path through the fog created by this playing of words, three conditions of performance (following Perform or Else's indexation) will be addressed: the *technological performance*, the *organizational performance* and the *cultural performance.*

The temporal and instrumental definitions offers the action of reading (seeing) and designing (doing) as a theoretical connection between Architecture and Performance. I will follow along these same lines, and endeavor, with McKenzie's, to "rehearse a general theory of performance."[39] This is begun by declaring this a *rehearsal* -based on the unfinishedness of the complex task ahead, the task of rewriting a complete general theory of Architecture- but also, I would add, because of the close ties between an action in progress and under permanent revision as opposed to a final and conclusive representation derived from any such process. McKenzie's theoretical attempt acts and performs while it simultaneously builds itself up, unfolding the connections between the different understandings and uses of performance, this thesis aims at operating similarly. But at the same time this fact enables the reader to construct another reading of such an open network of relations: that of *embedding*[40]

What Performance?

Design disciplines have dealt with the notion of performance in different ways, and although today performance seems a ubiquitous term in design it is worth tracing its origin and examining it from the standpoint of these three, fundamental distinctions; this is done in order to better understand the different perspectives that have been introduced and the fields brought together through the adoption of this term. This will also allow me to distinguish the different connotations implied by the word Performance, its overlaps and coincidental crossovers that are bound to occur given the apparent virtual exchangeability of these different notions as they appear in current design and practice.

Technological Performance

The way in which design is traditionally conceived in engineering as related to the idea of problem resolution within optimal condition[41]. Given this notion of "optimal solution, performance is also a fundamental aspect of engineering problem solving, especially when improving problem solving capacity is crucial. It is likely that this understanding of technical performance was the first to permeate the architectural discipline, doing so in a time when architecture and engineering were different aspects of the same field of knowledge. This is the performance of machines and instruments that allows for measurement and manipulation, the performance of those techniques developed in order to manipulate machinery and to process its output. The metrics of this performance are temporal (having to do with efficiency in time, striving for that which is closest fit to an optimal state), and physical (having to do with structural configurations subjected to varying conditions).

The role of modeling and simulation has become central to technological performance, allowing designers to foresee and prevent as well as estimate and forecast, checking potential situations for the best results. This is an empowering action, as technological performance gives them the capacity to predict and anticipate. The expression of techno-performance in architecture today would be most evident in structural analysis and systems management, in computer assisted environmental and behavioral simulation, an in the systematic engineering design approach of problem solving through design methods. These areas of specialization require (inherit) the breaking up of that which is most complex into simpler fragments in order that each piece may be analyzed, understood and then replicated; this allows for their more successful integration into the design process. Techno-performance operates through fragmentation, isolation and assumption.

Organizational Performance

Organizational performance, as opposed to technological performance, is one expressed through the efficacy obtained from the arrangement and management of resources, both material and immaterial. Human resources as natural resources are managed in order to maximize the output derived from the processes from which they are constituent factors. Management and Economics operate and develop Organizational Performance through their understanding and utilization of allocation, distribution and monitoring practices, understanding them as essential conditions in guaranteeing a high yield from a given system.

This is the performance of corporate executives and of workers in a manufacturing plant, the performance of funds and stocks, but it is also the performance observed in waste management policies for example.

To put this all in more architectural terms, for organizational performance, the form and function are essentially inputs that must be managed in order to best optimize results. The metrics of organizational Performance are the profits, stock prices, organizational efficiency and achievement of annual corporate management goals. In architecture, organizational performance is pushed forward mostly through programmatic and material agendas, and it is something that becomes more explicit as the design scale increases. Urban design and City Planning are the organizational performance arenas *par excellence,* since the amount of resources to be allocated is increasing on an exponential scale. And while no architectural problem or scale prevents organizational performance from exercising its influence, it is more evidently necessary in the urban scale discourse, since the number of agencies and factors involved more often require a managerial and economic perspective in order to deal with the territorial, social and political implications of any such enterprise. Organizational performance operates through distribution, order, hierarchy and delegation.

Cultural Performance

From a physical and theoretical perspective, the expressions and manifestations of cultural performance have always overlapped with architecture. Some more explicit connections were elicited by cultural movements of the 20th century, like the Bauhaus movement, which explicitly attempted to amalgamate all of the arts through its design pedagogy system, or the Situationists with their performative vision and discourse. Cultural performance is simultaneously linked to the re-enactment of traditions and myths and the transformation of their cultural implications (the end result of which is the creation of new implications). It is the performance of the actor on the stage, the poet's public reading and the sculpture's installation at a site. It is also the performance of cultural critique and performance historians, academic performance fills a large a role as that of the orchestra or the soprano singer. Cultural performance in this sense then is already a manifold field of forces, one which operates on a representational level in terms of the re-enactment of these distinctly cultural and historical conditions. Yet cultural performance is also at work on the presentational level in terms of the acting or actuation of critical contemporary and future conditions. Its metrics are related to cultural values and aesthetics, but may also be measured taking into account the social and political impact it produces. Cultural performance incarnates the "living, embodied expression of cultural traditions and transformations".[42] Cultural Performance operates through aesthetics and tectonics, but also through experience and discourse.

How does architecture perform?

With the shift in understanding of the concept of architecture, with its move from noun to verb, the question about how architecture performs has become a crucial one[43]. For decades this discussion would have seemingly pointed to the debate between formalism and functionalism. Does it perform because of its form? or does it perform because it functions? The interpretation proposed here is one in which the performative question situates itself between this two conditions as a mediating or operational concept. From a formalist approach it is because form performs that it is possible to have it function at all, but from a functionalist point of view it is because a function is in itself performative that is embodied in a form. Form and function have tried to establish a hierarchy and define which follows which, but it is obvious that they need each other in order to perform.

Despite this fact, many would try to embed one condition or the other on *performance,* in an attempt to transform its performativity in an adjective that qualifies, as in a "high performance" something, rather than admitting that there is more to be found in the word *performance* than the action itself.

Kolarevic, comparing architecture and performance, situates performance "above, or on a par with, form-making."[44] Performance in that way somehow reinterprets form-making, as Kolarevic proposes that it replaces form-making. According to this postulate, form does not *follow* function, *form per-forms* and by doing so informs itself through the process of its creation. We could say that, according to this definition, form may be seen as *formation*, and it is precisely because of this that it performs. It performs in its capacity to reproduce itself.

The performance that Kolarevic alludes to resonates with the organizational performance of Mckenzie, one of order and distribution, physical allocation and logical conformation; yet it resonates as well with the tectonic aspects of cultural performance, as *form* is something that emerges out of a specific *performance*. A form is that which has to do with material and formal conditions, deployed in a certain order which allows it to take form. Leatherbarrow on the other hand focuses on the effects of the produced form, how form performs in the sense of *how it affects.*[45] For Leatherbarrow the fact that *form performs* implies that form works. Leatherbarrow's work also reflects on the old discussion of functionalism vs. formalism; he criticizes contemporary works that, according to his judgment, resorts to aesthetic appeal to mask functional incompetence, resulting in an instance of "underperforming."

When Leatherbarrow critiques Gehry's Experience Music Project[46] as an instance of formalism being used to disguise the inadequacies of its more functional features, he indirectly implies that, while Gehry's work may be highly discursive on a tectonic and aesthetic level of cultural performance, it is highly inefficient in its organizational performance.

Leaving the physical actualization of the functionalist vs. formalist debate aside, Leatherbarrow later petitions for the effects of architecture as a performative discourse and practice in an attempt to unveil its modes of performance. "(...) Ask not about the work but about the way the work *works,*" he writes.[47] To asses this, the *act* of architecture, he returns to the notion of an *event*. The argument about architectural "eventness" is revived, but this time in relation to a performance *of* architecture (as opposed to the performance *in* architecture) bringing with it its inherent unpredictability and vagueness. The question of *where*, *how* or even *if* the given space works and how it affects the subjects/audience of the performance cannot be predetermined is his assertion. Leatherbarrow supports a performativity independent of both aesthetics and technologies[48], but rather somehow manages to straddle the space between them, *what architecture is* ; and how both aesthetics and technology are affected and transformed by its performance, *what architecture does*.

Interesting parallels can be traced between the two categories (as they could be called) of Leatherbarrow's and McKenzie's perspectives. Leatherbarrow describes a type of performance "device paradigm," one which relies on all the parts and components of a building that can be and are operable and able to be manipulated.[49] All of these moments embody a potential condition for change and transformation. A building's performance, seen in this way, may be understood as the orchestrated but unscripted choreography of its movements and variations, controlled mechanically or manually by humans (for humans here are just another element of the environment), machines or by other environmental conditions during a specified period of time defined as the lifecycle of a building. This is a category of performance that relies on mechanisms and assemblies; it relies on screens, doors, windows, hatches, furnishings—it is contained within the dimension of Technological Performance announced by in McKenzie's *Perform or Else.* [50]

Another paradigm that does *not* rely on a positional or translational status but rather on a change of state is one, again by Leatherbarrow, called "economical performance."[51] The economy of this work relies in its efficient exchange of energies and forces *through* and *by* architecture. This type of performance is generally observed in the capacity of a building to endure changing external and internal conditions, such as load, climate[52], human usage and natural disasters. The building itself doesn't change, but its capacity to *not change*—to resist change—is precisely the mechanism needed to measure this kind of performance[53]. This type of performance works in places where architecture defines its static equilibrium in its structure and its enveloping walls and foundations through their being—simultaneously—at the core but eccentric to the building's physical material structure[54]. This is a performance that has to do with material densities, structural distributions, and chemical assemblies; it therefore falls within the the category of Organizational Performance. The capacity of a building to perform in resistance to the variable, external and internal forces that act upon it depends on its organizational structure and its capacity to change or not change this organizational status. Emerging from the core of this manifold conception of performance in architecture are two central ideas: *action* and *commutation*.

Whether architecture performs by *changing* and *adjusting* itself, or by *confronting* and *resisting* change, or if perhaps it performs *in response* to the environment or is the environment that performs *onto* architecture, the central point remains: performance *is* that which *enables* these transformations, taking architecture from noun to verb, from *inert* to *active*.

Case Studies Part Two

The three cases studied here discuss the notion of performance as new concept to describe the mediation between form and function, and as a new way of understanding the relationship between artifice and environment. Each of the cases is concerned with different length scales, yet they are all multi-scalar in nature. *"Kinet"* functions on a product or component scale, focusing on material properties and construction details. *"Ichtyomorph"* deals with parts and systems on a large building scale, and is concerned about part-to-whole correlations, with inner and outer environments and their interfaces. *"Zambana"* operates on a territory scale, focusing on the relationship between the building, village and the reconfigured landscape. It deals with large, systemic assemblies and ecosystems. In all of these cases, the imbrications of computational design strategies and environmental engagement methods are conceived of as being dynamic and continuous in time and space.

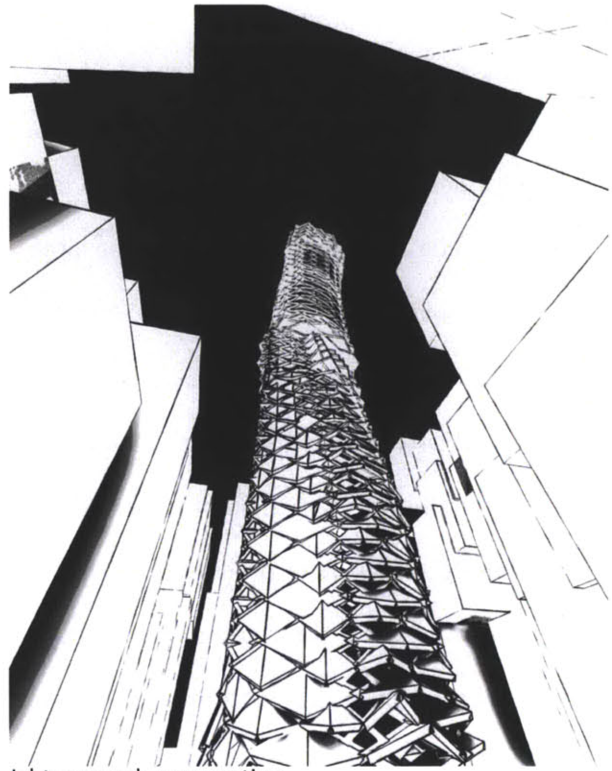
The projects seek to produce the conditions appropriate such that a performative act may be played and replayed both by artifice and nature, creating a continuous negotiation of boundaries and states. Evident in this action is a constant search, the hope that design will become an active protagonist in the choreography of variables displayed and enacted by such a design process.

Performance becomes the lens through which this new relationship is conceived and observed. Performance describes the action, the enactment of these conditions, not any finite state or stable phase resultant of the action. Spaces affected by this type of design logic and operation become entangled with its immediate context, since their responsive aspects root attributes of such designs into the qualities and characteristics of the places themselves. Responsive environments here is not a search for *interactive spaces* (as in the early nineties sci-fi futurism), but rather responsive as in response and responsible.

The performative responsiveness pursued here extends beyond an experience that is founded on purely aesthetic or technical values, it extends its capacity to respond smartly to its own environment—to adapt and change—as an *autopoietic*[55] entity would. The examples also depict how similar principles are scale independent as well as being field independent. The same design rules or concepts can be used to operate on a agricultural (biological) landscape proposal or in a micro-controlled robotics (mechanical and electronic) product proposal. This sort of openness is natural to the design process, with its capacity to infiltrate any field or scale of invention and create anew. It is precisely this that is of interest to me in my three cases: the comparing of strategies, results and shortcomings because, to a designer's eye, scale and field specificity are simply a temporal definition, and are therefore subject to opportunistic implementation or suppression.

It is also important to emphasize that while many of the design concepts and operations may derive from observation of natural phenomena, in my work there is also explicit interest in trying to create principles that *respond* and *enact* the conditions which allow them to mediate the artifice-environment relationship. Recent methods have been developed and promoted, like *biomimicry*, which implements a strategy of deriving principles and bio-inspired concepts through the development of synthetic analogues of their natural counterparts, in order to replicate nature.

But following the premises described earlier in this thesis, a different method must be used, one which following the purposes of this research, doesn't attempt to imitate or replicate. While I understand the value of such work (bio-mimicry) specifically within scientific fields where the main objective is to understand, describe and explain how the phenomena occurs, it is a different case altogether with contemporary design, where bio-mimicry is too close to re-vindicating the old Vitruvian paradigms of nature as a model. And this is not the direction toward which my work is directed. The three cases studied here describe design principles and design methods whose operation embraces natural and artificial phenomena and proposes performative strategies to mediate between the two. Human habitation or use is just another factor being mediated, and is thus considered nothing more than an aspect or facet of the environmental engagement of these design strategies.



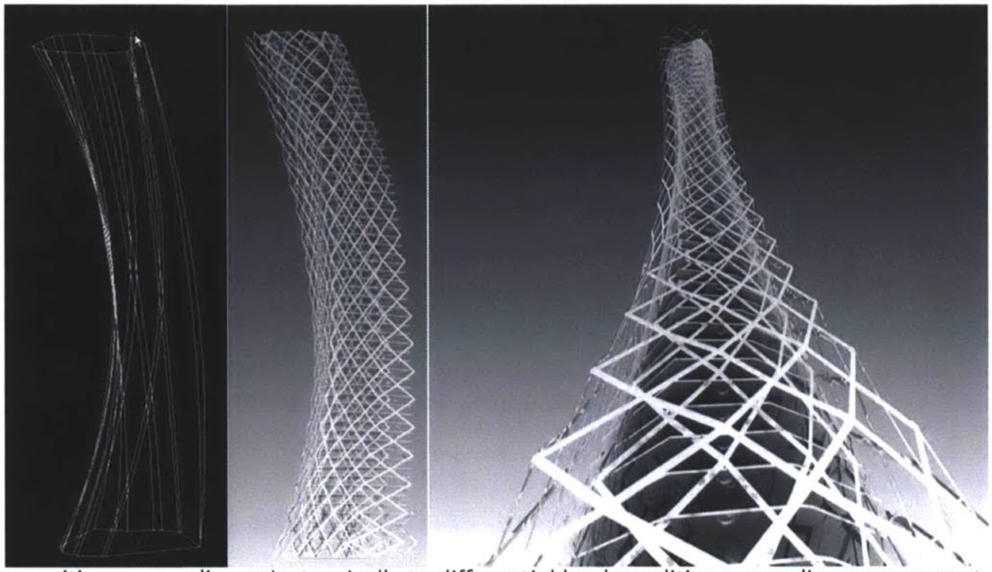
Ichtyomorph perspective

Ichtyomorph

Fragments of this chapter have been previously published as a research paper for SIGRADI Conference in in2005, Lima Peru.

Case

This second case study is a research project that investigates a responsive double-skin façade system. The project focuses specifically on the facade of extremely tall buildings. The name of the research project, *"Ichtyomorph"*, was inspired by the skin structure of fish. In some cases, the skin system of fish can have a great effect on the ability to quickly turn while swimming. This allows the fish to change direction rapidly, in order to escape from a predator. All of this is dependent on the skin system of the fish. This skin structure is composed of a mesh of layered fibers which pulsate, driving undulating patterns along the surface of the fish's skin. This reorients hundreds of smooth, operable scales which in turn reconfigure the hydrodynamic surface of the fish's body, providing a slippery surface and precise swimming control, granting the fish its agility in the water. Ichtyomorph, as



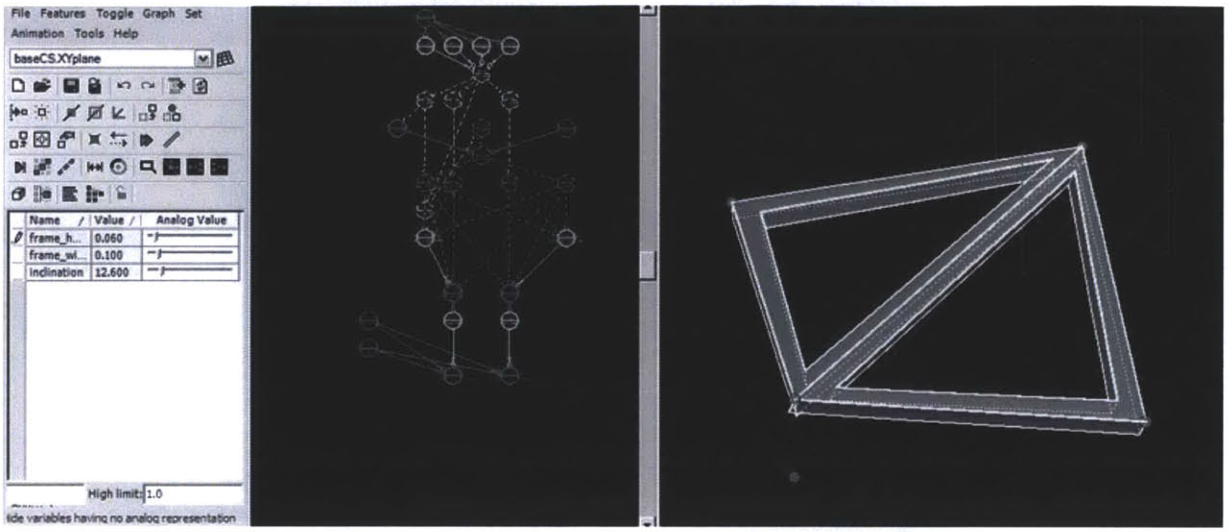
Dia-grid structure composition responding anisotropically to differential load conditions regarding non-symmetrical geometry and dynamic loads.

understood within the bounds of this project, is an adjustable façade structure constructed to respond to varying environmental conditions, the end result of which is to give a performative agility to the building it surrounds . The project's secondary objective is to study the design of a façade system in articulation with the supporting load-bearing structure, as a flexible structural composition that may be reconfigured to respond to dynamic load changes or programmable spatial reconfigurations.

Methods

Parametric Shape and Adjustable Building Silhouette

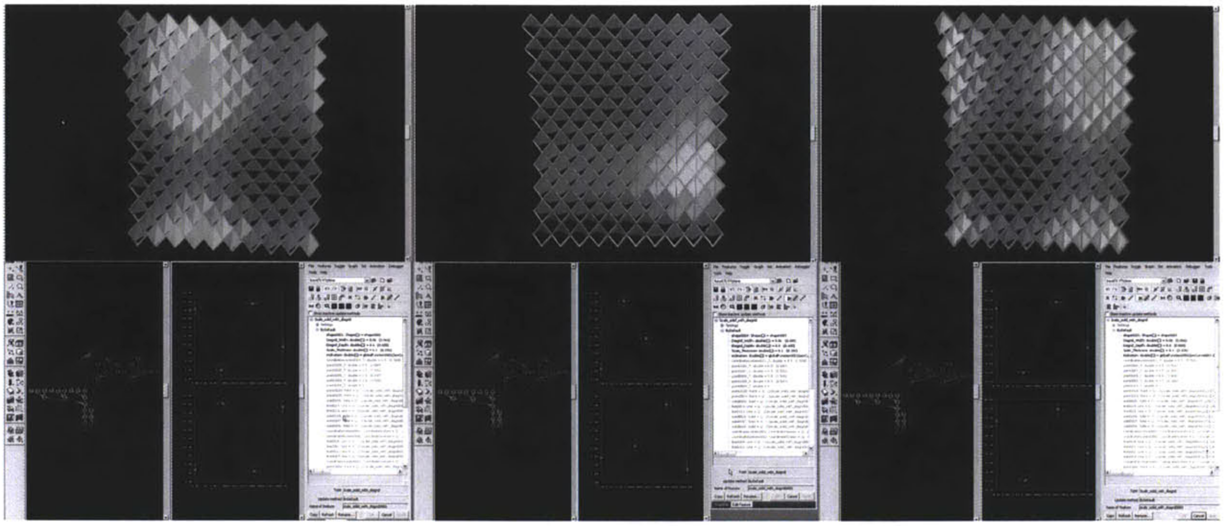
Beginning with a rationalization of the building geometries, the shaping process was developed using the Sketcher module of the Catia software program. The overall form of the building was treated as a surface-based envelope that, despite having a few constraints, was a fit for incorporating structural and functional principles into the design. The idea of working with an extremely tall building required a decision regarding the function and structure of the elevator core structures, which in this case were located in the center of the building. A parametric structure would collaborate with and complete the vertical load bearing structural system of the building, and would become an cohesive overall system via the slabs that would connect the central core to the parametric structure.



Parametric designs developed in order to obtain 3D printed prototypes to demonstrate versatile parametric variations and multiple configurations of the responsive facade system.

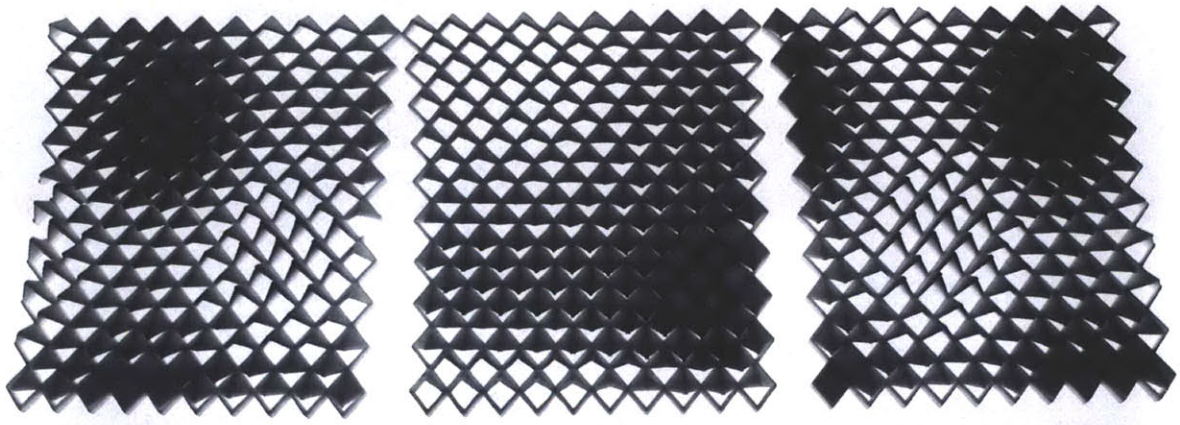
Double Diagrid Structure

The principle structural of the building has to respond to both vertical and horizontal loads, loads that can be static and dynamic. Twisted-shape buildings provide structural advantages to absolutely vertical and orthogonal designs as they inherit through this rotation (or twist) a diagonal relationship to the vertical axis, something that provides the building with a natural diagrid structure. Diagrids are efficient counters to the demands of both vertical and horizontal loads, and are particularly suitable for solving the types of structural asymmetries usually derived from complex shapes. Given its central, *spinal* core structure, a parametric diagrid structure completes the support frame of the building in a way that resolves local geometric conditions while maintaining a global cohesion. The diagrid in question was developed as a nested parametric feature based on a subdivision function on the shape surface. A rhomboid feature was created utilizing the parametric software Generative Components. We began by using a four point shape as initial input reference. A lofted surface operates as the shape of the building and is used to locate an ordered array of points based on UV values of such surface, subdividing it according to a resolution factor, a global variable able to be independently controlled. A second diagrid, offset at a determined yet variable distance from the previous one has a higher resolution (in this case four times higher), and acts as the support structure



Models ilustrate potential parametric proliferation of positional change, simulating adaptive response to changing environmental conditions: solar gain, wind pressure.

for the rainscreen surface of the façade. Thus, the structural nodes of the diagrid—those points in which the structural diagonal posts connect, crossing one other—occur every four floors; but, it should be noted, the rainscreensupport diagrid (based on floor levels) is aligned and connected to nodes at the edge of each slab at each floor of the building. This second diagrid is a flexible structure that can be reconfigured as needs be, allowing for the changing of the silhouette of the building. A special parallelogram articulation scheme was used, providing proliferation of deformation along the structure, partially reducing the need for numerous distributed actuators as the articulation system is able to "transfer" this deformation or kinetic operations throughout the whole structure. A parallelogram articulation works only on one plane, so as I began my work, I implemented a spherical ball-socket articulated joint to provide three axes of freedom instead of two. This rotational joint was developed as another parametric feature, with controllable, variable radii and a tolerance for its articulation. This design was tested using 3D printed prototypes. The tolerance was adjusted according to the FDM (Fusion Deposition Modeling) process used by the Stratasys 3D printer, the system used for these prototypes. Finally, a connection node was also developed for those joints where the rainscreen structure is connected to the supporting diagrid, which was envisioned as a series of diamond-shaped glass pieces. Different iterations of this



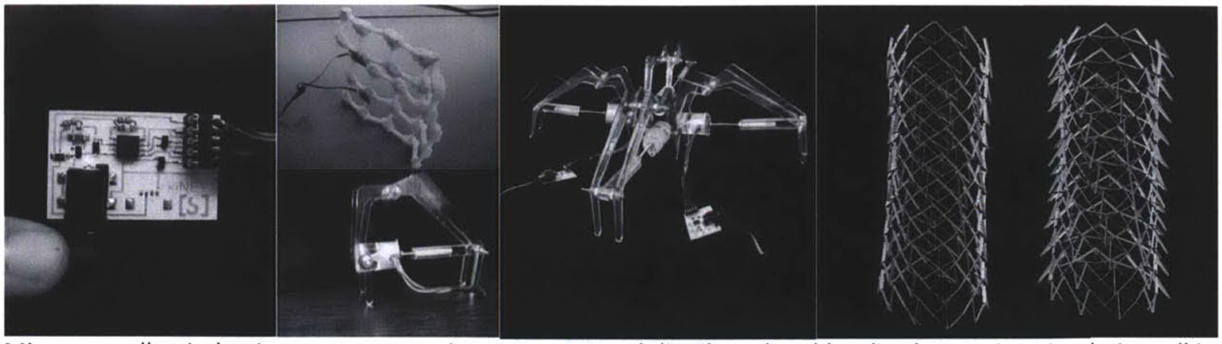
3D printed prototypes demonstrating versatile parametric model and multiple configurations of the responsive facade system.

design were performed and the results 3D-printed and tested. A 3D-printing of the building's shape was also done for use as a reference. Different prototypes of the two diagrids were printed independently and then combined in order to study the fitness of the two structures and the connection between them. The supporting structural diagrid was also fabricated to examine its variation in section. The double diagrid system was 3Dprinted to study both the overlaps and connection points.

Fishskin

The final feature to be incoroporated into the design was the scale feature used for the rainscreen. With the double-skin strategy in mind, we came to the conclusion that the external surface does not need to be hermetic, as the internal diagrid structure would already support the internal glazing of the building. Furthermore, the space between the two glass surfaces would provide an air chamber, allowing for natural ventilation: a cooling effect, which would reduce energy consumption when it was left open, or a greenhouse effect as a parametric air chamber around the building.

Warm air channeled into it, could be also used to heat the building during cold weather conditions. The scale was developed as a frame which would support two triangular glass scales in a rhomboid fashion; these scales developed to match the rainscreen diagrid. In the 3D printed prototype each scale feature is controlled by several global variables, working in order to reproduce its kinetic

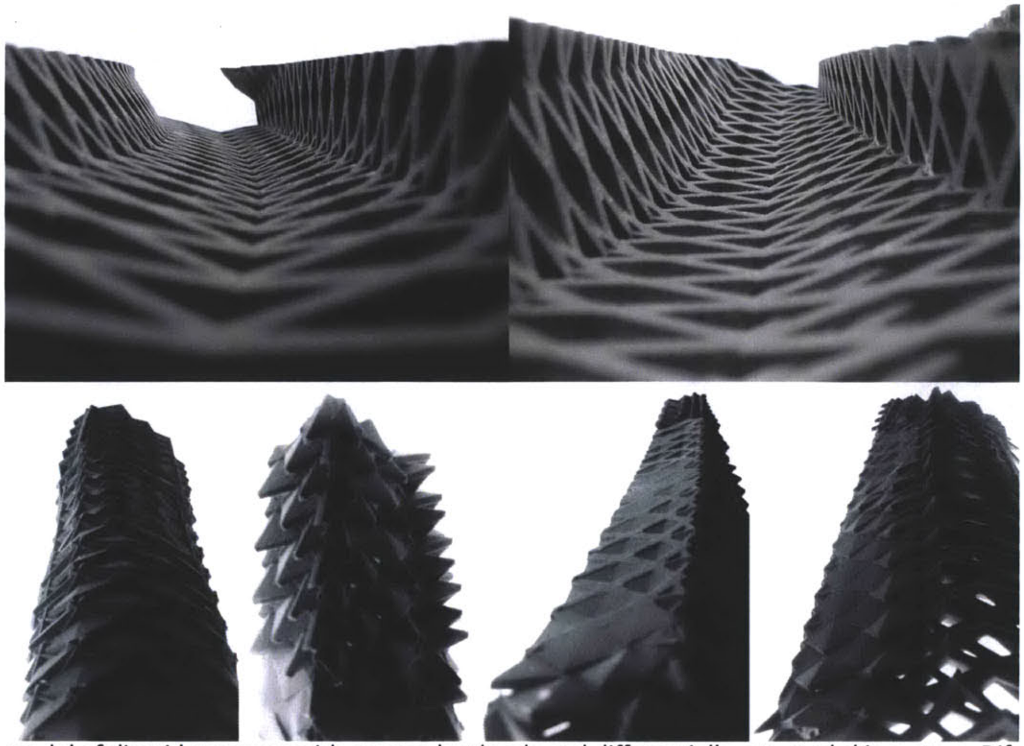


Microcontroller, induction sensor, actuation prototype and distributed and localized actuation simulation, all iterations of a design process aiming at discontinuous and distributed responsive behaviors on the large scale facade structure.

behavior. The frame is controlled in terms of its size, section, and shape, with the goal of allowing it different support/transparency ratios according to the orientation of the scales along the façade. A crucial function for the project is the variation of the angle of the scale as regards, for example, the weather conditions or internal programmatic requirements of the building. With the expressed purpose of studying the variation of the scale position and its proliferation over the system, function was specifically scripted to provide local yet distributed control over the parametric components. In the script this angle is controlled by two *law curves*—one for each direction of the surface—in order to produce a non-linear, yet consequent and smoothly varying series of values, the end result of which was to achieve surface-effect control over the entire scale-surface. The parametric model uses two law curves, as they control the vertical and horizontal orientation of the scales from the same floor. Several tests were printed to examine the results of the embedded parameters, resulting in possible variations. The tests were 3Dprinted as if they were to be solid as we discarded the transparency of the glass scales, favoring the visualization of the surface patterns obtained and the strength of the scale model. This also allowed for light/shadows studies.

Actuation

The implementation of a distributed actuation mechanism, one which would provide the necessary conformational change on each scale node, was developed. A *spider-joint* consisting of stepper-motors mounted on a lever structure and operated by a single microcontroller and photo-sensor was developed to control each scale joint. Several versions of the spider-joint were developed, with models ranging from those that



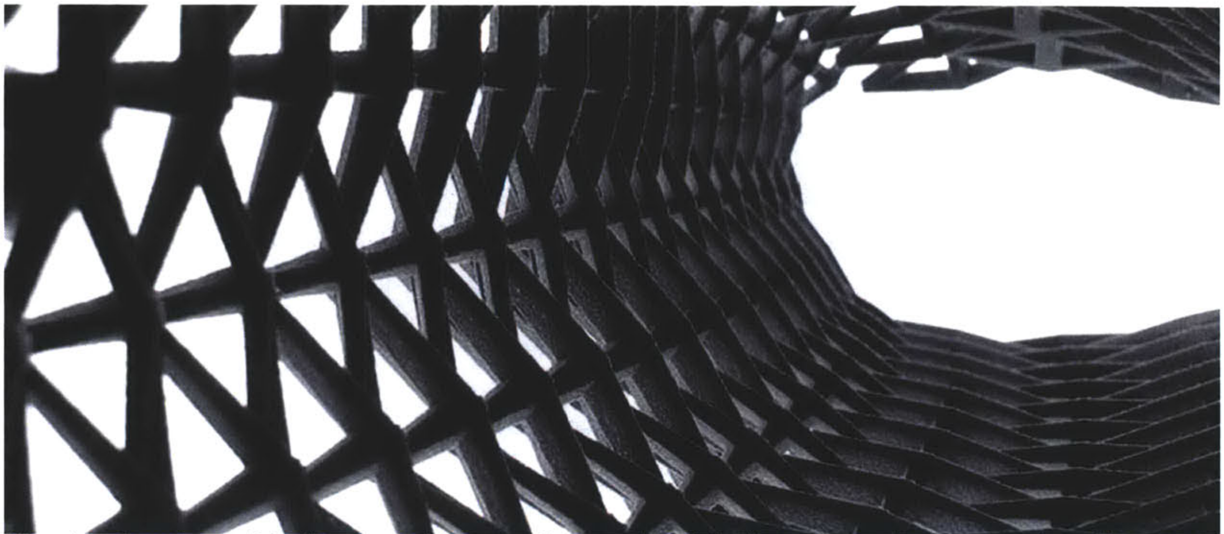
3D printed section model of diagrid structure with opaque but localy and differentially actuated skin system. Differential light control and non homogenous natural ventilation opening and control

actuated only the glass scale component to those that were actually actuating the entire diagrid, supporting all of the glass scale components.

The former model proved to be more manageable and was the type pursued for the rest of the investigation. Yet I found that there were interesting aspects to be explored with this second model, where not just permeability of the rainscreen membrane could be controlled, but the overall spatial conformation as well.

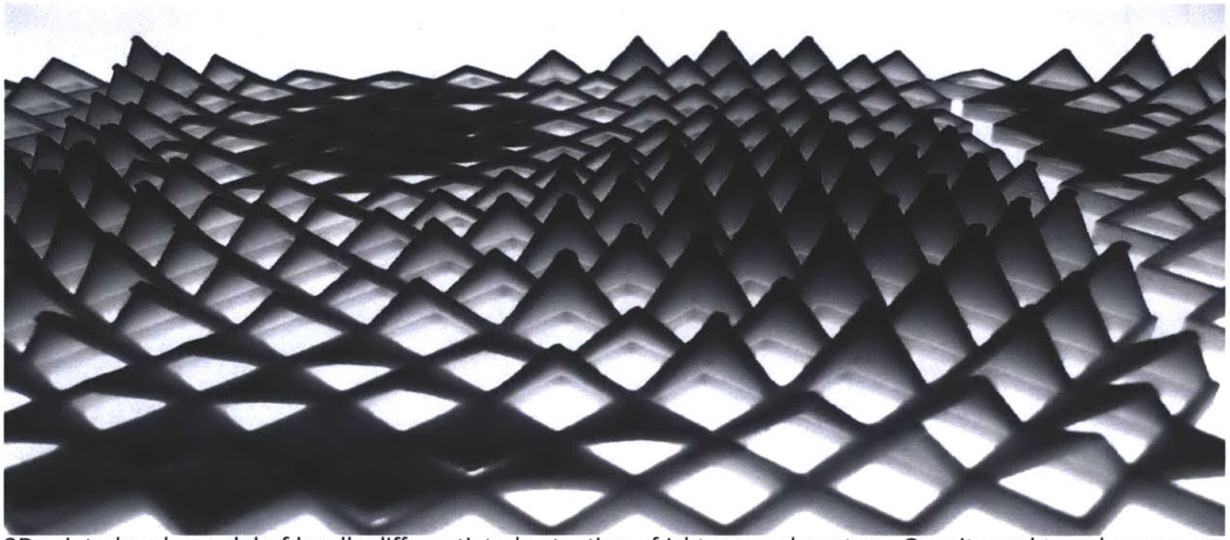
Discussion

This case is important in that it demonstrates the notion of responsiveness through its implementation across two different levels of performance. On one hand, the parametric model was constructed to study and develop the double diagrid system and its operation during the design process allowed us to explore possible configurations of the system (within the solution space given by the parametric association built in the system). On the other hand, the series of articulated joints and actuation systems (developed to test the real-

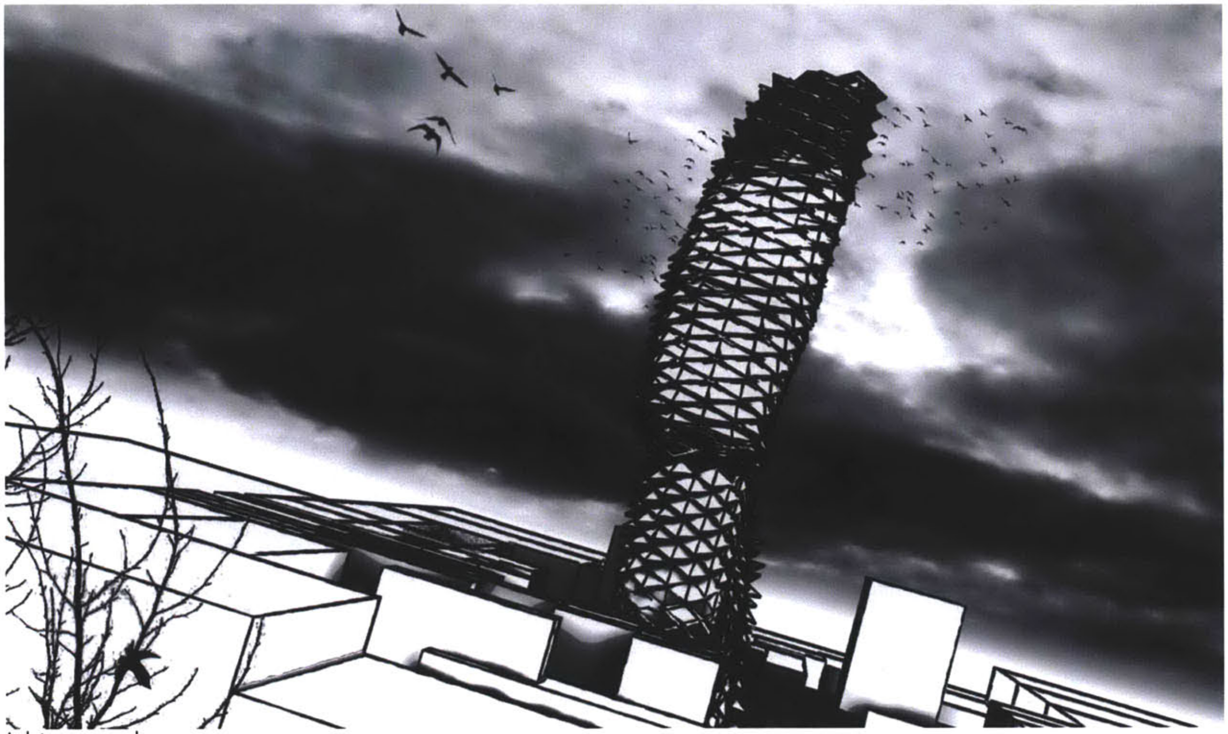


3D printed scale model of structural frames of actuatable fish-skin system of Ichtyomorph. Differentiated yet continuous variation of angle of aperture of each individual frame, responding to dinamically variable environmental conditions

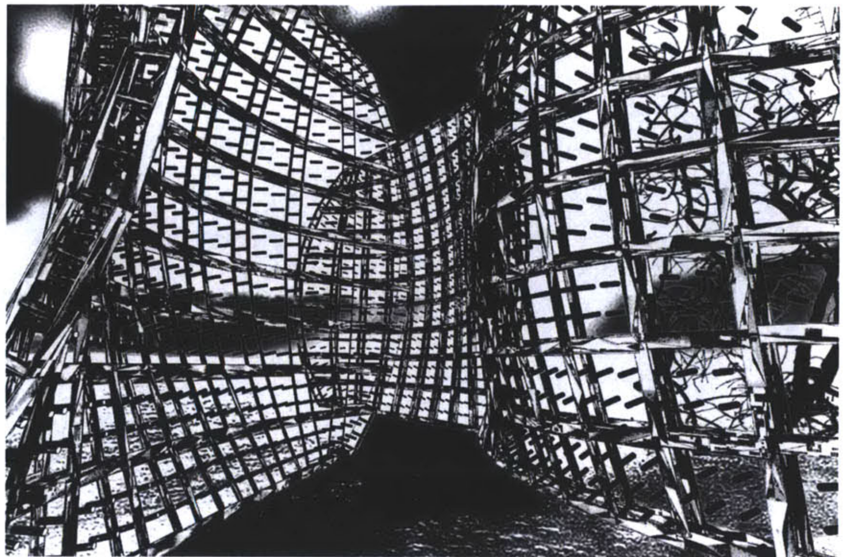
time reconfiguration of the components and the level of their proliferation throughout the structure) allowed for a responsive behavior from the built structure and, as it was operating in real time, performed discrete and distributed operations of sensing and actuation. Both of these actions are related to the responsiveness of the system—the parts (components) and whole (overall double facade structure Of these two levels of performance, the first one, although materializing as a mechanical system that operates on an analogue to digital parametric model, is somehow internalized into the logic of the structure's design. The second system, which electro-mechanically controls the actuation of the components, although is derived from the same logic of the first on a performative level, requires higher order systems in order to provide such performance. It is a mechanical system that requires a small yet multilayered electronic system to be able to operate. The microcontroller operates a small electric motor in response to a sensory system composed of a photo-cell that—one which determines when the spatial configuration of the scale component has to change and to which state it should conform. Since our choice had been to use stepper motors to fit the particular criteria for this case, the transformation of rotational motion into linear actuation was critical in allowing us to operate the angle change within the *scale component*. Our original concept involved using singular


3D printed scale model of locally differentiated actuation of Ichtyomorph system. Opacity and translucency are locally varying regarding specific local conditions, simulating realtime adaptive responsive behavior of the system.

microcontrollers to control each joint, which implied a distributed and non-centralized control over the scale components. This certainly reduces the computation demand to calculate simultaneously all actuation nodes at once, but the problem then becomes one of mechanical constraint. There are limits to what one actuator can operate before the scale components collide or self-intersect, potentially initiating a system failure or, worse, a crash proliferation with all adjacent scale components. Tolerance and clearance limits were introduced in the parametric model in order to safeguard against this possibility, but in the end it remained a question not fully resolved. Further attempts to implement physical constraints to each joint could possibly help solve this, but it is certainly a complex problem. A possible solution to this, that of implementing a centralized control system, also presents various hang-ups. All actuators should in this case perform in a coordinated fashion in order to avoid a possible collision, yet the change in the direction of the actuation—a change brought about by increasing the angle of opening rather than decreasing it—would introduce paradoxes in the system; we thus were required to consider a single averaged signal model for the whole surface of the building. This clearly countered the original concept of local responsiveness and distributed performance. Furthermore, it would happen that if one of the


Ichtyomorph

nodes malfunctioned, it would paralyze the entire system, seeing as it would then have to enact a total and global choreography of motion. One static element would halt the entire structure. Due to the nature of the 3D printed prototypes, the articulated joints became integral to the design of structure by contributing to its cohesive and continuous materialization of the kinetic principle. Although future developments of multi-material 3D printing technologies may facilitate the integration of other systems, the discrete materiality persists, a remainder left over from the inclusion of external systems into the structure. An interesting possible path would be to explore non-discrete material distributions, or to go even further with a material properties distribution—conductive or non-conductive for example—in order to design an inclusive performative system.


Responsive Modular Wall System

Kinet

(S.Araya - in collaboration with A. Bdeir)
Contents of this chapter have been previously published as a research paper for the GSM Conference in Delft, Netherlands, 2006.

Case

This third research case was based on the desire to design and fabricate a prototype for a responsive modular wall system. It was originally developed as part of the work done for a course at MIT but was further expanded to become a research project that explored non-mechanical actuation systems for large scale architectural structures. It attempts to distance itself from previous attempts at designing responsive performative constructs by explicitly working to avoid the use of external systems as a means of manifesting performativity. An intentionally restricted search was conducted, the object being to discover design principles that, through containing morphological and material (and thus physical) features, could provide the prospective and favorable circumstances necessary for the implementation of various degrees of responsiveness while avoiding as much as possible the use of complex mechanical systems. This case study offered me the opportunity to explore a dimension previously univestigated in my reseach: the design and computation of material *properties* rather than material *forms*. During and after my work on this project I became conscious of the possibility of embedding physical behavior into designed structures through a design that incorporated distributed material properties and morphological features rather than through the addition of external systems ex-post facto as a means to aggregate these behaviors into an otherwise inert/inactive structure.

The construction of the ephemeral.

Kinet reconciled two very distant conditions, the one being stability and structure, and the other of evanescent ambience and flickering light. Ephemera signifies something transitory. It is short-lived, fugacious, impermanent and, in many respects, volatile. Architecture has historically been defined using ideas of material stability, of monumentality and permanence. Kinet is an attempt to combine a sustained and unceasing desire for the creation of the ephemeral with the architectural vocation's traditional goal of moving towards a material, built environment.

> *When the material stability of our built environment shifts from a perception of stasis to one of motion; when it shifts from inert to responsive, flat to curved, static to kinetic, it is then the perception of the body inhabiting such an environment that changes with it. (Araya, 2006)*

Kinet is a performative wall. A wall that moves, changes, shifts and adapts. The principle that Kinet embodies is one of enabling: it is about enabling walls to respond both to us and to the environment; it creates walls that may alter themselves, and with them the spaces they define. An animated wall surface such as Kinet turns the tables on the traditional holders of passive and active roles. It changes the spectator into an actor while figure and background conflict into the same space, into the first plane of action. By provoking human interaction the usually neutral and stable role of architectural matter becomes a type of bait, the incentive for a new relationship between the human body and the architectural body.

While the physical structures of both bodies remains constant, the configurations and relative situations between them changes greatly.

By becoming an active character in space, the performative wall ceases to be a wall and becomes simultaneously a canvas and its paint; it somehow blurs the boundary between architecture and media art. The wall is no longer that opaque plane which encloses our bodies in space; rather, it is an active intervention in space: a window, a painting, a canvas. Of these three, only the canvas is not a static surface on which the artist lays his work; instead, it is a body in movement, a mural that is constantly being redrawn for and by the actor/ spectator who performs in this [un] defined space.

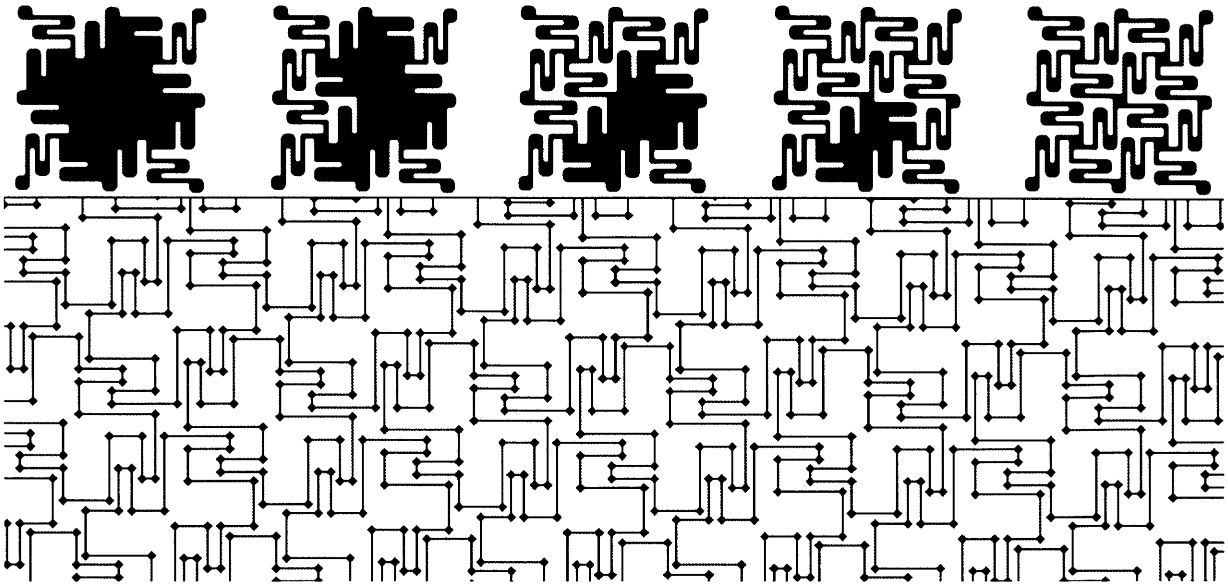
Methods

As this investigation was developing, different aspects of the project requiring individual attention were studied and then later reintegrated into the original whole. Different prototyping procedures were used to obtain the necessary mock-ups needed to test these individually modeled aspects.

Flexible Surfaces from Flat Panels

One of the self-imposed restrictions placed on this research was the desire to be able to avoid providing the sought-after kinetic performance via external systems. By constraining ourselves in this manner, we also refrained from using mechanical solutions, as they were deemed too close to this notion of an "external system" to be implemented. Another, second self-imposed restriction was the implementation of standard materials to maximize the cost-efficiency and the model's possible replication as we moved towards the scalability of a project that had large scale architectural structures as a goal.

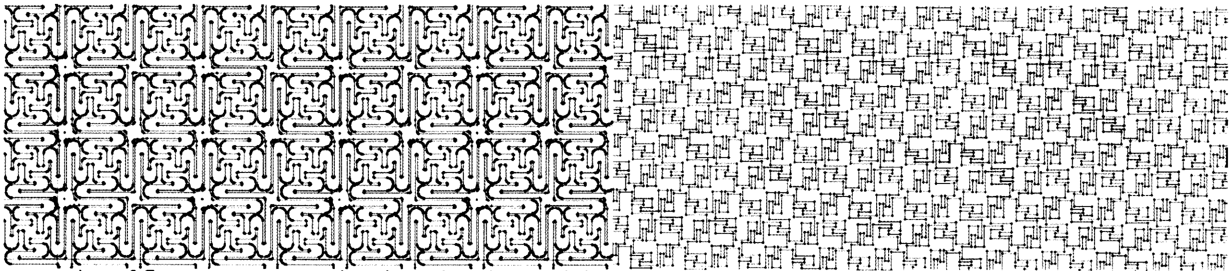
Since current construction industry practice is founded on standardization and modularity, most available construction materials come in flat sheets or panels. This project, however, describes a procedure we developed utilizing "flexure" structures developed through parametric models, which would confer elastic attributes to structures built from flat and previously rigid panels. This was done using diverse digital fabrication technologies.



Flexure patterns developed in order to increase in-plane and off-plane felxibility of rigig flat panel materials, applying a "flat spring" mechanical principle.

Flexure structures and surfaces

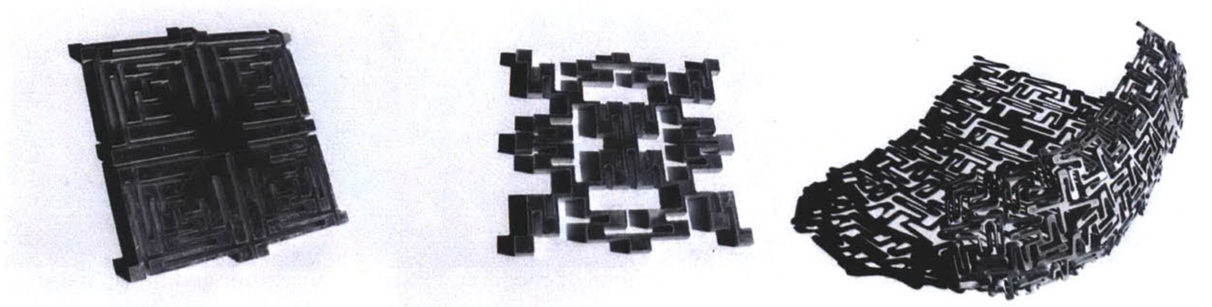
Compliant structures are defined as those which have the ability to change their shape with the application of force, and to then to return to their previous state if the force is removed. An easily understood example of this would a spring. Compliant structures are archetypal examples of mechanisms working within the elastic behavior of the materials of which they are made of. As stated previously, flexures are a type of compliant structures (one that behaves similarly to a spring) is called *flexure*. Flexures can change form elastically depending both on both their material properties and geometry, and thus present a high degree of repeatability of such elastic behavior provided that those forces acting upon them stay within the elastic tolerance of the material from which they were constructed. Our approach to this project was to create flexible structures from flat, rigid panels by developing these sorts of structures, making full use of their material and mechanical properties. According to Larry Howell[56], flexures are a special kind of mechanism, "a mechanical device used to transfer or transform motion, force, or energy". Typically Flexures are made of series of rigid links connected by movable joints.


Examples of flexures patterns developed and tested through lasercutting diverse sheet stock.

A compliant mechanism or flexure, however, while still performing the same basic functions of transferring or transforming energy/force, gains at least a portion of its mobility "from the deflection of flexible members rather than from movable joints only."

Flexure structures have several advantages. For one, they reduce the number of total components involved, something which reduces assembly time and effort and hence reduces cost. However, the benefit most important to this investigation is the fact that they can be developed from single pieces. Flexure structures are frequently used in machines that require very precise movements as they have a highly reliable positional displacement precision. The flexure's structure allows it to effectively isolate its movements, restricting them to its translation axis—where maximum flexibility has been provided as opposed to from other lateral movements where the system is rigid. This fact means that they can operate consistently, "reducing the vibration natural to hinged joints, eliminating the friction between movable parts and the backlash from their rigid body and hinged counterparts" (Howell 2001). Applying these ideas found in flexure structures to this investigation provided a method for morphological and material transformation, allowing us to transform rigid, solid flat board into partially flexible structures. This came to this process through experimentation, by designing and fabricating different geometrical patterns from which the observed performance was evaluated and compared to the behavior of the original solid material. The fabrication process chosen for this experiment was material removal: we cut these designed flexure patterns from the rigid boards.

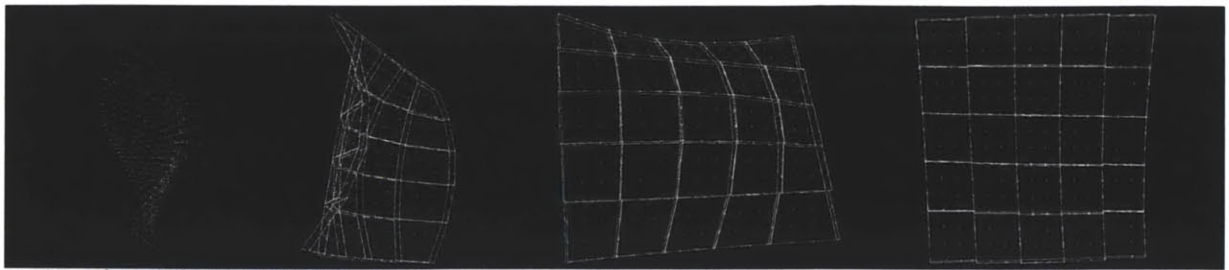
Normally flexures are used to isolate and precisely control in-plane displacement for high precision motion in mechanisms; but the objective for Kinet



Flexure structures in 6 mm thick aluminum. Elastic and non-elastic deformation of flexure structures.

was to be able to implement a type of out-of-plane displacement and to extend and use such a displacement through an in-plane load transfer. Initial prototypes were designed and cut out of paper, providing the first, preliminary tests of the flexure mechanism's behavior. Once a particular design was performing satisfactorily, groups of them were cut from single pieces of paper, in order to explore the repeatability of the pattern, the overall performance of the pieces and the potential of the pattern to be fabricated out of flat stock. The first attempt at producing flexure nodes yielded positive results in term of ability to obtain out-of-plane displacement, but the ratio of actuation force when compared to the resistance of the material to stay in-plane did not seem promising.

A second strategy to produce flexure surfaces was then developed, one by which the whole flat panel would become a flexure surface through the removal of material using custom design flexure patterns. This garnered much more elastic behavior than did the original stock material. The in-plane load distribution and the out-of-plane surface displacement proved to operate successfully as smaller force loads were applied to the surface. Numerous flexure surface patterns were designed and individually tested, first cut out of paper or cardboard using a lasercutter, and then those, the most successful ones, were cut from of thin metal sheets and plastic stock. These final versions demonstrated that functional flexure surfaces could be cut out of thin aluminum sheets and thin ABS plastic. Since the flexure patterns

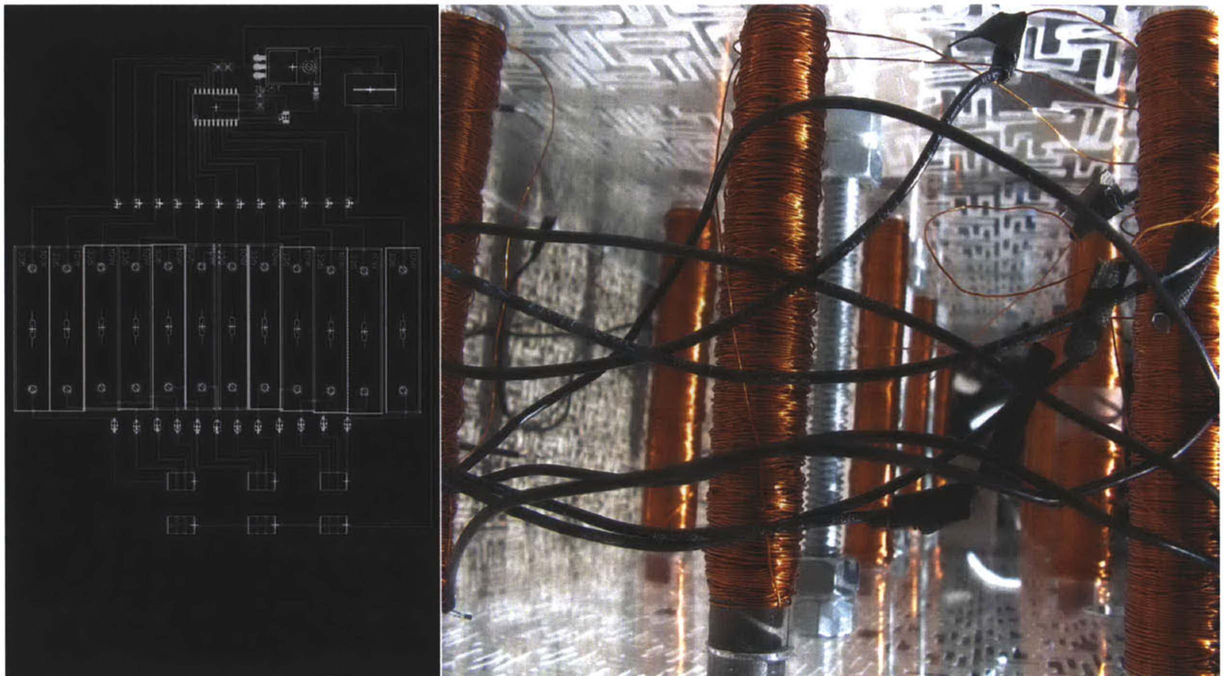


Design of mudularity of Kinet system, using a parametric model to extract each custom geometric parameters for fabrication.

were developed through a parametric model, several iterations of the patterns were fine tuned by changing the length/width ratio of the beam of the flexures themselves; the number of twists required for each pattern allowed us to fine tune the design of the final surface. Aluminum sheets proved to be the best choice as they presented the biggest out-of-plane deformation yet still retained their flat shape after the actuation had ceased. Plastic surfaces, after being subjected to repetitive actuation for long periods of time, seemed to deform beyond what we considered to be a comfortable elastic range.

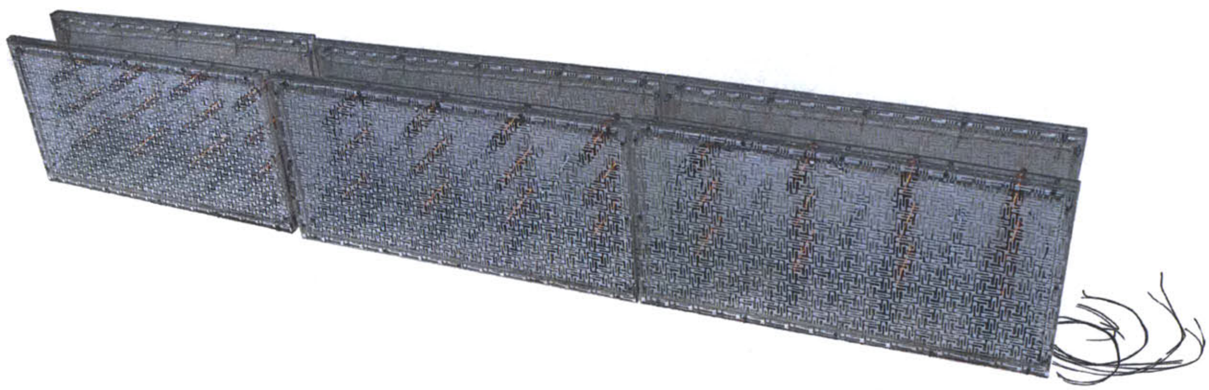
Actuation and Performance of Kinet

Kinet is a performative modular system, one in which each module is composed of disparate, distributed actuation nodes regularly scattered across its surface, a design that works to create a dynamic reconfiguration of surface patterns and light effects. The nodes are driven by electromagnetic fields, hence no visible mechanics are involved. This fact also has an aesthetic effect, as it creates the impression of magic, that the module eludes the obvious and embodies some mystery as a performative piece; yet apart from this, it also achieves one of the central objectives of this research project: to enjoin the performative behavior with the material and formal domains of the design, without intervention of foreign or external mechanisms. The actuation of those permanent magnets by the controlled electromagnets produces a low metallic tickling when they collide, polarity bringing them



Left: Microcontroller design to operate the array of electromagnets that actuate Kinet. Right: Custom made elctromagnets and positioning in relation to polymeric flexural surface of the module.

together, and the emitted sound is propagated, sent through the surface to drive the attention *beyond* the visual. These are the things that cause the module to engage with a wider range of the phenomena and the body. Kinet performs as a kinetic structure. Yet it avoids the structural and aesthetic mechanization of the system as it steps out of the visual and functional repertoire of the more heavily mechanized robotic systems used in kinetic architectural systems. Systems as the ones found in works by Kas Oosterhuis and the Hyperbody group[57], or the Aegis Hyposurface by Mark Goulthorpe's Decoi[58] succesfully implement and integrate these kinds of robotic mechanisms. In my work the desire was not simply to achieve an ephemeral effect, but to construct and embody a material structure with the same principles. The choice to use an electromagnetic solenoid as an actuator was one made with this in mind as it allows the actuation mechanisms to be removed from the visual field. This choice also allowed us to reduce the size of the actuation node, which in turn permitted us to build the whole system within standard construction parameters as the electromagnet could also operate as structural member of the assembly. Furthermore, it

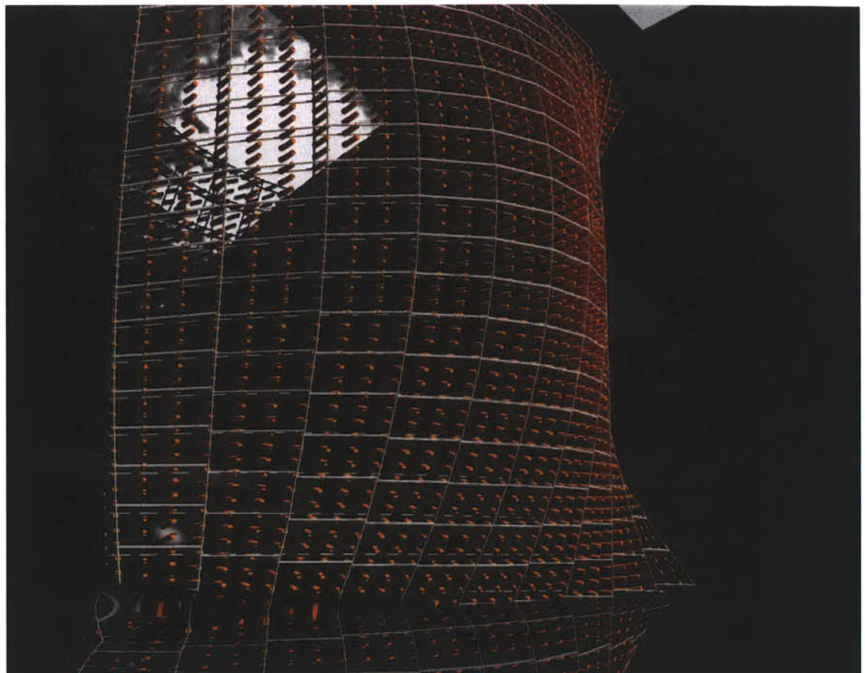


Three modules of kinet.

inherently provides actuation to both sides of the wall, an effect that doubles the actuation capacities of the system. All of this implies that, as opposed to the previous examples and prototypes studied, Kinet, by varying the entire section of the wall (as opposed to just one side of it), manages to affect the *internal space* of the element, not simply the space that surrounds it.

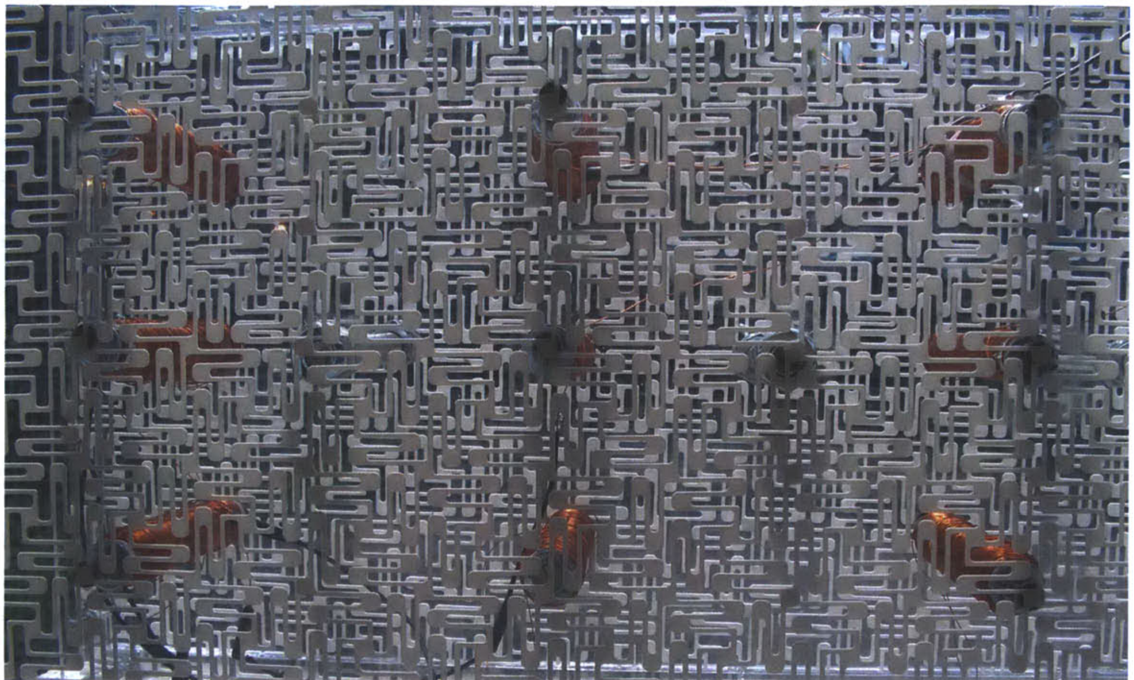
Module design

Each electromagnet was specially fabricated for this project, using iron 1/2" iron rods and copper wire and assembled using an electric bobbin winder and applying 2000 turns of 28AG copper wire to each of the electromagnetic solenoids. Each module consisted of 12 regularly spaced electromagnets that were fixed between two 11" x 44" transparent acrylic sheets. The acrylic sheets were perforated by a lasercutter at all of the points in which the tip of the electromagnets was to be inserted. Only the tip of the electromagnet would emerge from the perforation in the acrylic sheet, and the coiled copper acted as a stoppage point, preventing the solenoid from slipping through the perforation. The whole assembly was made structurally cohesive by virtue of the fact that the electromagnets were only penetrating the



Visualization of the distributed actuation system composed of arrays of elctromagnets that operated simultaneously as structural members of the Kinet wall system.

acrylic sheets slightly, and that the sheets could then be held together by three central threads. Kinet's surface then consists of two layers (or surfaces) that are separated by a small gap. The inner layer is composed of the fixed acrylic sheet that holds the solenoids in place. The second, flexible layer is composed of the outer flexure surface which holds in place the permanent magnets (positioning them in front of the electromagnetic solenoids) and gives it its performative morphological properties. On each of the nodes on the outer surface thin permanent magnets were placed. Electromagnets were placed on the nodes of the inner surface. The electromagnets are controlled from a microcontroller—a driver board that actuates each node individually. When a pulse is sent to the electromagnet, it becomes energized and is transformed into a working magnet. When this happens, it either attracts or repels the permanent magnet attached to the outer surface—this attraction or repulsion depends on the direction through which the current is passed (as this affects the polarity of the magnet)—creating on the surface a sort of in-and-out movement at that particular point.

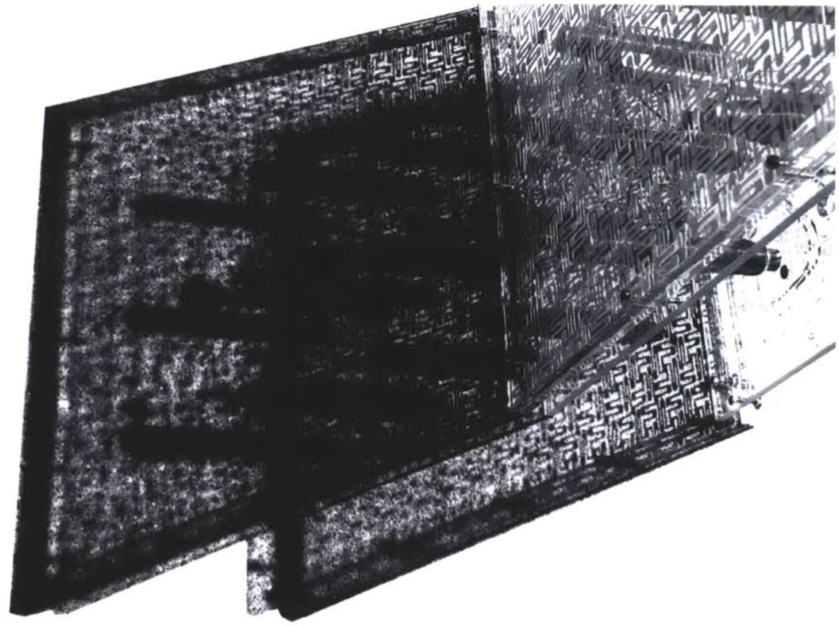

Kinet translucency, and moire effect while dynamically responding to local distributed actuation.

Driving Kinet

In order to energize the solenoids properly and create the desired movement, a microcontroller driver board was made. We used a small microcontroller, named the ATTiny26L, that would control the electromagnets via a switching mechanism. The switches were electronic ICS, mosfets. The way that the Kinet prototype functioned was that the microcontroller program loaded on the microcontroller sent a series of repetitive pulses to each node or column of electromagnets; the resultant movements of the nodes created the waving, undulating patterns seen on the surface. Future prototypes would later incorporate capacitance and/or IR sensors to activate the signals for each node, thus removing the need for a specific or hardcoded pattern. These future prototypes would use a responsive system that could be controlled by environmental stimuli or human interaction. Our ultimate goal was to make Kinet capable of responding to human presence and gestural interaction.

Discussion

Architecture has historically been defined through its material stability and permanence, yet the human mind has always been fascinated and drawn to what is volatile and moving. The



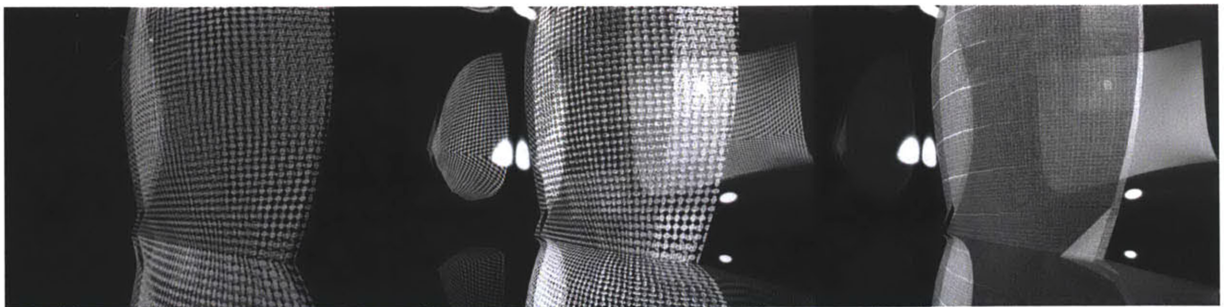
Kinet dinamically responsive shading effect in response to variable environmental or programmatic conditions.

research project described here was an attempt to reconcile our human fascination with the creation of the ephemeral and the architectural need for a material, built environment.

When the material stability of our built environment shifts from a perception of stasis to one of motion, from inert to responsive, flat to curved, static to kinetic—then the perception of a body inhabiting such an environment changes as well. As Merleau-Ponty sees it, our perception of the world is (partially) determined by a consciousness of our mobile body. According to Ponty's perspective on phenomenology[59], the act of perceiving is inseparable from a similar act of self-awareness on the part of the body as it recognizes itself as the object of such a perception. When we see an object, we are only able to visually perceive a portion of it. We can recognize that object if we had a previous experience with it. When we recognize that object, we merge together the different parts of our perception, moving the object around to capture as many different visual angles as possible. We do this in order to get at what the object *is*. This is how we form our perception of the world around us: we gather different fragmented views and, by stitching them together, we reconstruct the movement of our body as it moves through space.

But what happens when this perceived world is also in motion?

Motion sickness is the result of conflict in the brain as it struggles to deal with contradictory perceptions. The equilibrium apparatus in the ear signals to the brain a certain movement while the eyes, unable to perceive any corresponding motion, indicate to the brain that it is in an immobile state. How do we overcome this dizziness? this destabilizing of our senses? As the body looks for and requires a stable ground, the senses are constantly seeking out a fixed reference point. Sea sickness can be overcome by focusing on a distant point and recovering a relatively fixed reference point with which to reorient ourselves. Our bodies are conditioned to adapt constantly to our varying movements. Land sickness, on the other hand, is the result of the body reorienting itself to a fixed ground. The symptoms of land sickness may also occur, however, as the result of other types of sensorial signal conflict in the brain. We are all aware of the powerful hypnotic effect of the flames of a fire can have as they mold light into unpredictable shapes, or the same sort of effect from the motion of waves on the shore, or the shimmering reflection of the moon on a deep sea. Staring at the ocean while the rippling effect of the wind curls the surface of the water, bouncing the reflection of the sun, our body becomes a neutral instrument of perception—it nearly disappears and becoming part of this eternal movement. As human beings we chase ephemeral effects, liquid-like behaviors, the fluid, random vibrations of surfaces as well as objects responding unpredictably to subtle changes in force, direction or material resistance. Perhaps this fascination is one partially derived from a need to recreating the act of perception. This is an act of recreation that, as Merleau-Ponty points out, is inherent to our being as our consciousness comes into existence and we become aware of the self as a perceiving, mobile subject. We envision a provocative architecture, a sensuous, unpredictable architecture as that which challenges the senses and engages the body, directly placing it in the phenomenological experience of a conscious acknowledgment of the act of perception, indeed a creative act. We *create* the world as we perceive it, Shape Grammars would call this embedding. This unstoppable conditioning towards change has motivated our


Possible translucency configurations of a Kinet wall responding to environmental oscilation.

desire for embedded kinetic behaviors in typically static structures. Traditionally, architecture was build for cultural and social stability by using inert (neutral) material and attempting to achieve permanence (sometimes even an eternal permanence). It has been called the art of substantial immobility[60]—a vocation for the construction of timeless structures, built for permanence.

The advent of the digital era introduced (among other things), the concept of temporality. The ability of high speed calculation derived from digital computation allowed for the proliferation of digital tools that could function fast enough to explore real time geometrical variation and modification of formal conditions. In the realm of design this first lead toward the emergence of complex geometrical modelers, but with the spread of animation tools and (recently) the appearance of parametric environments, the combination of these newly available tools allows us to simulate changing temporal behaviors and incorporate them into designed environments. This has opened the door to the design of true dynamic environments.

At the feet of the Paganella, the new scheme for the re-founding the Villa of Zambana.

Zambana

Green Village

(S.Araya - in collaboration with

MEL, Design Laboratory, MIT)

Case

This project was the result of a research study I lead at the Mobile Experience Lab at MIT in conjunction with the Trentino Sviluppo and the Bruno Kessler Foundations in Trento Italy. We were working towards the design of a new, ecologically responsible, energy efficient and architecturally innovative village in Zambana, Italy. Zambana was a small settlement devastated by natural catastrophes: first by a landslide in 1955 and then again after a rock slide (a pair of enormous boulders crashed down from the rock façade of the Paganella's mountain face, finally forcing its population to leave and reestablish themselves several miles away from town's original location). It has been a long-standing wish of the old villagers and their descendents to re-establish the village in its original site and re-unite new generations with the memories of the past. The project therefore

Study of remaining structures, historic valuable buildings to be preserved and structures to be demolished.

faces a double challenge, on one hand to rescue, preserve and enhance vestiges of that lost past, some of which were partially buried underground after the incidents. On the other hand, to become a new, iconic, contemporary ecological paradigm for human settlements in Europe, implementing advance technologies while retaining its natural characteristics and values.

Background

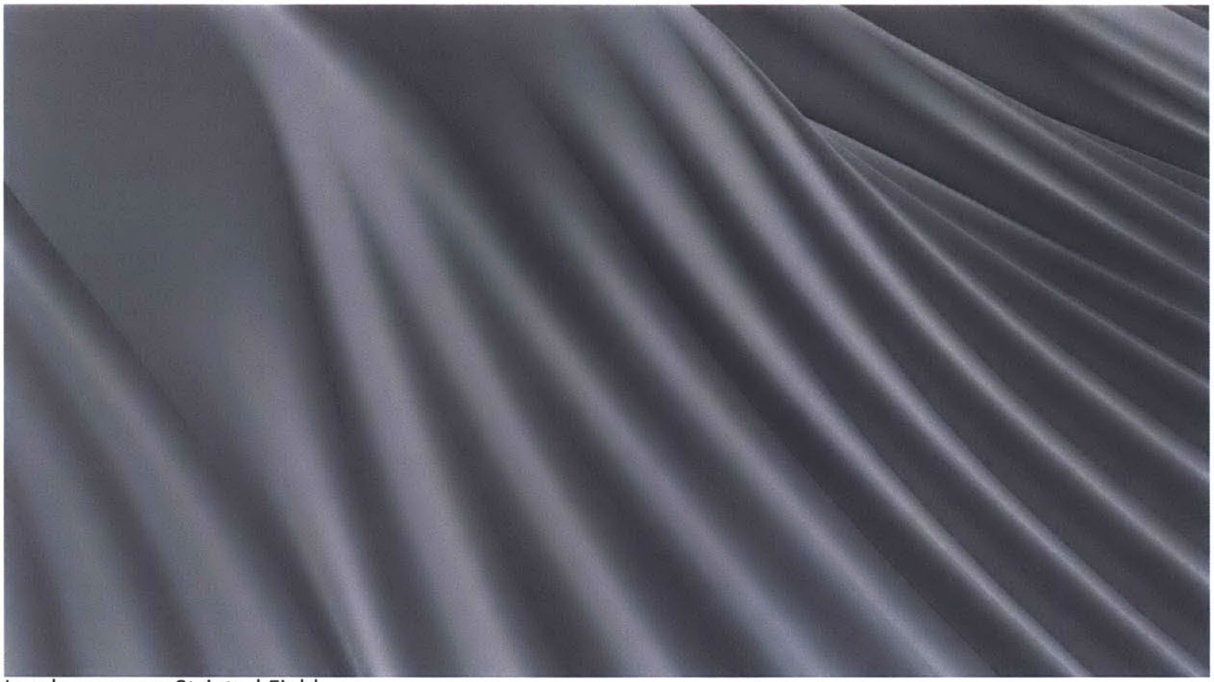
After having waited for decades, the mountain safety interventions installed by the central government have finally been certified and allowed the reauthorization of the area for building, providing a safe and secure opportunity for the original Zambana citizens to return to their original home. Moreover, a new provincial road connecting the northern part of Trento and the Rotaliana highway has been planned and is being implemented. The road will end the isolation for the village of Zambana. These are certainly precious developments in terms of the village's recovery, but they are in need of a radical yet rooted gesture to inaugurate this new era of prosperity and optimism. They are in need of a way of looking to the future, one that will allow

Study of historic evolution and growth of the Village in contrast with remaining structures after the landslides. A recovery of original locations and urban grid is designed to bring the memories back to the present.

them to gaze forward, but without forgetting the history and memories that lie behind them. It is with these considerations in mind that we decided to carry out a strategic study before beginning any work, and is the reason why this research project worked to establish a collaborative relationship with local agencies. We wished to ensure that all aspects of this challenge would be considered.

When we began this project, little remained of the old Zambana. Excepting the renaissance church of Saints Philip and Jacob, which luckily had survived, the historic district of the city had fallen completely into ruin. It had first been covered by the landslide and then, afterwards, the remains had been systematically demolished by bulldozers in order to prevent people from returning to homes now rendered unliveable—those buildings still standing deemed unsafe by authorities.

The precautionary measures taken throughout the years have deeply altered the state of the things in Zambana. Besides the demolition of the historic district, the watercourses have been rerouted, tubed and set underground and a rudimentary dam constructed upriver to contain the debris flow that are still proves to still be a problem for the Manara valley. Entire landscapes have been


Landscape as a Striated Field.

re-shaped by those forces intervening in the region, working to reduce the hydro-geological risk. In particular: a huge wall made of rocks and earth was created against the Paganella mountain in order to protect the village, right in front of a deep linear well that surrounds the rock wall. The wall protects the area where the historic village and the church were situated.

Challenges

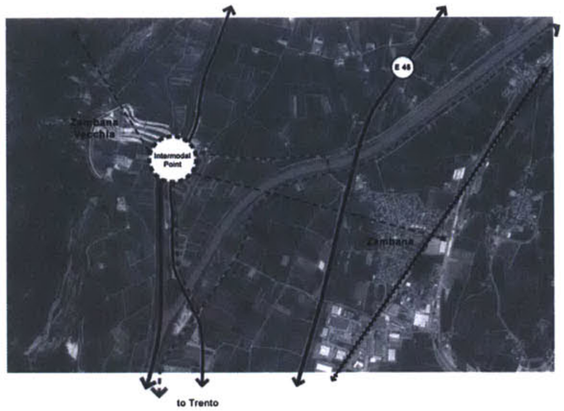
This research projects targeted two different design scales simultaneously and tries to develop new techniques and processes in order to engage with them as one, hybrid-scale enterprise. On the one hand, the project must respond to the challenge of re-founding a village, something which entails acting within the scale of the territory and the natural environment in which it is situated. On the other hand the project needs to address the scale of the edifice to be constructed, the architectural artifice that, as iconic and concrete proof of the concept we had in mind,could merge both the need for specific pilot dwelling facilities and (with the high level concept of a radical ecotechnological village), provide a new paradigm for ecologically responsible, high-end residential

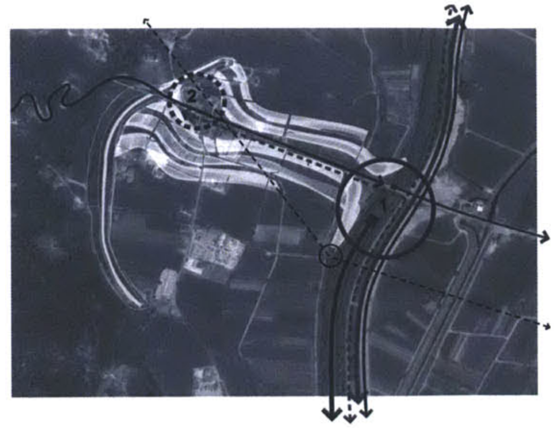
Preserved historical buildings emerge as sculptures in a park, becoming landmarks in the striated productive green fields of Zambana.

suburbs in Europe. This project then proposed that what was needed was to address the environment (landscape) and the artifice (architecture) as two simultaneous and complementary conditions of a single concept.

The general scope of this investigation is to address the design and fabrication of a *sustainable, connected* home. In this phase of development I am focusing on a smaller scale of design and implementation, one that concerns the architectural components needed for the skin of the building, something we have called the Infill. My work here focuses on designing smart components made out of materials with embedded behaviors.

This research investigates and develops procedures applied to an innovative technique used to design and manufacture composite materials with variable properties. The long term objective of this research is to develop a method to design and fabricate composite architectural components to be implemented in large scale architectural projects. I will do so by exploring their different levels of "embedded behavior" or responsiveness and by using these techniques to combine the properties of different physical material





Intergation of the prosed urban network and the proposed highways of the Province.

from newly designed "smart" composites. The immediate objective of the research is to develop the methodology and procedural techniques that would be used to design and manufacture composite materials with variable and controlled transparency properties. This work has been carried out as an aspect of my research, which focuses on material culture and design and fabrication techniques. As an added note, my work in this phase of the project has included also to coordinate the efforts and organize the contributions of different members of the design team, as well as compiling these preliminary results in the form of a report.

Methods

Landscape as a STRIATED FIELD

With an eye for both merging the actual language of the anti-slide safety innovations already present in the Zambana region and the undulating surface effect of the green patterned vineyard fields predominant in the region, a gestural approach towards an integrated landscape operation was devised, the key being a continuous corrugation formalism, which would allow a space where the urban and the natural could be

Topology of striated fields and the reconstruction of the memories of old urban grids

merged together. This new, artificial topography recalls the traces of the past by integrating infrastructural components that actually enable the area to be rebuilt. It does this, while at the same time creating and giving a coherent identity to the village. It creates a place where the natural and the artificial coexist. A new landscape of integration between natural and urban life. Preserving both the average height of the existing buildings and the East-West orientation (now made useful in terms of efficient solar efficiency), a new urban fabric is explored as a metaphor for an urban green park. In this setting each of the historical buildings that remained in a preserved state (or had been refurbished if refurbishment was required), these monuments and witnesses to the past, were kept as sculptures scattered about a now inhabited park. The new buildings partially disappear as they merge with the undulating landscape, this fabric becoming a new paradigm of integration between old and new, between past and present built environments.

Historical Traces

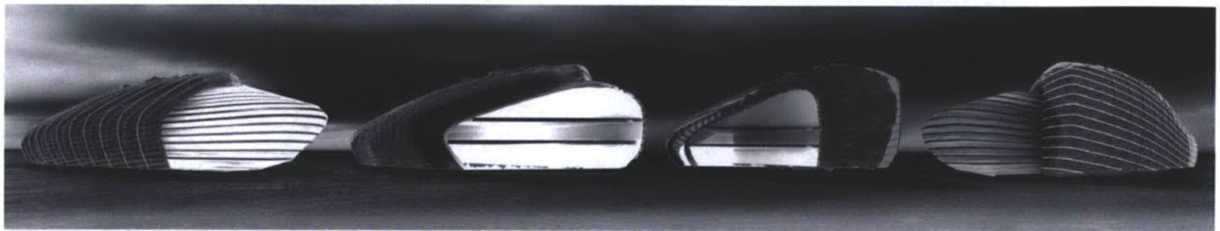
In order to preserve and rescue memories of the Villa we executed our project's operation of uncovering, tracing and revealing the past through

The green productive fields of Zambana's Green Village. Inhabitation within the foldings of the striated topography.

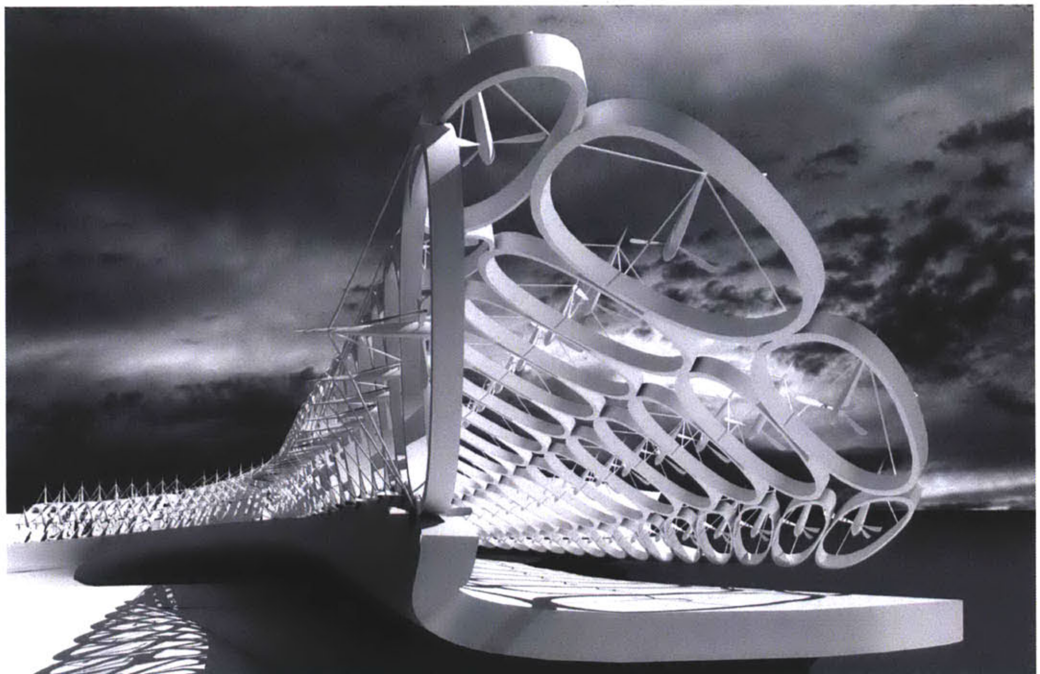
its urban traces (some are still present, some have vanished but will be recovered) with the goal of reconnecting the present and the future of the villa to its history. It is a new foundation that grows from its history. The traces of nature flow like water, and all of the urban interventions such the roads, the paths, the traces of the buildings that now do not exist (and of those which still remain) are recovered in this new vision that both transforms and preserves. The retaining wall that prevents future rock slides from coming down the Paganella mountain and protects the village is seen beyond its functional and cultural status as a protective device and is seen as an opportunity to construct a raised promenade, a privileged viewpoint over the village and a cultural centerpiece connecting the past, present and future of Zambana.

Artificial Nature

The striated field is a design operation that encompasses both a landscape strategy for the territory in question and an urban design strategy for the edifications and more open and public spaces in the village. The undulating striations, as a group, are designed to shelter inhabitable spaces under its file while partially retaining some of the agriculturally productive


Schemes of inhabitation within the folded topography of the village. Exterior green screen, interior inhabitable spaces.

capabilities of the rural space it occupies. For this effect a *Core and Shell* strategy is applied, especially for mixed-use buildings where an external structural surface is used to protect from inclement weather while an internal volume can be flexibly adapted to different programmatic conditions. The role of the external rain-screen is both to behave as a sheltering envelope but also to work as a functional component of the building; it has the potential to be used both as an energy collecting device, something which could provide the possibility for vertical micro-farming, or be used as a vertical garden in case the internal program is geared towards residential usage. The space between both envelopes would also be used for energy efficient treatment of air masses, isolating and containing air pockets to help insulate the buildings, and/or allowing for natural ventilation in summer when, due to higher temperatures, the idea of cross-ventilated and intermediate spaces could be recovered—recovered using the buffer spaces between the interior volumes of the structure and the rainscreen that is the façade visible in the public space of the Villa. As an extension of the retaining wall intervened and transformed into a promenade, our proposal for the new piazza is a sloping plane, connecting the ground plane to the top of the wall/

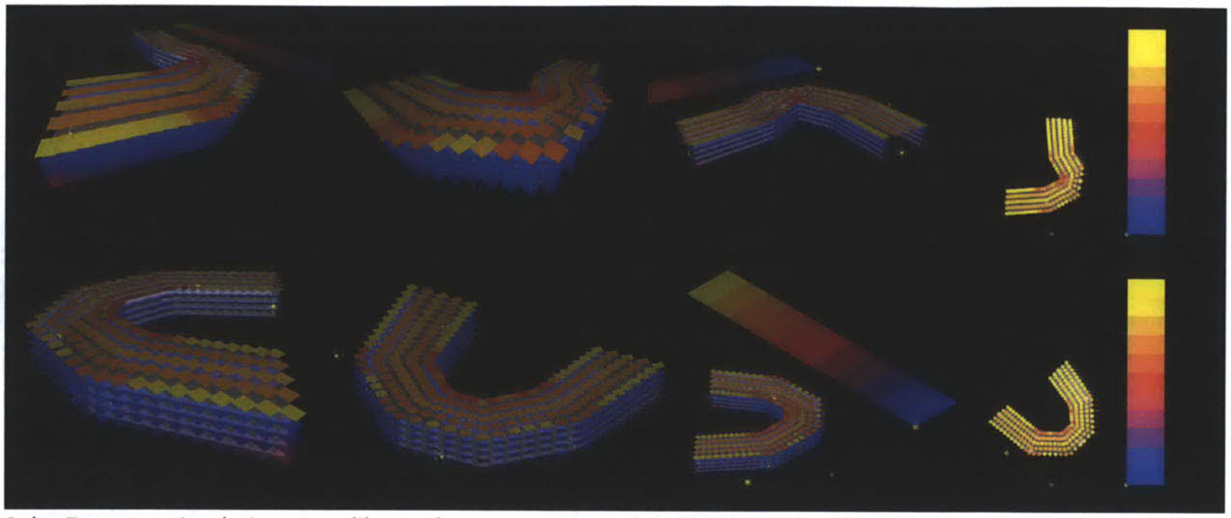


Zambana's new Marketplace and its roof structure composed of arrays of microturbines that contribute power to the Market and to the public spaces of Zambana itself.

promenade, both attenuating the barrier condition of this retaining infrastructure and increasing the passage (connection), between the villa and the old Zambana, thus re-enacting, in a way, the experience of going from the present to the future. This passage may also become an opportunity to collect and present some memories of the past: images, objects; or of the future: the project phases, the vision. The Space under the Piazza would then become a memorial to Zambana, a memorial that celebrates both memories and projections, yet recovering its practical use as well, becoming a central communal space at the heart of the village. To respond to the challenges of designing this new, multi-scale ecosystem, it is proposed that a model of composite structure be used: one configured by a *Chassis*, an *Infill* and *Embedded Responsive Systems*. These components respond appropriately to the context of the dwelling on different time scales and at different levels of decision-making and instrumentation, as well to the needs and desires of its inhabitants.

Chassis

The chassis is built to last for decades and to embody the principles of sustainable design that would inspire such a time scale—a scale that would



Solar Exposure simulations to calibrate the parametric model of the topographical folding of Zambana, optimizing trans-seasonal solar gain.

be particularly appropriate for passive climate response as well. It represents a long-term, site-specific intervention. The chassis provides the major structure, the outlet into which everything else plugs—it handles major service pathways and access points. It defines the sizes, proportions, broad organization and orientation for the spaces as they will be available within the dwellings. It changes very little over time. This chassis design responds to the most permanent features of the context: the topography and architectural context, access possibilities, views, climate and microclimate, local materials and processes, as well as local culture. Chassis designs for urban, suburban, and rural settings are likely to differ considerably. In general, a chassis design should respond to the particular physical and cultural conditions of a location and should address these issues specifically, with attention to contextual conditions. It should do this all while providing the opportunity to create a sense of local place.

Infill

The infill consists of modular elements with standardized interfaces. It can be varied according a time scale of minutes, days, months, or years—in order that it may respond to a family's changing

Plan view of proposed residential units for Zambana, utilizing vacuum solar tubes on the exposed facade flanks to create a distributed power harvesting community.

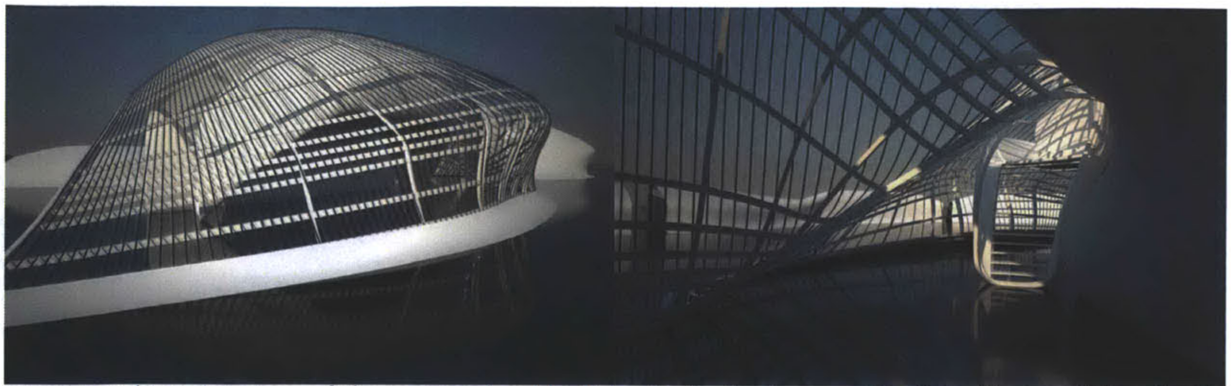
needs and economic conditions, to environmental change and seasonal variation and also to allow for the integration of new products and technologies. The infill elements basically provide the following:

- external cladding and climate modulation
- internal space division and service distribution
- living elements and their corresponding services (such as houseplants, window boxes, and nearby garden and landscape elements).

The infill elements enhance sustainability by allowing quick, efficient adaptation to changing environmental, social and economic conditions and by providing room for the integration of new technologies as they become available. They open up the possibility of innovative, open-source user/designer communities.

Real-time Embedded Responsive Systems

The real-time electronic systems are implemented in sensors, processors, displays, actuators and network embedded into portable devices and in the infill. They are incorporated as well in software backends to monitoring and control systems. The software of the real-time electronic system controls the response of displays and actuators



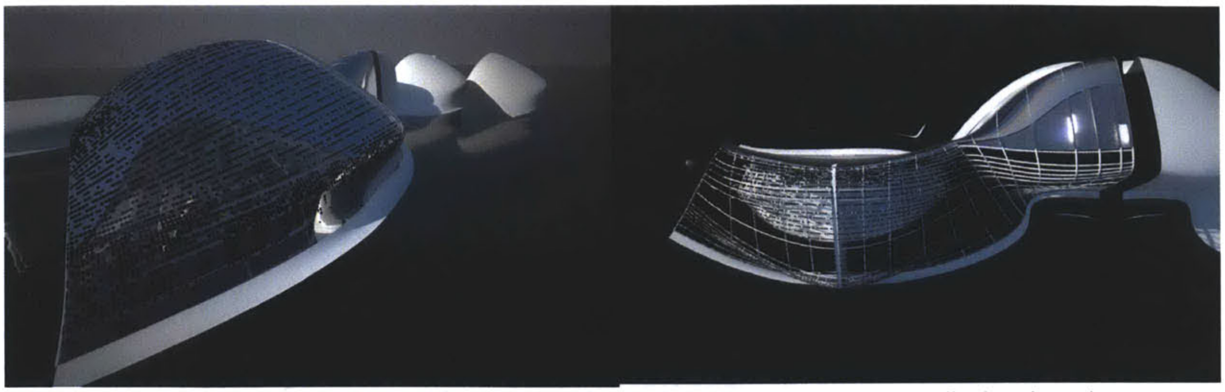
Exterior and interior views of the proposed residential units for Zambana an the Solar Vacuum tubes facade system being implemented.

to the conditions detected by sensors and to user commands. It automates a great deal of short-term decision making, enhancing sustainability by providing an instantaneous response to dynamic changes in user needs and behavior, external weather and lighting conditions and so forth. The software can be updated continually over the network and is seen as a starting platform for the testing and implementation of future innovations. It is an opensource community environment that works to foster innovation and sustainable practices. In order to calibrate the design of the striated field of the village which constitutes the Chassis of the proposal, a parametric model was produced in order to test its formal aspects in relation to environmental conditions of the site.

Discussion

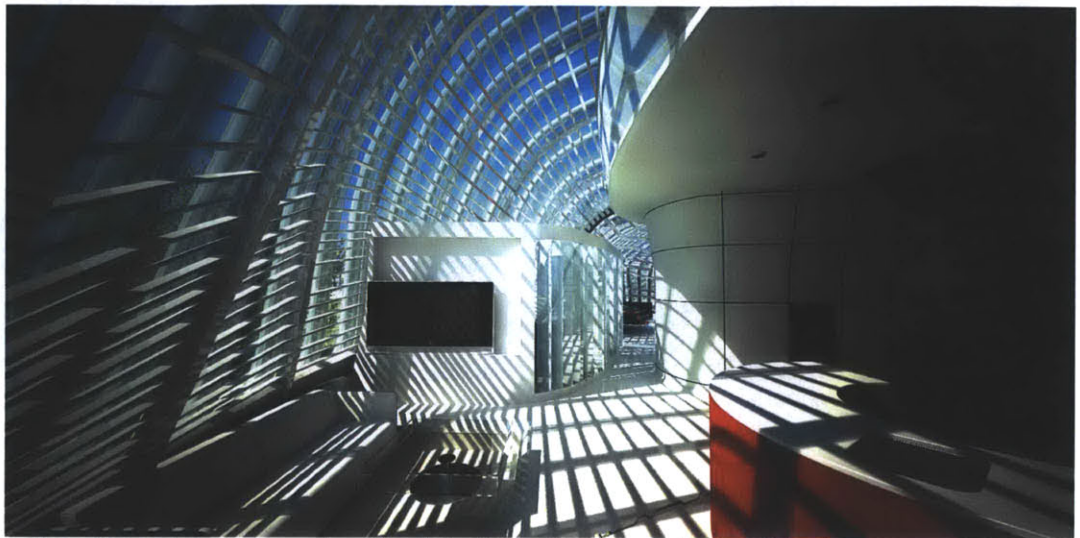
Parametric Evaluation of Form Factor for Design Grammars

The objective of these material experiments was to create a repertoire of potential procedures, to define the proper parameters for designing and manufacturing building components within the scope of the Infill concept (as defined previously), and then again to apply those parameters with



Variation of the residential unit proposed, using flexible photovoltaic cells, anisotropically distributed to optimize solar gain and control visibility/privacy conditions within the residencies.

the goal of designing site-specific configurations that would take advantage of these distributed performance materials under specific local environmental conditions. The next step in the process was to be able to relate, with specific conditions to natural and urban situations, the form factor of the external envelope of the building. For this purpose I conducted a study of the inflection of the geometry, the goal of which was to discover a way to understand the advantages and disadvantages of each formal configuration. With this in mind, I will show how this study was linked to an environmental analysis especially related to solar orientation, natural daylight and solar radiation as a potential investigation into supporting the implementation of a solar energy capturing system. The first phase of the study consists of building a parametric model using Generative Components (GC, Bentley Systems International, USA), linked with ECOTECH (now Autodesk® Ecotect™ Analysis, USA) models that can evaluate the environmental performance of the different configurations tested. A comparative study beginning with traditional typological forms and moving to the proposed novel topological striated field that was developed


Interior perspective of one of the proposed residential units for the Green Village of Zambana.

for the research phase of the Zambana project. The parametric variations allows for a transition from a standard cubic profile to a more traditional tilted roof version (or an angled facetted configuration) and finally to a smooth continuous surface; yet it always allows for scaling and orientation to become principal factors in the evaluation process.

The processes for designing the distribution of the material properties to produce anisotropic composite materials were applied to explore the possibilities of embedding smart behaviors to modular built components on a material level. Aesthetics as well as functional considerations are taken into consideration with this reorganization. Of particular interest were its applications for the implementation of natural daylight using inexpensive, low tech (not electronic but tectonic) components which would collect and distribute light onto buildings.

Parametric Evaluation of Environmental Performance

The form-factor parametric model was linked to ECHOTECH, one of the most accepted and renowned environmental evaluation tools available. The innovative aspect of this approach

Schematic visualization of the green facade of the residential units. Shown here as an external vertical garden, but also available as an enclosed vertical hydroponic garden.

is that an interface between these two tools (Generative Components and Ecotech) was being developed at Bentley Systems in collaboration with people at MIT[61] at the time and was available as a beta version to the designers involved in the Smart Geometry Community, a community of which I fortunately invited to be a part. Access to this platform and community enabled me to parametrically model and adjust a digital simulation of the project according to a performance analysis done through Ecotech, while having real-time responses to varying environmental conditions. The study shown here is only an initial step towards this, more ultimate goal. Additional data would be required to build a more robust simulation, one containing precise local data of the Trentino Region; in actuality that data is only being approximated by latitude to the north of Italy, but it was accepted by the interested parties as a proof of the concept, and it was understood that further research would be conducted when necessary. In addition, more topographical data would be required in order to calculate the exact solar occlusion considering the abrupt topography of the area. Nevertheless, this study illustrates the potential for developing a serious

A preliminary vision of an initial phase of implementation of the residential units in Zambana

environmental study using local data, with the goal of achieving an optimal solution regarding building orientation, form factor and material distribution. The initial studies with approximated conditions are illustrated by the following images. The diagrams showcase the analysis of the natural daylight factor for exposed surfaces. Initial studies confirm that that a traditionally modern configuration of vertical facades and flat roof take principal advantage of the horizontal surfaces of the roofs while losing an opportunity to optimize the building façades and achieve an increase in the daylight factor regarding natural illumination. During a day-to-day study, orientation seems to contribute to an increase in this factor, but examining a yearly average analysis, as shown above, the incidence of orientation on vertical facades is minimum and the majority of the gain is received by the roofs, which are generally not fitted to become natural light capturing devices.

Parametric Evaluation of Formal Performance

The final step of the study was to link the studies on material distribution and form factor and make them converge on a landscape or urban design strategy, optimizing location, form factor, orientation, materials and the fabrication processes. For the purpose of the present study, the final schematic design for the striated field was used, that which had been developed in the previous phase of research for Zambana. Beyond the required analysis of environmental conditions, further analyses were performed relating to the formal links between the different volumes as well as their internal geometry, as these would affect not just each the chassis volumes individually and collectively, but the neighbouring buildings, the impact on the existing and preserved buildings, the public space and landscape in general.

Gaussian and Mean Curvature Analysis

The first analysis performed related to the local inflection on the geometries of the suggested design. Local curvature relates to fabrication methods in a way that would allow for the visualization of complex double curved areas where custom fabrication would be required, but also to witness the abrupt transition from one situation to another in the realm of passive or active solar strategies, as studied before. The localization of these moments must be related to the differentiation of internal requirements or programmatic constraints. The second analysis reflects the averages of principal curvatures and hence detects major inflection moments on a global scale, something which would affect solar/shading issues and which information would allow us to correctly design and orient all surfaces of the striated field chassis, optimizing its environmental performance. Officially the research project finished with a report to the sponsoring organization in Italy. At this time, political changes had redirected the original interest in studying the rebuilding of Zambana to other topics, but the breadth and scope of the investigation had presented several crucial opportunities to explore areas of multidisciplinary condition and of multiple scales. Addressing the scale of the territory in concrete terms as we developed strategic plans for productive landscapes and new urban design paradigms, this became an open door to the experimental extrapolation of design principles belonging to the product/material scale. The scalability of material distribution algorithms enabled a new understanding of the impact of aggregated modular variation and its effects on the large scale proliferation of these cumulative, incremental differences. The relationship between the natural and the artificial in the research provided the opportunity to explore notions of artifice that combined biological and mechanical and electronic elements, all in one single bundle or construct. This notion of natural, one that is purposely and carefully designed via the inclusion of natural processes as part of the repertoire of "Embedded Responsive Systems" -such as the inclusion of certain strains of star moss[62] that would change their colour from green to brown and even black if the presence of CO2 were detected in the air- allowed the investigation to pursue a critical agenda in terms of sustainability and green design. This was done by questioning the very basis upon which the relationship between natural and artificial is founded. This became all the more evident when we dealt with the research on a landscape scale. Here the forces of nature and influence of the built environment were not just explicit—they were highly expressive and pervasive.

Part Three

Digital + Material Computations

Material Computation

> *"If we divide a volume of matter into two equal halves we end up with two volumes, each half the extent of the original one. Intensive properties on the other hand are properties such as temperature or pressure, which cannot be so divided."* 63

Widespread among architects and designers, the concept of materiality has become a wildcard to refer to various conditions, characteristics and attributes of materials and their multiple uses. In general it refers vaguely and ambiguously to attributes that range from a consideration of the use and choice of materials in design to a careful and studied theoretical position regarding materials. This occurs within a practice that deals both with virtual (abstract) representations and with actual (concrete) objects as products of its disciplinary exercise. Some critics argue that this vagueness makes the emphasis on "materiality" a merely superficial, if not shallow - and sometimes even obvious - inclination toward notions of perceptual interpretations of materials[64]. Within an architectural context, materiality evokes a "heightened sensibility toward the use of materials," qualities understood as the "applied material qualities of a thing"[65]. As Fernandez remarks, this notion is usually used to describe evident and explicit properties of materials and usually circumscribes the description and discussion of such material properties to only "the haptic and visual aspects of materials," which neglects other aspects related to its *performative* properties. While Fernandez asks for a deep, specific and concrete attitude toward materials - from the perspective of physical, chemical and mechanical properties - performative and qualitative attributes should also be carefully considered when choosing and using specific materials in design.

We could say that Fernandez points toward the need to avoid the use of materiality as symbolic reference and to consider materials as physical matter and how they perform independently of their historical and cultural charge. That is, we are now called to understand materials through their molecular organizational performance by considering the use of technological performance. On the other hand, Raoul Bunschoten describes his interest in the *dynamics* of materiality, which are present at different scales, as ranging "from the thinking hand molding a ball of clay" to the "process of human activities, exchanges and emotions at the urban scale"[66]. Bunschoten refers to the former as "skin of the earth as a dynamic materiality" and the latter as "the inhabited space: the second skin." He sees these processes as the place where "architectural artifacts (small worlds)" happen. Bunschoten proposes understanding these concrete material processes through a conceptual framework of meta-processes that consider the merging of the urban and the natural as their arena, their field of interaction. Matter in this sense is a metaphor that allows these interactions to operate at multiple levels of interpretation. These interactions are then conceptual interpretations, readings and writings about such *material actions*.

Bunschoten argues considering both the tectonics and the aesthetics of these actions as productive in terms of a discourse of materiality, a cultural performance of matter. Architects and designers have traditionally understood materials as the substance with which they work to create and shape their ideas. Katie Lloyd theorizes precisely on this relation between matter and form in the design process when she writes that material (matter) "is inert - as that which is given form"[67] through design where materials are shaped or formed. Historically, the architect's role has been regarded within the architectural discipline as that of the "form giver", a definition that relies heavily on the separation of both form and matter, as "form is that which can differentiate and form which can be differentiated"[68]. Katie Lloyd calls this differentiation hylomorphism[69] and places this dichotomist relationship between matter and form within a historical and philosophical context where the abstract representation has always had a predominant role in the practice of architecture. Lloyd Thomas points to an emergent attitude that she calls "material attention," which is not yet radical enough to question these assumptions but strong and broad enough to start shifting the balance in contemporary architectural discourse about its material practice. While this material attention still accepts the hylomorphist paradigm, it tries to reestablish some balance to the equation by at least replacing "neglect" with a new attentiveness. Lloyd-Thomas concludes by asking for (if not expecting) a more radical reinterpretation and implementation of this framework. This expectation takes on special significance given that after the soft(ware) digital revolution we are now experiencing the hard(ware) digital revolution when new technologies such as digital manufacturing are "re-centering the discussion as a link between conceptualization and production, undoing a gap which has been such an important part of the discipline's structuring"[70]. Lloyd-Thomas' argument, while supporting a discursive transformation of the traditional relation between the act of design - to give form - and the result of this action, also turns toward a reciprocal and multidirectional relation where matter may develop form through the unfolding of its performative behaviors. By the emergence and transformation of internal forces, the tectonics of matter develops new form where its internal organizational performance informs the new aesthetics developed by this process, which in turn transform the discourse's cultural performance.

The relational form that informs matter relies on the enforcement of extensive formalisms onto purely intensive fields of material properties. On the other hand, if matter is to produce formations, then design is the performance enacted by these field conditions and the relations between matter and environment. Design performativity becomes the force that influences the formal operation responsible for the formations. Some authors have come to refer to these new trends as "performalisms"[71], which attributes to performance oriented design the same driving influence that geometrical and compositional considerations had for the discourse of modern formalists in the 1920's and the revisions of formalisms of the late 1970's and 1980's.[72]

Digital Computation

> *"If at each stage the motion of a machine is completely determined by the configuration, we shall call the machine an "automatic machine" (or*

a-machine). For some purposes we might use machines (choice machines or c-machines) whose motion is only partially determined by the configuration (hence the use of the word "possible"). When such a machine reaches one of these ambiguous configurations, it cannot go on until some arbitrary choice has been made by an external operator. This would be the case if we were using machines to deal with axiomatic systems. In this paper I deal only with automatic machines, and will therefore often omit the prefix a-."73

When Turing submitted his paper with the results of his work on Hilbert's question on decidability in 1936 to the London Mathematical Society he was probably not aware of the implications that his contribution to the world of mathematics would have for the world of design. Turing was trying to define a mathematical method to solve problems that had previously been impossible to solve. Later he would call such method a "universal computing machine", which probably demonstrates that at that point he was starting to envision its potential beyond his original objective. But what is interesting for this argument is that when Turing was faced with the problem of defining this first machine or computation, he acknowledged two kinds of computational machines could be used and developed for such a purpose - automatic machines and choice machines.

Automatic machines could work independently given an adequate original output. Choice machines, on the other hand, could compute part of the problem but at some point would require another input, which Turing calls *external* and *arbitrary*. The full process would not be carried out unless this external agent were to *see* the actual computation carried out and then *decide* how to carry on the next computations. This will happen when a computation reaches a state of *ambiguity* in the results of the initial computation, and that had to be resolved by this external operator. For the sake of expediency, Turing chose to work first on automatic machines, which led him to build the computing machines he devised. Little is known about the choice machines, or arbitrary machines as pointed out by some of his critics like Post[74], but automatic machines, or a-machines as Turing called in his 1936 paper, soon became the model for computing machines[75], or as Church[76] named them, Turing machines. His proof of a method of calculation that could be devised to compute any computable number was based on the idea of a computing machine that systematically operates following a general algorithm.

Turing's foundational paper, written in 1936, establishes the basic layout for such a machine. However, at the time of his paper, Turing still thought of this abstract machine as a method for a human person to be able to perform the calculation, given the general algorithm, and he compares his abstract construct with the logic of operation of a human computer. But the idea of a mechanical machine that would perform such calculation is also suggested through the end of the paper.

Another mathematician, Alonzo Church, had a few months earlier published a paper on the same subject with a similar result but different approach. Turing's paper was delayed and published by the end of 1936, and although both men were unaware of the other's work on the subject, the London Mathematical Society forced Turing to correct his original paper and acknowledge Church's work. In 1937 in the same journal, Alonzo Church published some notes about his own paper on the *Halting Problem* and included a review of Turing's paper where he names Turing's abstract computing devices Turing Machines. Therefore, Turing's *a-machines* - as described in the 1936's paper - became one of the most influential models for what later would become digital computation.

How a choice machine would work and what kind of operator and operation would functionalize such a computing machine is, however, unclear. Turing may have been referring to an external human operator that would have had to oversee and control a set of outputs provided by the initial set of computations, but it is unclear why he would observe the arbitrariness of such a decision and corresponding input to the following set of computations performed. Why would a human make an arbitrary decision? Or why would a human decision be characterized as arbitrary? On the other hand, given the fact that the machine could only look at one state at a time, and remember one other state while deciding, given Turing's description, a human would have possibly been able to look at more than one state and could therefore decide based on those and possible other external variables. This could have been seen as an arbitrary decision making process but at the same time would have enabled the computing process to at least introduce a new state where before there was only a predefined number of possible results. It could have also allowed for the computing machine to erase the memory of the previous process and start redefining the computation from that step.

What Shape Grammars critiques in prevailing models of computation lies precisely on this (inherited) point, the fact that what the a-machine can see had to be pre-encoded for it to be able to see it. The machine that Turing described originally consisted of a *reader* and a *writer* device that would operate with a linear tape that would have pre-printed or marked squared cells. At any moment, by checking the last scanned cell, the machine was also able to *remember* the last symbol[77].

The a-machine would pull the tape until one square cell was aligned in front of the reader, would *read* the content of it, which could either be either a 0 or a 1 (a symbol that would represent a 0 or 1 value), would *remember* the last symbol scanned and would make a decision based on these two inputs. Beyond the operations performed, what is crucial is that the cells mattered insofar as they contained the symbol that the machine knew in advance, and, –therefore, had one and only one possible reading. This matching is essential for the machine to *see*. Either the square at any point was one state, or it was another state. If the square was empty, the machine would write a symbol in it. If each cell is its content, then each square is then undoubtedly the form it contains (form as in symbolic form, having only one possible reading). A c-machine would perhaps be closer to shape Grammars claims, since it should be able to perform the same functions but would also eventually be able to see among other cells and infer or decide based on that "broader" but also "external" knowledge. For Shape Grammars, this would happen through embedding, i.e. when you see, you can break the rules of what you are supposed to see and see whatever you want. But in order to be able to see other possible states, a c-machine requires the ability to forget the state that it was supposed to look at and flatten all possible *seeable* states from which one could potentially select to initiate the next set of computations. Regardless of whether this operation was to be performed by a human operator, it introduces uncertainty into a model that is trying to be certain. Proving, then, became the antagonist of designing[78].

Visual Computation

Shape Grammars refers to the process that makes a computation, by describing such operation through the notion of embedding and the application of rules or transformations. As its name suggests, Shape Grammars work mostly - although not exclusively - in the world of shapes, that is of two and eventually three-dimensional figures and forms. It explicitly suggests a paradigm shift from the zero-dimensional world of points, the models of computation based on counting numbers, toward a one-dimensional world of lines - and possibly to higher multi-dimensional worlds. Shape Grammars first explanation almost always addresses descriptions of the operations of embedding within one-dimensional constructs and uses the metaphor of the hand drawing and erasing a sketch as performed by a draftsman or a painter, to describe how embedding happens. These examples are used since they are easy to visualize and are highly pedagogic. Shape grammars is concerned with *seeing* and *doing*, with *embedding* and *operating*, and within these calculating operations it contains the actual - and could potentially contain other - models of computation. For the *seeing* operation to happen, a capacity to *forget* all we know from before is fundamental, since it allows for the new seeing operation to *start anew*. This principle is crucial and integral to its ideology, the ability to *forget* or reset the *memory* that the seeing aspect of the embedding operation implies, and it is, together with the notion of embedding, the most relevant theoretical concept that the thesis presented here attempts to further develop.

One reason is that in the world of linear shapes, which references drawing and sketching, this flattening operation would always return a result which is within the world of one-dimensional lines - and points, since zero-dimensional conditions are contained within one-dimensional lines. Therefore the *seeing forgets* what it knows about *lines*, but does it forget what it knows about *shapes*, or what it knows about colors, or textures, or temperatures, or light intensities? How this forgetting flattens it all down, is of critical for design.

What the sketching metaphor skips to emphasize though is that for the flattening process to be fully executed it would have to flatten all elements, which implies that all one-dimensional elements and the space in which they are contained should be flattened *together* and *simultaneously.* To continue with the drawing metaphor, the canvas or paper on which the lines are drawn or the blackboard on which chalk is traced are as integral parts of the embedding operation as the lines traced on them. But during the design process, the canvas is usually treated differently than the actual drawing in the sense that the canvas is abstracted to a level of depth and spatiality that differs from the concrete and precise description that a line, even if for only a brief moment, contains as it is being drawn. Effectively, such a line can at any moment change and become part of a different description, but at every single moment it is part of a perceived set of relationships that are happening within a certain environment.

This environment, nevertheless, does not often change nor is it often forced to change at the same time that the line description does. That is, the embedding is happening on the shape level but not on the canvas level. And where it might be argued that some patterns - ice rays for example - may play with the notion of figure and ground perception, it is not less accurate to say that they do so because of the peculiarities of the shape descriptions and not because of the actual operation on the background itself.

C-Matters

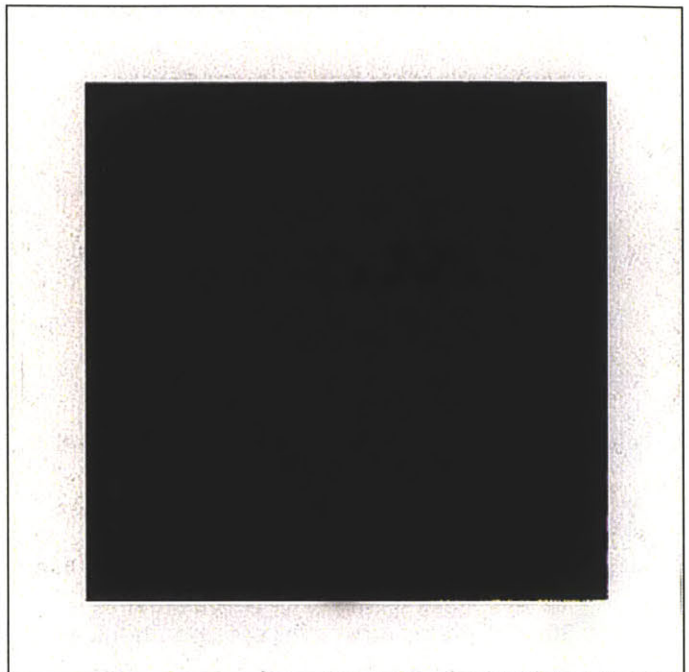
> "A gross figure ground distinction, showing structure and infill, for instance, is insufficient. The transmission of effects across a field is impossible when a dialectical relationship occurs from the start. The different zones of structure and infill have to be first described as a field of similarity in order for them to register difference. This establishes them as densities in a common field gradient."79

For Shape Grammars is to be taken further as a general design theory, it has to be demonstrated how it could operate equally outside of the world of shapes and deal with other sets of relations in different environments. Such is the attempt of the following work and the cases that will be introduced in this third section of the book. Stiny refers to most of these conditions as weights, which can be included in the grammar computation through the use of labels[80]. The fact that the labels are first attached and later carried by shapes while the shapes are being computed does not allow foreseeing a situation where these conditions are computed independently from shape conditions. If in the absence of a shape we cannot define the limits of a condition, then a critical question about boundary definition arises: How could embedding possibly occur? For embedding to happen, something must be seen – and therefore extracted - from its present environmental condition. Hence, the boundary definition of that embedded or extracted condition is critical. In a shape, the boundary condition is the shape itself. In a situation where no such definition exists, some other method for defining a temporary condition has to be devised. I propose that the notion of *continuum*[81] could possibly become instrumental for this purpose. Stiny states that during the embedding process, which applies a rule to see or extract a shape:

> *"The shapes (parts) in the rule are lost once it's applied. There's no record (memory) of the part identified in stage 1 or of the part added in stage 2. Calculating always starts over with an undifferentiated shape"*[82].

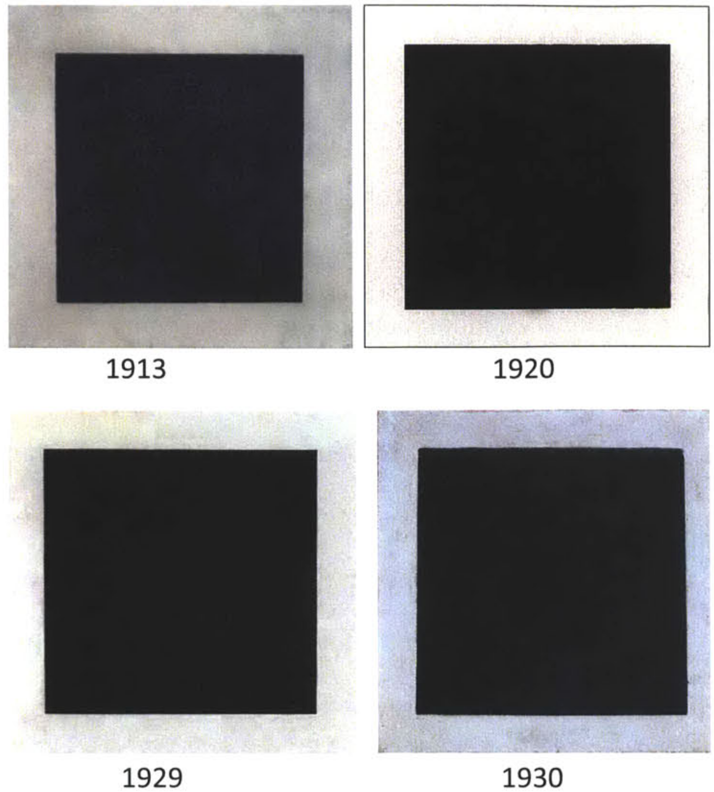
What is lacking is the process of how shape itself gets erased from memory and all is but a field on undifferentiated intensities from which shape may be one emergent formation picked up to calculate with.

Let's use an example from the art world, since Shape Grammars often draws resources from art or design to describe its mode of operation. Let's take one of the most influential modern paintings, *Black Square*[83] by Malevich. If we stripped away the cultural, social and political connotations, what Malevich proposed was a field deprived of figures, pure ground and no shapes. Yes, the black square



"Black Square", K. Malevich, 1913

floats on a white background, but at the same time the white and black become together a flat field of forces and tensions. Malevich intended the spectator to embody the perceptual experience of the field, "pure sensation". So despite the obvious mention of the figure of a square playing against the squared figure of the frame and how black and white mediated by the black-white outline play a role in the painting, once we get past that first initial aspect the painting is a black field where perception and interpretation are open to the eye of the spectator. Speaking from experience (I saw Black Square for the first time in 1994), the eye wanders through the field, detecting depth at certain moments but also flatness at others. One experiences densities of color or total absence of it and the playing of ambient light on the paint's surface, yet at moments it seems one stares through a window and that light or shadow are coming from a space further away, paradoxically within the frame but also behind it. I stared at the painting for several minutes, and I found myself coming back to it after I finished the rest of the exhibition just to see it one more time. I found myself once more staring at it for several minutes. It could have been hours as I can't really



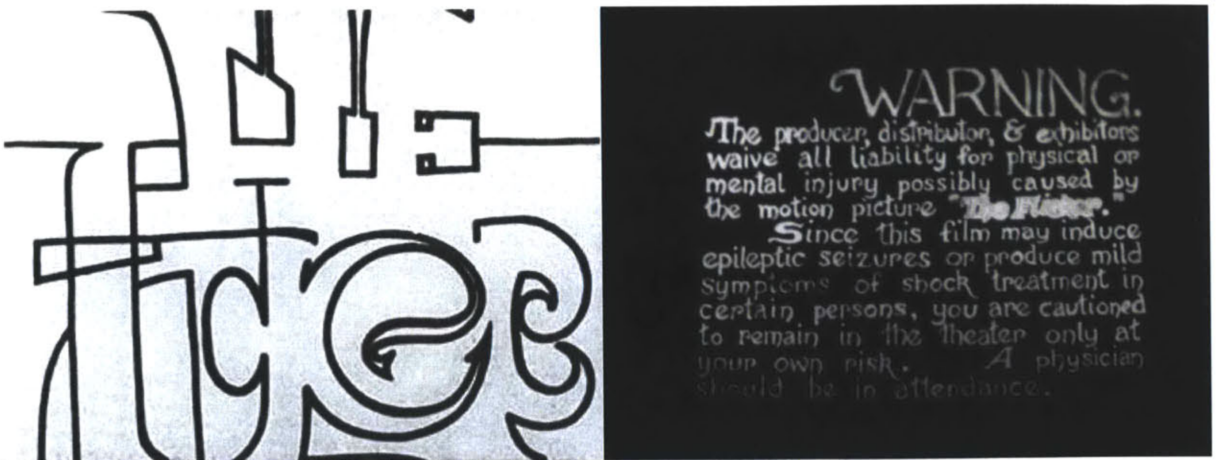
The four Black Square paintings created by Malevich throughout his life.

tell. In shape grammarian terms, it is an experience of pure embedding. Yet it is not entirely and fully described by Shape Grammars, since there is no shape involved (besides the square itself); it is a sort of color grammars, material grammars, visual grammars, or something else. In fact, finding a name for it, somehow defeats the purpose in the first place, it "kills" the memory of the experience. It is not that Shape Grammars doesn't explain the phenomena, it is just that a proper explanation of how Shape Grammars would operate in these *fuzzy conditions* has not yet been described. But the theoretical model certainly supports it. What is fascinating about this painting is that Malevich took two years to paint it. Malevich dated the back of the canvas 1913, but it was first exhibited in 1915 and there is no previous record of it being finished and shown to anybody before 1915. Whether it actually took two years for the artist to paint it or not is irrelevant but that he insisted on painting, and repainting, and repainting it, over and over, is a fact. Over the course of his career, Malevich painted four Black Squares. He painted the first, arguably, in 1913, a second one in 1923, a third in 1929 and a fourth that is dated around 1930 to 1931, only a few years before he died. This black square contributed to his arrested and brief incarceration on two occassions for the revolutionary connotations of the painting and its rejection to natural subjects. Some argue that his later years and return to figurative painting was but a mask to allow him to continue pursuing his revolutionary agenda[84] through texts while maintaining an acceptably low profile in front of Russian authorities. He was buried with the last Black Square painting behind his coffin, the only one that was kept hidden by his family. All other black squares were safely kept away from him and the authorities.

So we can only imagine Malevich in front of his canvas, applying black paint over black paint, then stepping back and staring at it, and then again insisting on applying more black paint here and there. Indefinitely. For over 16 years, almost until he died. His own design process of discovering what happened on the black field somehow resonates to the experience of contemplating it[85]. It is not that more hours of work by the artist guarantees the spectator a deeper or richer experience, It's that the same experience of embedding is at work.

However, it occurs in a paradoxical moment since logic would say *there is really nothing to see there*, which is what obsessed Malevich and what still intrigues and fascinates me. Even more startling is the fact that every time he painted the black square, it was slightly different. As if each time he tried to capture that moment of immersion in a space of pure perception he had to resort to a slightly different gesture, a slightly different calculation of the precise balance of the paint's color and texture, of the stroke's thickness, whether to apply *pastoso* strokes.

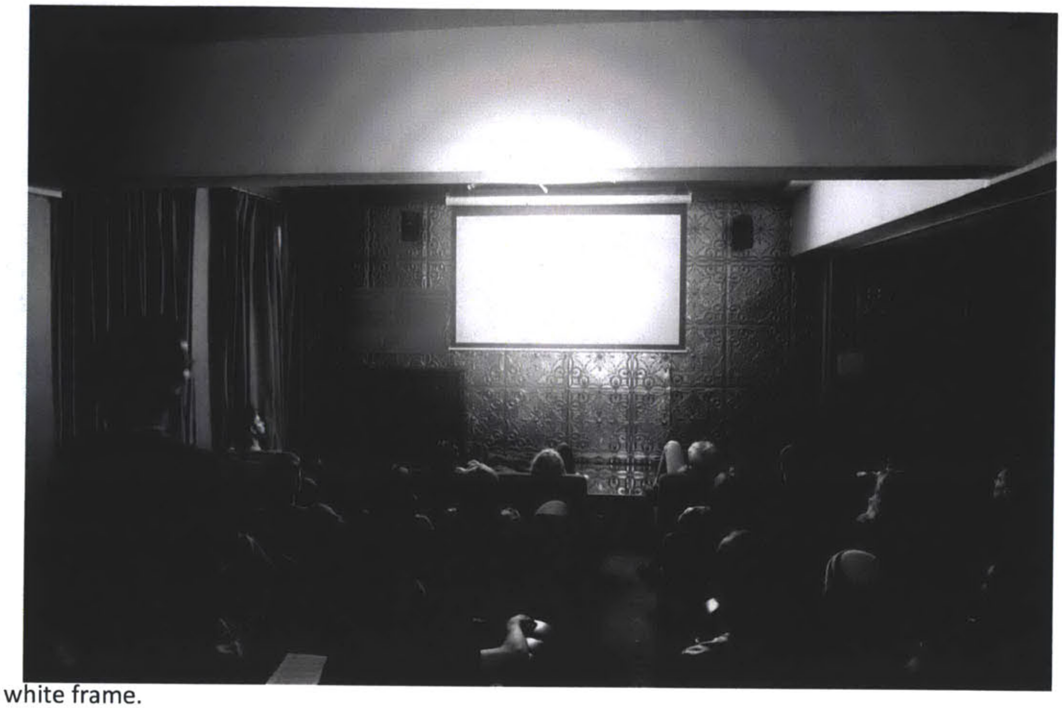
In order for the eye to see, it has to define a condition, and before that act of definition the eye is blind - it *sees* but it doesn't *grab*. When the eye actually grabs, it does so by finding or choosing a condition and tracing the degrees of continuity of that condition. If one observes lines on a piece of paper, the shape that I pick is related to the specific definition that I picked, which was, in turn, based on some continuum of lines that I *detach* from all the lines on the paper. The isolation of this particular continuum allows me to extract it from its medium and enables me to operate with it. Until I let go of such continuum



Initial frames of Tony Conrad's film "The Flicker", 1966

definition, which would make the eye blind again and where a new continuum condition could be picked, I am allowing my eye, by holding such definition of continuum, to select and extract, to embed, a different shape or condition. Lines on a paper have a starting tipping point toward shapes. That is, the contrast between the shapes and the flat and uniform white of the paper itself makes it easier for me to see the lines.

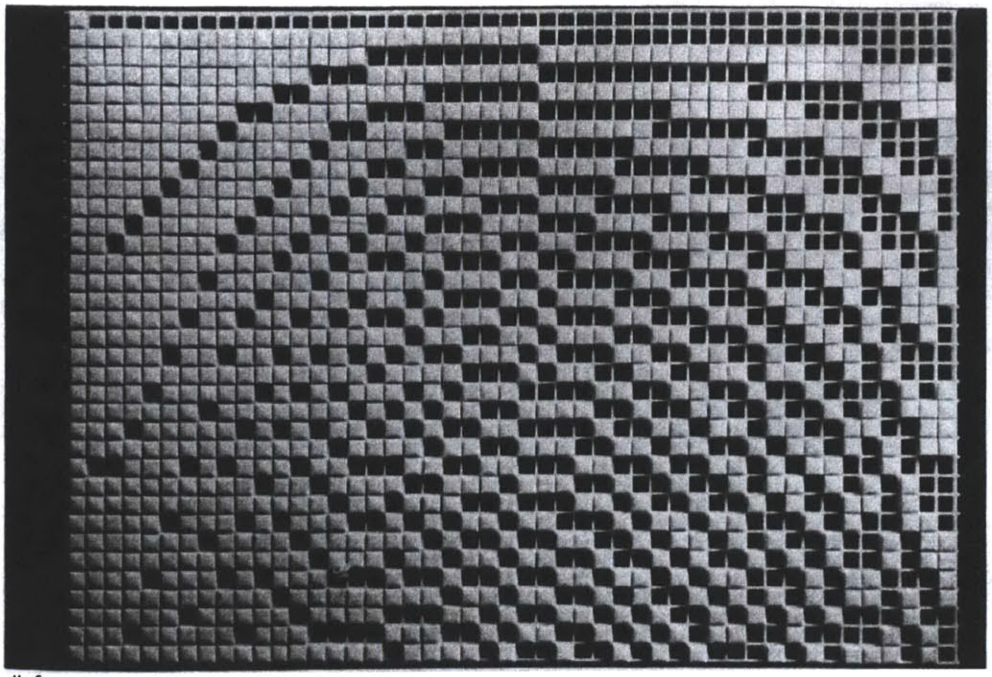
But how does this happen in *Black Square*? There are no lines or outlines to trace, and, therefore, the definition of continuum is not based on figure-ground relations. Yet while observing the field of black there are degrees of continuity. The ambient light that reflects subtly on the surface of the paint to create an almost invisible light gradient on the canvas allows me to see that gradient as a continuum. Not a fixed continuum as a line that stays line along its path and that keeps its weight along that course, but a continuum that changes gradually from one condition to another. This variable condition still presents degrees of continuity within and precisely because of the linearity or non-linearity of the transition from one state to another. So now we see a gradual depth on the flat square for just a moment, but



"The Flicker", a white frame.

then we are blind again. We still see, even if the conditions we perceived now are not contiguous, as we are focusing on the subtle grains of texture of the oil paint's thickness on the canvas, and if what we see (grab) this time are the scattered, speckled reflections of paint blots on the canvas, and how their density varies along the surface of the square, flocking. We still see, even now when what we trace is the continuum of a pattern, the continuum of a dispersed and non-homogenous condition, which allows us to grab and define such a condition. And yet, with a blink of the eye, we are back again to the black square floating in front of a white canvas.

In 1966, the visual artist Tony Conrad presented an experimental performance and precursor of the *Structural Film*[86] movement called *The Flicker*. It is a thirty minute film that consists of a lengthy three to four minute disclaimer at the introduction, a brief title screen, and a final credit screen. Everything in between is composed by virgin film tape where some frames were black and some where left clear. The result, hence the film's title, was an alternation of white and black screens at various speeds and changing rhythms. Conrad spent over seven months to calculate and



Conrad's "the Flicker", frame sequence.

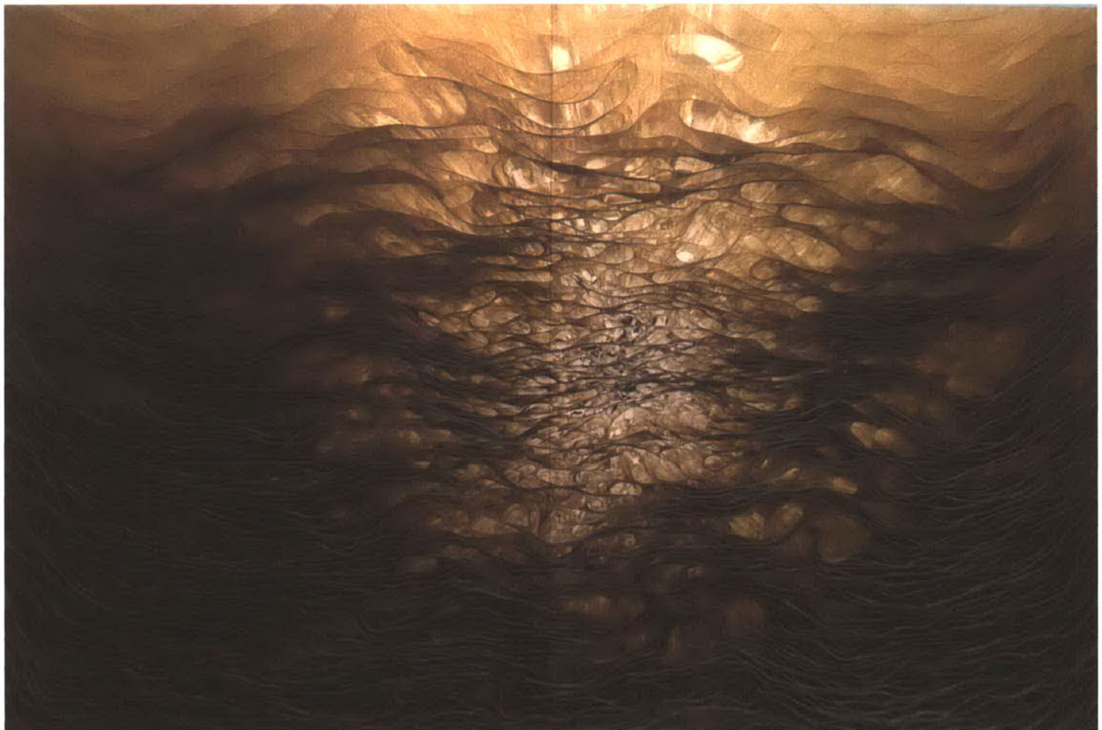
re-calculate the proper sequences of "frames per cycle" and to then fine-tune them to the actual projector, its cycling speed and the shutter speed. The study aimed to induce visual stimulation to the point of producing perceptual effects in the audience. Conrad, as other Structural filmmakers, treated the medium of film as matter[87] - which required processing and organization - in order to affect the subject.

For Conrad, in order to immerse the body in a pure perceptual space where form emergence was a dynamic and active process, the creation of form in this case implied first of all the elimination of all references to form.[88] Independent from the neurological or psychological assumptions and interpretations of his work, the fact is that the audience would exit the screening commenting on the figures they saw, even attempting to *decode* or *decipher* a narrative from the film. Again, people saw something where there was - arguably - nothing there to see, yet they struggled to describe their experience of the film. Conrad's carefully designed flickering pattern can be appreciated in a different perspective when one studies the film's exposure timing sequence (see attached figures). On this flattened and re-

Tara Donovan's Cube II and Cube III.

arranged version of the film's frames, what Conrad called tonic patterns[89], one can actually see formal patterns. Form in this case can be said to emerge out of the organizational performance of such tonic patterns. Organizational Performance.

I would like to refer here to the work of the artist Tara Donovan, whose motivations and artistic sensitivity are very far from that of Malevich but whose contemporary work somehow touches upon similar issues in my view. Her work uses found objects that are rearranged to the point of disfiguring them as individual objects and incorporating them into fields of material interactions[90]. I wouldn't want to force a comparison but I would like to state that her installation work proposes and engages the environment in which they are situated what Malevich did with the paint and the light on his Black Square. Donovan's work creates fields of intensity and distribution of tensions precisely by playing with the figuration and disfiguration of the objects, where the eye is always wandering between what is recognizable at first sight and what emerges out of the aggregation of material and interactions with the environment. In that sense, Donovan's work enables material to



Fragment of Donovan's especially comissioned piece for Boston's ICA monographical exhibition.

produce variable experiential forms and material formations, just as Malevich produced visual sensation from light perception. Where Malevich utilizes monochromatic fields and paint thickness, Donovan uses aggregation and repetition of familiar objects. Where Malevich uses placement of the picture and the available light to induce paradoxical effects, Donovan uses the cumulative material properties of the standardized elements deployed in her installations. Donovan uses iteration as a method to erase identity. In shape Grammars terms, repetition would enable forgetting. Iteration and recursiveness are precisely what enables the erasure of identity.

We *repeat* in order to *forget,* and we *forget* in order to *see*, for *to design* is to see *anew*.

If for Conrad film was matter, in Donovan's work environment is as much the matter of the performative as the objects that constitute the material construct of the work. Donovan's installations actually inhabit the space in which they are deployed and profit explicitly from the environmental conditions surrounding them. These imbrications happens to the point that the installations somehow blend into the spaces they are installed by incorporating though reflections and translucencies the lights, colors and textures of the space, and by folding themselves around the architectural surfaces on which they are placed. This performative behavior is similar in a way to Conrad's work, where the black frames in the dark room seem to submerge everything in darkness, even if only transitorily. During the projection of a white frame, no room for distraction is left since the light effectively inundates the space. When a black frame is projected, all is dark again and film and environment are the same. Bodies in the dark also become part of the environment Malevich on the other hand, exhibited his first Black Square among thirty-nine other paintings. All thirty-nine paintings were exhibited on the two perpendicular walls of the '0.10' exhibition except for *Black Square,* which was mounted in a very unusual manner. It was hung in a corner where two walls met, with only two sides of the painting in contact with the walls. It was also mounted high, close to the ceiling. The effect was that the white ground of the painting blended with the white walls of the exhibition, leaving "the effect of a black square 'optically' floating or hovering in space".[91] The flattening of the painting in the canvas of the wall by means of matching the white ground of the painting and the white walls leaves a figure floating in space. Yet when attention goes to the black square, all white disappears too, and spectators are left in the desert of black, the desert of pure perceptual embedding. The kind of embedding that happens everywhere, anywhere. Even when there is *nothing to see*.

Case Studies Part Three

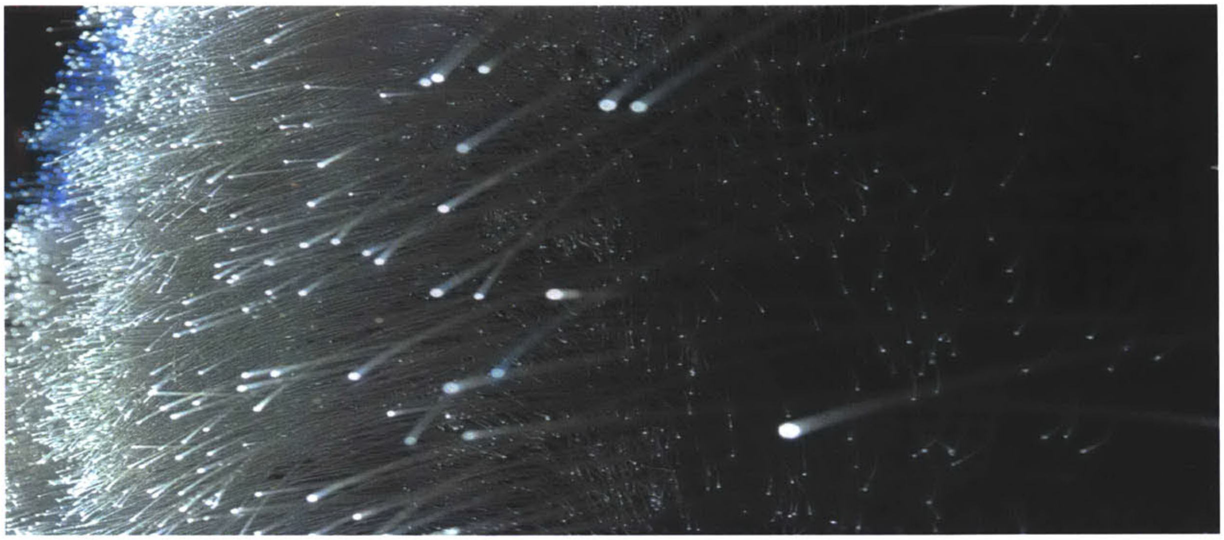
The four cases described in part three propose a novel perspective both on a theoretical framework to understand and discuss design and on an empirical methodology that addresses design questions and engages with the complex issues raised earlier in this book regarding environments, artifacts and performance.

The central hypothesis common to all of them is to depart from a conventional understanding of design as a mere formal or functional set of operations that work through the agency of matter and to instead understand design as something that extends into a larger and more general realm of physics. Design operates, or should operate, at the level of physical properties or attributes that are present both in live and inert matter. Since it is proposed that for design purposes that there *is no distinction* between artifice and environment - or between context and object or natural and artificial - design operations can focus without distinction on either attribute and operate on it.

It is proposed that Shape Grammars proposes a valid model for this methodology since it is ideologically blind to any distinction and claims precisely that all differences must be, and effectively are, *erased* or *forgotten* in order to operate with new emergent and temporal definitions. It is further proposed that these grammars can be then extended and expanded beyond shapes to a more general and inclusive realm of material or physical grammars. Since it has been proposed that Shape Grammars operate through the notion of weights and labels[92] with qualities or properties that are associated with shapes, in these examples, design operations escape common boundaries of design in terms of scale and of disciplinary field in order to experiment in the application of design rules and methods into *shapeless* environments or at least into situations where shapes are not the subjects being manipulated but an emergent manifestation of properties or attributes being operated upon. Form and function in this way become a performance of the negotiating variables at play.

I propose that this *performativity* of the system *is what mediates* between inner and outer environments, between context and artifice and between form and function in the classical discourse.

The cases presented here focus on material properties, on the design of material composites and strategies for distributing physical properties rather than formal characteristics. In particular the last two examples Polypteron and Xylinus, are attempts at trying to operate on eco-systemic levels, pushing to extremes the multi-scale and undifferentiated-field premises of the work. While this are experimental design exercises, with research objectives as primary goals, concrete applications are proposed as ways of connecting discourse and practice and imagining scenarios for implementations of this concepts and methods.


Photograph of a prototype of The Cloud Installation.

Phototaxic Anagenics

Algorithmic Transparency

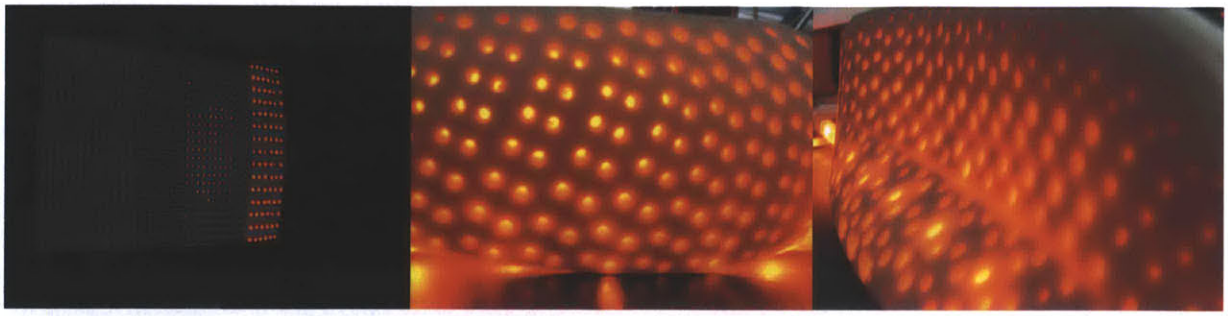
(S. Araya - Part of this research was done in collaboration with Mobile Experience Lab, Design Laboratory MIT)

Contents of this chapter have been published as research papers at the "Critical Digital Conference" at Harvard University in 2008, at the "(Im)Material Processes" Exhibition at the Architecture Biennale in Beijing, China, in 2008, and as an article for the "Digital Cities" Issue of Architectural Design Journal (AD) London, UK, in 2009.

Case

> "Transparency may be an inherent quality of substance, as in a glass curtain wall; or it may be an inherent quality of organization. One can, for this reason, distinguish between a literal and a phenomenal transparency."[93]

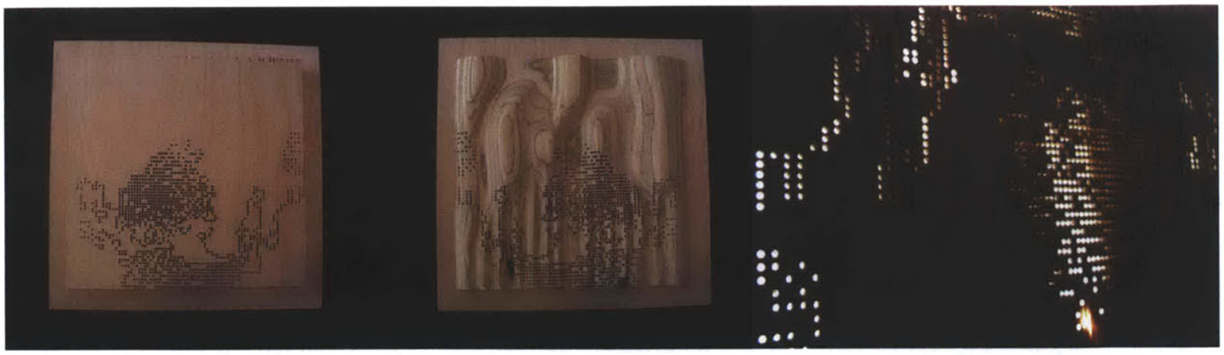
One very evident consequence of the adoption of modern technologies in the contemporary city is the separation of structure and skin that is



Material composition and performance distribution. Left: Lasercut wooden prototype on with threaded optical fibers. Center and Rigth, 3D printed protoype with RGB LED assembled inside and programable color change.

manifest in the proliferation of transparent building envelopes. For some critics this has also implied the vanishing of the façade, or of *'architecture's face'* as pointed out by Anthony Vidler.[94] Several years before, Colin Rowe established a distinction between literal and phenomenal transparency by comparing façade treatments on Le Corbusier and Gropius buildings. In doing so, however, he left open questions about the use and interpretation of transparency as a material, physical condition and/or as a spatial or organizational condition. While this chapter will not attempt to respond to or contest of Rowe's interpretations, it tries to build on these distinctions by presenting an operational and instrumental approach within a framework initiated by these distinctions.

This chapter elaborates on the possibility of applying a procedural design approach to develop non-homogeneous material properties, transparency and translucency. Fixed definitions of such properties, where for example transparency and opaqueness are interpreted as absolute values and pure states, are challenged by creating actual gradual variation and continuous yet heterogeneous performative values. Furthermore, it explains how a different condition, specifically

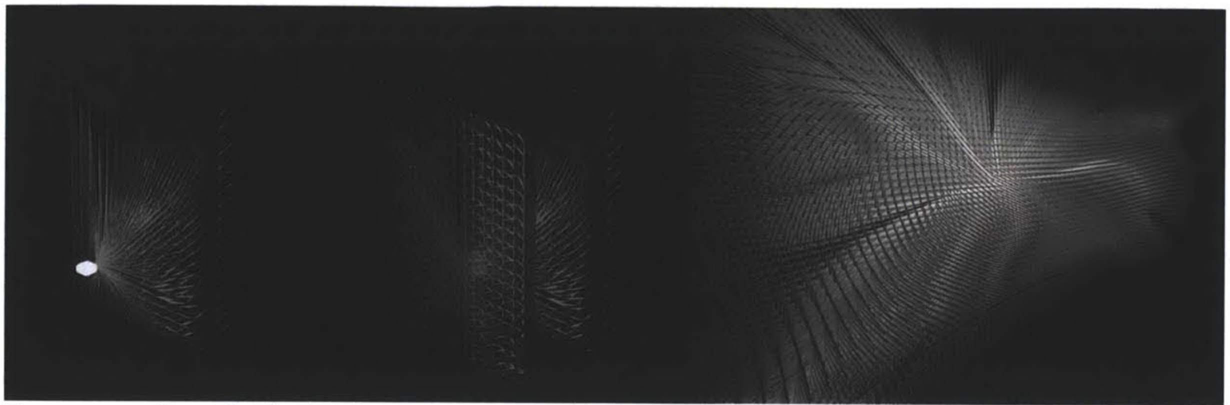


Wooden CNC milled prototype. Continuous gradients of material distribution through algorithmic organization of porous structure. Parametrically designed and machined to test distributed array performance and material depth variation incidence in transparancy qualities.

related to material transparency, is developed that could be categorized as an ambiguous or intermediate stage between the literal and the phenomenal stages defined by Rowe: a *multifarius transparency* where these stages can be present simultaneously.

The method developed here consists in using procedural composition techniques that combine different materials with different material attributes to create new properties. Optical fibers were chosen to take advantage of their conductive qualities. Optical fibers conduct light because of their absolute internal reflection. This gives the composite another characteristic that is different from that of glass or other transparent materials: depth, or freedom of location. And it embeds in the component the possibility of spatial depth or spatial transparency beyond surface depth into volumetric and spatial depth. I will call this *deep transparency*.

> "The figures are endowed with transparency; that is they are able to interpenetrate without an optical destruction of each other. Transparency however implies more than an optical characteristic, it implies a broader spatial



Homogeneus fiber distribution from a concentrated imaging source, with variable protrusion length -organizational spatial transparency, beyond mere physical.

order. Transparency means a simultaneous perception of different spatial locations. Space not only recedes but fluctuates in a continuous activity. The *position of the transparent figures has equivocal meaning as one sees each figure now as the closer now as the further one"*[95]

A second question raised by Rowe comes from his formalistic and compositional analysis, where the precise formal organization beyond the material conditions played an essential role in identifying the critical compositional characteristics. In that regard, this chapter presents the layered logics embedded in the creation, development and fabrication of these elements in a number of prototypes of different degrees of development and with different levels of functionality. This organizational relation creates a second characteristic: divergence, or freedom of coherence. I will call this *distributed transparency*. The methods developed break down a particular input into a myriad of small bits, transporting each of them through space and then reassembling them, giving them the freedom of location and of unity (location because this method allows for transparency to be translated from its origin to a new, possibly distant spot). Fibers can be bundled, piped and embedded within a substrate, transporting information/data from one point to a more distant one. Freedom of unity is acquired

Transparency variation controlled by material depth. Gradient light produced by physical depth in contrast to gradient light produced by organizational performance of distributed perforations.

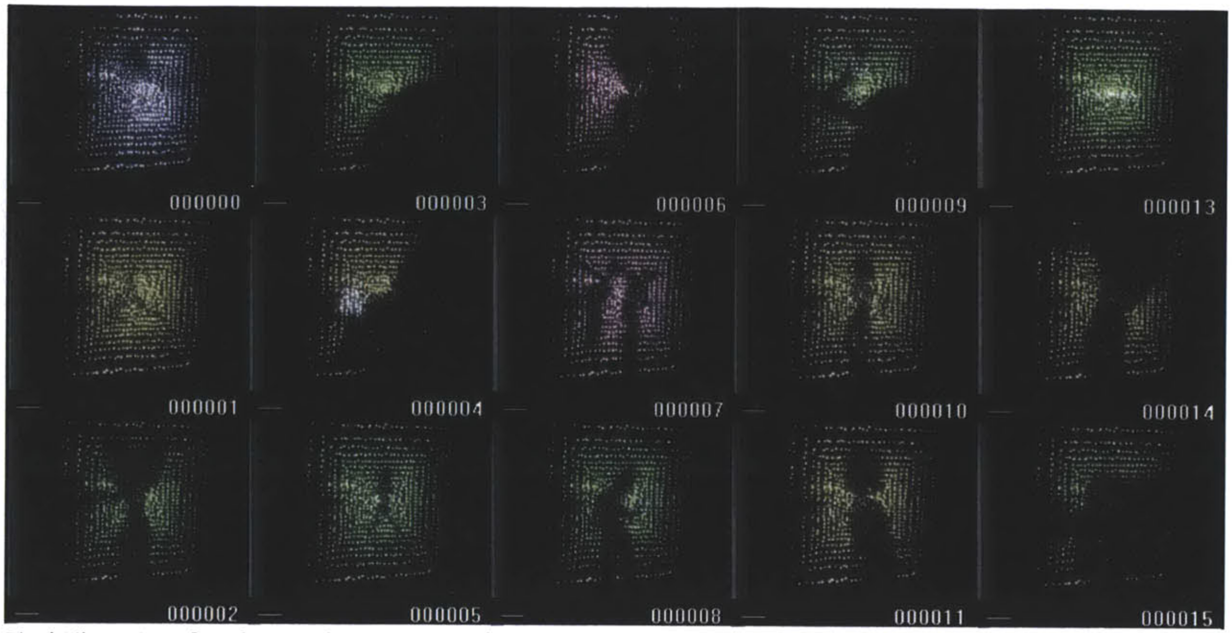
because, this light source or energy input has to be reorganized after being fragmented and rerouted, in order to reproduce the light/data (image), and this can be done in an infinite number of ways.

It can be reassembled consistently with the original input, but it can also be fragmented and distributed, in which case it can be reorganized to encrypt the original input source or simply broken down into a myriad collection of bits to be scattered through space. In the work presented here, a testing prototype incorporating optical fibers of varying sizes and grid ratios illustrated the effect of material composition in the performative attributes achieved.

Methods

Deep transparency, distributed transparency

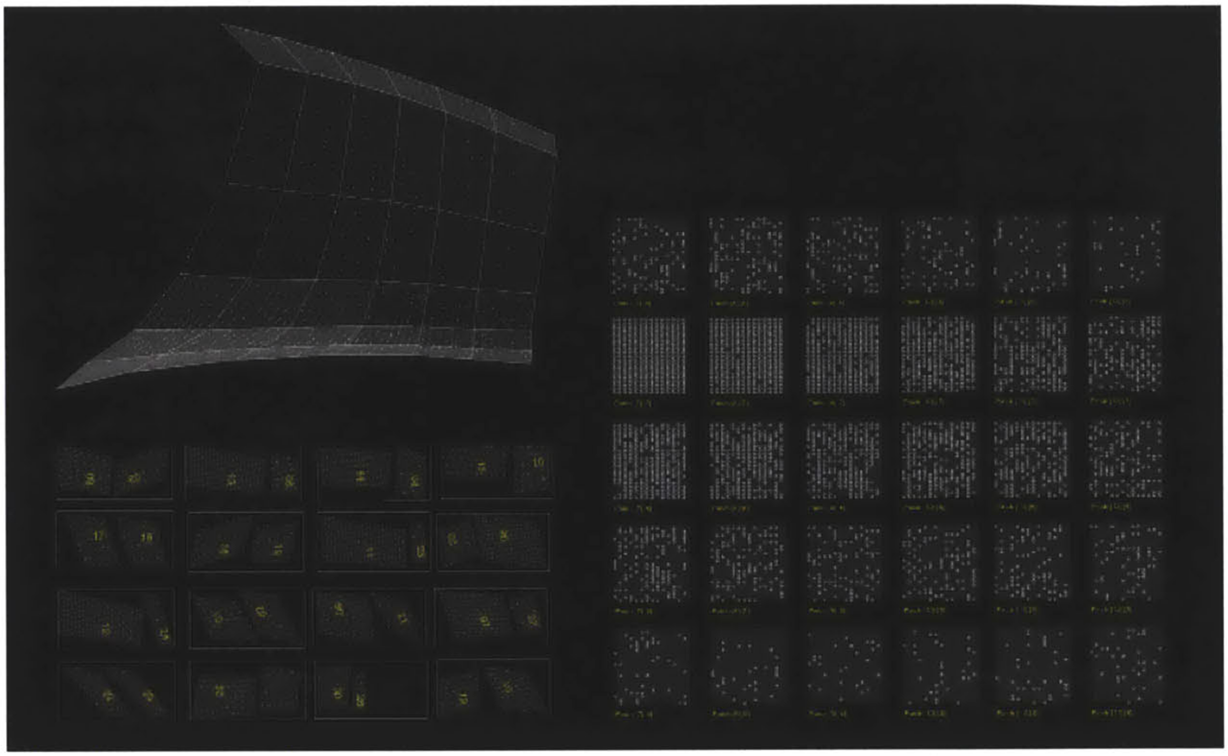
The research described in this chapter is conceived of as a sequential series of explorations that combine design routines and CNC fabrication techniques. Custom procedures were developed for these experiments, and learning from each implementation adjustments and, therefore, variations within these procedures were pursued in order to exploit observed properties in the resulting prototypes. The application of this research is used later in further implementations to create three-dimensional display systems.



Pixel Liberation: freedom to fragment light/image source into individual pixels to be rearranged remotely, enabling image light/image manipulation and reconfiguration.

This further development required additional investigation on image and signal processing in order to match the right bits of information with the distributed array of pixels produced through the method described in this paper. That specific aspect of the research, developed by designer Orkan Telhan, will not be included in this presentation and is subject to its own publication, but I would emphasize the relevance of such multidisciplinary work in the realization of this investigations. Detailed here is the research related to the design and fabrication of the physical implementation of such a system. Part of the investigation and prototyping was done in collaboration with designer Hector Ouilhet, especially those aspects of the research related to the adaptation of these principles to the later implementation as a three-dimensional display system.

The method developed decomposes a particular media input into a myriad of small bits, transports each of them through space and then reassembles them, gaining in the process two degrees of freedom: location, which enables deep transparency, and coherence, which enables distributed transparency. Freedom of location because this method allows having transparency translated from its origin to a new, possibly



Organizational Performance: Fiber routing algorithm through matirx transformations between compact regular standardized input and expanded irregular non standard (spatialized) output.

distant location. Fibers can be bundled, piped and embedded within a substrate, transporting information/data from one point to a distant other. Freedom of coherence because it has to be reorganized to reproduce the information/data, and this can be done in infinite ways. It can be reassembled consistently with the original input, but it can also be fragmented, distributed and reorganized to encrypt the original input or simply decompose it to a myriad of bits scattered thorough space. This enables the physical routing of the fibers to act as a material computing device, which creates "image editing filters". A diagrammatic representation of a process of splitting the source into a number of bits and then routing them through a distance was designed to understand the transformation required. Later, a reassembly of such bits or pixels is required to reconstitute the source. The starting point for a matrix distribution is a regular orthogonal grid. A grid is an optimal distribution of the fibers on the matrix material from a logistical as well as from a data management perspective, but a non-homogenous and organic distribution was a design driver of this research. A driving design direction specifically targeting the gradual distribution of material properties in the final composite. Gradients, scattering, patterning and other forms of clustered yet anisotropic organization are made available as performative variations.

Several layers of transformation were overlaid in order to produce an ambiguous yet defined condition of organization. As in liquid crystals, a *nematic phase*[96] is sought and achieved, a condition that is *in-the-process-of-becoming-but-not-yet*, between order and disorder, between fluidity and rigidity. Both aesthetics and function are affected by this reorganization. Prototypes were developed to display and test a composition where both depth (location) and distribution (coherence) are variable and non-homogeneous.

Current developments, including some new products available in the market today, have used fiber optics embedded in building materials, such as concrete. Most of these designs, however, exploit the properties of the material only in their physical transparency. Those developments ignore the capacities present in the composite material in their organizational transparency, which adds the two new degrees of freedom, location (depth) and coherence (order). Furthermore, those attempts are basically recreating properties present in glass, so the concrete tiles behave similarly to translucent glass. The explorations depicted in this research in contrast, intend to expand the range of effects embodied in these components, to enhance the ways in which they affect architectural space.

Material Composition

Composites materials are generally made by the combination of two basic materials, a matrix and reinforcement. The matrix surrounds the reinforcement and fixes it in place, while the reinforcement contributes the mechanical and physical properties that enhance the matrix properties. This method proposes the creation of a non-homogenous composite material. Such a material is formed by the distribution of a transparent reinforcement (fiber optics) within a non-transparent matrix. The distribution is done using a custom development program that operates on a parametric model where density, variation and location are variable parameters.

Given the conductivity of optical fibers, light travels through in both directions. A system where this potential could be used to display a video source is created when each fiber is paired to a pixel of the video source. A prototype was developed to perform a test where a video source is fed to the input end of the fibers, therefore making the reorganized fibers act as a distributed pixel system. The optical-fibers prototype built for this effect, accidentally demonstrated the bidirectionality of the conductivity when the prototype was placed outdoors. While being fed a video source from one end, on the other end a person that passed by produced a shadow over the output end of the prototype, and the shadow silhouettes were translucent at the video input side, this while using the sunlight as a counter source of light in comparison to the artificial source of the projector. To operate such matching, a series of transformations are required and are described below. The procedure implemented consists of a series of scripted functions that manage the different stages of the material design. The project implements five stages of development:

On-surface distribution (this procedure takes a digitally modeled object and uses an algorithmic distribution to create a pattern on the surface of the object using local variables and adjustable parameters)

Unfolded distribution (this procedure takes an approximated faceted and unfolded set of shapes and unfolds the distribution pattern based on local positions)

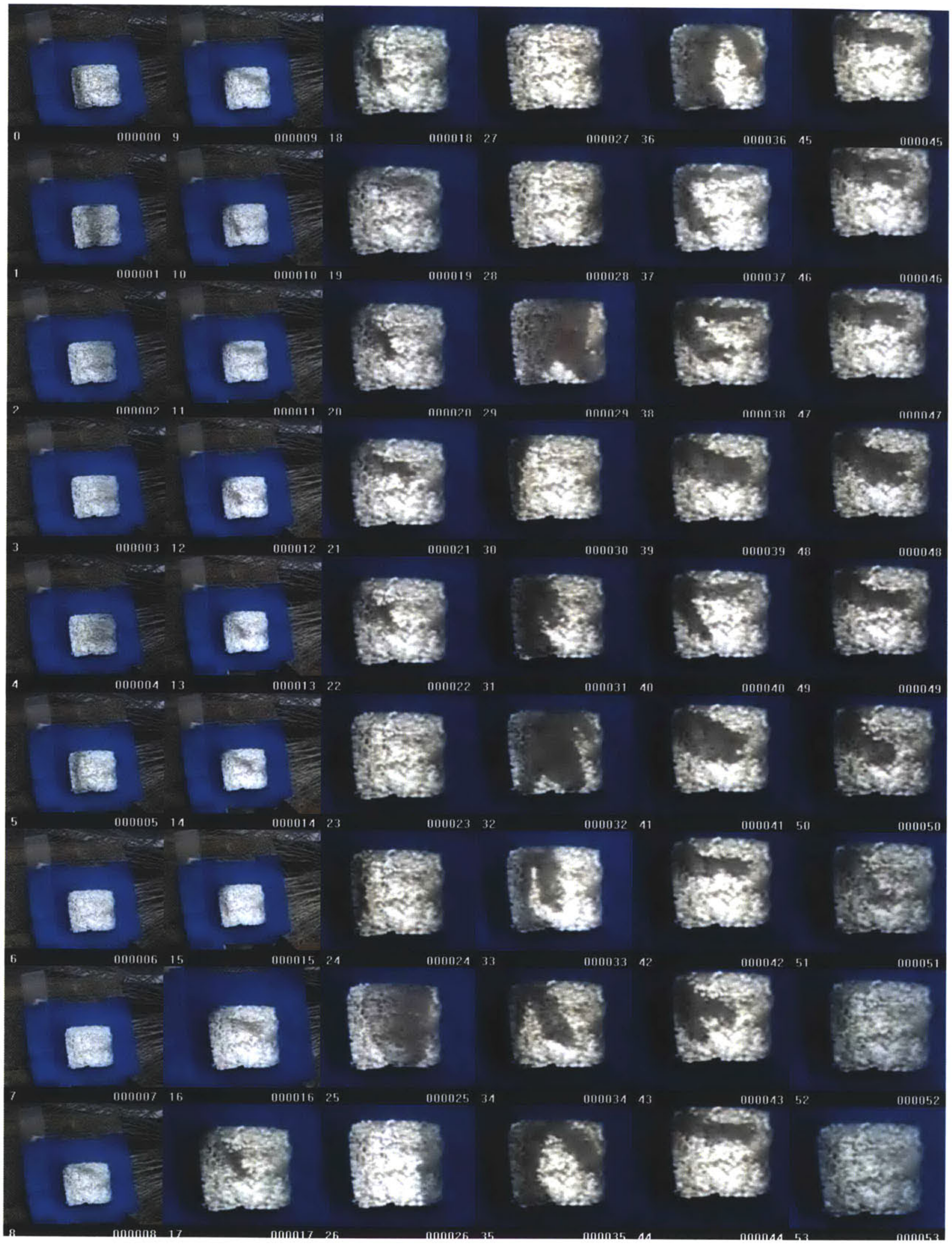
Optimized distribution (this procedure reorganizes the distribution pattern using a transformation of the original relative positions to an absolute position on a rectangular grid of tag-numbered shapes)

Matrix distribution

(this procedure creates a list of every point or fiber location so it can be read by the parser application which would later be responsible for assigning the correct pixel to each fiber. Each fiber location is still relative inside the local surface in order to relate to the actual distribution but is ordered in a uniform grid in order to relate to the input distribution)

Uniform input distribution (this procedure takes the total number of fibers in the matrix and optimizes their location in order to create a consistent and uniform grid for the input side)

Although in theory only two distributions – input and output - are needed, in practice



Accidental discovery: Input end of the prototype while receiving light signal to transmit to the opposite Output end, receives light signal, traveling in opposite direction. Uninterfered bi-directional light conductance enabling dual display/light sensing performance.

when the prototypes were scaled up in size and number some intermediate steps were required. Specifically targeting the later implementation as a display, the complexity of the assembly process and taking into account possible maintenance issues demanded a series of "control screens" in order to properly track and organize the fibers in smaller groups and to aid in the error correction process after assembly. This set of solutions is required to locate and control each fiber position individually and for checkups and maintenance purposes in case a replacement is needed.

On Surface Distribution

The fiber distribution over the object's surface was written as a scripted routine inside a parametric platform known as Generative Components. The objective was to facilitate the early design phases, iteration and decision-making by controlling certain variables that would determine the distribution. The routine requires a digital model to apply the distribution, which it is independent of, precisely to be able to explore different design alternatives. The object's surface is then subdivided to be able to address local areas with ad hoc precision. This subdivision is controlled by a set of values that provide both linear and non-linear sets of values, which results in a non-uniform subdivision system that enhances the ability to target specifically conflicting areas (such as extremely convoluted double curved moments of the surface).

The density of points to be created inside each surface subdivision is controlled by independent variables for its relative U and V values. This implementation used a uniform set of values for each surface subdivision, as it was easier to manage later on the backend by individually assigning each pixel to a specific fiber.

Unfolded Distribution

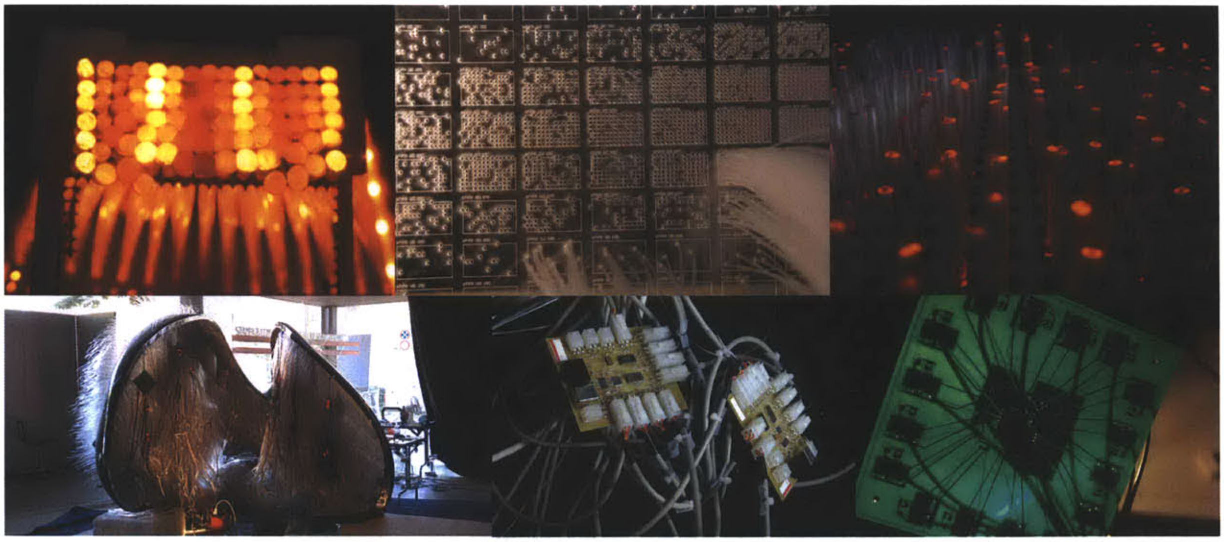
Several tests were performed using CNC techniques, but given the complex form factor of the later prototypes, a 5 or maybe even 7 axis CNC router would be required to align the spindle normal to the surface at every point and drill accordingly. Given the limitations in time and budget, some prototypes used approximated surfaces and all-parallel milling, some in a three-axis CNC router. The more complex prototype used a different procedure. An alternative path was determined in which a printed set of patterns that covered the surface of the object it was used as a template to drill all the holes and to pass and fix each fiber. The procedure then takes the information of the surface subdivision obtained in the previous stage and projects a new approximated surface using flat triangular facets. This projection is needed in order to unfold the surface of objects that have a complex double curved surface and are, therefore, not developable. Each facet is then translated to another plane and aligned and rotated in order to unfold the faceted model in continuous strips using the V-direction as guidance. The local relative position of each fiber is read from the On-Surface distribution pattern and then reapplied to locate every point on the new set of unfolded surface subdivisions. Finally, each unfolded strip is tag-numbered in order to facilitate the assembly process later.

Optimized Distribution

The process by which a light source is going to be focused and directed to one end of the fibers in order to channel the light through them requires a packed set of fibers on one end and a distribution of all the tips on the other end, according to certain rules. In order to track and identify each fiber in the system (individualize each pixel) it is imperative to build a registry that targets both distribution patterns (both ends). For this purpose, a distribution set holds each group of fibers, and as they are located in each surface patch, it creates an isolated and unfolded version of each patch and tags each of them so each fiber position can then be localized and isolated for checking or maintenance. There are two panels, and each of them belong to one half of the object, which for management as well as fabrication purposes was designed as two complementary halves that lock together magnetically.

Matrix Distribution

This transformation takes each new fiber position on the object and records its relative uniformed and normalized version of each of the patches. The gaps and spaces are still present as in the original pattern, but the aspect ratio of the patches is now uniform and can be matched to the media aspect ratio. This new distribution has all panels organized in a continuous grid where all patches are contiguous, as they are now all of the same dimensions. By this method, the fibers are packed together although still maintaining



Organizational Performance: Performance management through material distribution. Physical redistribution and computational mapping of fibers enable new levels of performance, reorganized light - algorithmic transparency.

their positions. These new relative positions are recorded and used to manufacture a control panel where the fibers are assembled and packed. These positions are also recorded by the program by exporting a text file with the location of each fiber on each isolated patch. These locations are based on UV values that are then read by a parser that interprets these positions in order to send the appropriate bit of information, or pixel in the Cloud project case, to the corresponding fiber.

Uniform Input Distribution

This final transformation is required as the media input from the projector needs a continuous medium to project onto or some bits of light would be lost between the gaps. This function basically packs together all the fibers, eliminating the spaces in between, creating an homogeneous bundle of packaged fibers. For this distribution, each fiber exists in a two-dimensional array, as they belong to the patch based on UV values. They are then rearranged in a one-dimensional list (linear) where each fiber is consequently listed and concatenated with the next fiber from the next path, leaving a "gap" value to indicate the end and beginning of a new patch. The transformation is recorded and passed to the software parser as it needs to locate each fiber in the new arrangement to mask and send the proper bit or pixel.


Tactile interaction with the fiberoptics display contributes a physical level of connection with the information being showcased. Viewing and reading become part of playing.

Discussion

The work presented here is an ongoing research project and therefore no definitive conclusions are made, but open discussions relating to the design procedures, the material results and the theoretical implications of such practices are opened and offered.

The mass availability of new technologies and the emergence of whole new paradigms of manipulating and making material are slowly transforming the ways in which form is thought of in relation to the matter it would shape. In the adoption of digital technologies - from the "personal computer to the personal fabricator"[97] - we are stepping into the field of *Digital Craft* where both conceptualization and materialization take place virtually and actually.

To speculate about the implications of these emergent techniques within the practice, this chapter presented some explorations on developing techniques within a design process to be implemented using CNC technologies. This exploration's aim is to investigate possible avenues for further research when applying design methodologies to specifically develop and exploit material attributes and qualities.

Transparency distribution (pushing glass)

By engaging in an investigation that sought to

The cloud installed in the entrance gallery to the Fortezza de Pitti in Florence, Italy.

depart from exploiting material configurations rather than formalistic design exercises, the initial explorations were freed from a global design objective and remained open at a local physical level. Form in those cases was a resource used to pursue and develop material properties. Shapes and patterns then become vehicles for addressing gradual distribution of material conditions, rather than formal results. When in 1998, William J. Mitchell talked about the future of the city as a networked machine, he used the term "*Pulling Glass*" to refer to the act of wiring physical places, of building the Infobahn. Today we all live in such spaces, and the spaces, places and infobahn as conceived of by Mitchell are facts. The transformations of such places - and how that transformation has impacted human behavior - have been studied extensively. I will borrow a similar term to refer to a new possibility of what I call "*Pushing Glass*". In this, I refer to pushing beyond standard conceptions of finite and absolute conditions, of standardized and uniformed attributes and qualities that are derived from the modern paradigm of mass production and standardization. I also mean the pushing of material distribution to enable performative functions

Study of remaining structures, historic valuable buildings to be preserved and structures to be demolished.

beyond the standard inherent physical properties of matter, making possible deep transparencies and distributed spatial transparencies.

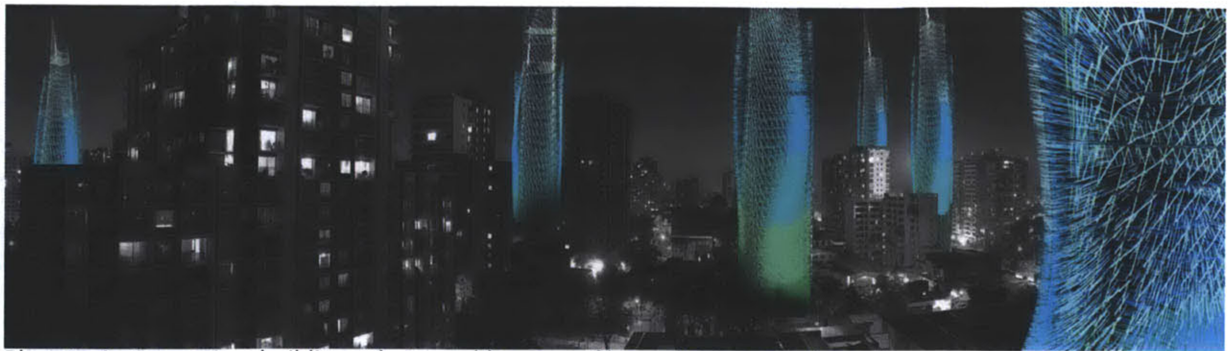
Algorithmic Transparency

This conception of matter as a continuous gradual allocation of performative functionalities instead of a simple aggregation of discrete elements with diverse qualities allows a new understanding our material practice. Traditional divergent values can now be seen as converging forces in continuous fields of variation. The relation between interior and exterior, between built object and landscape, can be reinterpreted or at least challenged. This presents an opportunity for altering and radically challenging our physical environment, which has been transformed virtually during recent decades, by concretely affecting its physicality, transforming passive material into active matter. Enacting these transformations specifically through the explorations described in this chapter, by extending standard notions of material properties, such as transparency, to that of algorithmic transparencies, for example. To explore transparency distribution, different procedures were scripted, which resulted in several different patterns being produced.

The algorithmically designed transparency that would enable an opaque structure to become translucent.

Manipulation of the distribution allows creating distortion or altering effects to the light/image source. Through these ordering procedures, a sort of analog filter for image manipulation can be created, relying on the physical conductive properties of the fibers and their translation in space from their input to their output. The study of distribution patterns isolates every variable parameter involved in the final distribution algorithm:

- Relative position (plane location in relation to the original grid)



Phototaxic Anagenics, buildings that would grow a fibrous integument in order to capture light, becoming phenomenologically translucent while operating as distributed energy harvesting devices to remediate solar occlusion and redistributing natural light as a basic resource. Even at night.

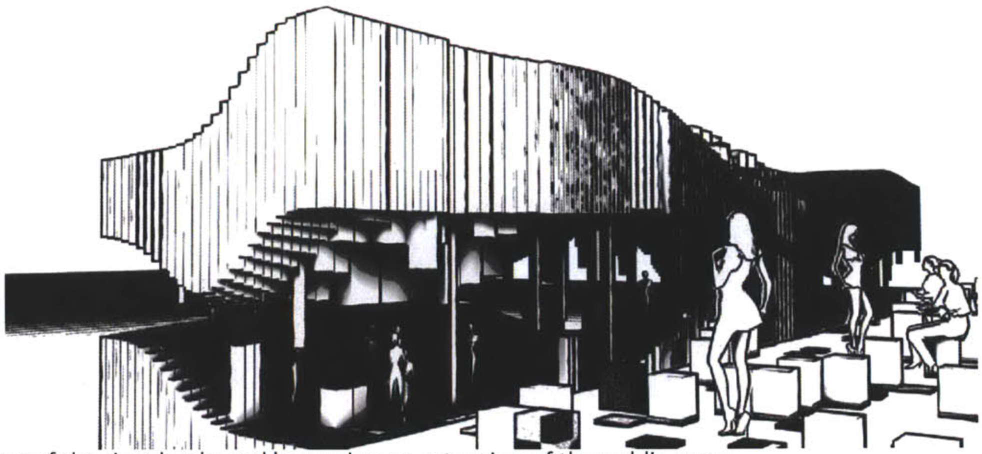
- Relative depth (in relation to the plane)
- Relative distance (in relation to their neighbors)
- Continuity (homogeneous distribution versus scattered distribution)
- Size (variation in fiber diameter)

These algorithms should be refined and further research will be conducted in order to explore other potential behaviors derived from the manipulation of these and other parameters.

Material Computing (machine matters)

A machine, as derived from the latin root *machina*, means "an assemblage of parts that transmit forces, motion, and energy one to another in a predetermined manner"[98]. Hence, by pushing beyond the physical transparency properties of glass toward a distributed multifarious transparency, we could think that these artifacts behave as computing machines.

Starting with the different patterns studied, several potentials in terms of material properties and possible embedded behaviors appear. This includes a potential for extending these transparency properties through larger spatial conditions and exploring light conduction both for ecologically responsible natural lightning purposes as well as for performative display implementations. Relocating transparency from one space to the other. Rethinking transparency through its potential organization (design): encrypted transparency, displaced transparency, scattered transparency, distributed transparency.



Hidrone docking on one of the river banks and becoming an extension of the public space.

Algaenan

HiDrone and other algorithmic ecosystems

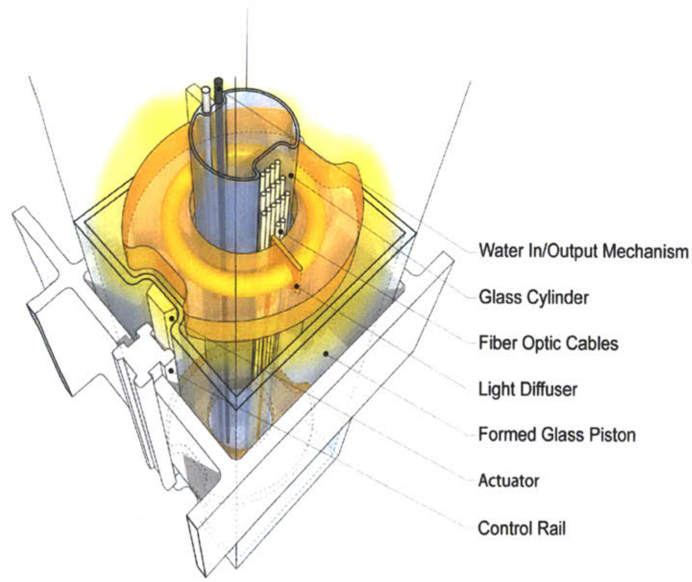
(S. Araya - in collaboration with Alexandros Tsamis, Orkan Telhan and Duks Koschitz)

Contents of this chapter have been published as articles in "On Original Form, SCCL2110 Chile; "Urban Competition London 20008" UK)

Case

This project was initially developed as a competition entry to design an architectural gallery space that could be transported along the Thames River. The design competition asked architects to reactivate the banks of the river through an itinerant public space. The concept proposed was manifold, responding to requirements of the competition while adding other central issues like environmental remediation strategies and responsive re-configurable public-spaces.

The competition project was developed by SPARC, integrated by Tsamis, Telhan, Koschitz and myself. The topics initially proposed were later developed as a research project by me in an attempt to fur-



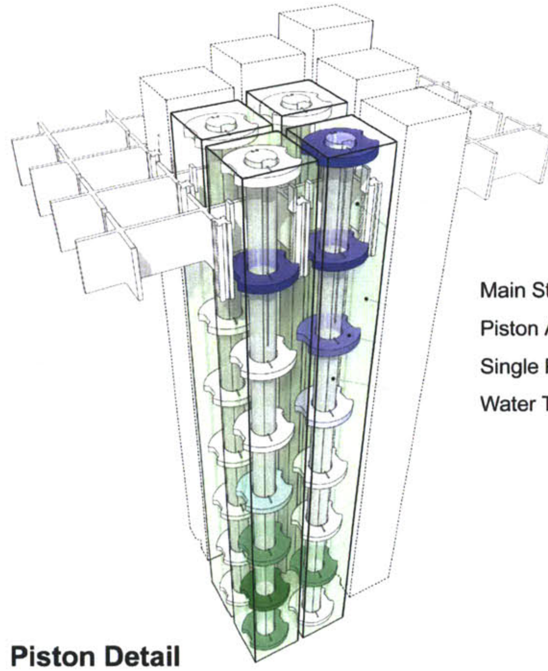
Hydraulic Piston Detail, and light difussion components.

Pixel Detail

ther develop some of the original proposal's key aspects such as the incorporation of biological systems into a dynamic ecosystem in order to embed performative qualities into the proposed building matter.

Programmable Space

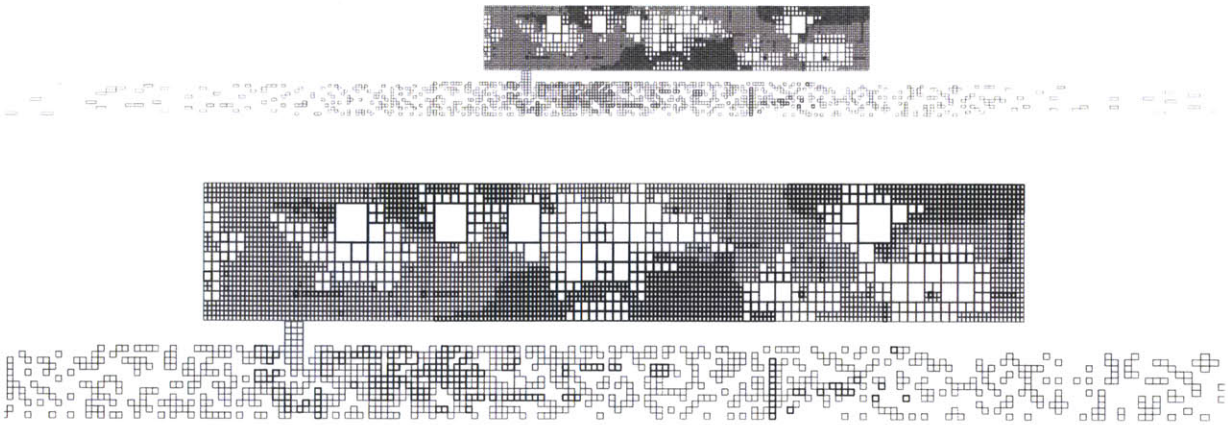
HiDrone is a programmable floating vessel that serves as inhabitable public space for the city. The proposed building was a gallery that had infinite spatial configurational states. When fully closed the building would resemble a solid glass block measuring 6.5 meters wide by 45 meter long and 6 meters tall. When in its closed state, it is a regular horizontal rectangular glass volume that would dock along the banks of the river allowing visitors to step in it. In order to create a space where the visitors could enter, HiDrone displaces the modular vessels that act as hydraulic pistons. Every module is composed of two rows, placed vertically on top of one another, of glass pistons. These are fixed in position by a mechanical suspension system that varies with the weight of the piston. To affect the weight of the piston, water is pumped in or out, which actuates the piston accordingly. As the piston gets lighter by pumping water out, it would move towards its maximum height position, and as it is filled with



Hydraulic Piston set, with light diffusor embedded and in a pre-stressed (Closed) position

water the piston would go toward its maximum lower position. Gravity is the actuating force and operates slowly by a solar water pump. The water being pumped is taken from the river on which the building floats while it travels. It is expected that this actuation would be very slow, taking maybe days to change configuration of some pistons. The structure would change in a fashion analogue to tidal rhythms, or seasonal changes. Therefore, the structure would always arrive at a docking station with different configuration but would never be reconfigured so fast so that movements would be visible to the visitor's naked eye.

Each of the pistons or glass containers, would be equipped with an array of collimated light diffusers, each of them connected to bundled together optical fibers that would travel vertically through the center of the piston. As each light diffuser is controlled by a centralized interface, each diffuser becomes a single light source in a three-dimensional array. Since the array is regular and each light point in the array is controlled individually, lights would be turned on and off in sequence in order to create patterns. The exhibition capacity required from the Gallery Space, as a condition of the call, is addressed by the



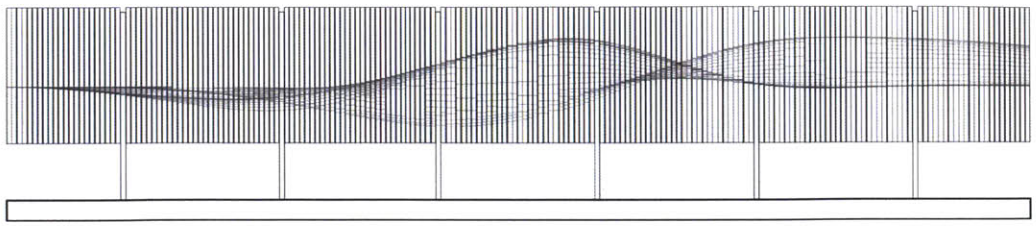
Top: Plan view of Hidrone docking next to a river bank and the potential configuration of "activated" docking station. Bottom: Hidrone plan shows non uniform distribution of pitson sizes regarding functional and structural considerations

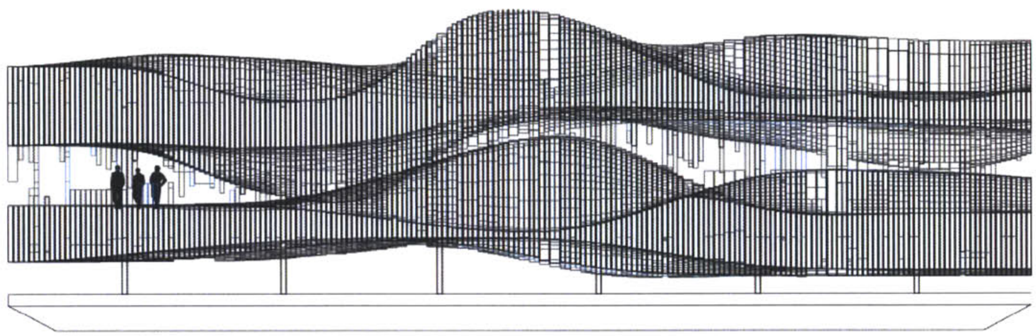
capacity of the building to itself become a three-dimensional display by this light performance capacity. When fully closed, a maximum and more regular array of lights is achieved, which allows for light patterns representing the exhibited objects to "travel" around the space of the gallery by patterning the lights in a fashion similar to stop motion animation.

HiDrone has two states: when closed, it is a three-dimensional public display, a digital landmark for the spectators at the river bank. In this state the fiber optic light emitters act as voxels (pixels in 3d) that can be programmed to show graphics, video and event specific information. When open, it becomes inhabitable space. And the light performance happens within the space confined by HiDone and around the bodies in motion.

Algae Culture

A final dimension of the project presented to the competition was related to the medium used for its actuation and the very site of the building interventions: water. The water pumped in and about operates by gravity, changing the configuration of the pistons. Therefore, when all the lower pistons are empty and all the upper pistons are full, the gallery is fully closed. But as the pistons release water or gain weight by the water being pumped into them, the upper pistons would move up, and the lower pistons would move down, creating an interstitial space that

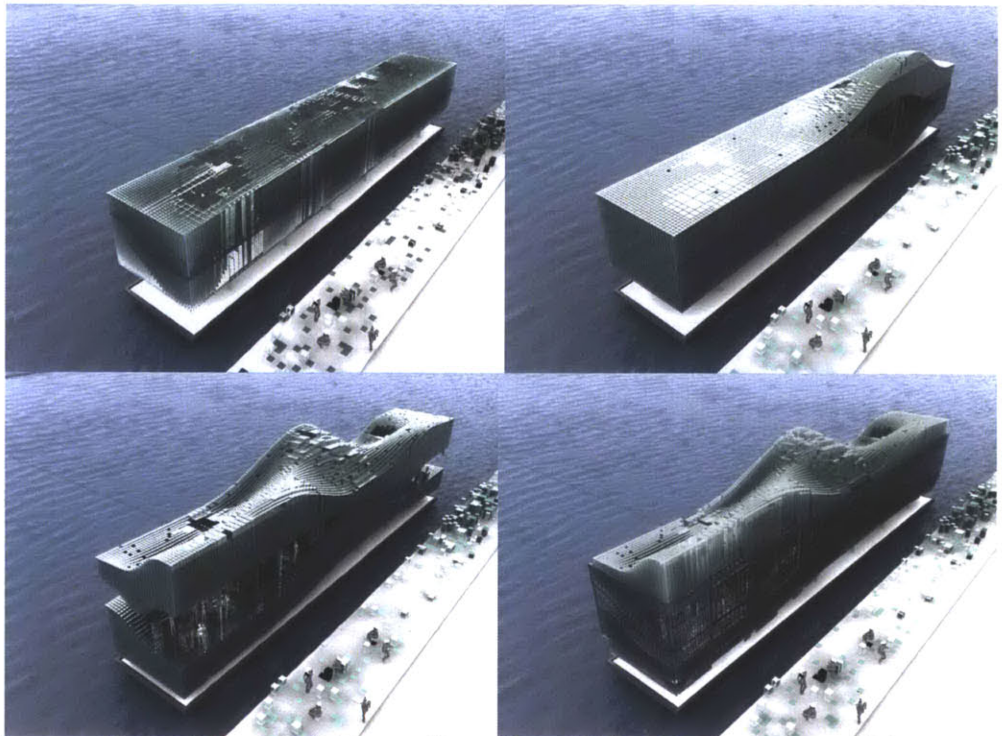




Hidrone elevations in two states. Top: closed state. Bottom: Possible Open state.

can be inhabited - HiDrone. Since every piston can be actuated independently, pistons can take different spatial functionalities: They can be floors tiles, columns, walls or ceiling modules. And since not all the pistons have the same dimension in plan, some of them host some of the more sensitive programmatic requirements and are not actuated like the rest of the pistons. These are the ones that contain restroom facilities and critical installations. The pistons can form ramps, rooms and furniture depending on their configuration. They can also create variable spaces: a cafe, gallery, amphitheater, etc. The pistons operate distinctly at various scales as display or seating units, structural support elements or as enclosure of occupiable space. All of this occurs while slowly displacing and filtering the water they contain.

HiDrone is a river sweeper, moving from point to point taking in river water, using it to re-configure its space as it displaces water. Dirty water pumped from the river is stored in HiDrone where it is treated with an algea-based filtration process. By having and distributing dirty or clean water into each transparent container HiDrone changes transparency slowly over time, allowing privacy and public exposure to be adjusted by having



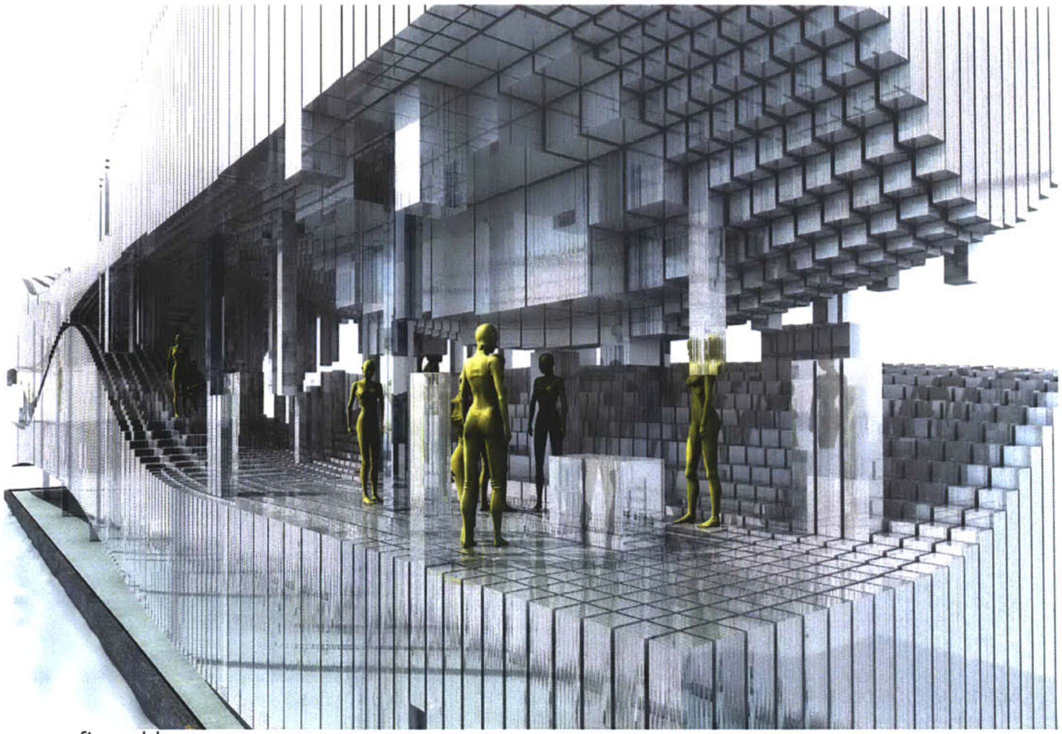
Sequence depicting four possible spatial and exhibition configurations of Hidrone, or a sequence of them over some time.

opaque or transparent enclosures. When docked along the river's edge, HiDrone becomes a host for exhibitions and entertainment events, serving festivals and community gatherings throughout the course of the year.

Methods

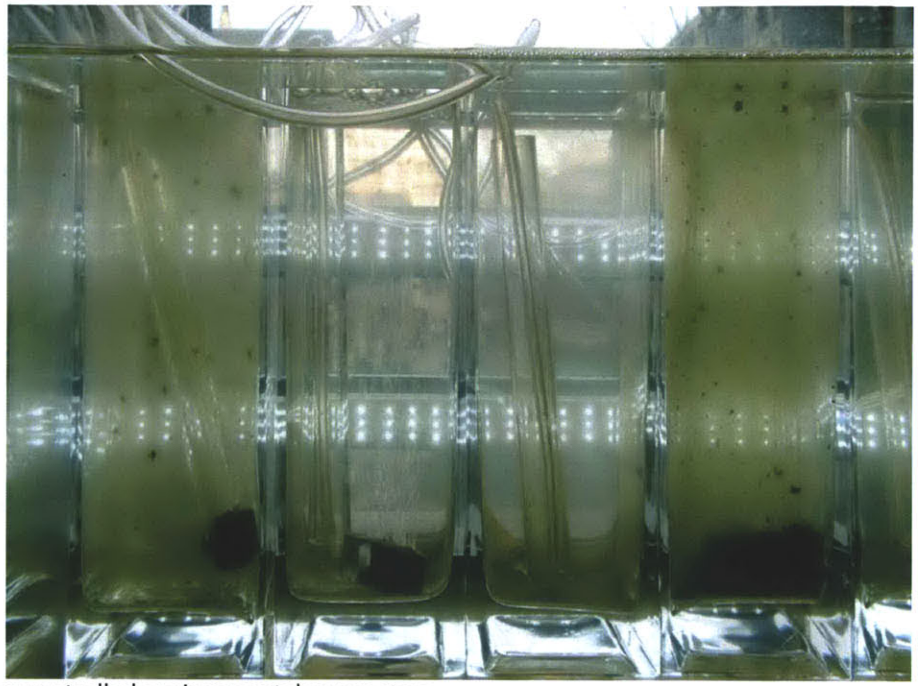
The investigation path opened by the HiDrone project was further experimentally explored by attempting to control a few environmental parameters and to study their effect on the performative functions of the system. A prototype for the algae ecosytem was designed and prototyped in order to test how environmental variables would impact material properties of the composite system, such as the color and transparency of the components. A controlled change in coloration or in translucency is desired in order to provide programmatic needs with effective responses by, for example, providing privacy in some spaces or control of lighting and shading in the internal spaces.

To this effect, a prototype consisting of six rectangular glass containers, analogue to those proposed for the competition entry, were placed inside an aquarium tank. The tanks' dimensions


Hidrone and its reconfigurable space

were 20 inches long by 10 inches wide and 12 inches tall. Each of the transparent glass containers measured 3 inches by 4 inches by 8.5 inches tall. Each culture tank was equipped with a fine air diffuser connected using clear plastic tubing to a valve regulator, which was connected to an air pump. The air pump is a TOPFIN AIR 4000 running at 3.5 watts and has a dual output. Each output was connected to one four-valve regulator and then in series between them, in order to increase the pump's efficiency. In order to cover them and avoid contamination, acrylic lids for each glass container were cut using a laser cutter. A small hole was cut on one corner of the lid to provide room for the plastic tubing and to provide oxygen to the cultures. The valves on the air regulators were set at medium intensity. An acrylic lid was cut for the aquarium tank to prevent water evaporation and changes in the ambient temperature of the containers.

To control the ambient temperature, all containers were placed inside the aquarium tank, which was filled with water up to 1 cm. below the top of the glass containers. A mini submersible heater was placed inside the tank, operating at 25 watts and with a dimming control system in order to achieve


Algae culture prototype under controlled environmental parameters.

the desired temperature. A digital thermometer with a submersible probe was placed with the probe at mid-height of the water in tank. To control the light source for the algae, a dual fluorescent light was used, a Coralife Freshwater Aqualight with dual T5 linear fluorescent strips. To replicate ideal growth conditions one of the fluorescent fixtures is a 10000K daylight tube, and the other is an Actinic Bluelight HO tube. The combination of these two fluorescent tubes is ideal to target plant growth in aquatic environments, since 10000K Daylight bulbs cast bright white rays and simulate the strong light of the sun at midday, while Actinic lamps show softer shades of blue of dusk, dawn, and deep water, which complements the spectrum of light required by aquatic species for optimal growth.

Algae

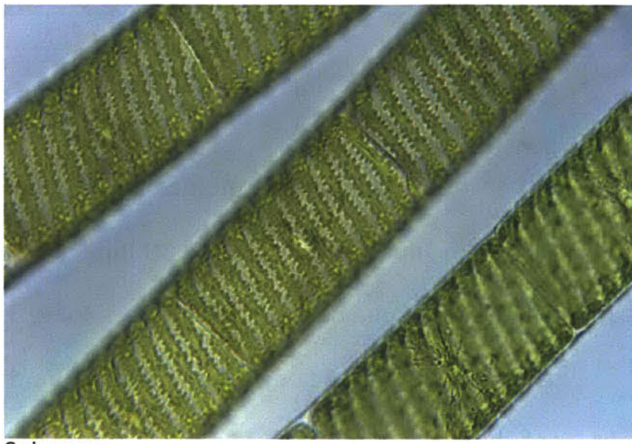
At first, a sample of unknown green algae extracted from my own home aquarium was used to test the system. The green algae was grown in similar environmental conditions, but in an aquarium where several species of fish exist, which clearly alter the ecosystem's chemical balance. After several weeks of controlled growth, it was very difficult to maintain a consistent growth pattern on this first algae specimen, which was contrary to the phenomena observed at the home aquarium where it was becoming difficult to keep the algae from having explosive growth bursts.

Two species were then selected and bought to further investigate. The two species were purchased from the Carolina Biological™ Supply Company and are known as spirogyra and euglena. The environment was set in advance to the purchase of the algae to avoid excessive time under less-than ideal conditions for the species. All the water used in the experiments was treated with API Tap Water Conditioner (API Aquarium Pharmaceuticals, PA USA) in order to degrade the chlorine content in the tap water used. The conditioner was used according to instructions: 1 ml per 5 gallons of regular tap water. The pH was regularly tested and kept at ~7. Algae were fed enriched media Alga-Gro Freshwater Medium according to instructions.

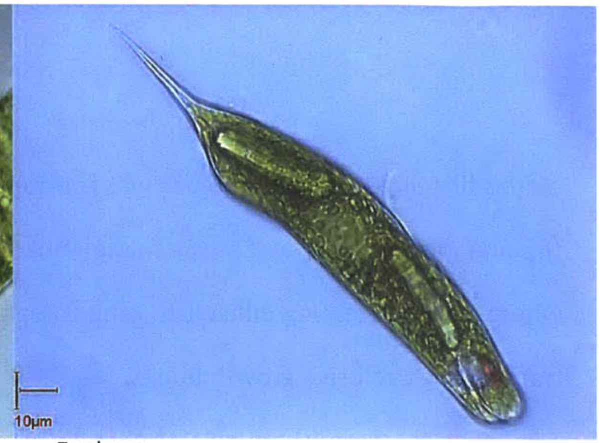
Spirogyra is genus of filamentous green algae, which is named after the helical or spiral arrangement of the chloroplasts typical of this genus. It is commonly found in freshwater areas, and there are more than 400 species of Spirogyra in the world. Spirogyra is a multicellular algae and measures approximately 10 to 100µm in width and may become several centimeters long. This particular algal species is commonly found in polluted water and is often referred to as "pond scum," which makes it an ideal candidate for this research since it feeds on chemicals present in stagnant and polluted waters.

The second genus of algae, euglena, is a unicellular protist of which over a 1000 species have been described. A particular characteristic of the genus I obtained is that it sports a flagellum, which enables it to move by vibrating the flagellum. Therefore, a phototaxic behavior is commonly observed, a behavior in which the algae moves towards the light source.

I obtained this species in order to test control over the concentration of algae colonies according to light sources, especially considering that for the HiDrone project a distributed light source control was in place that would possibly allow for control over the algae density patterning inside the container.



Spirogyra



Euglena

Scientific Classification of the species:

Kingdom	**Protista**
Phylum	**Chlorophyta**
Class	**Zygnematophyceae**
Order	**Zygnematales**
Family	**Zygnemataceae**
Genus	**Spirogyra**

Kingdom	**Protista**
Phylum	**Euglenozoa**
Class	**Euglenida**
Order	**Euglenales**
Family	**Euglenaceae**
Genus	**Euglena**

Reference: Integrated Taxonomic Information System (ITIS) Catalogue of Life - Species 2000

A webcam was set up in order to monitor changes in the ecosystem's behavior and to register variation in the parameters being observed. The webcam was operated by a free open source application, YAWCAM. This application allowed me to program the webcam to take pictures at regular intervals, which was set to one picture a day and saved to a local folder. I will elaborate on the results of this experiment and the possible further steps of this research.

Discussion

First, a slight failure and setback. A fourth species of algae was also purchased and cultured, but although the initial results were promising, it proved to be harder to keep the appropriate conditions stable in time, and they did not last very long. This fourth algae species was a pyrocystis fusiformis, a non-motile marine dinoflagellate that is particularly interesting given its bioluminescent characteristics. That is, this unicellular algae is capable of producing a chemical reaction that emits intense blue light under mechanical or chemical stimulation. This genus seemed particularly interesting since its bioluminescent capabilities would have been ideal in the HiDrone project if proven to be tunable according to culture density and controlled stimuli. But the marine nature of this species made them difficult to keep them alive -species were more sensitive to environmental changes and more parameters had to be controlled- even after new enriched media was added to the cultures.

Kingdom	**Protozoa**
Phylum	**Dinoflagellata**
Class	**Dinophyceae**
Order	**Pyrocystales**
Family	**Pyrocystaceae**
Genus	**Pyrocystis**

Reference: Integrated Taxonomic Information System (ITIS) Catalogue of Life - Species 2000.

Further research on this species will be pursued later since its bioluminescent capabilities, which were empirically observed but weakly documented for the purpose of this research, are promising paths toward a programmable bioluminescent composite structure design.

Programmable biological material

In order to study the variation in the growth of the algae species, two parameters were tested: oxygen (air regulation) and nutrients (enriched media). The variation in colour and transparency shows that while both parameters have an effect in the growth of algae, nutrient content is significantly determinant of the speed and duration of the growth bursts with greater nutrient levels resulting in faster and more prolonged outbreaks of algal growth. Nitrogen contents due to high levels of dissolved minerals from the food source Plant Gro (Nutrafin, Hagen MA USA) and/ or from decomposing organic matter (from food or vegetal matter, possible decomposing algae) seem to affect growth positively. According to the literature, high levels of nitrogen are beneficial for the species and promote algal blooms. While the outbreaks manifest themselves in about a day or two, an equivalent reduction in the density of the colony usually took double the time, from four to five days. The decaying algae looses its deep green colour and turns slightly yellow or brown. It can, however, effectively be reactivated by another dose of nutrients.

Light limitation has a powerful effect too, and although for this experiment the light source was always fixed in place on top of the aquarium tank and protected with an acrylic cover it is clear that varying light conditions, including incidence angle, wavelength and duration, can play a significant role in determining the density of the cultures.

It is interesting to note that dense cultures allow less light to penetrate to neighbouring containers and therefore act as an occlusion mechanism.

The colour gradient obtained then ranged from pale green to deep dark green and then to yellow-green and eventually brown green hues, including of course interpolations various degrees of density or dissolution given the water/algae content ratio.

Overall, spirogyra proved to be more resilient than euglena, although both presented similar recovery characteristics from decaying phases due to over- or under-feeding.

Given the known characteristics of these two species, it is safe to assume that they would reproduce the behavioral patterns observed when grown on a larger scale, especially since in larger scale cultures conditions are more stable and less affected by subtle changes in the water chemistry, which results in a lower level of stress on the biological system.Several research studies explore the potential of using green algae like these to produce bio-fuels by pressing the extracted vegetal mass and obtaining a concentrated oil from such a process. But burning that oil would somehow defeat the purpose of having implemented a beneficial ecosystem in the first place as algae not only cleans toxins from the polluted water but also captures significant amounts of CO_2 in the process. Burning these treated algae for biofuel content seem to defeat the purpose.

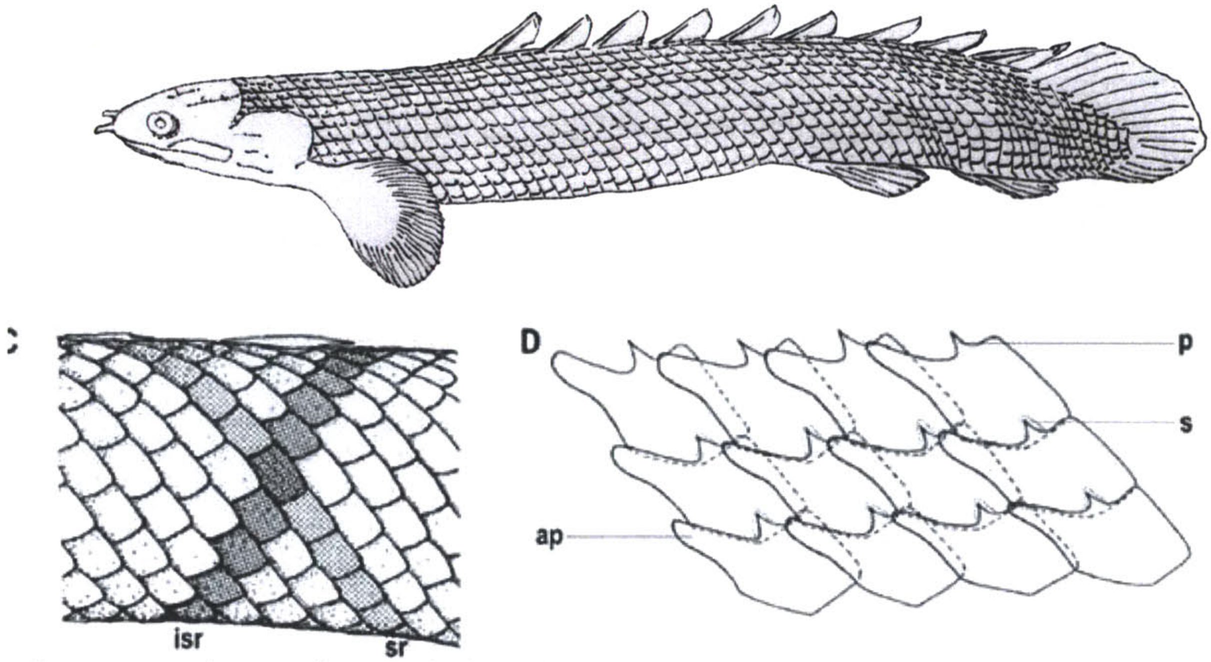
Another interesting path would be to use the vegetal mass in the production of biopolymers, which would retain the captured carbon content and place in a stable form the material structures that could be used as inputs for manufacturing technologies.

This is a promising line of research that I will pursue later, since it may provide a way to close a loop


Using photographic study of changing algae cultures over 7 months, a design of distributed conditions produces a threedimensional visualization based on color and transparency fluctuation.

between resource exploitation and manufacturing consumption and product development, which would induce resource relocation.

Finally, this investigation allowed me to explore closely the relations between environmental variables and programmable material properties, where a modular prototype like the one implemented could become a scalable composite structure that would perform at multiple levels and scales. A design that would potentially enable these performative behaviours, that range from environmental responsiveness to material properties, to biochemical productivity to aesthetical enactments of an embedded biological material computation.



Polypterus Senegalus: Top: illustration by the author. Bottom: illustration of squamated armor system, Gemballa and Bartsch.

Polypterus

Flexible articulated structures

(S. Araya - in collaboration with Ortiz Lab, School of Engineering MIT)

Contents of this chapter have been presented at the NSSEFF (National Security Science and Engineering Faculty Fellowship) Conference Washington US, 2010, and at the Synthetic Aesthetics Symposium, Massachusetts 2011.

Case

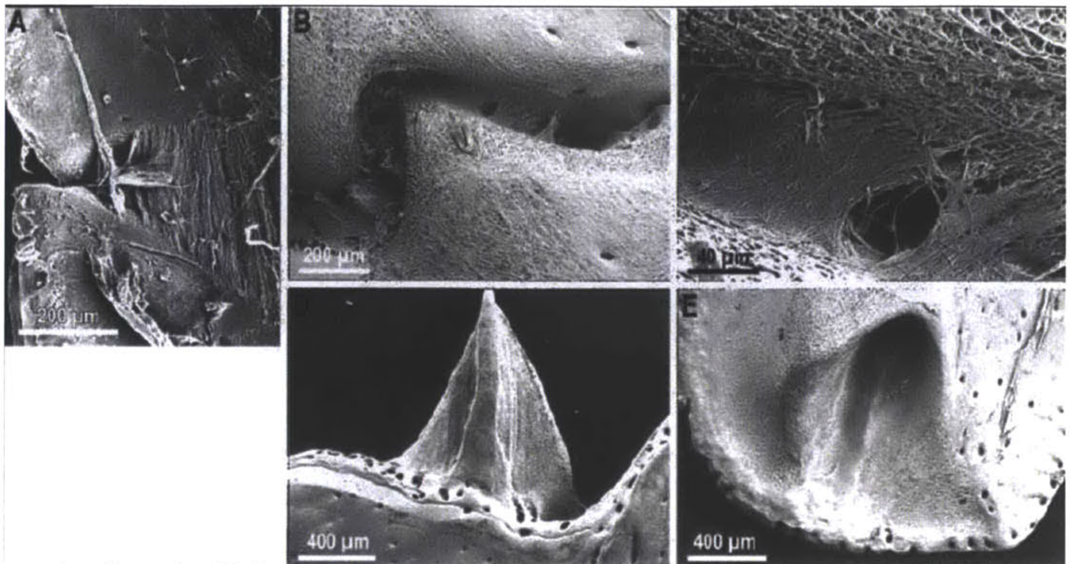
Polypterus Senegalus

This study case is about investigating the morphological and material microstructures of the squamation than forms the protective exoskeleton of an ancient fish species, Polypterus Senegalus, in order to increase the knowledge base on the biomechanics and material properties of flexible protective systems. The principal objective of this study is to design, develop, fabricate and test innovative, continuously flexible protective structures - developed after the study of ancient fish armor systems at their microstructural

Left: Polypterus, photography by the author. Right: Micro Computerized Tomography of a Scale of Polypterus.

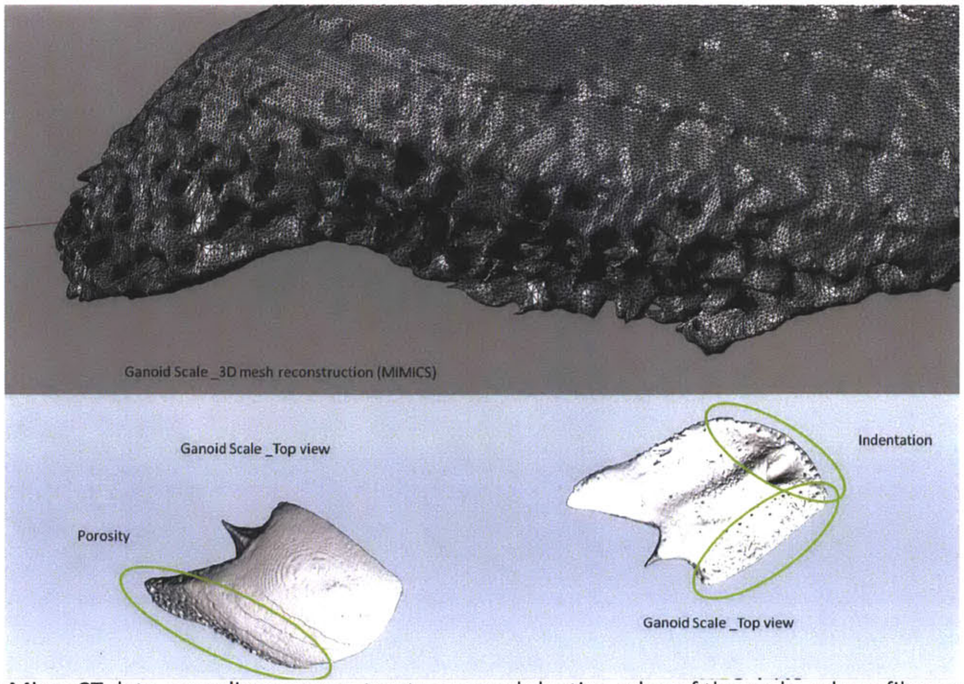
level - that provide novel design concepts and systems at a macro scale for protective structures and articulated flexible armor. The study aims to expand the understanding of articulated protective systems in biological organisms with an aim to derive novel design principles and material structures to inform future innovative designs with enhanced flexibility and resistance. The research will characterize and increase the understanding of basic microstructures and morphological features that are present in these species with the goal of implementing abstract design principles similar to those present in nature. The project seeks to make progress toward the design and fabrication of scalable articulated structures with optimized load-dissipating and structural-resisting capabilities. Following the study of morphological and microstructural features on the exoskeleton of Polypterus Senegalus, the work focuses on characterizing the different components of the system, assembly and non-assembly logics, material composition relations and morpholometric parameters to develop fundamental design principles to design flexible/ articulated structures.

The Polypteridae family from which the selected species for this research belongs, the Polypterus Senegalus, is a family that has been in existence for around 96 million years and is therefore considered an ancient fish species and is commonly referred



Series of Micrographs of a scale of Polypterus armor system, revealing fibrous tissue connecting scales with skin of the fish, and the peg-and-socket connection that articulates the squamated armor.

to as the "Dinosaur Bichir" among fish researchers and aquaria collector. This fascinating species has retained many of the characteristics of the dermal armor of palaeoniscoids[99], specifically in relation to its interconnected scale system and the quadlayered material structure of the scales[100]. The armor system in Polypterus is highly efficient since it has to protect the fish from different kinds of predators, especially considering that P. Senegalus lives at the bottom of freshwater estuaries in Africa[101]. These estuaries often dry out, leaving muddy shallows where the voraceous Polypterus survives using its paired lungs. Since the Polypterus is equipped both with gills and lungs it thrives in various environmental conditions, which, in turn, leaves him exposed to a variety of predators, aquatic and terrestrial. It is a predatory fish that possesses a teethed jaw structure and skull that makes it capable of powerful bites with which it captures and eats other fish and insects, both in the water and on drying shallows. It has been seen undulating on the vegetated marshes of water streams and then returning to the water where it combines its eel like motion with the thrusts provided by its pectoral fins.



3D reconstruction from Micro CT data, revealing porous structure on subducting edge of the scale, where fibrous tissues have been observed to connect the scales with the skin of the fish

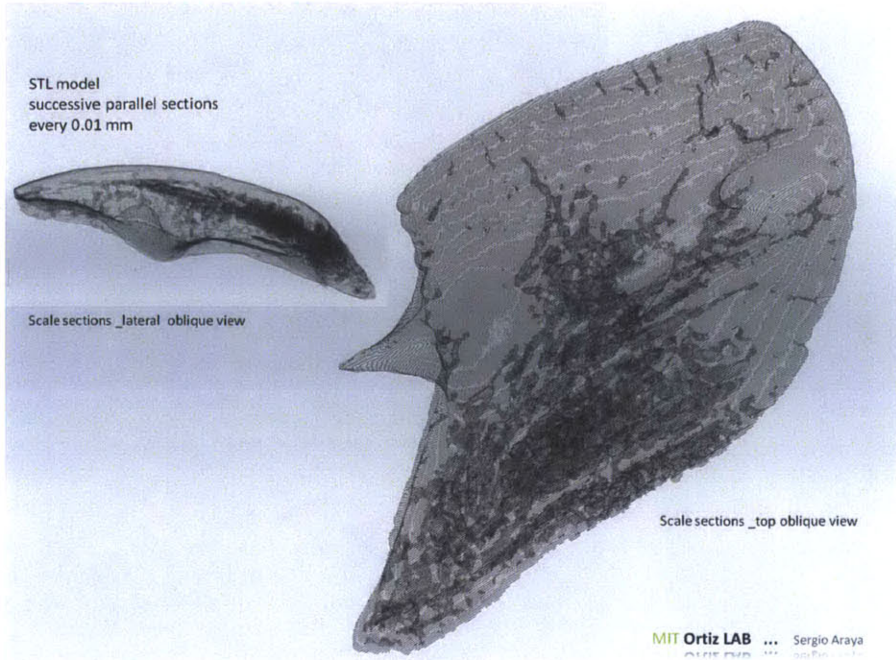
Kingdom	Animalia
Phylum	Chordata
Subphylum	Vertebrata
Superclass	Osteichthyes
Class	Actinopterygii
Subclass	Chondrostei
Order	Polypteriformes
Family	Polypteridae
Genus	Polypterus
Species	Polypterus senegalus

Methods

Design Of Flexible Protective System Through Parametric Modeling and Multimaterial 3D Printing Prototyping

Previous Research on articulated squamated armor

The ganoid squamation that forms its armor is made up of an articulated biomineralized scale system with a highly efficient material composition and microstructure to resist attacks from predators. The layered material structure of the individual scales is composed of four layers of composite organic-inorganic nano-composite materials: ganoine, dentine, isopedine and a bone

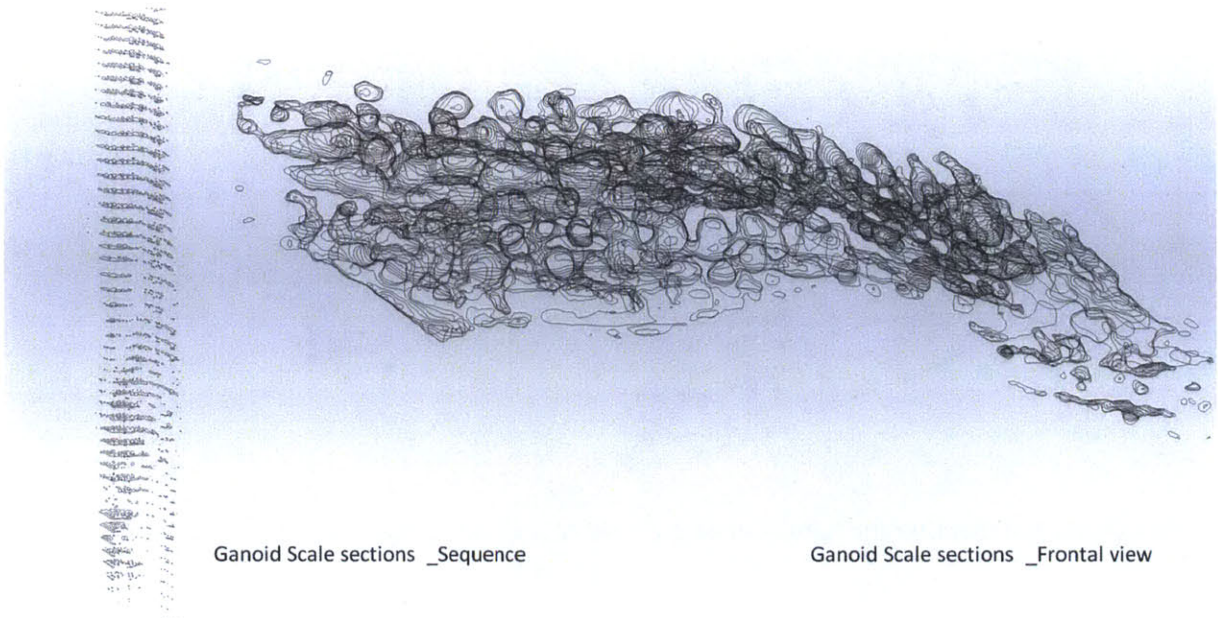


Scripted function to obtain sequential cross sections of the scale reveal an internal porous microstructure, not document in previous research.

basal plate102. The thickness and composition of each layer strongly determines the mechanical properties of the multilayered structure. The first and outermost layer is composed of ganoine, a type of enamel with a highly mineralized non-collagenous structure and low organic content of less than 5% and a thickness of around 10 μm103. The second layer is dentine that has a lower mineral content relative to the ganoine layer and includes collagenous fibers. Its thickness is around 50 μm. The third layer is isopedine, which is composed of orthogonally oriented collagenous fibers in multiple layers similar to a plywood-type structure, which decreases in mineral content further away from the surface (ganoine layer) and has a thickness of40 μm. The fourth and inner-most layer is a basal bone plate composed of vascularized bone lamellae with the fibrils oriented relatively parallel to the surface of the scale. This final layer is thicker than the others at with a thickness of about 300 μm.

Given this material composition and nanostructure, the scales show a number of advantageous characteristics.

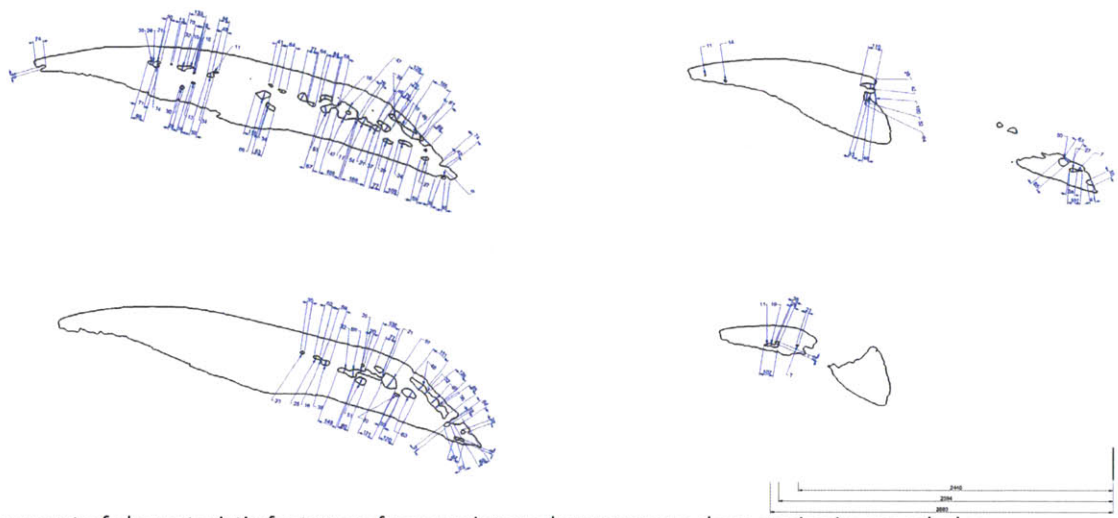
- Due to the specific properties of each layer and the functionally graded



Analysis through cross-sections of the porous structures to characterize its morphological attributes.

interface between them, the multilayered composite combines the stiffness and hardness of the mineral ganoid layer with the energy dissipation of the more flexible underlying layers. [104]

- If compared to similar bi-layered composites consisting of ganoine-dentine scales, the multilayered structure of the P. Senegalus scales is approximately 20% lighter than its bi-layered analogue yet retains the strength and resistance of the latter. [105]
- The multilayered composition promotes circumferential cracking in response to indentation loads, which is highly beneficial since it isolates failure to a particular unit and minimizes the critical impact of stressing loads from offensive or predatory attacks. This system compares positively to more common and disadvantageous radial cracking.[106]
- Given the interconnected and articulated biomechanics of the scale system, a second aspect that has recently been studied is the force-dissipation capacity of the squamated structure[107]. The articulation of the different scales is a key aspect of the system's energy

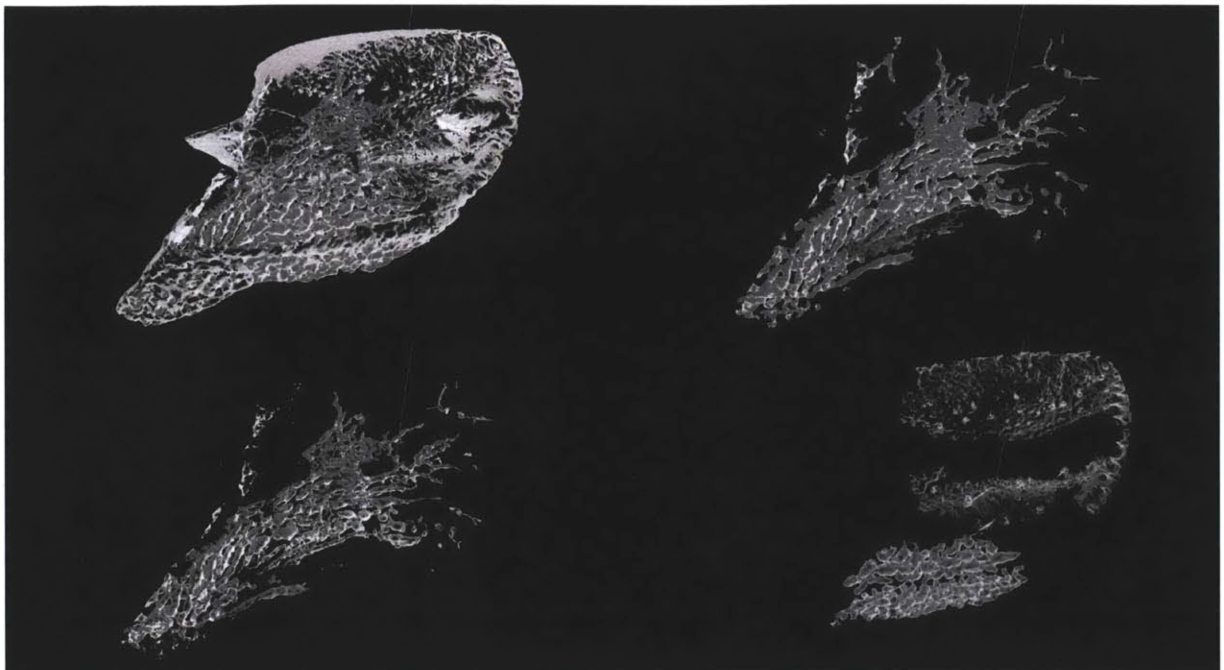


Measurement of characteristic features of porous internal structure to characterize its morphology.

dissipation efficiency while still providing a highly flexible integument capable of large body curvatures and speed bursts. Previous studies have investigated the joint mechanisms between the ganoid plates, which resemble a peg-and-socket mechanical connection[108]. Departing from these studies, the research conducted for this project explores the squamates 'material gradients and microstructural features that contribute to its high degree of flexibility while retaining its material strength and resistance properties.

Experimental methodology

The work consists of a combination of computational three-dimensional reconstructions of the characterized morphological structures and analytical modeling studies using the computational three-dimensional parametric modeling platform Grasshopper[109] - and digital fabrication technologies -multimaterial 3D printing using Objet Connex 500[110]. During this investigation, I developed and tested novel designs for non-assembled yet articulated armor structures through the production of several digital parametric models and their physical prototypes. The work required obtaining three-dimensional models of the scales of the P. Senegalus integument, using high resolution visualization techniques - computerized micro CT - that were translated into three-dimensional mesh surface models. The study of these three-dimensional digital models through the CAD software Rhinoceros allowed me to characterize the morphological aspects

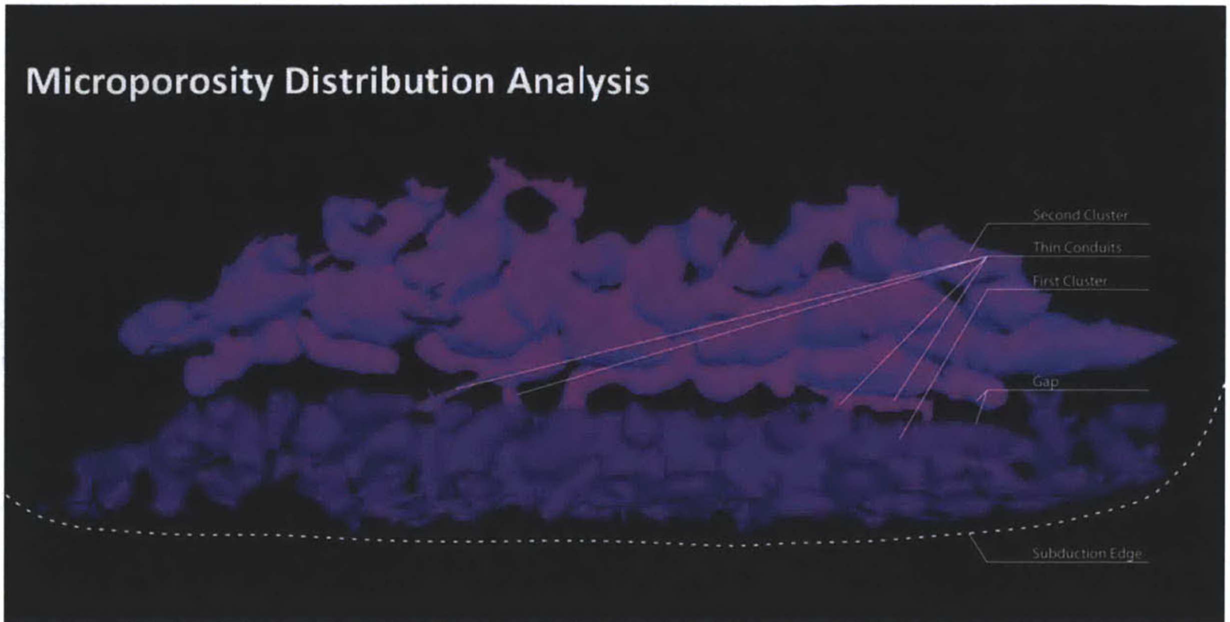


3D model reconstructed from microCT data that works as specimen for a digital dissection of the specimen in order to study its internal porous structure and the transition between organic and non-organic material components of the scale structure.

of the scales form and internal microstrucure and produce data for a morphometric study of these specimens. The study of joints and articulation features between each individual scale in the system and between the scales and the underlying layers of connective organic tissue provided the basis for understanding the complex biomechanics of the P. Senegalus armor system and the microstructural features of these highly efficient yet flexible protective systems. In order to conduct the investigation of the individual scales, the following methods were implemented. I started by scanning the specimens obtained from the fish, then converting the image data into three-dimensional information to be exported into a parametric CAD platform to be analyzed and where new designs would be develop. Finally, solid multimaterial printing technologies were used to produce physical prototypes to test design principles and the structures' material properties. The details of these steps follow.

Dissection of specimens

The specimens were obtained from a dead P. Senegalus body (aproximately 150 mm in length) that was kept at ambient conditions and from a living P. Senegalus (aproximately 220 mm in length) that was kept in an aquarium tank with a fresh water environment at 26 Celsius degrees and

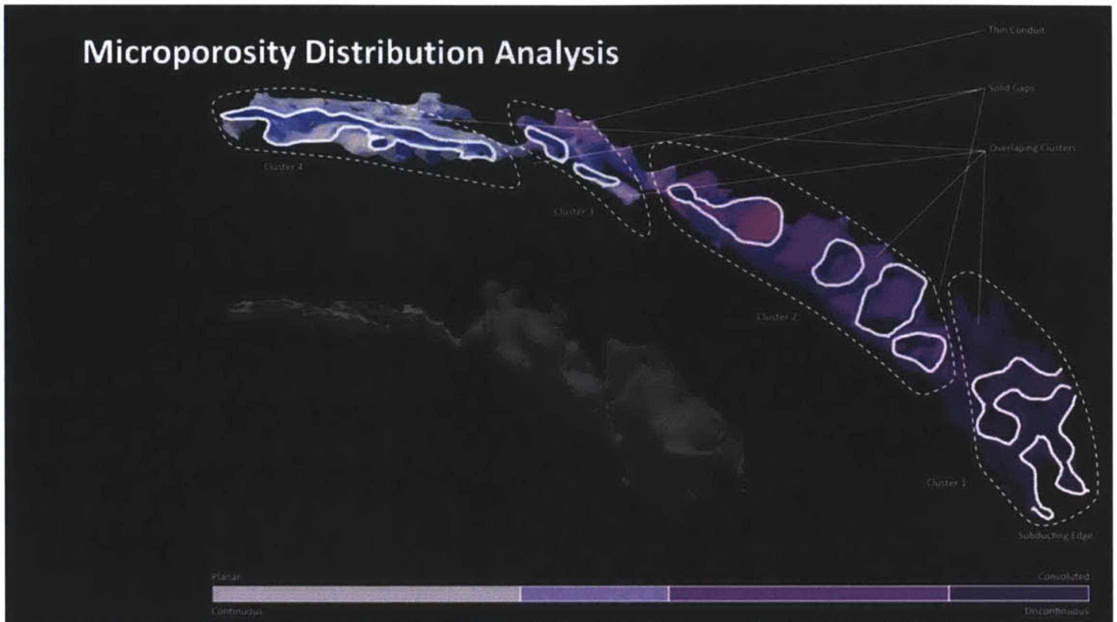


Plan view of isolated clusters of porous structure that present similar morphological features and characteristics.

a stable pH of ~7[111]. For the measurements and scale removal surgery, the living P. Senegalus was anesthetized and individual scales were surgically removed from the posterior region of the fish's left flank, which corresponds to the fifth column/fifth row, the fifth column/tenth row, the tenth column/fifth row, and the renth column/tenth row respectively. All dissections were performed by fellow PhD student Juha Song[112]. Previous scales had been dissected, but their relative position had not been exactly documented, so while initial research on those specimens showed interesting results, these samples were obtained in order to conduct a comparative study of the relationship between morphometric characteristics of the squamation and their relative position/function along the body of the fish.

***Imaging_** Optical Microscope*

Despite available images of the scales, which were obtained through optical microscopy, little was known about the scales' internal microstructure. From existing images[113], a series of localized patterns of porous surface features were visible on the anterior and posterior edges of the scales as well as along the ridge parallel to the joint axis on the scale's internal side. To obtain these images, a stereo microscope (Olympus SZX2, Tokyo, Japan)

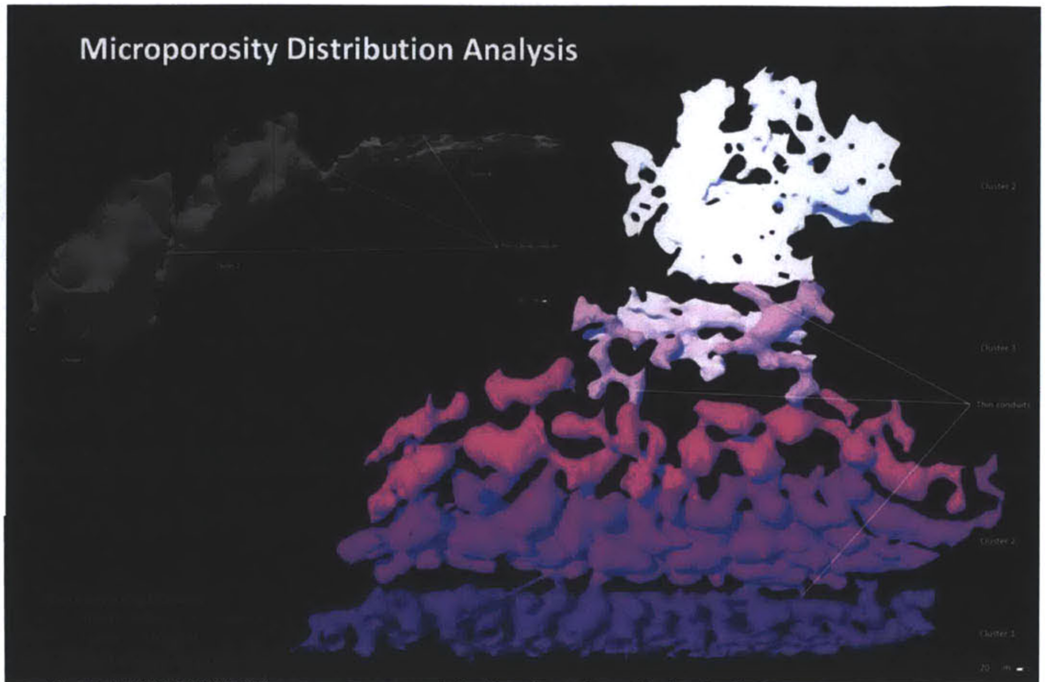


Cross section of clusters of porous internal structure and characterization of morphological features in each cluster.

was used. Images were obtained by Juha Song.

Imaging_ *X-ray Microcomputed Tomography* ***(Micro-CT or μCT)***

The samples of P. senegalus scales were scanned using a Micro-CT (μCT) system (Viva CT40, Scanco Medical AG, Switzerland) operated at 45 kV and 177 μA. Microtomographic slices were recorded every 10 μm and were reconstructed with 10 × 10 μm voxels (volume elements) in plane. A constrained three-dimensional Gaussian filter (σ = 0.8 and support = 1) was used to partially suppress noise in the volumes. The information from the scanned samples was converted into three-dimensional polygonal meshes (stereo-lithography - STL, bilinear and interplane interpolation algorithm) using an interactive medical image control system (MIMICS 9.0, Materialise, Belgium). That system applies a variable threshold parameter that limits the image data, which allows for the recognition of edges that are used to create the polygonal meshes. Since this parameter is a key factor in how the final polygonal surface model is produced, a study was conducted in order to optimize the parameter value that minimizes ambient noise from the scanned samples; the final parameter value chosen was a threshold of 2500. The converted STL files were then

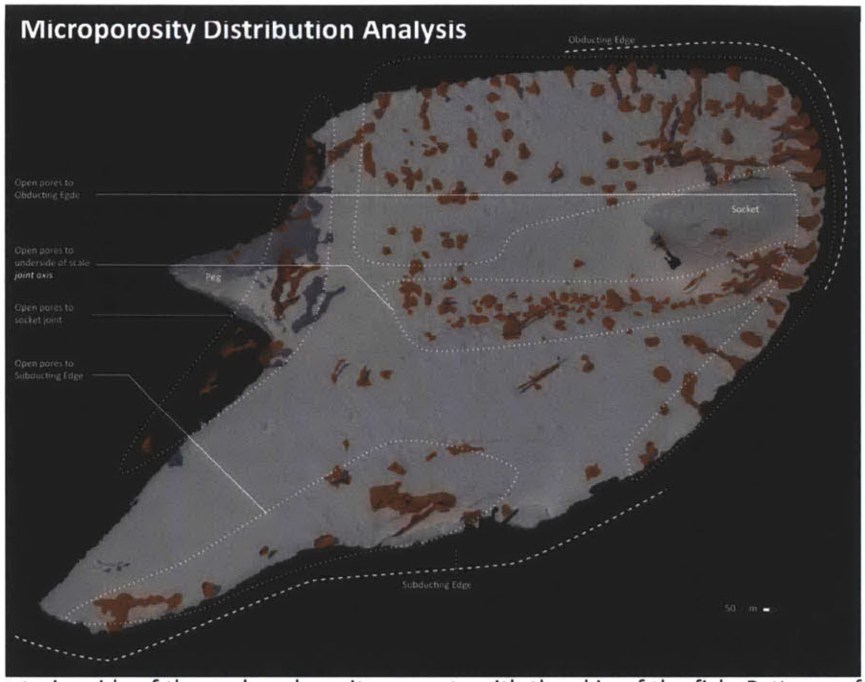


Complete disection of internal microporous structure and distinction of morhological clusters.

imported into a CAD (Computer-aided design) software (RHINOCEROS®, Robert McNeel and Associates, USA). Experiments were performed in collaboration with Juha Song.

Parametric Modeling

Parametric environments provide a platform for design where variable conditions can be explored by allowing certain design parameters to be modified that affect the design output or model. In a parametric environment, the resulting design is produced as a consequence of setting up a number of conditions regarding the geometry of the design and the mathematical relations between these geometries, the functions applied to obtain or derive these geometries, and the relations between these functions. There is a higher level of control over the resultant design, since the design algorithm can and is in effect designed by the author, yet there is also a higher level of constraints, since every step of the modeling process requires an explicit step or decision. Usually associated with fabrication, parametric modeling allows the design process to be streamlined in terms of different design iterations and the testing of different values for variable parameters. This contributes to optmization of manufacturing output, allowing for quick evaluation of different alternatives for a

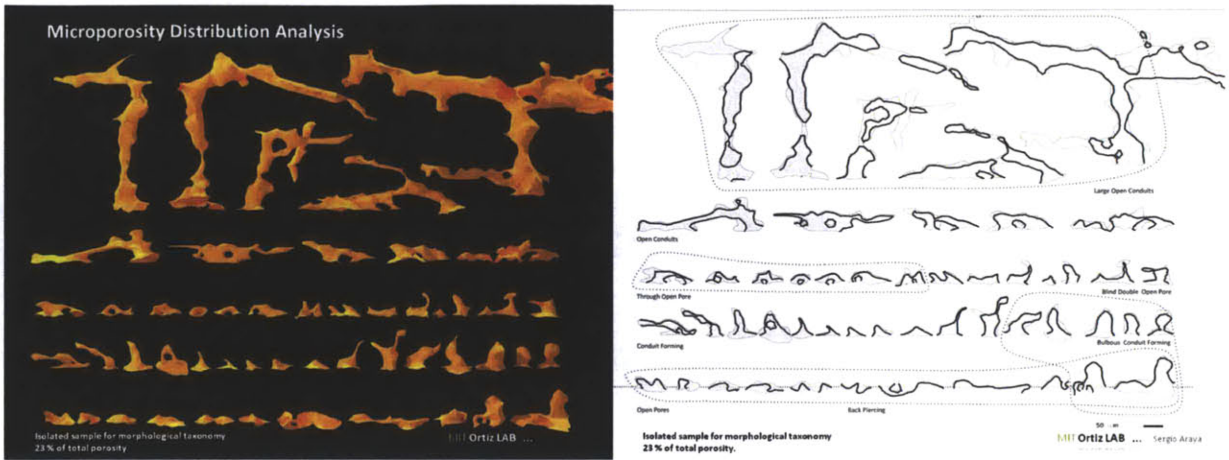


Porous structure discovered on anterior side of the scale, where it connects with the skin of the fish. Patterns of porosity are observed and defined along ridges.

particular solution.

A parametric approach provides the opportunity to build a set of relations between design and modeling operations' and/or functions in order to allow the design to be "tuned" or "calibrated" later without undoing old work, which helps prevent having to restart the design from scratch. As mathematical functions that produce geometries are incorporated into the model's parametric "intelligence", these geometries can be "adjusted" to test different configurations. These adjustments can also be distributed over time or based on local characteristics of parameters of the geometry itself. In the case of this project, a parametric model was built to control internal features of the individual scale and the internal vascular structures, and then another parametric model was created to control the distribution and proliferation of the scales on a larger array, with multiple scales, for fabrication. These parametric models were then exported in different file formats, particularly STL files that can be imported into the fabrication system's software interface.

RHINOCEROS 3D® was used as a three-dimensional modeler, and in conjunction with GRASSHOPPER® - a plugin for Rhinoceros - parametric models were created. Since both RHINOCEROS and GRASSHOPPER allow for embedded custom



Left: Taxonomy of all characteristic porous structures detected and isolated through digital disection of the 3D reconstructed model. Right: Cross-section of the taxonomic study.

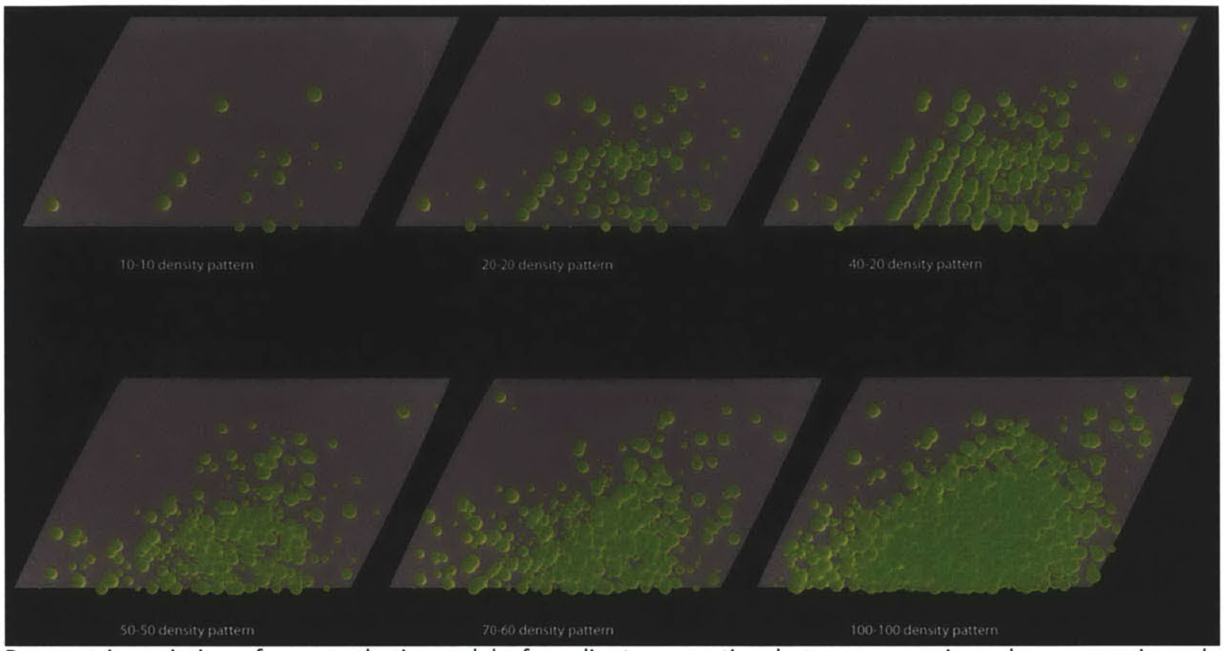
scripts using Rhinoscript (based on the VBScript programming environment of Microsoft® Visual Basic®), several custom scripts were developed in the process of creating the parametric models of the scales and articulated scales series (larger continuous arrays).

Prototyping and Fabrication

The methods used for this research are a combination of computational parametric modeling and analysis and multimaterial three-dimensional protoypes developed to test the mechanical behavior of the material composites and the articulated structures. Two different technologies of rapid prototyping were used in the production of physical models to test the mechanical properties of the models.

A 3D printing machine (ZPrinter® 310 Plus, ZCorporation, USA) was used for the initial phases of the prototyping process. This machine utilizes a commercially available plaster powder (ZP®131 powder, ZCorporation) that creates layers of 89 micrometer thickness deployed with a speed of 25 mm/h. The printed object rests within the powder bed for a minimum of one hour to gain strength as it heats and dries. After that time, the models are excavated, loose powder is blown away in a chamber using compressed air, and the objects are saturated in a wax bath and dried in an oven to achieve maximum material strength. This technology was used to create fast inexpensive surface prototypes that would allow testing and verification of the scales' morphological features.

A second instrument was used to combine two materials into one object was used to create



Parametric variations for a synthetic model of gradient connection between organic and non-organic scale component.

composite, materially graded prototypes that could be articulated while being printed as whole solid objects. The OBJET Connex500 3D printer has a tray size of X = 500mm x Y = 400mm x Z = 200mm. 3D objects can be printed with a resolution of up to 1600 dpi in Z-axis (16-microns) and 600 dpi in X- and Y-axis (42-microns) with an accuracy of up to 0.1 to 0.3mm (0.004 to 0.01 inch). For the Objet multi-material 3D prints, all designs were generated using the parametric modeling environment (RHINOCEROS and GRASSHOPPER). The scales, connective and soft tissues were designed together in the parametric environment, exported as separate parts and then re-combined inside the Connex 500 software interface using the "assembly" mode. To communicate with the 3D printing machine, all 3D parts within the assembly were exported into separate STL files. For each imported STL part a specific materiality can then be applied within OBJET Studio.

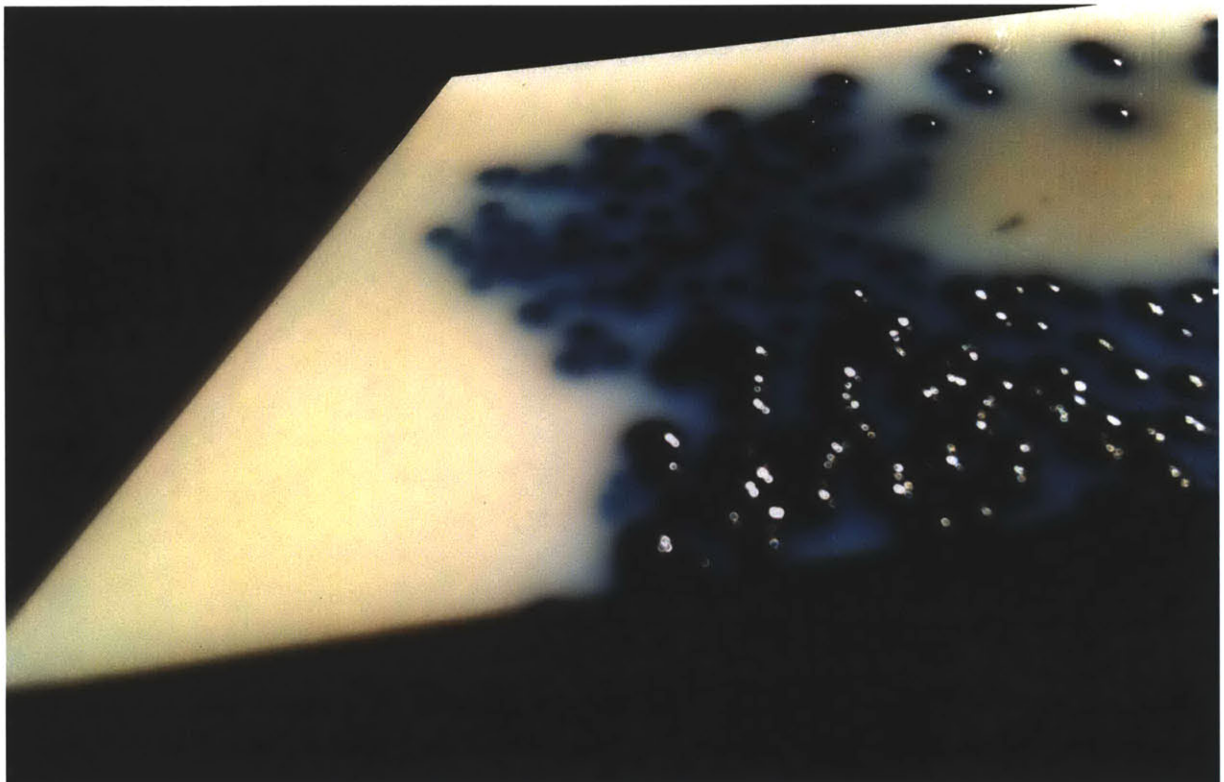
During the 3D printing process the following materials were used. The ganoid scales were simulated using two kinds of rigid materials called Objet VeroWhite and Objet FullCure 720. For the connective and soft tissue, two other soft and flexible materials were tested, TangoBlack+

Two examples of the algorithmic distribution of material properties and their fabrication using multimaterial printing technology (Objet Connex 500). Left, gradient from flexible to rigid in two similarly translucent materials. Right: transition from flexible to rigid with two differently colored and translucent materials.

and TangoPlus DM9740. While the selection of the materials have to consider their mechanical properties and physical properties, translucency and surface finish were also considered. Objet VeroWhite and TangoBlack+ are opaque materials, the former an off white color and the latter a matte black rubbery material. Both FullCure 720 and TangoPlus DM9740 are translucent light yellow materials. As the mixable, digital materials called Objet TangoBlack DM_9110 and Objet TangoBlack DM_9130 performed less flexibly than desired, the material system was changed to include predominantly the much more flexible Objet TangoPlus DM9740 for the design's connective and articulated joint structures. For all print jobs, the digital printing mode was used with a resolution of 30 microns (0.001 inch).

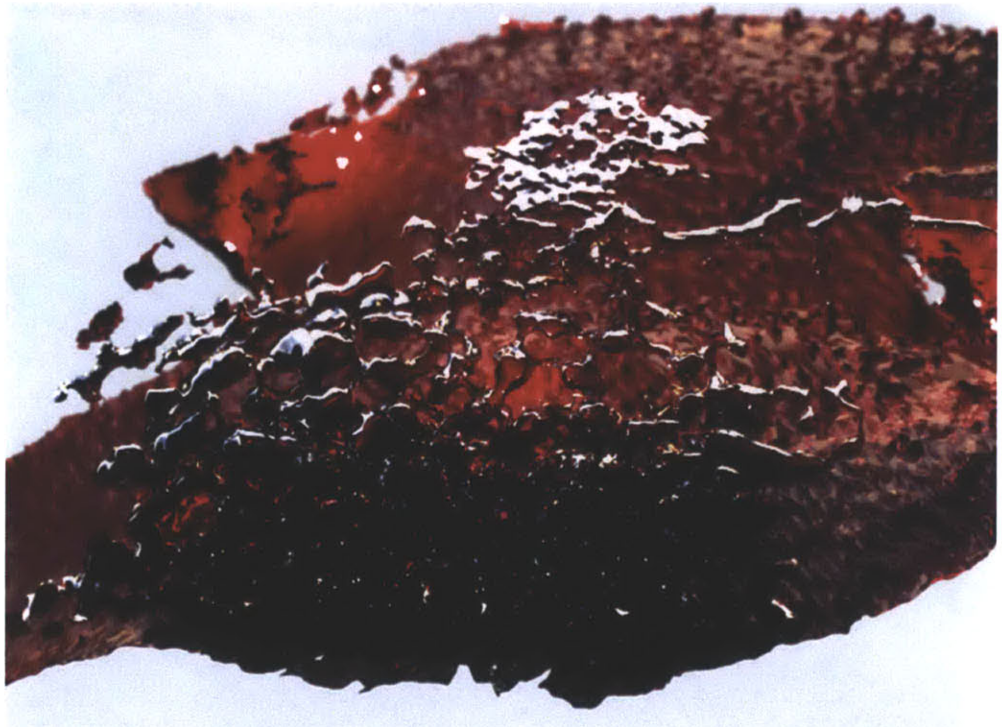
Discussion

This research project builds up from current research on the armor system of P. Senegalus and the study of the integument of this species[114] at the Ortiz Lab in MIT. My investigation on the material composition of the individual scales began by analyzing existing microCT data from a scale that had been removed from the dry body of our dead P. Senegalus specimen. After thresholding and converting the DICOM data (microCT file format) into a surface mesh model in MIMICS and exporting it as an STL file, I was able to study the structure of the scale as a three-dimensional surface model in RHINOCEROS 3D®. The first step involved removing artifacts from the model that clearly belonged to ambient noise of the solution or media where the scale was scanned.



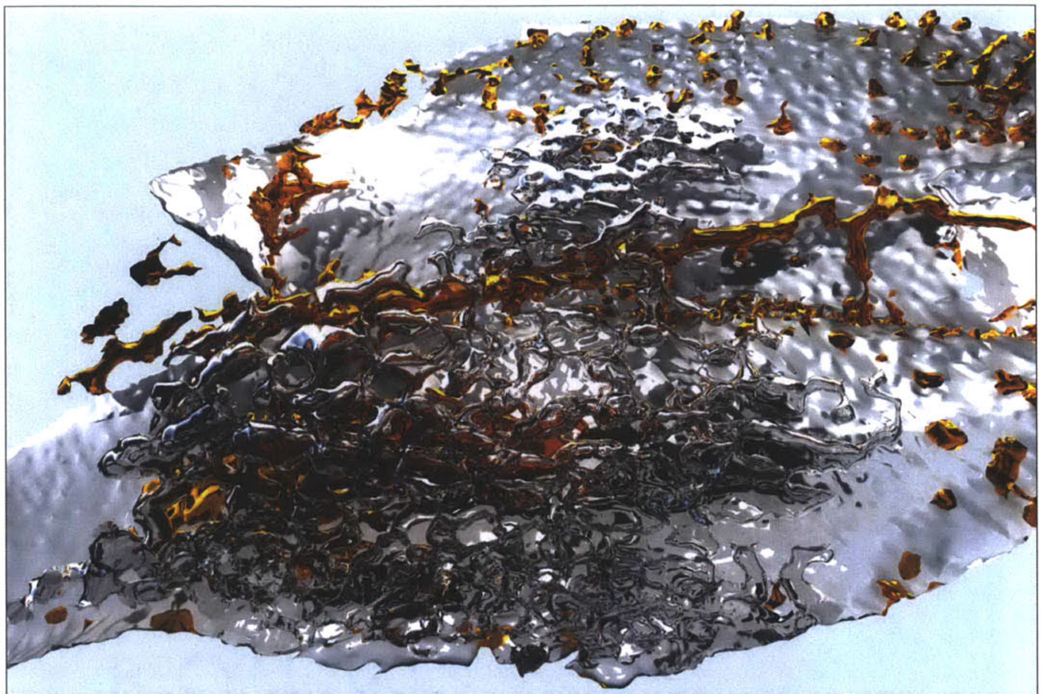
Anisotropic material properties distribution using multimaterial printing to produce continuous material transitions and interfaces,

This process was done manually by selecting the artifacts and deleting them from the file. After a clearer model of the scale was obtained, a definite internal anisotropic structure was evident inside the model of the scale. Due to the convoluted nature of this internal structure and the high-resolution triangulated mesh of the model, a clear observation of the structure was not possible. A script to create parallel consecutive sections of the model was created and used to analyze it in sections both longitudinally and transversally. These sections clearly depicted a vascular convoluted and yet continuous internal microstructure of interconnected pores with some defined areas of connection to the exterior both on the subducting edge of the scale and along the ridge of the peg-and-socket joint. According to literature[115], this latter area is known to have Sharpey's fibers connecting the scale to the dermal layers of the fish, specifically to the Stratum Compactum. Therefore, it is assumed that the internal porous structure is related to the fibers that connect the mineralized scales to the soft organic tissue of the skin of the fish. According to previous studies[116], these organic Sharpey's fibers are responsible for connecting



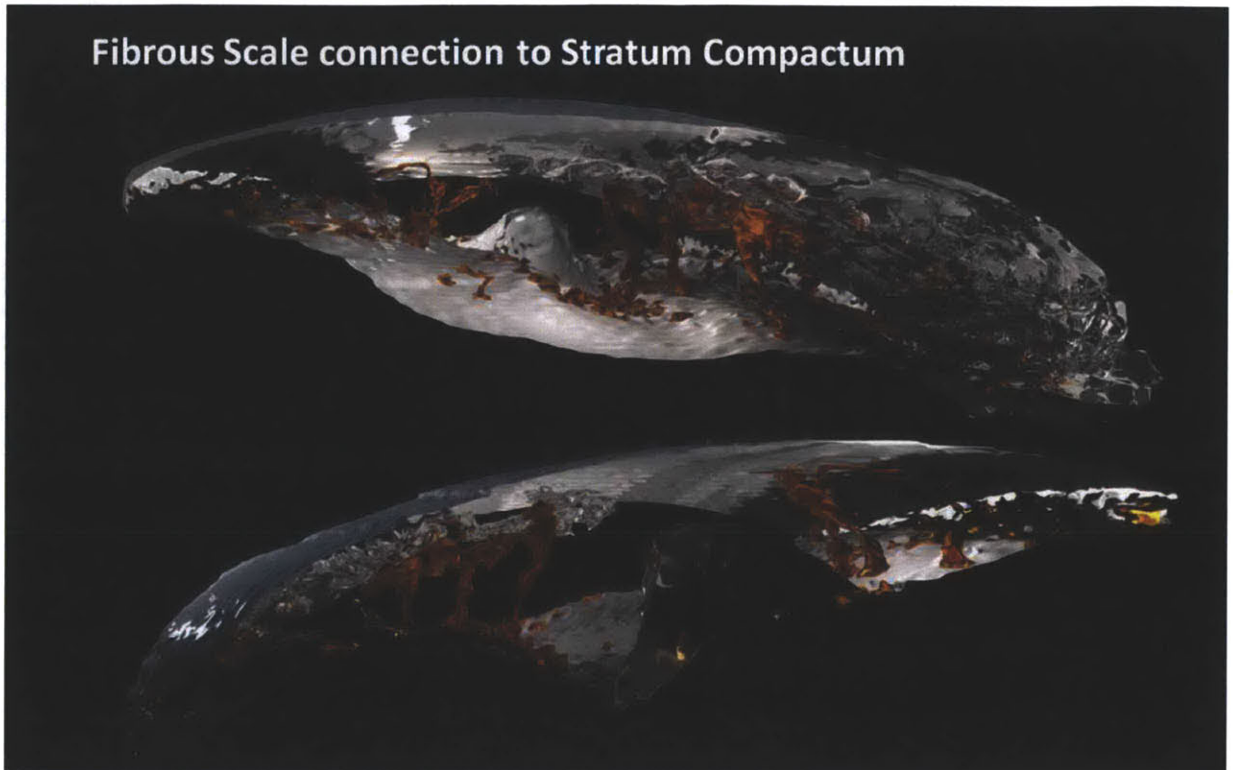
Visualization of porous structure morphology in Polypterus Senegalus Scale, especially regarding the imbrication of fibers from the integument penetrating into the bio-mineralized sections of the scale.

the mineralized scales to the soft dermal tissues, and they have been reported to be present along this central ridge on the under-side of the scale. Analysis of the surface model of the scale reveals that this pattern of open pores is present on the area mentioned in previous studies and is also present and clearly situated along two other linear areas, along the anterior subducting edge of the scale and on the posterior exposed edge of the scale, being denser and more evident on the subducting edge of the scale. All three areas are linearly shaped in the paraserial direction[117] and are therefore relatively parallel to one another. The study of the parallel section of the scales shows that the distribution of the internal microporous structures is clearly allocated anisotropically within the scale volume. The scales show a higher density toward the anterior subducting edge and progressively diminish in density of porosity and in area of occupancy toward the exposed posterior edge of the scale. While the porous structure seems to concentrate on an area parallel to the surface of the scale, and not centered within the section but closer to the exterior, its shape follows the external side of the scale. In order to perform a thorough analysis of the



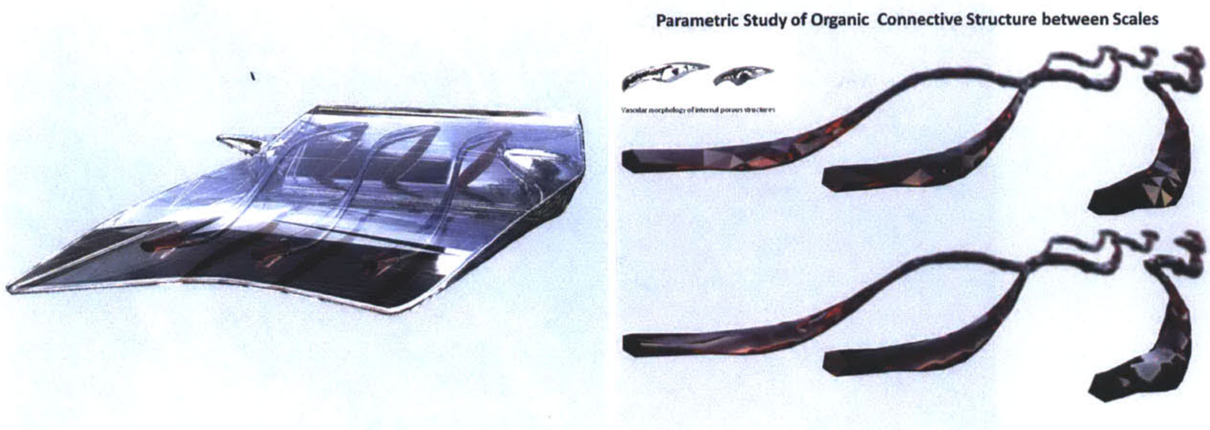
Visualization of the microporous structure in P. Senegalus, where the highlighted yellos structures are penetrations of fibrous organic tissues on the anterior side of the scale and that are connected with formations penetrating from the subductong edge of the scale. This organic tissues effectively weave through the scale and provide multiple functionalities, from mechanical attachment to nutrient distribution.

different morphological features of the observed microstructure, the mesh surface model was manually dissected into various components. Each part or component that was isolated from the surface model was placed on a different layer to allow for a selective visibility switching of all different and individual components and parts. The exterior surface of the scale was segmented into two parts, an upper/external part - the external side of the scale - and a lower/inner part - the internal side of the scale. Since the internal microporous structure is clustered in four different groups that present different morphological characteristics, transitioning gradually in size and formal aspects from the anterior subducting edge towards the posterior edge, it was separated by cluster. By isolating each cluster in combination with the parallel sections, measurement and characterization of the micropores was carried out. The first cluster showed the largest pore formations, spheroid in shape and interconnected through narrow stenotic passages that varied in size between approximately 50 and 90 micrometers (μm). The second cluster presented more continuous pores that were also connected through stenotic connections but that were less



Cross-sections that depict the internal connections of the structures penetrating from the anterior side, with structures penetrating from the subducting edge of the scale.

pronounced. The pores in the second cluster were also less spheroid and more tubular in shape. The third and fourth cluster were smaller in size and area, and the pores progressively become more of a continuous flat cavity with some interruptions. The pores on this cluster were clearly aligned with the external side of the scale. Connections from these two clusters with the posterior exposed edge and the central axis ridge links these structures with the external surfaces of the scale. In order to visualize the progressive mutation of the porous structures - the porous structures and formations that either penetrate the scale from the inner or outer surfaces of the scale and those that connect the internal microporous structures with those surface - they were isolated and taxonomized. When examined this way, a pattern of gastrulations and tubular conduits is observed, clearly demonstrating that the pores play a role in the adhesion and connection of the scale to the fibrous connective tissue of the stratum compactum. In order to verify such observations, four more scales where obtained. The scale was removed from the flank of the fish, and the area corresponds to the fifth column/fifth row (5C5R),

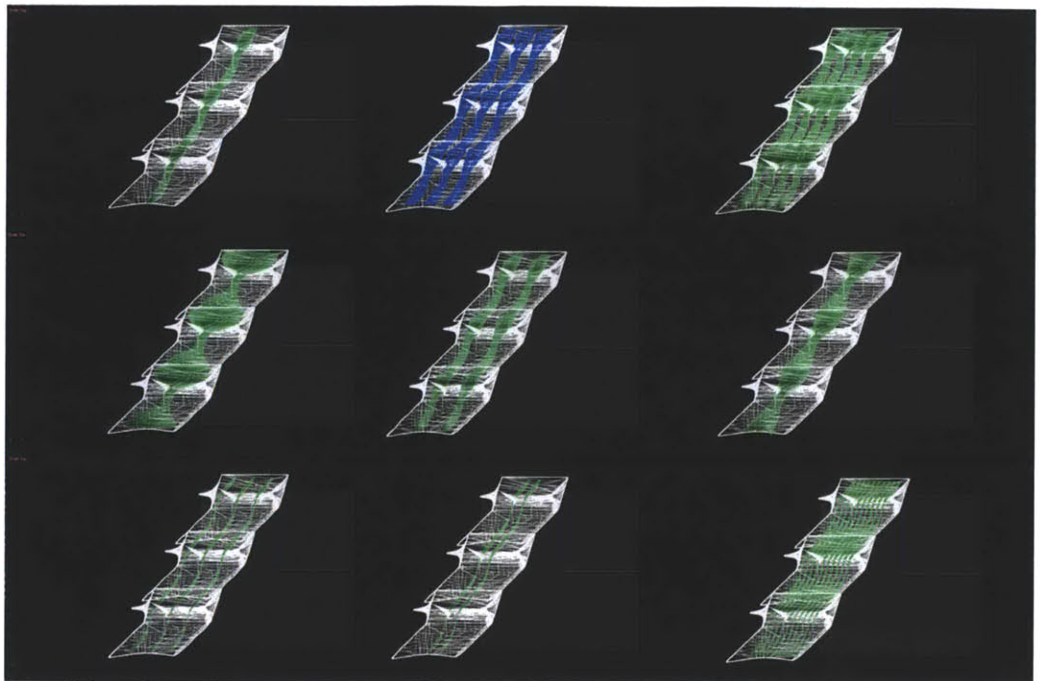


Visualization of parametric model applying the "interconnecting structures" principle observed in P. Senegalus scales.

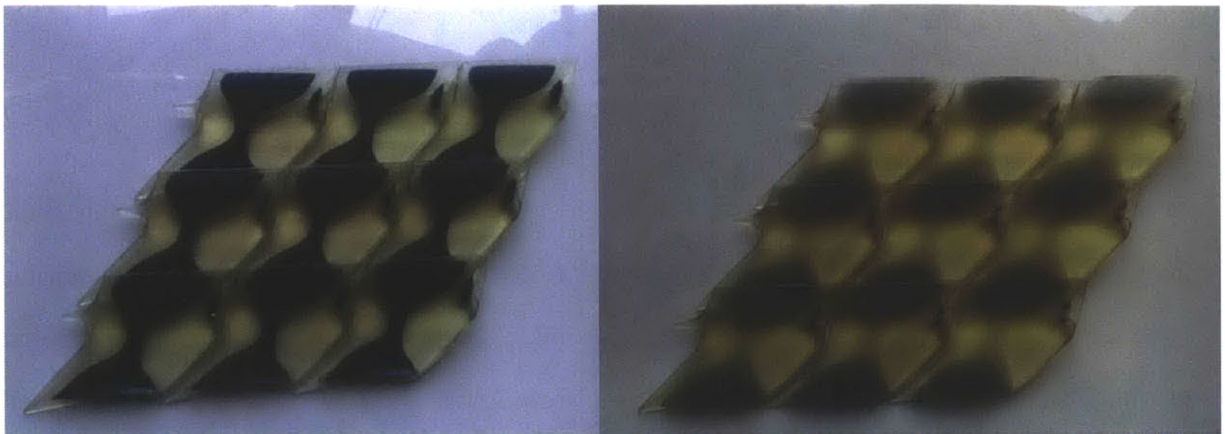
the fifth column/tenth row (5C10R), the tenth column/fifth row (10C5R), and the tenth column/tenth row (10C10R) respectively. The scales were prepared and scanned following a similar protocol as previously, and micro CT data was converted to three-dimensional surface models and imported into Rhinoceros. While the scales presented some variations in terms of the anisotropic location and distribution of the pores, the internal microporous structures were present in all of them and in similar gradient patterns as first observed with a higher density of pores connecting the outside of the scale at the anterior subducting edge of the scales.

Morphometric Analysis

Following previous studies of the morphometric characteristics of the P. Senegalus scales[118] and based on the shape analysis models currently used in various fields that follow the basic statistical shape analysis premises of David G. Kendall[119] -"all the geometric information that remains when location, scale and rotational effects are filtered out from an object."- , a morphometric analysis was performed. The shape of the scales vary according to their location on the body, and while these 4 scales are located relatively close to each other - no further than five rows or five columns apart - it is clear that the morphometric variations are more pronounced as the scale location progresses along the spiral – paraserial - direction as compared to the variation that is observed while they progress alongside the body length of the fish. Scale pairs 5C5R - 5C10R and 10C5R - 10C10R show similar features and little variation as compared with the pairs


Parametric variations of the interconnecting structures model, where discrete rigid/mineralized components are continuously connected and articulated by flexible structures.

matching the first column. So it is expected that along the same row, although some morphometric variation is expected, similar features persist, and greater morphometric variation is expected to occur along the columns of scales, including the symmetrical scale examples previously observed at the dorsal and ventral scale connections[120]. To perform the morphometric analysis via a procrustes fit, an available application was used called MorphoJ (Klingenberg Lab, University of Manchester UK). For this operation, outlines of the scales were obtained by creating planar sections parallel to the XY plane of the model in Rhinoceros 3D, from which landmark points were selected. A custom script was created to extract the coordinate points of these landmarks and export them to an excel spreadsheet that could be used to enter the data into MORPHOJ. For each scale, twenty landmarks were selected and their data was imported as covariates through MORPHOJ interface. In parallel, another set of twenty landmarks per scale, obtained not from a planar section of the scale but from critical locations in three-dimensional space data, was exported as coordinate points in a spreadsheet format to be used in a custom three-dimensional procrustes fit



3D printed multimaterial models showing different material combinations in order to test material and structural performances.

developed by a colleague, Yaning Li[121]. This custom morphometric analysis aimed at comparing three-dimensional landmarks in relation to the two-dimensional morphometric analysis performed via MORPHOJ, which could allow for a more precise understanding of the vectors and energies involved in the transformations of the scales along the body of the fish.

Parametric Microporous Anisotropic Materials

Research on the internal microstructure of the scales of P. Senegalus have shown a multilayered structure with a vascular microporous internal structure that is connected to the underlying layers of the dermis of the fish. The characterization of this internal microporous structure through 3D models reconstructed from microCT images have resulted in novel concepts for articulating rigid protective systems through graded composite materials designs. Parametric models applying the morphological principles derived from these studies have been implemented through physical prototypes using the multimaterial 3Dprinter Objet Connex 500. The articulated scale system previously developed by our group (Ortiz, Boyce, Reichert 2010) is expanded into a materially graded and continuous flexible system in this research by providing a non-assembly articulated structure that takes full advantage of multimaterial three-dimensional printing manufacturing capabilities by implementing gradient material composites that produce smooth continuous transition between joint components. A comparative test was performed on 3D printed prototypes, ones using material transitions with flat and continuous interface and ones using the novel algorithm for material gradient in the prototypes implementing the vascular internal structure observed as microporosity in Polypterus Scales. The convoluted morphology of the vascular interface has a significantly better performance compared to the flat interface that showed delamination problems, which introduces the opportunity to parametrically modify the vascular structure of the composite material gradient in order to optimize the armor's structure toward flexibility and stress resistance. This research project extends previous investigations regarding joint-articulated scale systems[122] in order to develop new algorithms to distribute multiple materials through additive fusion deposition techniques in order to achieve multifunctional high-performance articulated composite material structures while eliminating the need for multiple-parts assembly processes. By reducing the number of parts involved, and the need to assemble these parts together, it reduces the structure's fabrication complexity, decreasing time involved, weight - derived from the multiplicity of parts required to join all the pieces together - and risk of failure at the weakened spots of the structure where the joints are.

Continuous Graded Multi-Material Fabrication.

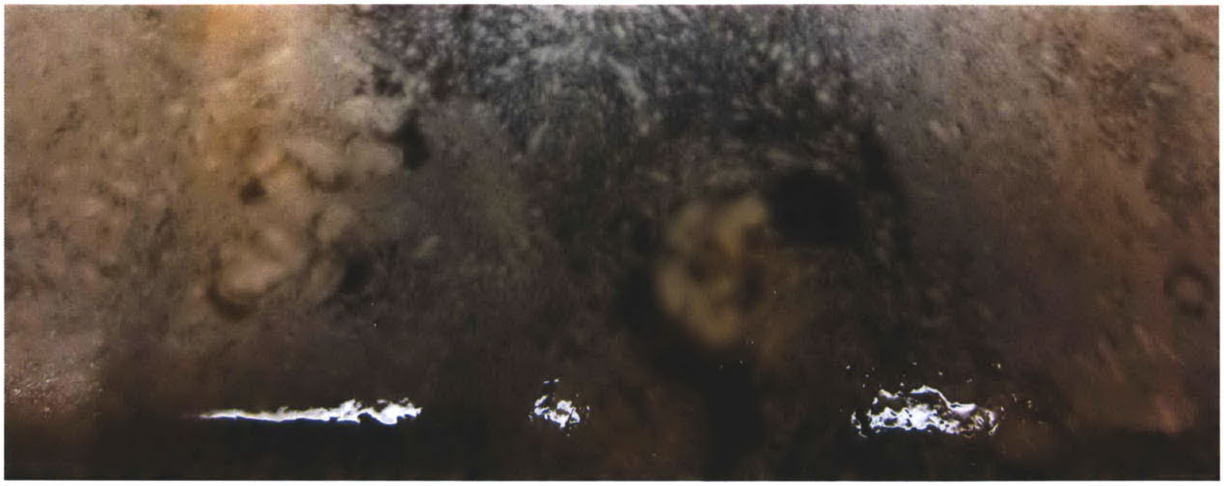
On local scales and confined to the material articulations at the joint level, the aim is to develop the ability to synthetically design and fabricate graded materials using additive fabrication in order to increase the joint's structural and environmental performance, to enhance material efficiency, to promote material economy and to optimize material distribution. The mechanical response of materials designed and engineered with spatial gradients in composition and structure was researched in local scales of joint and sub-joint components. Damage and failure resistance of surfaces to normal and sliding contact or impact is substantially controlled and modified through such gradients. In order to pursue these objectives, two paths were explored:

- A parametric gradient distribution of vascular and spheroid structures of graded size and shape to induce a gradual material transition between two materials. This algorithm is scalable from macro scale to the micro scale that the resolution of the Connex 500 permits.
- A parametric vascular connective structure that *weaves* through the scales, which creates structural and material continuity while enabling controlled ranges of motion. This algorithm is scalable and offers continuous or discontinuous material structure possibilities.

Several prototypes are developed in order to test the system's efficiency and to calibrate the values for each parameter in the digital model for the mechanical properties of the material used in the prototype at the scale the model is to be fabricated. Mechanical test of the prototypes will follow in order to statically compare performance in tension and bending. Interestingly, when both translucent materials are used, the transition between flexible connective tissue and rigid strong material is almost invisible, allowing for a visually continuous material that nevertheless has anisotropic material properties distributed along it - providing multifunctional opportunities. The scalability of this particular procedure, using either algorithm, introduces the possibility of micro to macro scale material systems using solid-object, non-assembly principles, that nonetheless remain operable and articulated at critical or required moments. The objective of this research being the design and articulation of protective systems, one can achieve this using these methods, especially by replicating the model observed in nature that allows the transition from organic tissue to inorganic tissue. One path for further research includes how these graded material interfaces could lead not just to material property distribution algorithms for design and fabrication of graded multifunctional material constructs, but to actually gradually integrate, as in

Sequence depicting four possible spatial and exhibition configurations of Hidrone, or a sequence of them over some time.

nature- organic and inorganic tissues in a seamless interface of continuous exchange, which may allow for mutations and adaptive transformations as one becomes the other. This performative aspect of the microstructures observed in this research could have a significant impact if scaled up to macro-structures through the design of continuous graded multimaterial structures.



Cellulose pellicle being formed by Xylinus

Xylinus

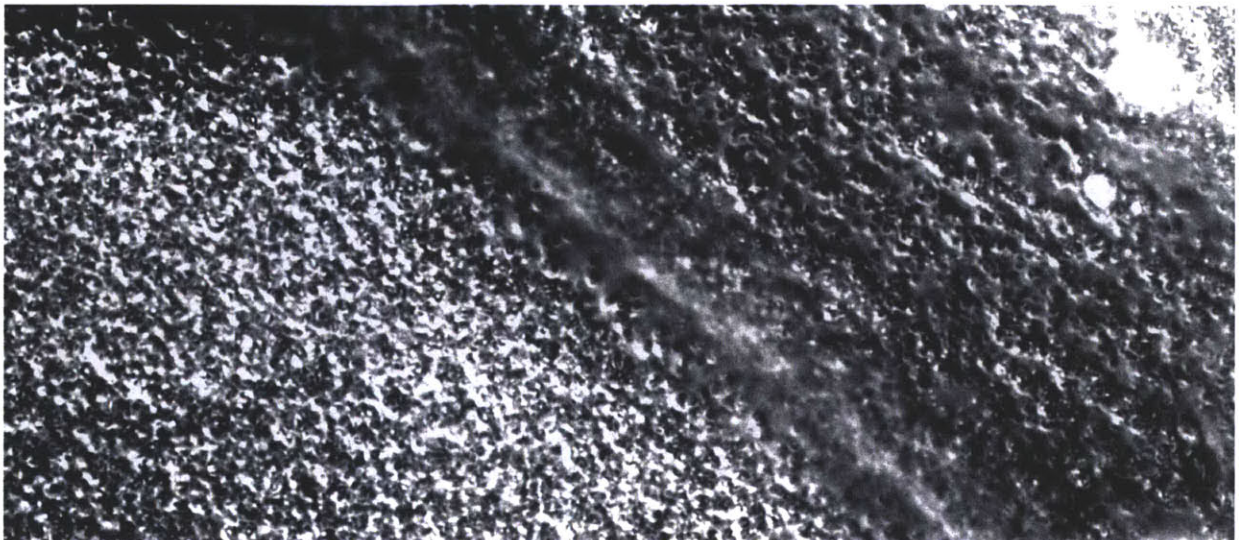
Micro Performances of Bio Fabrication

(S. Araya - in collaboration with E. Zolka, J. Babb and Weiss Lab, Department of Biological Engineering MIT)

Case

Acetobacter Xylinum

This last research case entails exploring novel modes of design and fabrication by utilizing live biological systems within a controlled environment in order to induce specific biological functions and material processes. The study focuses on the study of the Acetobacter Xylinus. This particular bacteria metabolizes glucose synthesizing cellulose. As opposed to plant cellulose, which through industrial treatmentis used to make paper, cardboard and other materials[123], bacterial cellulose is chemically pure[124]. While cellulose is the most abundant biopolymer on the planet[125] and its economic importance is enormous, as it is based on a model of industrial mass processing of plant material, it is responsible for an explosive consumption of natural resources. Cotton crops and wood timber are major sources of cellulose

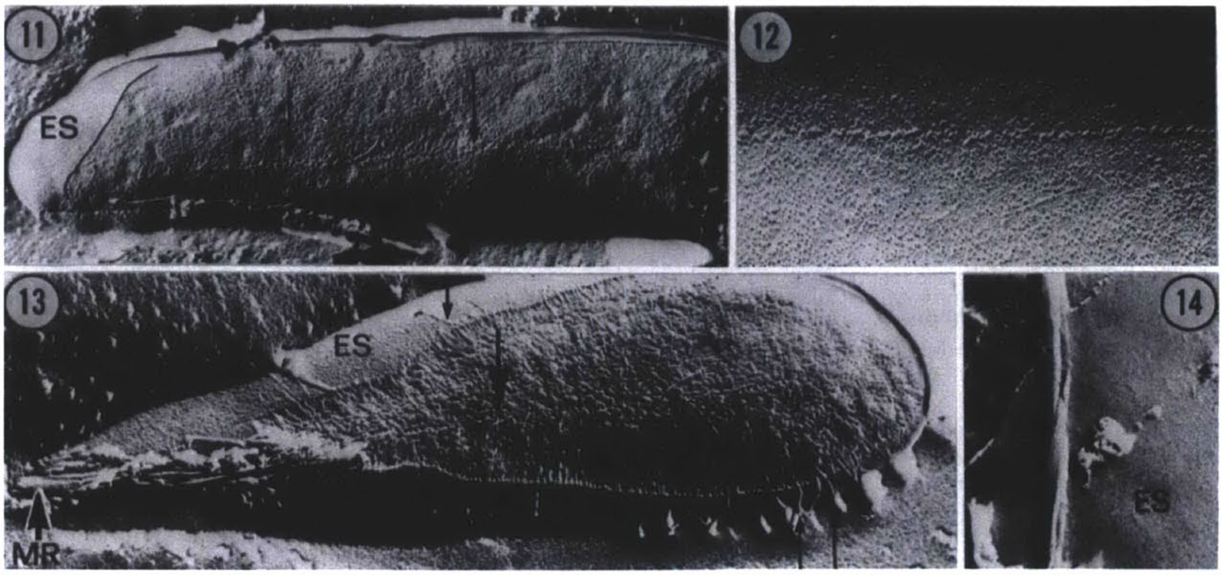


Snapshot from a video sequence of a cellulose pellicle containing Xylinus bacteria that are still drifting in the liquid contents over and within the pellicle.

and drive enormous industries, which are often the single most important industries driving a country's economy[126]. The environmental impact of such global industry is massive, and this has triggered extensive research on alternative sources of cellulose. For decades it has been know that marine microbes and other microorganisms can also biosynthesize cellulose, and research has focused on understanding the growth processes involved, the resulting cellulose structures and their material properties in addition to the genetic encoding responsible for the production of cellulose in such organisms[127]. Most of the research has targeted biomedical applications[128], although some research has been done in applying bacterial cellulose to plant cellulose to enhance its material properties due to the high purity of bacterial cellulose.

A. Xylinus is a very prolific producer of cellulose. One single cell is typically able to synthesize up to 108 molecules of glucose per hour into cellulose. Since one single liquid droplet can contain as many as a million cells, the productive capacity of A. Xilinus is significant.

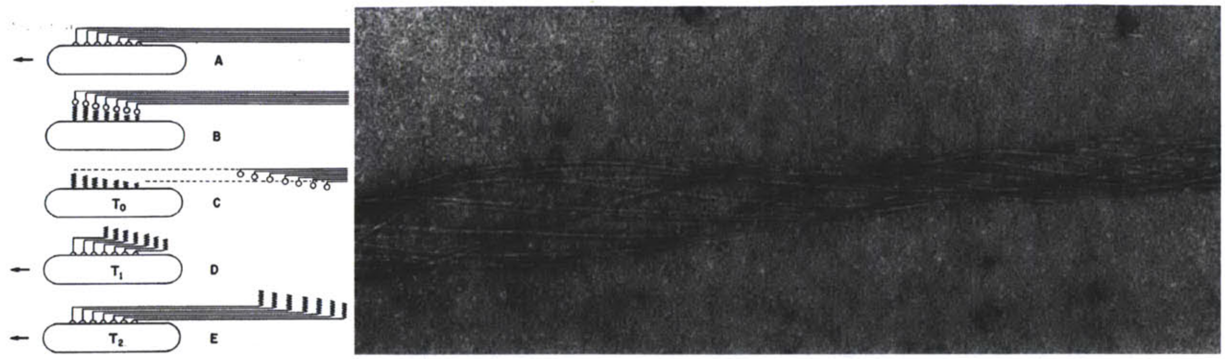
Kingdom	**Bacteria**
Phylum	**Proteobacteria**
Class	**Alpha Proteobacteria**
Order	**Rhodospirillales**
Family	**Acetobacteraceae**
Genus	**Acetobacter**
Species	**Acetobacter Xylinus**



Freeze-edge micrographs depicting A. Xylinus and cellulose fibrils. ("Cellulose biosynthesis in Acetobacter xylinum", R. Malcolm Brown, Jr. et Al, 1976)

Reference: National Center for Biotechnology Information (NCBI, USA)

The goal of this research is to investigate how the design of environmental conditions and the control of its critical parameters can induce the fabrication of material structures and their performance. Moreover, the long-term objective of this investigation is to be able to genetically modify the bacteria in order to insert new genetic instructions that enable it to trigger or stop cellulose production. A second objective would be to transform the bacteria in order to include the biological mechanism to produce the enzyme cellulase, which through hydrolysis degrades cellulose back to glucose molecules[129]. This would enable control of both an additive material process and a subtractive material process, both of which could be programmed or controlled via chemical or physical promoters. This study tried to develop a design methodology in order to implement a biological fabrication process that directs criticism toward contemporary manufacturing paradigm, which was inherited from the industrial revolution. That paradigm is one of extraction and exploitation of anisotropic and heterogeneous resources and materials that are processed in order to become homogenous and standardized. Remove and sterilize living matter in order to



Left: Diagram describing lateral pores responsible for the production of cellulose nano-fibres in A. Xylinus. ("Cellulose biosynthesis in Acetobacter xylinum", R. Malcolm Brown, Jr. et Al, 1976)
Right: Electron micrograph of loosely arranged cellulose fibrils. ("Microbial Synthesis of Cellulose", R. Malcolm Brown, Jr. et Al, 1976)

make it inert, sanitized before it can be consumed safely at the cost of making it hard to metabolize again when it is returned back to the environment. The implications of this paradigm have been thoroughly discussed in contemporary critical discourse, from its impact on ecological balances, to the economical and social costs of this methods of production and growth, to the political implications in terms of national and international dependency on scarce material sources.
From a design perspective, the paradigm of matter that acquires form though the creative act of design, the homogeneity of the material is key, both conceptually and physically.
Form is what differentiates; matter is continuous and homogeneous, often flat and in squared proportions or in stable and pure liquid form.
This investigation proposes a new paradigm of symbiotic co-adaptation where anisotropy and irregularity are embraced and where the role of design is not to give form but to inform the environment in which active material performances take place. It proposes a rather reciprocal and dialogical approach with the inner and outer environments of the system that contrasts with the monodirectional linearity of the current industrial paradigm.

Methods

The study was performed as a sequence of experiments that were designed both to learn about the system being observed and cultivated while at the same time to inducing behaviors by designing environmental conditions that would have an effect upon such systems. The series of experiments was partially planned in advance but

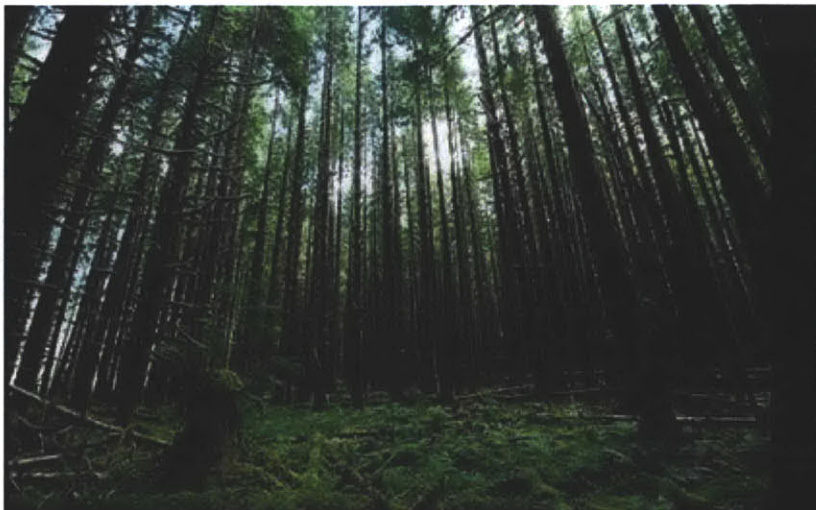
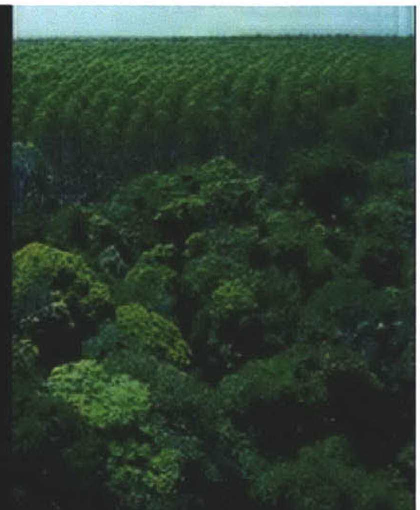

Experimental methodology of observation through micrographs, controlled growth environment and multiple parallel parameterization of variables to conduct parallel experiments in order to optimize a culture protocol for Xylinus.

had to be calibrated and adjusted as results from the first tests were evaluated.

Part of the research involved undergoing lab training in order to gain access to the lab facilities at MIT; another part involved learning about bacterial cultures and instruments used in the lab. Finally it involved learning about this particular species and its ideal growth conditions. We used a protocol developed by R. Malcolm Brown Jr, using a Hestrin and Schramm (HS) Medium and recommended ambient conditions for the culture of the bacteria. The HS medium formula was the following:

HS Medium	
Chemical	**Quantity**
D-Glucose	**10** (grs)
Peptone (Bactopeptone)	**2.5** (grs)
Yeast Extract	**2.5** (grs)
Sodium Phosphate	**1.35** (grs)
Citric Acid	**0.75** (grs)
Distilled Water	**500** (ml)

The Medium was produced in sterile one liter (1ltr) sealable jars that were only half full (500 ml of water) in order to autoclave them after mixed and was produced in batches of 3 to 5 liters at a time in order to store medium to feed the cultures. The strain of acetobacter was

FACTS

EU 2005 – Forestry based Industry turnover............EUR 380 Billion

World Land area is occupied by forests (2005) 30%

Deforestation pace 1990 - 2005 ....130.000 km2 per year



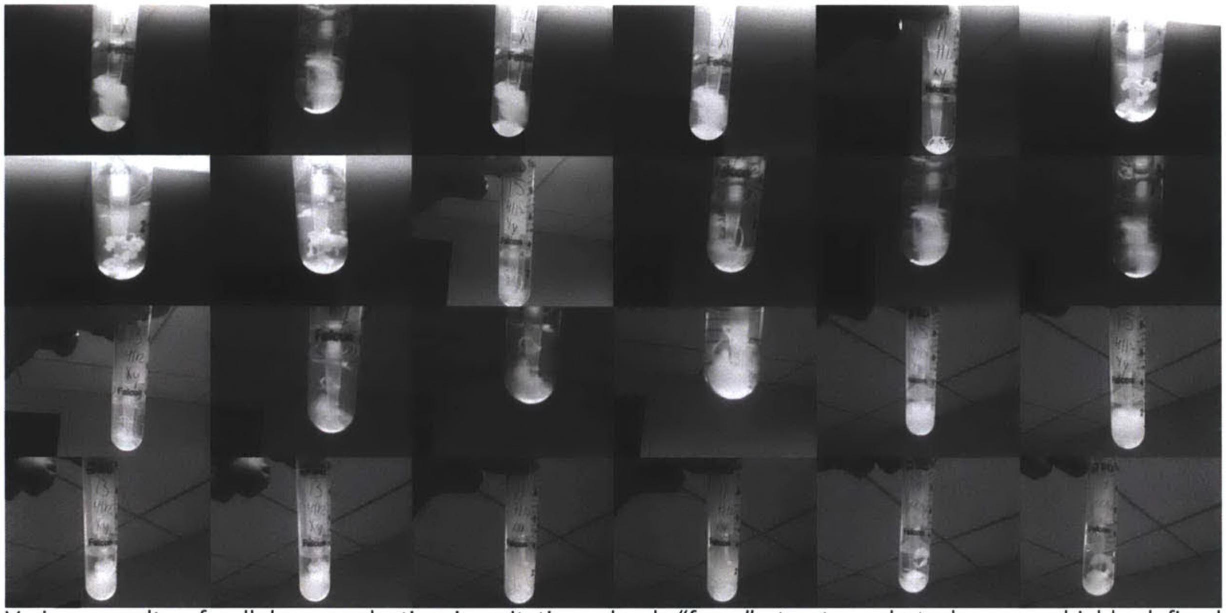



FACTS

Wood production per year.................................aprox 50 Million mt3

Used as fuel...25%

Used as sawnwood, venner, pulp and paper............................75%

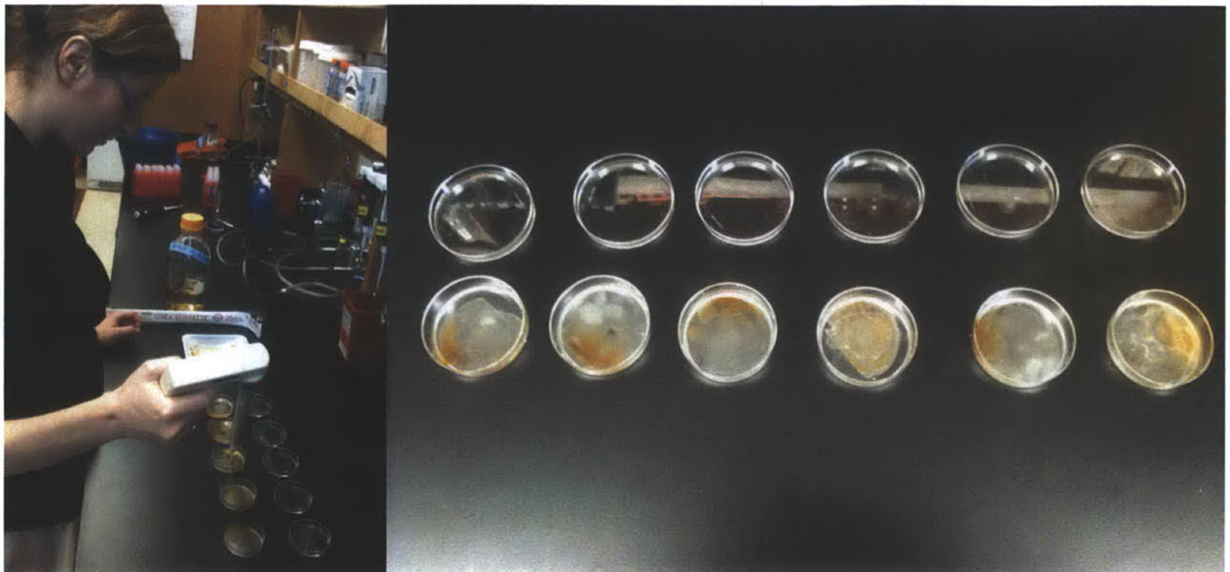


Various results of cellulose production in agitation, cloud, "fuzzy" structures but also some highly defined granulated formations.

obtained through collaboration with Dr. D. Kaplan and B. Panilaitis at Tufts University School of Biomedical Sciences. The Acetobacter Xylinum was transported frozen and stored at -80 degrees Celsius. A plasmid that had been previously used by Dr. Kaplan's team in order to transform the bacteria was also obtained and stored. The following steps and experiments were designed and executed in order to first attempt to grow the bacteria and then to learn about the parameters that affect its growth and the consequent production of cellulose.

Small Cultures - Test Tubes (Day 1)

We used 25 falcon capped tubes, each containing 3 ml of HS medium and inoculated with the Xylinum strain. They were all placed in the 30 Celsius incubator, in agitation, to produce an overnight culture. Twenty four hours later the tubes were examined and some of them presented cellulose growth. Samples were taken to the spectrometer where one milliliter (1ml) of the sample was compared to the same amount of pure HS media, which was used as a blank. The sample is read at six hundred nanometers (estimated according to literature to be the size of bacteria) was 0.0098



First pellicle formations obtained from static cultures in Petri dishes.

OD (optical density), which clearly showed that there had been reproduction in the overnight culture under the conditions implemented.

Medium Cultures - Diversifying Conditions (Day 2)

While a number of falcon tube cultures were kept and stored in the incubator, we wanted to compare growth on agitation to that of static cultures, known from relevant literature to be able of producing cellulose pellicles with stronger material properties[130]. The contents of a successful culture (after spectrometer test) approximately three milliliters of HS Medium and bacteria, were placed in one hundred milliliters of HS Medium in culture flasks. Two of these flasks were prepared and stored in the incubator, secured and left in agitated overnight culture. A small Petri dish containing ten milliliters of HS Medium was prepared and the contents of a falcon tube culture was poured in it. Three of these Petri dish cultures were prepared and placed in the incubator for static overnight culture. Twenty fours hour later the falcon tubes contained larger cellulose production, which differed widely from tube to tube and could be categorized in mainly two groups:


Fuzzy cellulose formation of Xylinus culture in agitated flask.

One group of cultures produced a fuzzy, disperse and fibrous cotton-like cellulose mass that floated in the HS Medium.

The second group of cultures produced a compact, dense and spheroidal-like granules of cellulose, which were well defined and tended to sink in the medium to the bottom of the tube (higher density). The cultures from the flask gave uneven results, one flask showing a significant amount of cellulose of the cotton-like variety floating in the medium. It was bigger than the faint traces of cellulose from the culture that was used to start it, demonstrating that the ratio of HS Medium and bacteria is relevant for the growth rate and cellulose production speed. The other flask became turbid but did not exhibit visible traces of cellulose production.

The static cultures on Petri Dishes showed subtle growths of cellulose pellicles on their surface. The pellicle was not yet fully formed and was difficult to classify as either the fuzzy cotton-like type or as a more compact and denser cellulose structure. Evaporation of HS Medium was apparent, so more medium was added to the cultures. Due to their horizontal aspect, these Petri dish cultures had a bigger surface area exposed to air (oxygen exchange) which could potentially have positively affected the bacterial growth but could also have affected it negatively by providing a larger surface for evaporation. Samples from the successful flask were analyzed in the spectrometer and shown an OD of 0.02. This order of magnitude in difference in the number of bacteria present in the culture may have accounted

Grow-around-a-mold experiment, where 3D printed molds were inserted in the liquid medium and the bacteria grew cellulose structures around the molds.

for the larger amount of cellulose being produced. The same procedures were repeated the following days, placing successful tube cultures in Petri dishes and adding media for static cultures, or placing them in flasks for agitated cultures. The objective was to increase the total amount of bacteria to target a large-scale culture.

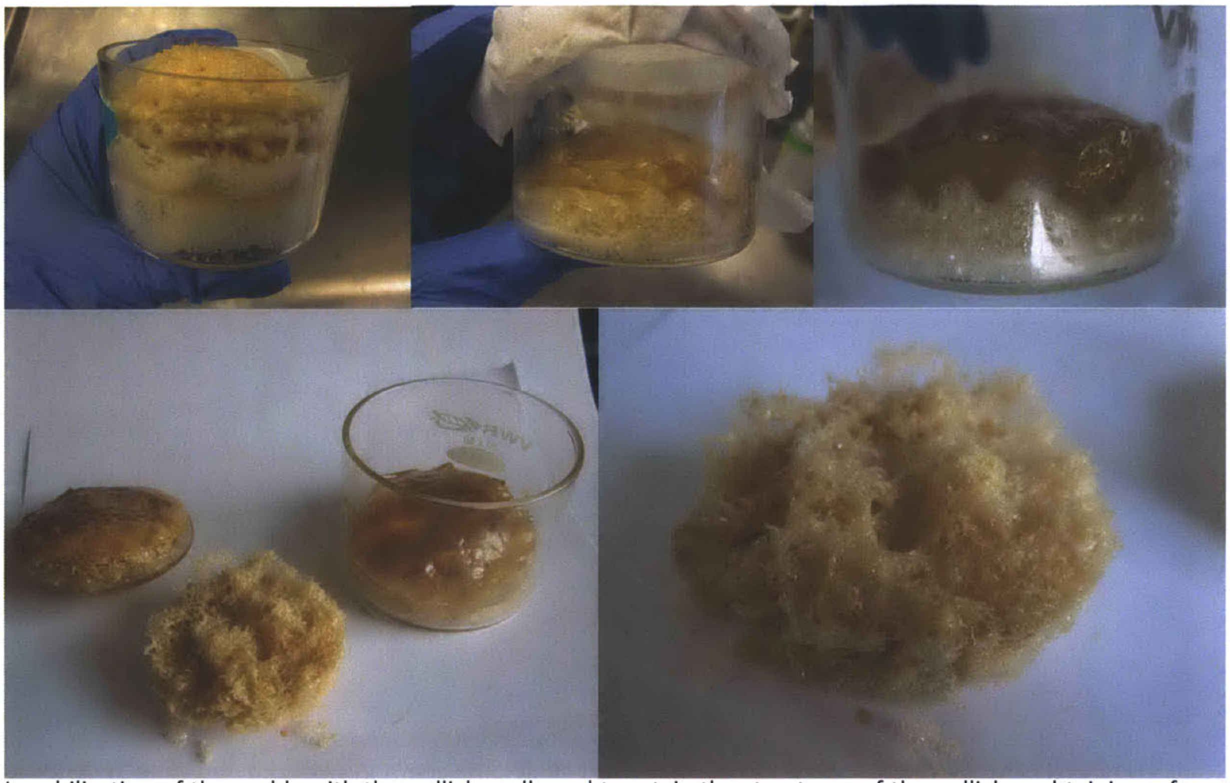
Large cultures - cellulose production experiments and molding tests

Seven days after we started the experiments we had several cultures and different degrees of cellulose pellicles and clouds (floating cellulose in flasks or tubes). We sterilized a twenty-five gallon aquarium tank and proceed to fill it with six liters of HS Medium and then introduced the cultures from six Petri dishes with well formed cellulose pellicles. The tank was placed under an enclosed but mechanically ventilated hood and the medium was kept constant at a constant temperature of twenty-seven Celsius. The tank was covered to prevent evaporation, and a webcam was set up and programmed to take three images a day for the extent of the experiment.

For the molding experiments, we explored the chances that the pellicle would form *around* or *against* a surface or *mold*. For this effect we designed and 3Dprinted five elements with different surface patterns and textures in order to explore the optimal scale of features to affect the pellicle formation and the best morphological characteristics for this effect.

Left: variety of 3D printed molds used to test the conformational capacity of the cellulose structures. Right: Cellulos pellicle being extremely thin when dry, remains elastic and deforms inevitably when de-molding, retaining only partial aspects and features of the molded shape.

The first attempt was to extract a pellicle formed in a Petri culture and, after having rinsed it with distilled water, to place it over one of the molds resting over an open Petri dish and letting it dry overnight. Another sample obtained from one of the flasks, containing a fibrous cotton-like cloud of cellulose was also deposited on a mold in similar fashion. Both molds were left overnight to dry. Twenty-four hours later the pellicles were dry and removal was attempted. Both had lost most their volume, becoming thin films. In the case of the pellicle, they became translucent. The cotton-like cloud was hard to remove since it was not well structured. Bundles of dry fibers came apart and were impossible to maintain as a cohesive structure. The pellicle mold showed some conformation to the 3Dprinted mold but was also difficult to remove. Being a very thin film, it stretched while being peeled out of the mold, affecting the original conformation to it. Nonetheless some features were successfully preserved, and a better planned de-molding protocol would likely provide significantly better results. It is important to note that through drying the pellicle became significantly stronger and resilient, even if stretched. It was strong enough

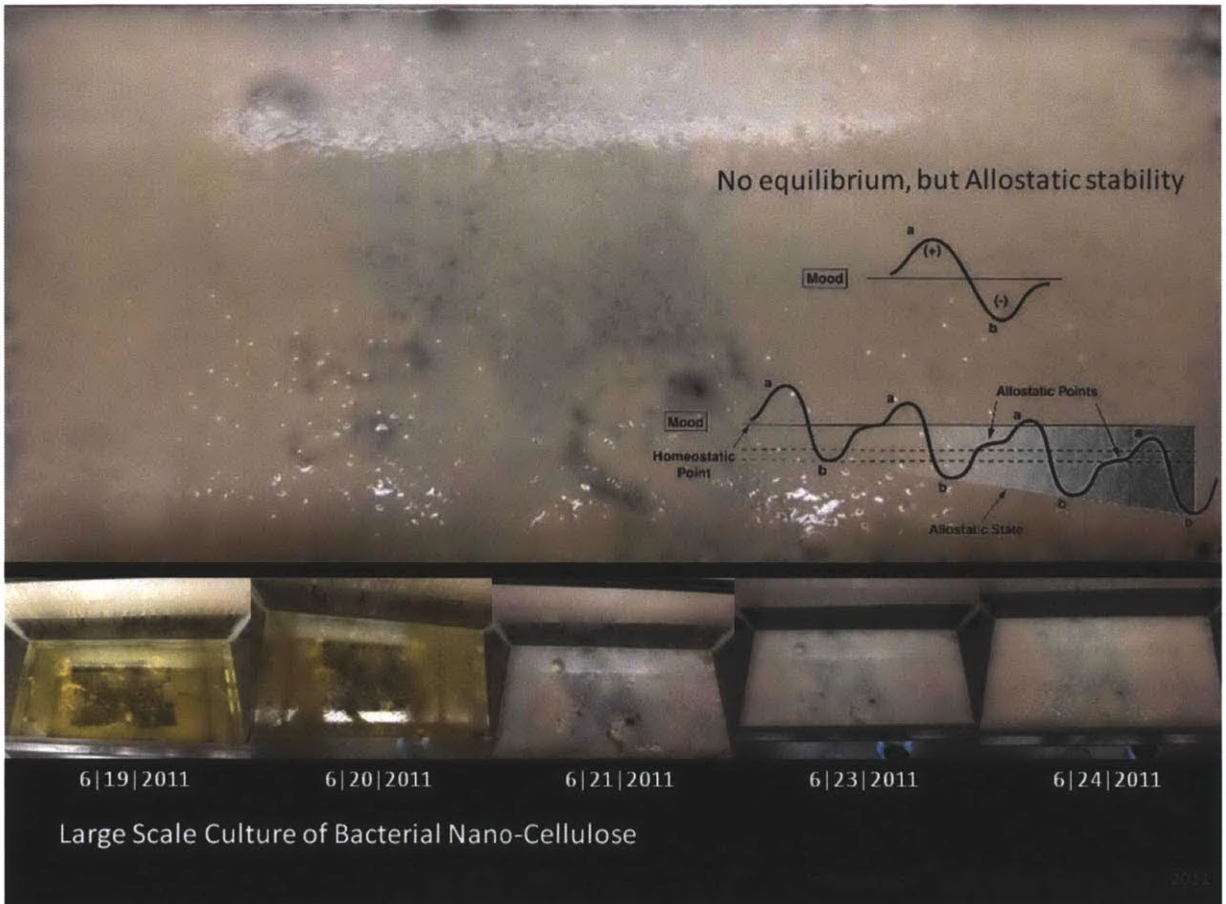


Lyophilization of the molds with the pellicles, allowed to retain the structures of the pellicles, obtaining a foam and porous structure.

to support itself vertically after being partially peeled of the mold, quite impressive for a very thin, translucent mold given its thickness.

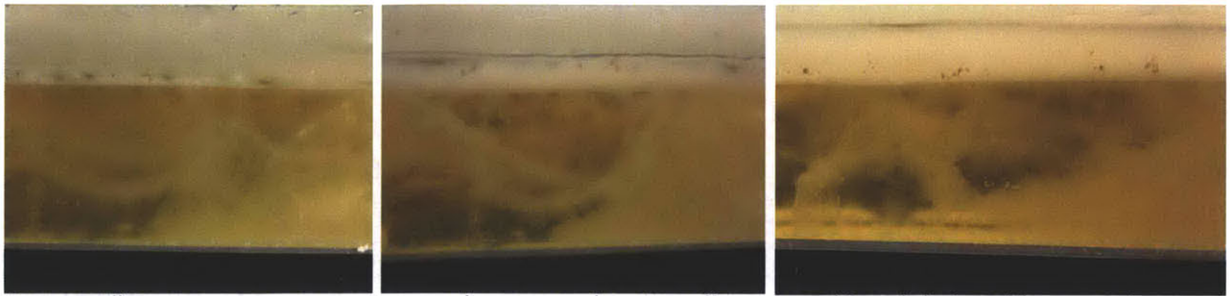
A second attempt was carried out to explore the molding capabilities of the cellulose structures but this time not as a post-process protocol but within and during the cellulose formation process. The idea was to include the forming variables within the framework of the bacterial culture growth and cellulose production itself. Five glass containers of one hundred and fifty milliliters were used and around a hundred milliliters of HS Medium was placed in each of them. The molds were suspended in the middle of the liquid and pellicles obtained from static culture Petri dishes were placed both above and below the molds. We had observed that in some cases the pellicle would seem to be formed by fibrils of cellulose floating up until reaching the surface, but in other cases the pellicle seemed to just stay suspended mid-height in the HS solution. Placing pellicles both over and under allowed us to test which cellulose formation would be more suitable for molding using this protocol.

Pellicle growth was observed in all molding experiments with various degrees of conformation



Time sequence indicating speed of cellulose pellicle formation.

to the molds. The pellicles had clearly grown around and against the molding surfaces, yet we knew from experience that any removal attempt while wet would mean losing the morphological conformation. We knew also that removal in dry conditions would imply a significant thinning of the structures given to the evaporation of the water volume. The structures would be more resilient and structural yet the de-molding process would still damage them. Since the objective was to preserve the actual structure of cellulose, formed while growing in the culture floating in liquid medium, I decided to freeze the cultures, therefore solidifying the liquid media and the cellulose structures. A first attempt was made by placing one sample at -20 Celsius, and twenty four hours later it was frozen and the structures were preserved. We then placed all of our molding samples in the freezer to attempt a lyophilization process in order to dry them and extract them. In collaboration with B. Panilaitis and the Kaplan Lab at Tufts University, we took



By controlling temperature, nutrients and oxygen, a layering effect was achieved, being able to produce two layers of cellulose which in time started to become imbricated by bridge-like structures in the form of catenaries that would connect both pellicles. A panel structure.

our frozen samples, which were then frozen at an even lower temperature (-80 Celsius) and then placed in the vacuum chambers of their Labconco lyophilizer. Samples were left for five days in the chamber, and were dry when retrieved. Cellulose structures were preserved. Samples were taken back, and kept at -20 Celsius before de-molding was attempted.

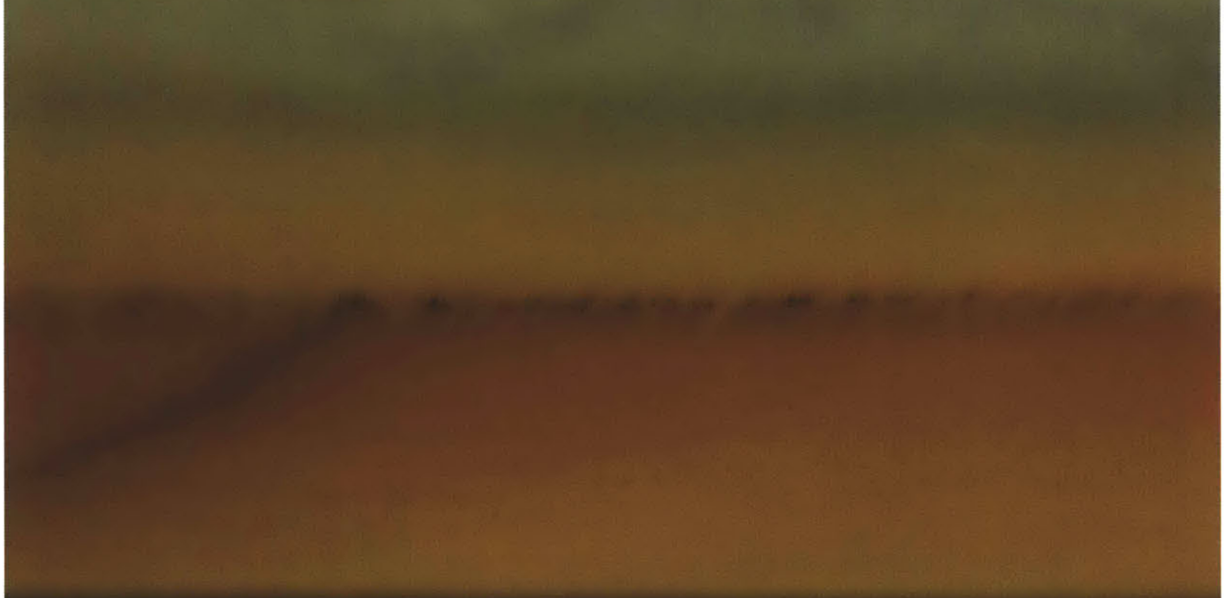
Discussion

Although the results obtained so far and presented here as part of this ongoing research project are still preliminary and partial, I believe they offer important and relevant insight on critical aspects of this thesis.

We have obtained satisfactory results regarding production of bacterial cellulose pellicles and cloud-structures. In fact the large scale culture resulted in the growth of a twelve by twenty two inches surface pellicle, and with about eight millimeters (one third of an inch approximately) of average thickness. The resulting pellicle showed significant strength compared to the pellicles observed in Petri dishes, given its large size, we were able to extract it from the tank culture with no signs of stretching or any elastic deformations. It was placed on a tray for transportation, and was later placed over a CNC milled wooden mold prepared with Petroleum Jelly to allow for an easy de-molding process. It was left to dry at room temperature for four days.

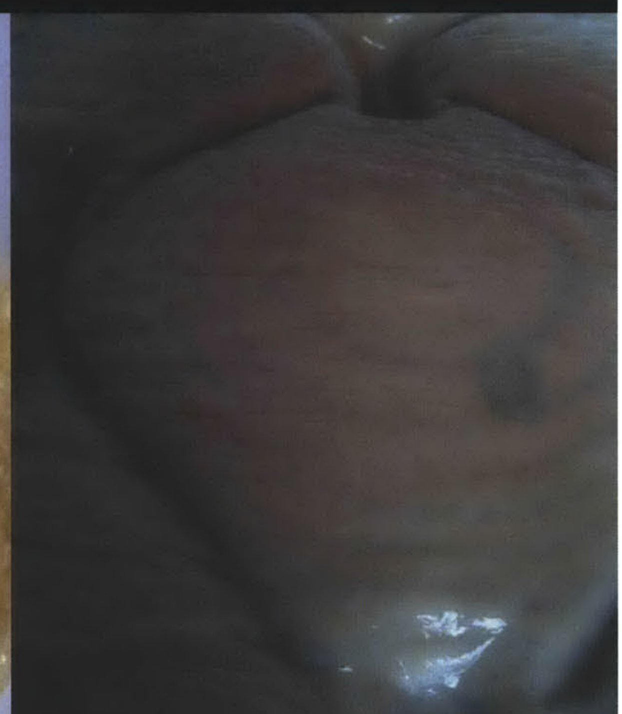
Form the analysis of both series of experiments, the large-scale pellicle growing and the small scale

Performance: Self Healing material through environmental parameter design



Nano fibrils weaved into micro fibers
forming linear colonies of entrapped bacteria.

Linear cellulose chains bridge both layers together



Molded Growth - Lyophilization (dry-freeze)

Layered Growth – Molded - Dried


Thick wet pellicle applied over a dry mold in order to test conformation of the pellicle to a mold.

moldgrowing, certain preliminary conclusions can be derived. First of all, the growth rate of bacteria and its consequent production of bacterial cellulose is directly affected by environmental parameters and its variation in time. Our parametric modeling of these environmental parameters -temperature, nutrient-medium (HS), and the variation of such parameters have resulted in variation of the cellulose structure produced. We were able to replicate successfully a layering effect -separate layers of cellulose being produced by the same culture, by affecting the nutrient-medium parameter: adding medium after one layer of cellulose pellicle had been formed. We also proved that these effects are transitory and that after they have been grown separate, the increased production of cellulose could grow structures between these and create one cohesive cellulose structure. We also proved that bacteria are actively producing cellulose even if entrapped in the cellulose film itself.

While we have yet to test different extreme environmental parameters for the cultures, we now know that the bacteria can resist and survive under unfavorable temperature conditions -dry media, complete evaporation and high temperature- and still be able to be reactivated after several days, and to resume cellulose production after a few hours and the proper medium and environmental conditions.


Detail of the pellicle being molded.

This realization allows us to speculate about the capacity of cellulose structures to become self-healing structures. It would be possible to think of structures that under fracture or failure due to stress, might recover by locally reactivating the bacteria entrapped in the cellulose structures in those areas and opportunistically recreating optimal culture environments, to therefore grow new cellulose structures that would patch up those fractures. But it would also be possible to speculate about structures that could grow differentially in time responding to varying programmatic or functional requirements or to changing environmental conditions in large period of time. The challenge of designing and operating with design principles and parametric logics at a chemical and physical level in order to produce three-dimensional material structures involved first of all a reframing of the goals and expectations, but also of the methods and techniques applied. Since there is no direct influence on the formal aspects of the produced, since the production

Left: Wet pellicle over CNC wooden mold. Right: dry pellicle after being demolded.

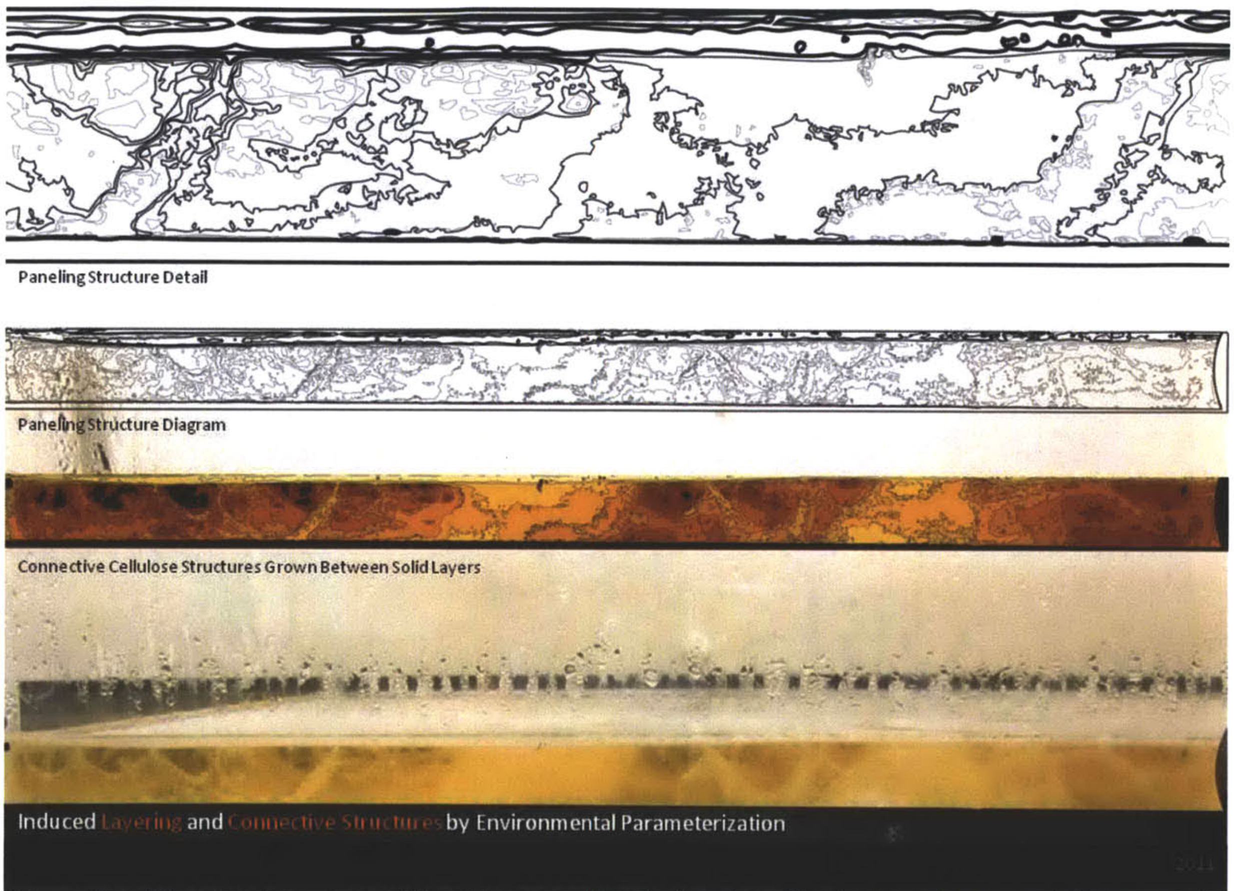
process is first of all differed in time and secondly because it is the result of a complex balance of controlled but also of some uncontrolled variables -aspects of the biomechanics of the cellulose material fabrication by the bacteria for example- the actual design process happens in a sort of delayed feedback loop, where input operations affect certain conditions which in time change due to these effects and return new modified conditions with which to operate. The design process becomes a mutual self-adaptive set of relations where designer and artifice engage: the designer adapts and reacts based on the new artifice, the artifice adapts and reacts to the new operations and processes unleashed by the designer. Both designer and artifice can be understood as environmental conditions for the other one.

The ecological implications of developing such a manufacturing system are comparable to the scale of the impact of the cellulose industry and its ecological footprint. To imagine the fabrication of


Dry cellulose membrane demolded.

cellulose panels and products harvesting bacteria instead of harvesting forests is in itself quite a radical possibility with potentially large scale impact. But also relevant from the perspective of the environmental impact it could have if waste glucose-rich sources were to be utilized. Waste residues from crops like corn, rice, and wheat[131] could be used as glucose sources and therefore offer large-scale and low-cost alternative resources for the production of bacterial cellulose. And of course there is the fact that cellulose products could always be degraded back to glucose sources, using enzymatic cellulase protocols, especially since this particular type of cellulose is of a high degree of purity in comparison to that obtained from plants.

But leaving the appealing and sound ecological benefits of such a project, it also opens up



Schematics of the panel structure achieved by controlling the layering effect in the culture. Lyophilization of this structure would be ideal, but wasn't possible due to lack of availability of a freeze-dryier of such dimensions.

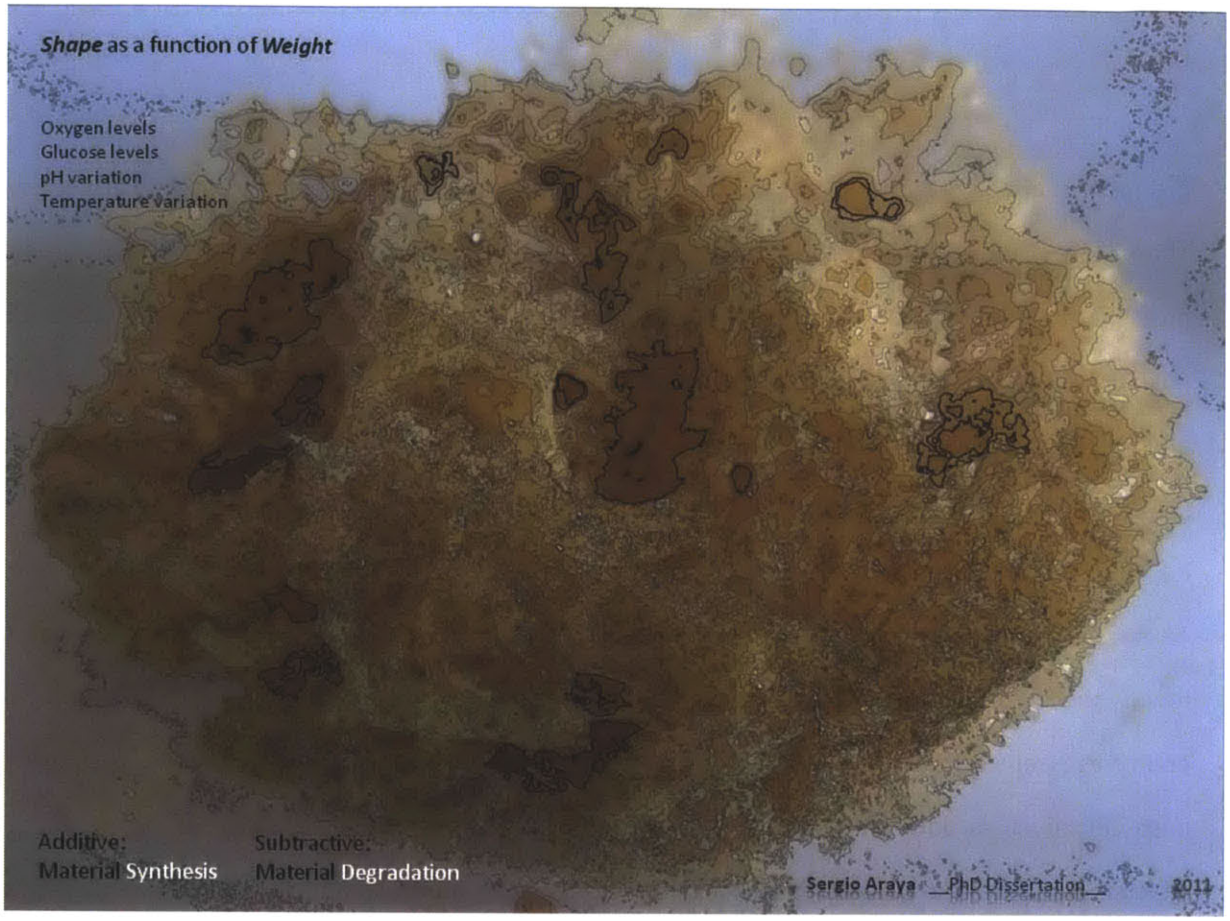
interesting lines of exploration in terms of design manufacturing techniques. The layering effect observed and produced, could be analogue to similar layer-by-layer process of current 3D printing technologies, where in this case, the fabrication machine would be a biological one instead of an electro-mechanical one, and the input materials would be fed to and metabolized by the system instead of being just simply a raw input processed and deployed. Specially since the "fabrication mechanisms" are integral part of the fabricated material itself, being able to resume production and fabrication at a later time, modifying not just the state and configuration but its generative and productive capability with it.

These are but initial results and further investigation should be carried out, where a future goal aims at understanding, and then controlling and eventually programming the genetic sequence in A. Xyllinus in order to promote or deactivate selectively the cellulose production. Alternatively, we plan to attempt to genetically modify the bacteria to add a sequence that would enable the transformed bacteria in order to allow it to selectively produce the cellulase enzyme, which metabolizes the cellulose degrading it back to glucose.

The capacity of controlling both production of cellulose and of cellulase is regarded from this research perspective as being able to control both additive and subtractive mechanisms in a material production system. It offers enormous opportunities to design a manufacturing system that would combine both material techniques, material deposition and material subtraction, in order to provide a more accurate and versatile manufacturing system. Literature shows that oxygen supply and pH control are also key parameters in regulating the bacteria growth cycle and the cellulose production[132], which would, if regulated, allow a higher degree of control both on the ratio of growth and of cellulose production but also on the structural properties of the cellulose structure produced.

Further investigations will attempt to control the formation of cellulose pellicle and cloud structures by the dynamic control of these environmental parameters. It is an objective of this research to provide methods and techniques to design and operate the anisotropic distribution of material properties on the cellulose structures produces, as much as to drive the fabrication of these three-dimensional structures.

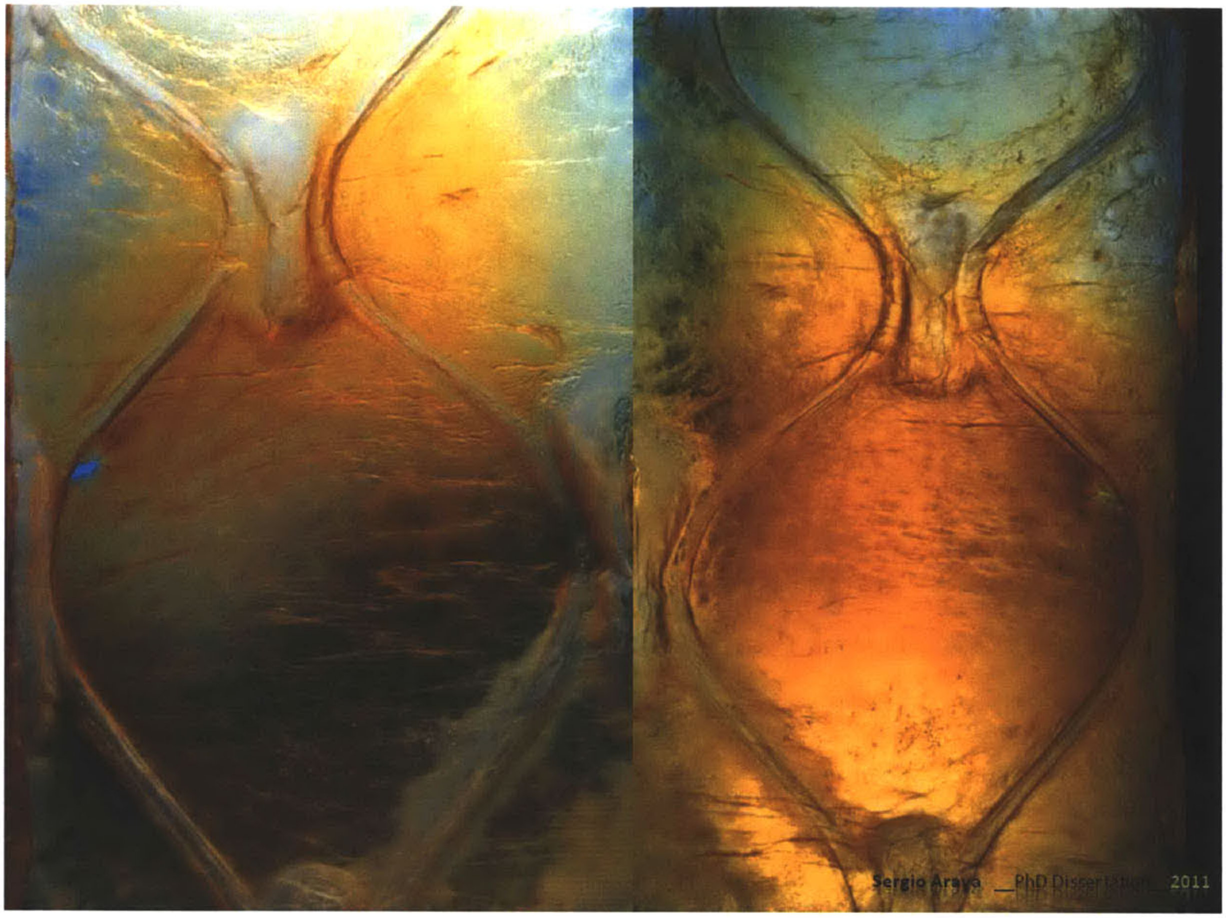
This responsive performative behavior programmed in the system and induced by the environment enable a homeostatic, or even further transistatic, momentum where both artifice and environment dialogue, the environment by inducing transformations in the artifice but being transformed by the material production of the system, the artifice by responding to the dynamic



The parametric design of environmental conditions produced in the allostatic formation of the cellulose pellicle, a localized distribution of morphological features and material properties. Form as a function of performance.

conditions adapts to the changes and changes the physical relations between both by adding or subtracting material.

Furthermore, bacterial cellulose structures are currently used in tissue engineering as scaffold structures where tissue cells can be allocated and grown[133]. In a similar fashion we propose co-cultures where cellulose structures would be grown as scaffolds initially then partially resorbed by another growing culture with different material properties. An ecosystem composed of symbiotic agents negotiating material configurations and adapting to changing local and global conditions. There is no doubt that the potential impact of developing such design techniques and material nano-technology can be of unprecedented relevance, both in terms of influencing a paradigm



shift within the manufacturing industry and in terms of its ecological implications. The trans-disciplinary nature of this research case, spanning from biology, computer science, engineering and architecture is but a reflection on the scope of such an enterprise, designing a bacterial nano-cellulose biofabrication technique for large scale anisotropic three-dimensional structures, or the possibility of growing your own chair, a house, maybe a city.

Closing Remarks

The aim of this thesis has been twofold. On the one hand it introduces the idea of performative architecture (performance in design), and has done so with the desire to contribute directly to the expansion of design education and practice. It proposes stretch the boundaries of the discipline by incorporating this notion of performance; a gesture which is offered here to convey an axiom of active engagement between two or more artifacts and/or between artifacts and their corresponding environments, human users/inhabitants forming a part of such an environment. It does so by blurring or replacing the distinction between such terms.

Performance is here proposed as the *action* that *mediates* the two forces of artifice and environment. The second objective of this thesis has been to offer a distinct point of view regarding analogue relations—as asserted by this work—between the design process—as it relates to pedagogy and in practice—and the performance of design (considered through that which is built, materialized and produced) as it engages with its surroundings. What a design theory like Shape Grammars enables through *embedding* at the level of the design process could potentially be *embodied* (or incarnated) into the formal and material properties of a design, something which would open up the possibility for the enabling of an ongoing dynamic feedback loop between design and its context—a sort of physical/material embedding that I present as *performance*.

Part One

The goal of the discussion as presented in part one was to describe a paradigm shift as regards the relationship between artifice, a product of design, and the environment, as it is defined by a culture. It described the shift from a conventional understanding between fixed, absolute and hierarchical terms (ones in which the environment as nature is given and fixed) to a contemporary comprehension of the dynamic nature of the same and the new, different relationships that have been formed because of these new understandings.

This change has had a dramatic effect, as it has radically affected the theoretical backbone of centuries of architectural theory, upending to a certain degree those conservative values and principles inherited from those classical theories of architecture dating back to Vitruvius. The case presented in this part of the text operates partially as a reflection of some of these more conventional values, though it attempts, through primitive design operations, to establish a new relationship: one based on the idea that the built artifact is a design action that operates on its environment. This is important in that, although the techniques described as operating there lack the theoretical or methodological instruments to operate within the conditions that emerge out of such design process—dynamic, immaterial, intensive instead extensive, qualities without boundaries and variable parameters—it opens up a door for further investigations on how to *design instruments and methods*, as well as ad-hoc rules and operations to deal with such variables.

The light reflecting and color (or color bleeding) capabilities of the materials used in the design elements could be seen as the properties of a general grammar of pure weights, associated, but not necessarily, with the more formal grammars of the elements themselves. Most compelling of all, perhaps, is the study of the light and shade effects of the interior of the building through physical scale models and mockups. While digital representations were produced to convey and visualize the process and potential results, the design process actually came to fruition through the *manipulation* of both the formal and material aspects of the elements and environmental parameters (simulating the changing luminous conditions and the atmospheric effects) involved. Given the implicit inheritance of the conventional historic paradigm, almost all operations performed on a formal level: in their engagement with the site as they shaped the landscape, in their disposition towards and conformation to the built components and elements of the built artifice and even in the orientation and formalization of the fenestrations on the built components themselves.

Despite these formal bases however, the operations also attempted to function on both material and immaterial levels. Formal transformation operations which would be understood and enabled by a grammar of shapes consequently affected physical but immaterial properties. An appropriate example would be that of the light/dark contrast produced by those shadows produced by the folding facets of the artificial landscape as the angle of the folding involved is controlled by regulating the level of sunlight upon these faces. Although there was no *grammar* or explicit set of *design ruled operations* for the material choice in the interiors, the choice of matte and reflective surface finishes and materials for the flooring was a direct consequence of attempting to design and control the lighting and shading qualities of the built elements, as well as their spatial aspects. This concerned the walls, floors and ceilings. The empirical nature of these experimental design operations, since they derive from the direct observation of simulated phenomena while using scale models, enabled us to utilize these operative design decisions and specifications; it allowed us to use them while somehow contradicting *classical,* conventional design principles and therefore escaping the hallmarks of traditional formalisms. They allowed for the creation of new principles, new techniques, ones that had been given a custom tailoring in order to address the issues at hand; they somehow became proto-rules and operated precisely as weights in a shape grammar implementation.

Part Two

The cases presented in the second part of the thesis purposefully depict the creation of material (weights) rules and transformational operations (shapes and both weight and form variation) working on multiple scales and in different contexts. The discussion offered a manifold understanding of the idea of performance, one that was organizational, technical and cultural. The discussion of how form and function are mediated through performance is presented as a novel theoretical concept, one that explains the association between form and function through the enactment of such a relationship. The cases permit the visualization of these principles by materializing or enacting such actions in their conformational changes (or the material variations) or in the responsive structures described in these study cases. The layers of performance in each case are multiple: they respond to environmental goals or changing internal or external variables, all the while depicting both environmental conditions and their responsive actions as a dynamic display of values and rules. This in turn makes room for the enactment of certain adaptive operations, done in order to maintain a dynamically balanced equilibrium of functions as a function of time and to ensure the efficacious technical use of formal and material qualities and properties; dynamically reassessing its available resources and reallocating them to serve material organizational performance criteria.

In this second part, through the discussion of transparency properties, energy harvesting, ambient regulation etc., phenomena which were in the first part described as *given natural phenomena,* here become the subject of design itself. I will use one example to discuss this point. The strategies for how to use and qualify the daylight conditions presented in the study case from Part One of this thesis operates on the effects it produces on designed artifacts. In this second part, the same phenomena is understood as a design condition, one which can be transformed and operated upon. Daylight is transformed in energy which then is in turn used to power and fuel a responsive system that reorients and reshapes the external envelope or surface cladding system in the Zambana buildings. It performs on both the technological and organizational level by determining both the particular local as well as the general global management and distribution of resources. In Kinet this is transformed by the reconfiguration of the responsive flexural patterns, which affect the shading and patterning effects of the interior spaces. In Ichtyomorph the movement of the sun in the sky would determine the solar radiation level and thus instruct the design's need to open or close, varying the configurational angles of each scalar component, the temporal areas of the tower facade. As the sun moved, the building would actively reshape itself, reconfiguring its skin to vary the light-incidence angle on the glass components, something which would increase or decrease solar gain, allowing for the reduction glare and increased visibility.

Here light became a technical, organizational and cultural performer, driving forward such embodied behaviors and being transformed into a different resource or phenomena: energy, pattern, heat, distributed actuation, etc. From a theoretical perspective the discussion and design exercises presented in this second section advance the idea of performance as an action that mediates the *inner-* and *outer-*

environments of the design artifact[134] yet while also mediating the form and function within. From a methodological perspective, the questions and cases discussed illustrate performative strategies implemented through schemas of rules and operational techniques. They display and expose the instrumental aspects of performance, the infrastructure of (and for) performance.

Part Three

In this third part of the work, I further developed those performative strategies initiated from the discussions (conversations) and cases (design processes) presented in the second part of this work. The objective in doing this was to develop new modes of engagement with the design process, applying a *Shape Grammars* perspective into purely *Weights Space*. It was an attempt to apply schemas and rules to the sort of situations in which intensive conditions cannot be defined by boundary conditions. *Shape Grammars* without *shapes*, simply pure *Weights intensities*. The discussion introduced different notions of computation, moving from the well-understood digital computation (numeric and symbolic calculation as inherited from Turing machines) to material computation and finally to performative computation. I use here the term computation as it is understood in terms of Shape Grammars theory, where the two meanings of the term imply both computation as calculation (rules and operations described within the Algebra(*i,j*)) and computation as design (computation is design, design is computation[135]. The discussion, by introducing these forms of computation then, actually advances an understanding of both calculation and the design notions that accompany them.

In this section the notion of *aggregation* plays an important role, both as it is understood through the idea of *proliferation* and *component population,* derived from parametric logics and the differential replication of parameters and geometries, but also in terms of the performative effects produced simply through the cumulative material and physical attributes derived from sheer repetition and juxtaposition, the additory layers of fields of variable intensities amassed with the passage of time. The work of Tara Donovan is introduced to describe the material effects that are borne out of such a ruled-based iterative aggregation processes: $\mathbf{x \rightarrow x + tx}$.

Aggregation seems to be a basic and possibly recurrent notion for architecture. Since the discipline's first theoretical conceptions, the repetition of components has been a fundamental need and driving force both conceptually (in terms of modularity and discrete functionality) and practically (i.e. constructive constraints and resource management). Yet, influenced by the industrialization and standardization of the 19th Century, aggregation and modularity have become identical. And with this notion reinforced by the symbolic/numeric model imposed by digital computation, the identical was expanded to the digitally identical. This differs greatly from a tradition in which the identical was the result of human labor and hence an identical that pointed towards the indexical.

Yet even with this, a taxonomy of similar values yet of inevitable differences could still have been applied. But for the past two Centuries, with digital computation driving the new paradigm for identity (the symbolically, numerically identical) repetition is more of the same. The movement towards other modes or forms of computation, ones which would enable a loose translation, one where the iterative may or may not have been identical since the calculation may happens at a material level, not at an abstract numeric or symbolic level, was opening a door for emerging new behaviors. A performative computation takes place while it simultaneously transforms that place by simply occurring. Because of this, the field in which such a calculation/design happens is a result of such dynamic negotiation or computation of the unleashed situations and conditions. While parametric logics in design software (something which is used extensively in this work) offer some instrumental opportunities, they are deeply rooted in a digital computation groundwork, therefore inheriting the paradigm of the identical, despite all their attempts to mask it using parametric variation and associate interconnections.

Experimental, rule-based protocols on the other hand, like the several ones explained and implemented in the cases studied in this third section, all offer modes of engagement in which *design embedding* takes place on different levels and in a space where symbolic reductionism is not an obstacle. Yet it is due to this openness that it also entails a high level of complexity as regards any attempt to rationalize these manifold dimensions of embedding, in order to establish reproducible protocols. It is for this reason that scientific and engineering approaches to experimental work are rooted in systematic reductionism and abstraction; they utilize them in order to isolate variables and parameters to operate with. Meanwhile, design protocols operate at a different pace and are not (necessarily) concerned either with the complexities and multifaceted aspects of the system or with its top-down symbolic reductionist constraints. For design, this is invariable—at some point it all must take on the same hierarchical relevance and no-strings-attached aspect; reductions and complexities are but temporal categories, and both integrate well into the other temporal categories established as necessary in the design process.

While the different questions posed by the writing of this book and those posed through the experimentation may differ substantially due to the discipline specific disciplinary and technical jargon in which they had to be framed and given the multiplicity of disciplines and fields that were explored during this thesis, it is also important to note that certain concerns have been relatively constant, and that while the perspective I have had of them may have changed in some respects, my engagement with phenomena has not been radically changed because of it. In the third section of this thesis, I have given attention to material composition and the inclusion of material properties as they are used to program material behaviors becomes a central aspect of the argument. And as the cases show their proof and the discussion is developed, the twin topics of transparency and light became ubiquitous and multifaceted. The concern for the manipulation of variables (variable used to design certain effects or the attention to the design of certain properties) that affect space and experience are similar in principle to the questions present in every case study. Even from those that began this thesis, begun nearly a decade ago.

Architecture: Place and Change.

Post rationalization of architectural education *–a biographical perspective.*

When I was 10 years old, living in Santiago, Chile, I began taking oil painting classes. I enjoyed drawing and painting, but I had not been at it for long before I found myself faced with a trivial yet (in my eyes) crucial problem. I was given an assignment, the rules of which were to observe and decide upon a "subject" to paint that was *outside* of the teacher's studio, where all of my classes had taken place. All my previous subjects had been static, still life models. I chose for this assignment to paint the urban view observable from the studio's balcony—a scene comprised of the rooftops of the neighboring buildings and small houses cut out against the greenery of the San Cristobal Hill. The sun was setting. The still life models had been set up by my teacher for very practical reasons: they were easy to arrange and keep in place, the artificial lighting could be directed and controlled and, most importantly, everything in the frame would remain constant. The point of view always remained the same as well, since my instructor did not move our chairs from class to class. I was able always return to the same spot, with the same subject, in the same position, with the same light, and worked to capture whatever "scene" had been presented.

The techniques taught included sketching first on canvas, then shading with different pencils and charcoals, and then utilizing those first, diluted colors on the canvas in order to "impregnate it" before any actual painting could occur. This process usually took place over a few different sessions, each one a few hours long, once or twice a week. Her efforts were to stress the emphasis, a sort of pedagogical emphasis, on the repetitive nature of the act of painting. It was the same sort of repetition used by children as they memorize their multiplication tables, and it was a *sketch, shade, paint* process that occurred each time I entered the classroom.

The imposed challenge of painting something out of this "fixed" and "controlled" setup seemed to me at the time to be one of extreme difficulty. It was no longer simply a matter of how well I could sketch or draw, given what my young eyes perceived (or even understood) about depth, perspective or proportion, but the fact that, in the case of the view from the balcony, part of my subject was always constant (the buildings and the houses), while another (the sunset) was constantly changing. I couldn't reconcile myself to the fact that every time we gathered to paint the scene the natural background was changing while some of the more fore-grounded geometry remained intact.

The trees and grasses on the hill in the back, the light of the sun, the cloudiness of the sky, even the wind affecting the profile of the tallest trees—all had an impact on the static geometrical profile in my eyes: these things changed the colors, shadows, reflections, and textures of the buildings I was trying to portrait. I tried for several weeks until I ultimately decided to "wrap up" the painting and call it "finished".. I had never been satisfied with my results, and though my mother still retains the painting of this particular scene and proclaims it to one of my best, this is the one painting I was never proud of, the one I always felt was a bit "off," and that consequently made me feel that I hadn't really been able tackle and overcome the fundamental "conflict" of the space involved.

Seven or eight years later as I was beginning my studies in architecture, my very first studio assignment faced me again with the same dilemma: the assignment asked for each student to draft a type of promenade along a stretch of land near a hypothetical coast. The terrain was abstract, and the work was simple yet constrained. It was an assignment in which everything had to work within a given grid, an orthogonal grid of course.

I spent all my time designing and later in writing and sketching to try and explain, through my drawings, that my design was most concerned with the movement of the sun and subsequent shadow patterns, and with how the changing color of the light would affect the color of the "gridded modules" that I had created. I remember arguing with my professor with the naïveté only a first-year student can bring, that he had to "imagine" or "see" beyond the gray sketches to the fact that the *whole purpose* of my design had been to *incorporate* and *embody these fluctuations*, these subtle variations I saw occurring on the surfaces and textures I had created with my design. *The design was changing*, I told him. I failed that Professor's first assignment, and quite a few more, though (or rather because) I was unyielding in my opinions and intentions.

The last of these anecdotes happened towards the end of my first year in architectural school, I was given an assignment, a design to be done in concrete, a *material assignment* given so that students would learn about sand and cement, molding and casting, weight, volumes and textures. The design I developed was of an *organic series of rooms* profusely perforated and of *varying* wall and slab widths and thicknesses. I designed them with the idea that they would contain a number of different, sequentially active responses or behaviors and achieve visual (light and shadow) as well as material effects (erosion in time due to the action of water flows).

This was my first "real material" assignment, one in which I was not working with cardboard models. I was expected to give a discussion, justifying my design. Anticipating a heated discussion, I had prepared what I saw as a thorough explanation, and considered myself ready to present it to my professor. After all the presentations had been given, my Professor selected what he considered to be the best piece from the course. It wasn't mine. The design he selected was a nice, finely composed, cubic piece, one with stairs and squared windows placed within a rectangular grid. It looked organized, clean, soft and even. Mine, full of holes in varying orientations, looked eclectic and rugged. It wasn't a cubic, but a *worm-like* structure, one in which every surface had been treated to have a specific reaction to either rainwater or sunlight. In my model, the designed interior chamber would change color due to light conditions daily, and would change its shape, over months and years, due to the erosion of rainwater. I thought I had the multi-scale temporal argument all figured out. However, I lost that argument as well.

After I *learned* this lesson, I started to get the best grades of the class, as I kept my designs within the expected "formal" and "abstract" requirements. I learned about possible "disruptive" gestures, such as "rotation" or "displacement" or even the "superimposition" of one grid over another. Yet at the same time, I was becoming somewhat skeptical about what I was doing, about designing a composition within a fixed criteria. This to me seemed equivalent to a set of absolutes, to a set of inescapable rules.

Abstract space and simple geometrical form seemed to me to have become the subject and content of a doctrine. Changing conditions were not accounted for, and zero "rule-breaking" was tolerated. Good design had to do, within these parameters, with consistency—with obeying the rules. Even if an assignment might ask me to take changing natural conditions into account, it would never do so beyond their impact measured upon the static, permanent, monumental, stoic, architectural structure that they would affect. The relationship between *designed form* and *place* or *context* had already been set long before I arrived at the school. It was not a design concern or a design question. It wasn't even up for discussion. Over the years, as I've moved through periods of both design research and practice, I have come to realize that other thought models actually do include the type of concerns that affected so strongly the designs of my youth.

What I have attempted to do with this thesis is to illustrate how these questions are indeed relevant to the discipline and how they may be incorporated into both design processes and pedagogies. Design has a unique ability in that it allows us to *see* conditions and relations, and to witness their dynamic interaction, even if only for a moment. This fact allows design to not only embrace but to *encompass* change and complexity; it allows it to incorporate the omnipresent issues of temporality and relativity. Design is the only field that enables this type of performance to take place, but what's more, it can create and enable them as well. The idea of *performance* as a cyclical process, one that is consistently providing new input and insight into relative and temporal conditions, artifacts and their environments and material and immaterial properties—all through a sort of "feedback loop," has changed my perspective regarding the work *I* do with design, both in theory and practice, and a work that has pushed me to write this book. I have in these pages defined *performativity* as a new type of relationship, one between a designed artifice and an environment, a relationship that breaks all the rules of a doctrine I grew with and saw as limiting, and I have tried to express how, by embracing this new relationship, we may not simply forego that which is old and uselessly, obtrusively static, but also embrace that which is fluid, changing, and new.

I have now forgotten the rules.

Endnotes and References

Notes Part 1

1 Wren Strabucchi PhD, is an Architect and Associate Professor at Catholic University of Chile. He was my first Master's Thesis Advisor and I also had the pleasure of working with him at his practice for several years. Prof. Strabucchi introduced into academia, by offering me a position as Assistant Professor at the University. His thoughts on architectural theory resonated and made a deep imprint in my experience as a graduate students and as a young faculty.

2 While constructing a general theory of the artifice, Herbert Simon (Simon 1996) differentiates between internal environment and external environment. This distinction positions the artifice itself, the product of design, as the interface between such environments.

3 (Lynn 1998; Lynn 1999; Schumacher 2008)

4 (Brundtland Commission 1987; Ryn and Cowan 1995; Spens 1996; Corner 1999)

5 "(...) the building is a form of body, which like any other consists of lineaments and matter, the one the product of thought, the other Nature" (Alberti 1991, 5)

" I assert therefore that, since architecture imitates nature (as do all other arts), it cannot endure anything that alienates and distances it from what nature herself permits." (Palladio 2002, 55)

7 Leon B. Alberti, "On the Art of Building in Ten Books", Trans. Rykvert, Leach, Tavernor, MIT Press, Cambridge 1988.

8 " If our designs for private houses are to be correct, we must at the outset take note of the countries and climates in which they are built. One style of house seems appropriate to build in Egypt, another in Spain, a different kind in Pontus, one still different in Rome, and so on with lands and

countries of other characteristics. This is because one part of the earth is directly under the sun's course, another is far away from it, while another lies midway between these two. Hence, as the position of the heaven with regard to a given tract on the earth leads naturally to different characteristics, owing to the inclination of the circle of the zodiac and the course of the sun, it is obvious that designs for houses ought similarly to conform to the nature of the country and to diversities of climate." (Vitruvius 2005)

9 See Vitruvius, "The Ten Books On Architecture", Book 1, Chapter IV "The Site of a City".

10 " All of architecture is founded on to principles, of which one is positive and the other arbitrary. Its positive foundation is custom and the useful and necessary ends for which an edifice is built, such that it is Solid, Salubrious and Comfortable. The foundation that I term arbitrary is Beauty, which is dependent on Authority and Habit." (Lefaivre and Tzonis 2004, 205)

11 "What is architecture? Shall I define it as Vitruvius does, as the art of building? No. There is gross error in such a definition. Vitruvius takes the effect for the cause. One must conceive in order to realize. (Lefaivre and Tzonis 2004, 470)

12 "The principal objection on which most emphasis is placed is founded on a prejudice and a false premise that is not permitted to diverge from the customary practices of the Ancients, that all things which do not imitate their manner must be deemed bizarre and capricious, and that if this law is not unviolate, the door is opened to license such as to so disorder in all the arts. (...) If this Law were to exist, Architecture would never have reached the point to which the inventions of the ancients have brought it, all those inventions having been new ideas in their own time" (Lefaivre and Tzonis 2004, 206)

13 " (...) city planners (has said Pinker citing Le Corbusier) should begin with 'a clean tablecloth. We must build places where mankind will be reborn.' An example of what he had in mind was his sketch of what Paris would look like if he had been granted his wish to bulldoze it and start over from a clean tablecloth: a vista of concrete high-rises separated by empty plazas and interconnected by

superhighways." (Pinker 2002, 170)

14 His famous design to reconfigure an area of Paris just North of the Seine, by replacing entire neighborhoods by sixty-story cruciform towers placed in a orhtogonal arrangement within a park structure.

15 (Heidegger 2002; Heidegger 2001)

16 His assertion regarding existential space as the subject of architecture, where the first was understood "the basic relationships between man and his environment", and where space and character were clearly differentiated.(Norberg-Schulz 1984, 5)

17 "Landscape is such phenomenon. In general we may say that some phenomena form an environment to others. A concrete term for environment is place. It is common usage to say that acts and occurrences take place."(Norberg-Schulz 1984, 6)

18 (Brundtland Commission 1987)

19 Ibid.

20 Ibid.

21 (Mostafavi, Doherty, and University 2010, 17)

22 (Mostafavi, Doherty, and University 2010)

23 Modernism effected a profound change in American architectural academe. By the 1960s there was hardly a school left that had not adopted its message. Is Sustainability going to have a comparably profound effect? Certainly not n the short term, but it doesn't take too much to realize that pressure is being applied. Its operative history, in this case is already visible." (Jarzombek, 38)

24 (Palladio 2002, 55)

25 Vitruvius, "The Ten Books On Architecture". Chapter 1, Book II. Trans. by Morris Hicky Morgan, Harvard University Press Cambridge, 1914.

26 Vitruvius, "On Architecture". Trans. by Bill Thayer, http://penelope.uchicago.edu/Thayer/E/Roman/Texts/Vitruvius/2*.html

27 David Leatherbarrow, "Uncommon Ground, Architecture, Technology and Topography". MIT Press, Cambridge 2002

28 United Nations, World Urbanization Prospects, Report on Largest Urban Agglomerations. 2007 Revision (URL: http://www.prb.org/Educators/TeachersGuides/HumanPopulation/Urbanization.aspx)

29 "The two, the building and the land, are on this account sharply contrasting. The first waits for the arrival of the second on the way a vessel anticipates its fill. I described this as noncoincident complementarity. Yet, despite this essential difference, both construction and location have aspects that are manifest and concealed in like ways. This makes them essentially the same" (Leatherbarrow 2002, 209)

30 A regional movement that initiated in 1952 from a splintering at the Catholic University of Chile, group leaded by architect Alberto Cruz and poet Godofredo Iommi, that founded a new School of Architecture at the catholic University of Valparaiso, Chile. It was based on the interaction and agency of Poetry and Architecture as a form of pedagogy and practice. Amereida was the manifesto that established the main objectives and methods of the School's vision, and gave birth to a foundational book Amereida (a sort of collective poem, anonymously published in 1965 by the group of poets and architects based at the School of Architecture), and the construction of the Open City, an experimental " designed city still in formation that has no master plan, no imposed ordering devices, and no hierarchical networks of infrastructure" (Pendleton-Jullian 1996). Built by students and their profesors, and being the place where Faculty Members of the shool would reside, it was a sort of built Architectural Laboratory. Amereida, the theoretical backbone of this intitution, had a marked influence

in generations of architects in the region between since the 60’s.

31 A particular mix of modernist style revindication and regionalist poetic ideology, influenced in teaching and through built works, students and a general cultural audience.

32 Artificial light conditions due to the geography of the canyon, which blocks the sun for approximately three hours in the morning and two in the evening for the specific site location, so direct sunlight is not available although the sky clearly depicts that daylight conditions outside of the canyon are different.

Notes Part 2

33 Herbert Simon, The Sciences of the Artificial.(Simon 1996)

34 Walter Bernard Cannon, “The wisdom of the body” (Cannon 1963)

35 Jay Schulkin, “Allostasis, Homeostasis and the cost of physiological adaptation” (Schulkin 2004)

36 Nicholas Mrosovsky, “Rheostasis: The physiology of Change”, (Mrosovsky 1990)

37 Martin Moore-Ede, Frank Sulzman, “The clocks that time US”(Moore-Ede, Sulzman, and Fuller 1984).

38 P. Sterling, J. Eyer, “Allostasis, a new paradigm to explain Arousal Pathology”, (Sterling and Eyer 1988)

39 (Sterling and Eyer 1988)

40 (Schulkin 2004)

41 (Schulkin 2004)

42 (Schulkin 2004)

43 Gordon W. Allport, “Personality and Social Encounter”, (Allport 1981)

44 (Allport 1981)

45 (Allport 1981)

46 (McKenzie 2001, 9)

47 (McKenzie 2001)

48 A central concern here is an attempt to attempt to describe a "general theory rehearsal" as McKenzie has put it, one that encompasses all others, one that includes instead of one that divides and specializes. Nevertheless my instrumental use of performance attempts to use it in a bidirectional manner. First following McKenzie, as an operation of convergence, and additive operation, that aggregates different aspects or specifities of architectural discourse and practice. This instrumentation will facilitate the construction of the first notion of performance, shifting from noun to verb, from fact to act(ing). Second, closer to Leatherbarrow's perspective, performance will become a kaleidoscopic prism which will allow us to see how, while maintaining its aggregate yet heterogeneous state, multiple levels of performance can emerge and occur. Here, the unique and the multiple coexist permanently and are constantly being redefined by interpretation - "what you see is what you get" - but at the same time are transformed through performative operations - "it's all about seeing and doing"(Stiny 2008).

49 While it may seem easier at first to propose that architecture as discipline, the act of designing it that is (drawing it, thinking it), is an action more than a result that operates as an ongoing process rather than as the presentation of a definitive condition, it certainly seems harder to argue for a similar case in terms of architecture as concrete artifice and built construct. A parallel between these two shifts on perspective will be drawn during the proposed discussion.

50 (McKenzie 2001, 9)

51 Ibid.

52 Ibid.

53 As understood in Shape Grammars, *embedding* as the act of creatively seeing *emergence* upon anything anywhere.

54 (Simon 1996)

55 Ibid.

56 " (...) a shift of orientation in architectural studies and practice, from what the building is to what it does, defining the first by means of the second" (Kolarevic and Malkawi 2005)

57 (Kolarevic and Malkawi 2005)

58 "In what ways does the building act? (...) How does the architectural work actually do? (...) A building acts to 'house' activities and experiences (...) the life on buildings that is predicated on use can be characterized as a borrowed existence, for it assumes that the room's or street's recognizable profile conform to our expectations of it".(Kolarevic and Malkawi 2005)

59 Refering to Gehry's Gehry's Experience Music Project from 2000, "(...)widely celebrated buildings of our time no longer insert art into functional solutions, but they use it to drape or cover them: yet here, too, sculptural form is essentially a compensation for the inadequacy of functionalist solutions"(Kolarevic and Malkawi 2005)

60 "In truth we do not so much enter rooms, but rooms (so to speak) happen to us.(...) Whether great or small, there is always some surprise when buildings are entered, and this results from the fact that the particularity of each comes from a past of which we are largely uninformed, each is 'charged with a history that exceeds memory' (Marion, In Excess), the result of unknown and unknowable initiatives. (...) Here we touch on an aspect of events that is essential –their unknowable beginnings and unexpected occurrence".(Kolarevic and Malkawi 2005)

61 "performative architecture is not the outcome of building or design technology, even up-to-the-minute digital technology. All technique can give architecture is enhanced functionality" (Kolarevic and Malkawi 2005)

62 "In what types of places do architectural operations unfold? (...) One obvious answer is the building's moving or (more exactly) moveable mechanisms."

"Design of this sort follows what might be called the device paradigm. The positions each element can take - the stops, levels and intervals - script the device's performance." (Kolarevic and Malkawi 2005)

63 In his analysis and although it is self evident and literal, Leatherbarrow starts by looking at the most obvious, prominent places where architecture acts interface with human subjects: on its operable, movable pieces. The argument is that operability can provide a range of action, a limit to the total movement that a part is capable of, within its physical constraints. Performance then happens in the enactment of this interface, in the act of operating a range. But then the spectrum of possible positions or states does not limit the way in which they can respond to overall changing unpredicted conditions, the author argues: "Approximate movements can be intended, but settings also yield, respond or react to unforeseen events. (...)The first step in the development of a performative architecture is to outline strategies of adjustment" (Kolarevic and Malkawi 2005)

64 "There is another site of architectural action in which performance is less obvious but no less determining: those parts of the building that give it its apparently static equilibrium, its structural, thermal, material stability. (...) When discussing these elements (columns and beams, retaining walls and foundations, but also cladding and roofing systems), it is common to talk of their "behavior" –not only talk but to anticipate it, even predict it."

"(architecture) must work with ambient conditions, such as gravity, winds, sunlight and so on. It must also work against these forces. And it must suffer their effects.(...) The economy of performance –in a site, as if on a stage –is always an exchange between forces and counterforces. To act is to counteract." (Kolarevic and Malkawi 2005)

65 (Mostafavi and Leatherbarrow 1993, 17)

66 " The design for performance of this sort is based not on a device but on a topography paradigm. Movement here is not the change of position but of state. (...) Stains on the building are evidence of its capacity for resistance. Crack in the wall show limited success on this front." (Kolarevic

and Malkawi 2005, 13)

67 "the point to be stressed is the building's eccentricity, its existence outside of itself, for its behavior testifies to a constitutional weakness at its center, a negativity at its heart, because it must wait on the environment to give it what it lacks –light, air, human events, and so on. Still, what the environment offers is always somewhat different from what was expected. The building's internal disequilibrium obliges it to accept into its make up conditions over which it has no control. With the different dimensions of the building's contingencies in mind, a second conclusion can be proposed: that architecture's performative labor has no end, for it is a task that continually presents itself anew" (Kolarevic and Malkawi 2005)

68 Autopoietic beings as defined by H. Maturana, entities that can transform and adapt in order to guarantee their autonomous existence.(Maturana and Varela 1980)

69 (Howell 2001)

70 Several *Muscle* projects have been developed through the research of the Hyperbody group, most notably the "NSA Inflatable Body" for the Non-Standard Conference, Paris 2003; the "Muscle Tower" project developed with students at TU Delft, 2004.

71 Mark Goulthorpe has continued developing the Aegis Hyposurface project since 2002, incorporating sensing and interaction to an originally pre-programmed robotic system. I was fortunate to collaborate with Mark for some time during one of the iterations of the Hyposurface when it was brought to the US and a piece of it was mounted at the Media Lab. I was stunned by its range of motion and spatial affection, yet also shocked by the huge actuation infrastructure to operate it.

72 (Merleau-Ponty and Smith 1995)

73 (Borchers 1968)

74 Kaustuv DeBiswas, a colleague of mine and also a PhD student in the Computation and Design

Group, was working in collaboration with Robert Aish at Bentley to develop this and other tools to expand the repertoire of functionalities of GC. My former experience as instructor of GC in several workshops in US, Europe ans South America enabled me to participate in the early stages of the then growing Smart Geometry community around parametric design systems, especially involving the GC community.

75 *Tortula Ruralis*, a species of of moss that can grow on rocks and hard surfaces and that can also survive underwater. Changes color when in presence of high levels of CO2 either in the air or dissolved in water.

Notes Part 3

76 (DeLanda 2005)

77 (Fernandez 2005)

78 Ibid.

79 (Bunschoten 2000)

80 (Thomas 2007)

81 (Thomas 2007)

82 The term comes from Aristotle notion of the relation of form and matter: *Hylo* - matter and *morphe* - form. But in this original concept matter was not necessarily related to a physical material presence, rather the substance that constituted form. Katie Lloyd Thomas describes a particular interpretation of this notion in Material Matters, focusing on the junction that originally differentiates matter from form. (Thomas 2007)

83 (Thomas 2007)

84 (Picon 2010)

85 (Alexander 1964), (Eisenman 2006), (Grobman and Neuman 2011), (Hagan 2009)

86 (Turing 2004, 60)

87 In 1947, Emil L. Post critiqued Turing's work on On Computable Numbers, publish almost a decade before, because its lack of definition about - according to Turing - arbitrary machine, arguing that he only went to further define his convention computing machine.

88 "The 'computable' numbers may be described briefly as the real numbers whose

expressions as a decimal are calculable by finite means. *(...)* According to my definition, a number is computable if its decimal can be written down by a machine." (Turing 2004)

89 Alonzo reviews Turing's work and called his abstract machines, Turing machines, to differentiate them from his own work on "effective calculability" which pairs with Turing' "computability" and that was published only a few months earlier than Turing's seminal work.(Church 1937, 43)

90 Although Turing is talking about 0 and 1 as possible figures to be written and read from the machine, he already expresses about them in term of "symbols" (Turing 2004, 59)

91 Leebeus Woods one wrote "Architecture's quality might rightly be judged, not by the problems it solves, but by the problems it creates."(Woods 2010)

92 (Reiser 2006, 93)

93 (Stiny 2008, 217)

94 This is a temporal definition for a concept I have not fully developed, but I am using in order to describe what should happen.

95 (Stiny 2008, 233)

96 Dated by the artist in the back of the canvas 1913, but not exhibited until "0.10" exhibition in 1915, in Russia.

97 Karshan notes that in conversations with Malevich's friend Hans Richter, the later admitted that Malevich feared the consequences of continuing with his revolutionary movement, one of the reasons why he sent and kept in Germany most of his work until his death.(Karshan 1975, 22, 24)

98 "I conceive Suprematism as the supremacy of pure sensitibity in crative art." He also then recounts the first impression from the audience by stating that when he "exhibited a picture that represented nothing but a black square in a white field, critics, and with them society, moaned: 'Everything that we loved is lost. We are ina desert... before us is a black square on a white ground'. But the gratyfing feeling of liberating non-objectivity tore me away into that 'desert', where nothing but sensitivity is actuality." (Karshan 1975, 20)

99 Structural Film was an experimental artistic film movement that grew strong in the US during the 60's and originated the Structural/Materialist films in UK in the 70's. "Structural/ Materialist film attempts to be non-illusionist. The process of the film's making deals with devices that result in demystification or attempted demystification of the film process." (Gidal 1976)

100 Gidal calls this the interpretation of Film as Material " The assertion of film as material is, in fact, predicated upon representation, in as much as 'pure' empty acetate running through the projector gate without image (for example) merely sets off another level of abstract (or non-abstract) associations. Those associations, when instigated by such a device, are no more materialist or nonillusionist than any other associations. Thus the film event is by no means, through such a usage, necessarily demystified. 'Empty screen' is no less significatory than 'carefree happy smile'."(Gidal 1976)

101 "In fact, the real content is the form, form become content. Form is meant as formal operation, not as composition." (Gidal 1976)

102 "(...)since perception of the flicker is frequency-related rather than actually rythmic, it is more fitting to speak of the projection frequency as a 'tonic'. Each pattern is then seen to suggest a 'chord' related to the 'tonic'. The patterns used were, in fact, constructed in such a way that each contains visible components contributed by up to three related frequencies. These flicker-triads represent, to

my knowledge, the first meaningful expression of harmonic principles to the visual sense." (Joseph 2008, 290)

103 (Donovan et al. 2008)

104 (Karshan 1975, 46)

105 Several authors (Stiny 1979; Knight 1993; Stiny 2008) have addressed the capacity of Shape Grammars to include qualititave aspects of shape, as color, line-weights, etc, over time. It is proposed in this text that the schemes that Ghape Grammars propose can operate with these and other qualitative features or attributes, even independent of shapes themselves, operating purely on the property intensity, distribution and organization level. A performative design strategy for physical attributes through Shape Grammars Schemas.

106 Colin Rowe, Robert Slutzky, *Transparency: Literal and Phenomenal* (Perspecta, vol 8 1963)

Colin Rowe, Robert Slutzky, Transparency: Literal and Phenomenal (Perspecta, vol 8 1963)

107 Anthony Viddler, *Losing Face: Notes on the Modern Museum.* (Assemblage, No 9 1989)

108 Gyorgy Kepes, *Language of Vision* (Dover Publications, 1995)

109 Liquid Crystals change from nematic phase to smectic phase, as the crystal molecules align themselves. During a nematic phase, the LC molecules behave and flow like a liquid, yet are all oriented parallel to each other like solid crystal molecules. The LC molecules have no positional order nonetheless they have a local orientational order. The concept of nematic phase is used in this text to describe an ambiguous state, like the one observed in LC molecules, between one condition and another, being solid and liquid simultaneously like Liquid Crsytals..

110 Neil Gershenfeld, *FAB*, The coming revolution on your desktop –from personal computers to personal fabrication (Basic Books, 2006)

111 (Merriam-Webster English Dictionary)

112 (Gemballa and Bartsch 2002)

113 (B. Bruet; J. Song; M. Boyce; C.Ortiz 2008)

114 (Kodera 1994)

115 (B. Bruet; J. Song; M. Boyce; C.Ortiz 2008)

116 Ibid.

117 Ibid.

118 Ibid.

119 Ibid.

120 (Reichert 2010)

121 (Reichert 2010)

122 Plugin for RHINOCEROS nurbs modeler software - (RHINOCEROS®, Robert McNeel and Associates, USA

123 Objet Connex™ 500, Objet Geometries Inc, USA.

124 The P. Senegalus was regularly fed dry fish food and during all the experiments and manipulations was handled in accordance with federal guidelines and regulations and approved by the MIT Committee on Animal Care (Protocol 0707-056-10) and the fish recovered well from the anesthesia. MIT has an Animal Welfare Assurance on file with the Office for Laboratory Animal Welfare (Assurance number A-3125-01).

125 Juha Song, PhD candidate, DMSE, MIT, Research Assistant at Ortiz Lab.

126 (Reichert 2010)

127 (B. Bruet; J. Song; M. Boyce; C.Ortiz 2008; Reichert 2010)

128 (Gemballa and Bartsch 2002)

129 (Sire 1990; Gemballa and Bartsch 2002; Gemballa and Röder 2004)

130 (Reichert 2010)

131 (Reichert 2010)

132 (David Kendall 1977; David G. Kendall 1989)

133 (Reichert 2010)

134 Yaning Li, Postdoctoral Research Associate at Ortiz Lab, DMSE, MIT

135 (Reichert 2010)

136 (Brown)

137 (Bielecki et al. 1996)

138 (Brown, Willison, and Richardson 1976)

139 (Brown 1985)

140 (Saxena, Chyr Lin, and Brown 1990)

141 (Svenson et al. 2004)

142 (Beguin and Aubert 1994)

143 (Brown 1985; Svenson et al. 2004)

144 (U.S. Army's Natick 1974; Hill 2010)

145 (J W Hwang et al. 1999)

146 (Svenson et al. 2004)

147 (Simon 1996)

148 (Stiny 2008)

Bibliography

Alberti, Leon Battista. 1991. *On the Art of Building in Ten Books*. The MIT Press, July 1.

Alexander, Christopher. 1964. *Notes on the Synthesis of Form*. Harvard University Press, October 24.

Allport, Gordon W. 1981. *Personality and Social Encounter*. University of Chicago Press, March.

B. Bruet; J. Song; M. Boyce; C.Ortiz. 2008. "Materials Design principles of ancient fish armour." *Journal of Nature Materials* 7 (September) (July).

Beguin, Pierre, and Jean-Pierre Aubert. 1994. The biological degradation of cellulose - Béguin -

2006 - FEMS Microbiology Reviews - Wiley Online Library. http://onlinelibrary.wiley.com/doi/10.1111/j.1574-6976.1994.tb00033.x/pdf.

Bielecki, Stanislaw, Alina Krystynowicz, Marianna Turkiewicz, and Halina Kalinowska. 1996. Bacterial Cellulose. In *Biopolymers*. Wiley-Interscience.

Borchers, Juan. 1968. *Institucion Arquitectonica*. Santiago, Chile: Ed. Andres Bello.

Brown, R M, J H Willison, and C L Richardson. 1976. "Cellulose biosynthesis in Acetobacter xylinum: visualization of the site of synthesis and direct measurement of the in vivo process." *Proceedings of the National Academy of Sciences* 73 (12): 4565 -4569.

Brown, R. M., Jr. 1985. "Microbial Synthesis of Cellulose." *BIOEXPO85*: 325-335.

———. Microbial Cellulose. http://www.botany.utexas.edu/facstaff/facpages/mbrown/position1.htm.

Brundtland Commission, United Nations. 1987. UN Brundtland Report "Our Common Future". United Nations. http://www.un-documents.net/wced-ocf.htm.

Bunschoten, Raoul. 2000. *Metaspaces*. Book & CD-ROM. Black Dog, July 1.

Cannon, Walter B. 1963. *Wisdom Of The Body*. Rev. and Enl. Ed. W. W. Norton and Company, Inc., April 17.

Church, Alonzo. 1937. "Review of On Computable Numbers, with an application to the Entscheidungsproblem." *The Journal of Symbolic Logic* 2 (1) (March): 42, 43.

Corner, James. 1999. *Recovering Landscape: Essays in Contemporary Landscape Theory*. 1st ed. Princeton Architectural Press, August 1.

DeLanda, Manuel. 2005. *Intensive Science & Virtual Philosophy*. Continuum, August 14.

Donovan, Tara, Lawrence Weschler, Nicholas Baume, and Jen Mergel. 2008. *Tara Donovan*. The Monacelli Press, September 16.

Eisenman, Peter. 2006. *The Formal Basis of Modern Architecture: Dissertation 1963, Facsimile*. 1st ed. Lars Müller Publishers, July 20.

Fernandez, John E. 2005. *Material Architecture: emergent materials for innovative buildings and ecological construction*. Architectural Press, December 14.

Gemballa, Sven, and Peter Bartsch. 2002. Architecture of the integument in lower teleostomes: Functional morphology and evolutionary implications - Gemballa - 2002 - Journal of Morphology - Wiley Online Library. http://onlinelibrary.wiley.com/doi/10.1002/jmor.10007/pdf.

Gemballa, Sven, and Katrin Röder. 2004. "From head to tail: The myoseptal system in basal actinopterygians." *Journal of Morphology* 259 (2) (February 1): 155-171. doi:10.1002/

jmor.10175.

Gidal, Peter. 1976. Structural Film Anthology. Text. http://www.luxonline.org.uk/articles/theory_and_definition(1).html.

Grobman, Yasha, and Eran Neuman. 2011. *Performalism: Between Form, Function and Performance in Contemporary Architecture*. 1st ed. Routledge, July 15.

Hagan, Susannah. 2009. Performalism: environmental metrics and urban design. Harvard University "ecological urbanism" conference, April 4. http://artsresearch.brighton.ac.uk/research/academic/hagan/activity/Hagan.performalism.pdf.

Heidegger, Martin. 2001. *Poetry, Language, Thought*. Harper Perennial Modern Classics, November 1.

———. 2002. *On Time and Being*. University Of Chicago Press, June 1.

Hill, Marquita K. 2010. *Understanding Environmental Pollution*. Cambridge University Press, May 24.

Howell, Larry L. 2001. *Compliant Mechanisms*. Wiley-Interscience, July 25.

Hwang, J W, Y K Yang, J K Hwang, Y R Pyun, and Y S Kim. 1999. "Effects of pH and dissolved oxygen on cellulose production by Acetobacter xylinum BRC5 in agitated culture." *Journal of Bioscience and Bioengineering* 88 (2): 183-188.

Jarzombek, Mark. *Thresholds : Massachusetts Institute of Technology. Dept. of Architecture : Free Download & Streaming : Internet Archive*. http://www.archive.org/details/thresholds181999mass.

Joseph, Branden W. 2008. *Beyond the Dream Syndicate: Tony Conrad and the Arts after Cage*. illustrated edition. Zone Books, May 30.

Karshan, Donald. 1975. *Malevich the Graphic Work 1913-1930*. Macmillan Pub Co, June.

Kendall, David. 1977. "The Diffusion of Shape." *Avances in Applied Probability* 9 (3).

Kendall, David G. 1989. "A Survey of the Statistical Theory of Shape." *Statistical Science* 4 (2) (May): 87-99. doi:10.1214/ss/1177012582.

Knight, Terry W. 1993. "Color Grammars: The Representation of Form and Color in Designs." *Leonardo* 26 (2) (January 1): 117-124. doi:10.2307/1575896.

Kodera, Haruto. 1994. *Jurassic Fishes: Selection - Care - Behavior*. TFH Publications, November.

Kolarevic, Branko, and Ali Malkawi. 2005. *Performative Architecture: Beyond Instrumentality*. Routledge, January 21.

Leatherbarrow, David. 2002. *Uncommon Ground: Architecture, Technology, and Topography*. The MIT

Press, March 7.

Lefaivre, Liane, and Alexander Tzonis. 2004. *The emergence of modern architecture : a documentary history from 1000 to 1810*. London ;;New York: Routledge Taylor & Francis Group.

Lynn, Greg. 1998. *Folds, Bodies & Blobs : Collected Essays*. 0th ed. La Lettre volÃ©e, June 1.

———. 1999. *Animate Form*. 1st ed. Princeton Architectural Press, January 1.

Maturana, H.R., and F.J. Varela. 1980. *Autopoiesis and Cognition: The Realization of the Living*. 1st ed. D. Reidel Publishing Company.

McKenzie, Jon. 2001. *Perform or Else: From Discipline to Performance*. 1st ed. Routledge, April 25.

Merleau-Ponty, Maurice, and Colin Smith. 1995. *Phenomenology of Perception: An Introduction*. 1st ed. Routledge, January 13.

Merriam-Webster, English Dictionary. Dictionary and Thesaurus - Merriam-Webster Online. http://www.merriam-webster.com/.

Moore-Ede, Martin C., Frank M. Sulzman, and Charles A. Fuller. 1984. *The Clocks That Time Us: Physiology of the Circadian Timing System*. Harvard University Press, February 15.

Mostafavi, Mohsen, and David Leatherbarrow. 1993. *On Weathering: The Life of Buildings in Time*. The MIT Press, March 22.

Mostafavi, Mohsen, Gareth Doherty, and Harvard University. 2010. *Ecological Urbanism*. 1st ed. Lars Müller Publishers, May 1.

Mrosovsky, N. 1990. *Rheostasis: The Physiology of Change*. Oxford University Press, USA, August 9.

Norberg-Schulz, Christian. 1984. *Genius Loci: Towards a phenomenology of Architecture*. Rizzoli.

Palladio, Andrea. 2002. *The Four Books on Architecture*. The MIT Press, September 9.

Pendleton-Jullian, Ann M. 1996. *The road that is not a road and the Open City, Ritoque, Chile*. MIT Press, November 1.

Picon, Antoine. 2010. *Digital Culture in Architecture*. 1st ed. Birkhäuser Architecture, March 1.

Pinker, Steven. 2002. *The Blank Slate: The Modern Denial of Human Nature*. 1st ed. Viking, September 30.

Reichert, Steffen. 2010. Reverse Engineering Nature:Design Principles for Flexible ProtectionInspired by Ancient Fish Armor of Polypteridae. MS, MIT.

Reiser, Jesse. 2006. *Atlas of Novel Tectonics*. 1st ed. Princeton Architectural Press, February 1.

Ryn, Sim Van der, and Stuart Cowan. 1995. *Ecological Design*. 1st ed. Island Press, November 1.

Saxena, Inder, Fong Chyr Lin, and R. M. Brown Jr. 1990. "Cloning and sequencing of the cellulose syntahse catalytic subunit gene of Acetobacter Xylinum." *Plant Molecular Biology* 15: 673-683.

Schulkin, Jay. 2004. *Allostasis, Homeostasis, and the Costs of Physiological Adaptation*. 1st ed. Cambridge University Press, October 25.

Schumacher, Patrik. 2008. Parametricism as Style - Parametricist Manifesto. http://www.patrikschumacher.com/Texts/Parametricism%20as%20Style.htm.

Simon, Herbert A. 1996. *The Sciences of the Artificial - 3rd Edition*. 3rd ed. The MIT Press, October 1.

Sire, Jean-Yves. 1990. "From ganoid to elasmoid scales in the actinopterygian fishes." *Netherlands Journal of Zoology* 40 (1-2): 75-92.

Spens, Michael. 1996. *Landscape Transformed*. Academy Editions, April 17.

Sterling, P, and J Eyer. 1988. "Allostasis: a new paradigm to explain arousal pathology." *Handbook of Life Stress, Cognition and Health*: 629-649.

Stiny, George. 1979. *Algorithmic Aesthetics: Computer Models for Criticism and Design in the Arts*. Univ of California Pr, May.

———. 2008. *Shape: Talking about Seeing and Doing*. The MIT Press, March 31.

Svenson, A, E Nicklasson, T Harrah, B Panilaitis, and D. L. Kaplan. 2004. "Bacterial cellulose as a potential scaffold for tissueengineering of cartilage." *Biomaterials* (26): 419-431.

Thomas, Katie Lloyd. 2007. *Material Matters: Architecture and Material Practice*. 1st ed. Routledge, May 15.

Turing, Alan M. 2004. *The Essential Turing: Seminal Writings in Computing, Logic, Philosophy, Artificial Intelligence, and Artificial Life plus The Secrets of Enigma*. Oxford University Press, USA, November 18.

U.S. Army's Natick. 1974. "Waste cellulose possible glucose source." *Chemical & Engineering News* 52 (21) (May 27): 20. doi:10.1021/cen-v052n021.p020.

Vitruvius. 2010. On Architecture. Roman Antiquity History and Latin Texts. Trans. Bill Thayer. *Lacus Curtius*. http://penelope.uchicago.edu/Thayer/E/Roman/Texts/Vitruvius/2*.html.

Vitruvius, Marcus. 2005. *Vitruvius. The Ten Books on Architecture: Translated by Morris Hicky Morgan*. Adamant Media Corporation, November 30.

Woods, Lebbeus. 2010. of A HUMAN NATURE « LEBBEUS WOODS. http://lebbeuswoods.wordpress.com/2010/03/31/of-a-human-nature/.