Alternatively, as a construction tool, information-rich materials and self-assembling systems can be utilized in a variety of applications from radical scenarios to humble bricklaying practices. Architects often spend significant energy, time, and money in controlling the quality of their structures built around the world with explicit drawings, local tolerances, and building practices. Alternatively, information-rich materials could contain assembly logic, be shipped to site, and either ensure complete and accurate assembly by eliminating the possibility for wrong moves, or simply constrain the possible assembly outcomes to a spectrum of acceptable solutions. This proposal building materials as a contractor’s designer/odeck, making decisions and aiding the assembly step by step as the building is constructed. Other construction applications may utilize greater off-site energy and time by infusing materials with information or dynamic capabilities so that while on-site the systems can be quickly deployed, released, and self-assembled. Off-site energy and information input can help minimize on-site time, cost, and energy, which constitute a significant portion of architectural budgets and energy expense. These applications demonstrate a far more humble scenario for utilizing programmable materials and the opportunities afforded by cross-disciplinary advances for a new vision of self-assembled construction.

6 CONTRIBUTIONS

The stage is set for a new paradigm of computation to reach beyond the screen and offer programmability and dynamic behaviors across scales, materials, and design processes. Various disciplines are blurring the boundaries with scientists, engineers, and designers making complementary findings through a variety of mediums and scale-lengths. This is also a time of increasing demands on our processes of physical production and construction, including environmental, energy, labor, time, and cost constraints. Similarly, new software and fabrication techniques are pushing computational processes into new realms, offering potentials for the design and materials that we utilize as architects. We will see increasing opportunities for automated construction techniques and ultimately information-rich materials that inform the building process and self-construct. As our knowledge base and ability to author computation through software, materials, and construction increase, we will be less reliant on industrial machinery and seek passive and embedded intelligence, where materials inform the people and machines that surround them. Ultimately, designer, machine, material, and program will collaborate seamlessly at nano to macro scales, physically and digitally, utilizing organic and inorganic behaviors for new paradigms of design and production.

7 ACKNOWLEDGMENTS

The Self-Assembly Line was a collaboration with Arthur Olson of the Molecular Graphics Laboratory at the Scripps Research Institute, La Jolla, CA. The Self-Assembly Line project would not have been possible without the generous support of the project team: Martin Seymour, Andrew Manto, Erioseto Wibawa, and Justin Gallagher. The Self-Assembly Line was funded by TED Conferences and SEED Media Group.

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ABSTRACT

This paper positions the development and performance of a responsive acoustic envelope system, called Resonant Chamber, within discourses in ecology, systems theory and cybernetics. The project is described through two dominant threads. First, a synthetic design process that entails engaging simultaneous computational and physical investigations which inform each other through various feedback and control regimes - from simulation and testing frameworks to material limits and behaviors to geometric, technological and manufacturing limitations or constraints. Second, the paper elaborates on the embedded communication, feedback and actuation systems that transform its performance as a kinetic, responsive environment, allowing for the possibilities of active acoustic control and open-ended interaction with inhabitants. Throughout the process, the designer operates in an adaptive mode, dynamically shaping possibilities, navigating digital, physical and affective logics, constraints, behaviors and opportunities.

DESIGN ECOLOGIES FOR RESPONSIVE ENVIRONMENTS:

RESONANT CHAMBER, AN ACOUSTICALLY PERFORMATIVE SYSTEM

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1 INTRODUCTION

Resonant Chamber is part of an ongoing research effort exploring kinetic and interactive envelope systems, emerging from an interest in developing architectural environments that are shaped through the complex interplay of matter, geometry, forces, information and activity. More specifically, in this project, we have been exploring the potentials for a dynamic system that has the potential to transform non-purpose-built spaces into flexible environments for multiple acoustic performance situations. The initial prototype of Resonant Chamber was installed in January 2012 at the University of Michigan’s Taubman College of Architecture and Urban Planning (Figure 1). The prototype is comprised of a thick, rigid, acoustically active surface consisting of reflective, absorptive and electroacoustically enhanced panels equipped with actuators and communication technologies that make it capable of kinetic adjustment, actively transforming the acoustic performance of a host space relative to different types of aural demand. This project builds upon work in tessellated and kinetic architectures that engage acoustics undertaken by David Geary, Brad Pitzer, Masa Maru and Eddy Spies, among others. The research of Resonant Chamber, which is still ongoing, aims to advance this work by exploring the application of (1) multi-functional material treatments within a (2) algorithmically variable acoustic space paired with (3) kinetic operation and (4) digital control via environmental sensing. The broader project is envisioned to become a dynamic, sensor-equipped platform whose ambition is less concerned with providing ideal acoustics and more interested in developing variable acoustic space that can interact with inhabitants and performers through dynamic physical enclosure and sound, itself becoming a performing instrument conceived of at the scale of architecture. This paper positions the wider project, its design and physical prototyping process within contemporary ecological paradigms, emphasizing the adaptive co-evolution of architectural material, form and performance in the context of digital analysis, manufacture and communications.

Ecology is defined most generally as the study of relations between dynamic interacting agents in co-evolution with their environment. Within the latter half of the twentieth century, the "ecological paradigm" and its language of systems theory has come to dominate the conceptual frameworks of not only the sciences but also fields such as economics, philosophy, politics and the other humanities, as well as culture at large (Capra 1999). The term ecology was first coined by the 19th century German biologist, naturalist and artist Ernst Haeckel and is derived from the Greek word οίκος (oikos), meaning "household" and logos, meaning "study" (Dunin and Barnett 2004). Haeckel, in his 1866 text Generelle Morphologie des Organismus, writes that "by ecology, we mean the whole science of the relations of the organisms to the environment including, in the broadest sense, all the conditions of existence. These are partly organic, partly inorganic in nature, both, as we have shown, are of the greatest significance for the form of organisms, for they force them to become adapted" (Taylor 2011). Although the science of ecology had its origins in the taxonomic biological study of organisms, the field has since grown significantly to encompass the synthetic totality of patterns relations within the environment, and combines both evolutionary and systems thinking approaches (Dunin and Barnett 2004).

As an epistemological foundation that informs design processes, an ecological approach presents a promising relationship of part to whole through the condition of evolutionary intertwinement where things can no longer be extracted from their relational and contextual webs; where the boundaries between matter, forces, software, code, logic and environment are of lesser significance and the focus lies instead on their relationships and information exchanges. Ecological thinking also dissolves traditional ontological dichotomies (culture/nature, subject/object, natural/artificial), replacing them with the functional relation of system and environment (Milne 2010). Resonant Chamber departs from the conventional dualism of architecture as a discrete object, developing instead a spatial envelope conceived of as a soft system, a dynamic skin of information and exchange (Price et al. 2012) intended not to constitute a dynamic environment, but also to be continually informed and re-produced by the feedbacks of acoustic and human interactions. Within the history of ideas, theories and models of ecology have themselves co-evolved with theories and models of cybernetics that is, mechanisms of control and communication, or feedback, which form the basis of evolutionary models. Gregory Bateson, in his seminal Steps to an Ecology of Mind, positions cybernetics as a fundamental (level of) defining mind, intrinsic to the processes of ecological adaptation and homeostasis, and determinant of which agents and ecologies persist and which do not survive (Bateson 2000), the ecological methods of Eugene and Harold Long relied heavily on cybernetic models, combined with General Systems Theory, to understand patterns of energetic flows, nutrient cycles and emergent within ecosystems (Bergman 2001). In his article ‘The Architectural Relevance of Cybernetics,’ Gordon Peak speculated on some of the transformations that cybernetic theory would have on the discipline, the paradigm shift from the design of buildings to the design of systems; the concepts of built environments cooperating and co-adapting with inhabitants; the growing usefulness of computer assisted design tools; and a transformation of the paradigm of design, that identifies the designer as a controller (hence Pask takes care to distance from purely managerial models and further defines as ‘an odd mixture of catalyst, crutch, memory and arbiter’) of control systems (Peak 1991). Indeed, this reframing of design agency can be further advanced by borrowing from models of biotic ecosystems theory to develop a refined understanding of the role of the designer as a kind of adaptive manager, negotiating within the hierarchically nested scales, interactions and logics of physical, informational and environmental domains (Ray 2002), at once charged with convening of systemic capability simultaneously with the potential applications and controls logics of performative delivery.
2 SYNTHETIC PROTOTYPING, COMPUTATIONAL AND PHYSICAL DESIGN ECOLOGIES

The design of systems entails a process that engages simultaneous practices, both digital and physical, that inform each other through various feedbacks and control regimes. Through an iterative cycle of simulation and prototyping the formal, spatial, material and manufacturing logics of Resonant Chamber were evaluated against acoustic performance simulations to be implemented into the first physical prototype. In the following sections, this nonlinear process of design is described thematically, emphasizing the adaptive role of the designer in negotiating the exchanges and feedbacks between computational analysis and physical prototyping.

2.1 Simulation Systems and Computational Environments: Acoustics

The contemporary computational environment includes a suite of increasingly sophisticated tools for predictive modeling and simulation incorporating physical behavior and material performance characteristics within dynamic models. The evaluation of acoustic performance involves a number of complex and interacting factors including: spatial volume and proportion, critical distance, reverberation time, noise reduction coefficient, reflection density, noise levels, dB ranges, material surface characteristics (smooth vs. textured), surface exposure and electrosound amplification. In order to account for these variables, several simulation programs with different capabilities were utilized concurrently to evaluate various combinations of material distribution and potential geometric configurations of the system. Initial geometric configurations within a defined space were evaluated using ray-tracing of the digital surface model, as well as in CATT (an acoustical sound pressure level analysis software), for their ability to diffuse and focus sound reflections (Figure 2).

A concave surface focused reflections at the listening plane when directly under the cells surface while a convex surface provided evenly diffused reflections at the listening plane at a higher dB range than the flat surface. From these initial simulations we could conclude that the rigid origami surface with variable absorptive and reflective panels could be configured to achieve a wide range of reverberation times, thereby offering opportunities for multiple program uses within a space (Figure 3).

2.2 Simulation Systems and Computational Environments: Geometry

Previous work by the authors in responsive envelopes has explored cable-net tensegrity sewn as a lightweight, distributed structural framework that would be able to support kinetic deformation (Falik et al. 2011). In this project rigid origami was explored as a flexible geometric system that would make it possible to achieve predictable axial outcomes through the variation of a continuous surficial assembly. Rigid origami is appropriate for use in kinetic structures as it has the property of being a developable, flat-foldable (folded from a single sheet) surface whose transformation can be substituted with rigid panels and hinges that maintain system performance within thick material surfaces (Tachi 2010a). As a result of the interconnected reactions between interior vertices and crease lines which determine the DFS of the surface and by virtue of the system of linkages comprising its structure, physical actuation in one location has calculable effects on the movement of adjacent elements, thus reducing the number of points of actuation and therefore the number of physical motors and actuators required to induce overall forward transformations, as compared to a cellular system.

Computational acoustic testing confirmed the plausibility for the use of rigid origami as a flexible acoustic system that could dynamically alter overall spatial volume, with volumetric deformations producing changes in resulting reverberation time and gross deformation influencing directional control of sound waves and reflections. This geometry would also allow for localized surface manipulation (i.e. folding) to vary the ratios and orientation of exposed reflective and absorptive surfaces. Real-time response digital models were used to anticipate the geometric limits of the surface and to provide information for the physical constraints and actuation logics that would transform the surface in space in order to control acoustic energies. Basic origami software Freeform Systems and actual performance. While electroacoustic controls have previously been combined within static systems and actual performance. While electroacoustic controls have previously been combined within static systems and actual performance. While electroacoustic controls have previously been combined within static systems and actual performance. While electroacoustic controls have previously been combined within static systems and actual performance. While electroacoustic controls have previously been combined within static systems and actual performance. While electroacoustic controls have previously been combined within static systems and actual performance. While electroacoustic controls have previously been combined within static systems and actual performance. While electroacoustic controls have previously been combined within static systems and actual performance. While electroacoustic controls have previously been combined within static systems and actual performance. While electroacoustic controls have previously been combined within static
capable of being milled to various depths to achieve different panel compositions. ARUP Acoustics tested a series of geometric shapes and sizes for subjective acoustic impressions, sensitivity and frequency response. In the sensitivity test, the 457.2 mm (18") triangle, square, and the 605mm (24") triangle provided the smoothest curve through the dB range across the third octave frequency (Figure 6). These results were fed back into the geometric evaluation of particular origami patterns and their potential spatial deformations. The team selected the 457.2 mm triangle for use in the prototype based on its combined acoustic performance, granularity of the resulting system afforded by its size and for its ability to be deployed within a versatile tessellated pattern (Figure 7). The performance of the initially selected triangular plywood panels was subsequently tested with a number of DML components to determine final DML equipment specifications (Figure 8).

2.4 Physical Prototyping: Operation and Manufacture

While paper origami's fold-ability relies on the fundamental physical property of optimum zero thickness, acoustic performance requires materials with variable thicknesses and three-dimensional profiles. Following the work of Tachi (Tachi 2010b), we prototyped various joint profiles, lamination techniques and membrane hinges that would allow for the flat-folding of the thick composite surfaces (Figure 9). Once prototype materials and geometries were selected, a series of manufacturing and physical assembly tests were undertaken within the Taubman College FABLab to further define the material assemblies and composition of the first prototype (Figure 10). These included material prototyping with laminated membrane hinge assemblies, development of panel profiles for folding, milling tests for various thicknesses and laminate styles of plywood; as well as milling tests for sound absorptive materials with three and five axis milling equipment. Porous Expanded Polypropylene (PEPP) was selected for its noise reduction coefficient of .85 for sound dampening effects, for its ability to contribute to panel rigidity and for its ease of milling to achieve the desired geometric configurations for flat-folding origami. Digital knife cutting was used to precut and crease the fold line of the membrane layer, which guides alignment between adjacent panels during assembly. Three types of performative composite panels were developed—reflective, absorptive, and electroacoustic—within a dimensionally standard panel framework consisting of 19mm plywood frames sandwiched between 6.35mm face and back panels (Figure 11). sacheting component parts that could be assembled into a composite panel allowed for material efficiencies and streamlined manufacturing logics while allowing for functional variations within the system. By creating a face panel separate from the frame, each panel type could be uniformly bonded to the continuous membrane of the hinge. A cap on the frame could enclose either a DML exciter component, electronic controls, or a solid acoustic surfaces (Corteel et al. 2011), integration within a kinetic surface has not yet been widely explored. The introduction of electroacoustics provides for an augmented level of material control as well as directional sound reinforcement, which can then be actively manipulated for greater acoustic control (Kiaa et al. 2004). Electroacoustics also add an entirely different interactive interface from the spatial-material sound control approach of the physical system, opening up a variety of possible applications for interactive sound installations, immersive live performance spaces or acoustically enhanced learning facilities.

The team explored extruded honeycomb aluminum, glass, glass-fiber reinforced gypsum, Plexiglas and bamboo plywood as potential panel materials. The bamboo plywood was assessed as providing a higher quality performance in mid-tone frequencies utilized in electroacoustic amplification and
For the second prototype we are collaborating with Dr. Jerome Lynch at the University of Michigan to incorporate a Narada based system of communication (Figure 12). The Narada system achieves wireless sensing, actuation and data processing in a low power, high-resolution module. Its 14-bit analog-to-digital converter allows a range of sensors to be simultaneously interfaced with the device and locally processed to respond within the distributed system. Similarly the 12-bit digital-to-analog converter can process voltage commands to the on-board potentiometer of the linear actuators to control stroke length and position feedback. On-board data processing offers distributed computational response rather than coordinating all inputs through a central programmed logic controller.

Resonant Chamber is conceived of as an open-ended system, a platform or infrastructure capable of being integrated with a range of sensing and actuation regimes with its performative goals remaining underspecified and open-ended (to use Pask’s terminology) as opposed to predefined. Integration of distributed sensing, processing, robotic actuation and electroacoustic technologies within the physical system of Resonant Chamber allows for custom geometric and acoustic response across the continuous surface and catalyzes dynamic and evolving relationships between sound and space, performer and audience, architecture and inhabitants (Figure 13).

For the first prototype installation of three seven-cell clouds, the system’s actuation was set to operate in a pre-programmed loop, testing basic operation, material and technological limits and spatial conflicts at full scale. For the second prototype, we are currently working on integrating a number of acoustic, motion and proximity sensors linked to on-board digital controls which will determine physical and electroacoustic response of the system. These would allow for the possibility of a number of performance regimes regarding acoustic output and participant engagement. For example, microphone-based systems can prioritize sound level samples to an average decibel range and inform the sound dampening cells to adjust accordingly, allowing more or less reverberation and optimizing aural conditions for listening to specific types of music or performance.
Through the introduction of human interaction capabilities, the Resonant Chamber can also operate as a responsive system (Fisher et al., 2012). We are currently exploring the incorporation of multi-modal sensors such as Microsoft’s Kinect to dynamically track locations of sources and receivers in order to calibrate performance spaces relative to audience position, number and spatial distribution. The control system might also be embedded with machine learning capabilities and practices beyond acoustic optimization, inviting new forms of interactive play and live performance to develop.

Alternatively, in a context of axial accessibility, individual hearing requirements can be addressed through the use of RFID receivers, tuning local acoustical conditions to the capacities of phantoms.

The ecological paradigms of system/environment intertwinement, co-evolution and cybernetics inform not only the hybrid computational and physical method by which the Resonant Chamber system and its components is being developed, but also influence an adaptive and open-ended role for the designer, both in terms of their relationship to the design process and also in terms of the constructed system’s performance and goals. As such, the Resonant Chamber becomes a system continually able to be shaped through the interests of multiple agents and agendas, rather than limited by its initial perceived function and application.

ACKNOWLEDGMENTS


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ILLCIT FABRICATION, FABRICATION BEYOND CRAFT: THE POTENTIAL OF TURING COMPLETENESS IN CONSTRUCTION

ABSTRACT

Over the last decades numeric control (NC) and robotics have become firmly grounded within architectural practice. While the hacking of CNC machinery, the development of production strategies specifically oriented toward architectural applications, and the development of robot and-effectors implementing new architectural fabrication processes are perceived as forms of craft, a vacant contradiction surfaces. While robotics has essentially developed in the field of industrial automation, in architecture, NC is increasingly understood as a form of digital craft. This year’s ACADIA conference is no exception; it refers to the increasing role of robotics in construction as digital craft. Is this a contradiction in terms? If so, what is the origin of this contradiction, and what consequences are implied? The state of the art in lights-out manufacturing (LONM) for plants operate unattended for a month, while on the other hand, handheld machining tools are being developed. The scope of NC has become so vast. The role of NC in fabrication is at a pivotal point in architecture, due to its widespread adoption, limitations of the approach have come within view. This article seeks to identify such limitations and backdoors and to develop a critical position for the coming decade of NC in manufacturing architecture.