Action Research and Prototype Testbeds:
Prioritizing Collaborative Making in Architectural Research

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ABSTRACT:

As the discipline of architecture becomes ever more concerned with the development of high performance sustainable buildings and systems requiring an increasingly complex set of interrelated and closely integrated technologies, assemblies, and material methods, the questions of what forms of research approach and what project contexts might best facilitate the advancement of related research are critical. Research methods that focus on isolated and specific aspects of building science, systems engineering, or occupant interface undertaken in the highly controlled environment of the laboratory or evaluated with simulation tools have done much to advance our understanding of individual components that might comprise the next generation of high performance buildings. However, given the complexity of integrated architectural research projects that address environment, performance and interaction, requiring multiple cycles of research and development, large interdisciplinary teams, and project cycles discordant with curricular duration, new research formats may be required. Within this context, the practices of 'action research' methodologies for interdisciplinary collaboration and the construction of physical prototype testbeds as both a focus for applied research and as living laboratories for evaluation, measurement and testing, offer a compelling pairing of practice and product. The model of action research developed by humanities and educational research teams is extended and modified to develop a format applied to architectural research projects. These strategies offer specific advantage to the architectural researcher, whose work often requires methodologies outside those of traditional scientific or humanities models, and greatly benefits from what Monica Ponce de Leon has referred to as "research through making". This paper describes the organizational and logistical context of two recent design research projects (*North House Prototype* and *The Stratus Project*) in the context of an action research framework as a means to illuminate this discussion.

CONFERENCE THEME: On Approaches: Research conceptual frameworks and their effect on forms of collaboration.
KEYWORDS: high performance buildings, architectural research models, architectural prototypes, action research, sustainable buildings

INTRODUCTION

The set of research practices known as *action research* refers to a format of research investigation in the context of applied efforts to improve the quality of an organization and its performance[3]. Action research typically is designed and conducted by practitioners who analyze research outcomes to improve their own practice and operational methods.(Bennett 1994) Initially focused on direct application to advancing educational practices with the goal of fostering sustained improvements in schools, it has since been engaged by a range of disciplines where the benefits of reflection on both process and outcome are structured to occur within cycles of the research project's design. Action research has been described by a range of terms, including *participatory research, collaborative inquiry, emancipatory research, action learning, and contextual action research*. Each refers to a set of cyclical practices that involve an iterative process of problem identification, action, evaluation and refinement. (O'Brian 2001)

> Action research...aims to contribute both to the practical concerns of people in an immediate problematic situation and to further the goals of social science simultaneously. Thus, there is a dual commitment in action research to study a system and concurrently to collaborate with members of the system in changing it in what is together regarded as a desirable direction. Accomplishing this twin goal requires the active collaboration of researcher and client, and thus it stresses the importance of co-learning as a primary aspect of the research process. (Gilmore, Krantz and Ramirez 1986)

What distinguishes the action research approach from other research formats, and, in this context, conventional design practices, is the emphasis on systematic study informed by *theoretical* considerations. Throughout the process, emphasis is placed on refining methodological tools "to suit the exigencies of the situation, and on collecting, analyzing, and presenting data on an ongoing, cyclical basis" (O'Brian 2001). While a variety of specific process models have been articulated, (MacIsaac 1995, Susman 1983) what is of import to our consideration here are the overarching principles that underlie action research methods, and the reflection as to how this structure might re-inform approaches to architectural research techniques particular to complex design projects. Winter, (1989) outlines six principles underlying action research praxis as applied to a variety of cycle-based models of inquiry:

1. The presence of *Reflexive Critique* in evaluating the situation of the research project to explicitly reveal through reflection upon the issues and processes comprising the project and its situation and make explicit the interpretations, biases, assumptions and concerns upon which judgments are made.
2. The presence of a *Dialectical Critique* as a means to illuminate relations surrounding phenomena and context, and elements that constitute a particular phenomenon. Specifically, through this form of interrogation, emphasis is placed on identifying "those constituent elements that are unstable, or in opposition to one another. These are the ones that are most likely to create changes."
3. Participants in an action research project are co-researchers. The principle of *Collaborative Resource* presupposes that each participant's insights possess equal agency as potential resources in formulating outcomes and insights negotiated among the participants. This principle is intended both to challenge the structure of perceived senior authority from the prior status of a participant, and open for consideration the contradictions both between many viewpoints and within a single viewpoint
4. In research projects that explicitly seek to challenge underlying assumptions or commonly held disciplinary consensus around an issue, significant risk may be perceived by participants relative to pre-existing formal hierarchies (economic, intellectual, academic, disciplinary etc) in expressing interpretations, perspectives or ideas around a particular matter. This potential reality is identified early in the research process and work is structured with the tacit understanding that all are equally exposed through participation, and that knowledge advancement will occur equally regardless of specific project outcomes.
5. The nature of the research embodies a multiplicity of views, commentaries and critiques, leading to multiple possible actions and interpretations. This plural structure of inquiry requires a plural text for reporting. A report, therefore, acts as a support for ongoing discussion among collaborators, rather than a final conclusion of fact.
6. For action researchers, theory informs practice, practice refines theory, in a continuous transformation. In any setting, people's actions are based on implicitly held assumptions, theories and hypotheses, and with every observed result, theoretical knowledge is enhanced. The two are intertwined aspects of a single change process. It is up to the researchers to make explicit the theoretical justifications for the actions, and to question the bases of those justifications. The ensuing practical applications that follow are subjected to further analysis, in a transformative cycle that continuously alternates emphasis between theory and practice.

From the perspective of sustainable design practice, and specifically architectural design praxis, the principles outlined above have clear affinity with the Integrated Design Process (IDP) (Busby 2007). However, in the particular considerations of action research models, inflections emerge that are particularly instructive in the academic context (in which much architectural research is undertaken), where there is explicitly greater horizontality across disciplinary participants than is structured in professional practice contexts and where research team members are also embedded within the hierarchical systems of the academy and research funding regimes. These strategies offer specific advantage to the architectural researcher, whose work often requires methodologies outside those of traditional scientific or humanities models, and greatly benefits from "research through making". With

Figure 1: Collaborative design environments across cycles of design and making; (above) Student and faculty team discuss overarching principles during initial project workshop; (below left) Architecture and engineering students developing working drawings in the project room at the University of Waterloo; (below, middle, right) Students working on site with custom fabricators and industry partners during the build. (Team North 2009)

respect to application in the context of architectural research focussed on delivering environmentally responsive design outcomes, we propose the centrality of the development of prototype testbeds, in parallel with the implementation of action research methods for collaboration. The construct of the testbed not only offers the value to the research project of providing a physical manifestation through which to evaluate the validity and or effect of experimental proposals, but forms a physical locus around which research participant discourse is structured – capable of providing complex forms of feedback to the research undertaking.

The following sections are intended to illustrate some of the potentials of this proposition, with the hopes of structuring provisional notes towards a model of architectural action research through the discussion of two recent research projects developed by the authors that focus on team based research projects prioritizing environmental performance; the *North House Prototype*, and *The Stratus Project*.

NORTH HOUSE

The North House project was initiated in response to the US Department of Energy's Solar Decathlon initiative, and evolved into a funded design-research project to develop a high-performance, responsive, net energy producing prefabricated prototype house specifically designed for northern climate conditions, as well as to question the ways in which architectural design can foster new forms of sustainable living. The project was selected as one of twenty finalists in the US Department of Energy's 2009 Solar decathlon, and is a collaboration by the University of Waterloo, Ryerson University and Simon Fraser University operating with a variety of partners under the umbrella of *Team North*[4]. A goal specific to the North House is to challenge the dominant 'good practice' paradigm projected by benchmark and measurement metrics such as LEED, which assume that buildings with high window-wall ratios are considered to be energy inefficient. Low-energy and passive buildings, particularly in northern climates, typically do not have highly glazed facades, as windows are traditionally the building envelope components that have the least insulation value and the highest air leakage coefficient. Most energy standards restrict the window-wall ratio to 40% or less. The North House aimed to deploy recent advances in glazing technology, shading systems, thermal mass, and control systems to develop a high performance house with a highly-glazed façade (75% window-wall ratio), which, when combined with on-site solar power, can reach goals of net-energy production while radically revisiting the ambitions of transparency that underscored early modernist housing in a context of daylight depravation in the near-north.

Within the University of Waterloo's Graduate Architecture Program, the project has been utilized as a catalyst to develop modes of studio and non-studio based education that have positioned architecture student participants as design team collaborators in the context of an interdisciplinary lab model over the course of an eighteen month period. Student team members participated as funded research team members, undertaking rigorous cycles of research and simulation, BIM modeling, systems coordination, prototyping, detailed design refinement, contract document production, fabrication prototyping with industry partners, hands-on training with licensed trades, manufacturing, field review, contract procurement and shipping logistics. Throughout the project, student and faculty team members worked with a variety of disciplinary experts, embedded extra-disciplinary student colleagues, industry partner collaborators, and software developers and programmers throughout all phases of the work.

WORKING PAST THE MYTH OF AUTHORSHIP

At the project's outset, student team members from Architecture, Mechanical, Civil, Electrical, Mechatronics, Systems, and Software Engineering met with faculty researchers and professional colleagues to form a team for the project and to define the primary project objectives. Criteria for design and performance were defined by an overarching set of principles and objectives that were developed with the team during a three-day workshop (Figure 1, above). In order to develop objectives relevant and appropriate to the expertise of the team, the workshop first called upon each participant to define the leading edge of their respective disciplinary perspectives and their own description of research interests that might broadly apply to the project, and then set out to describe a synthetic approach for project development that would position these objectives as both the drivers of design, performance, and systems criteria that would remain across the course of project development. The automated exterior louvers for example, which eventually became the defining aesthetic of the exterior of the North House, was the topic of a PhD thesis on external shading as a way to mitigate heat gain by one of the mechanical engineering students on the team. As a result of this process, the North House project set out to develop: (i) A *strategy* of construction and space-making for Northern Climate Extremes, capable of adaptation to regional and cultural differentiation; (ii) DReSS: a Distributed Responsive System of Skins that combines active and passive envelope

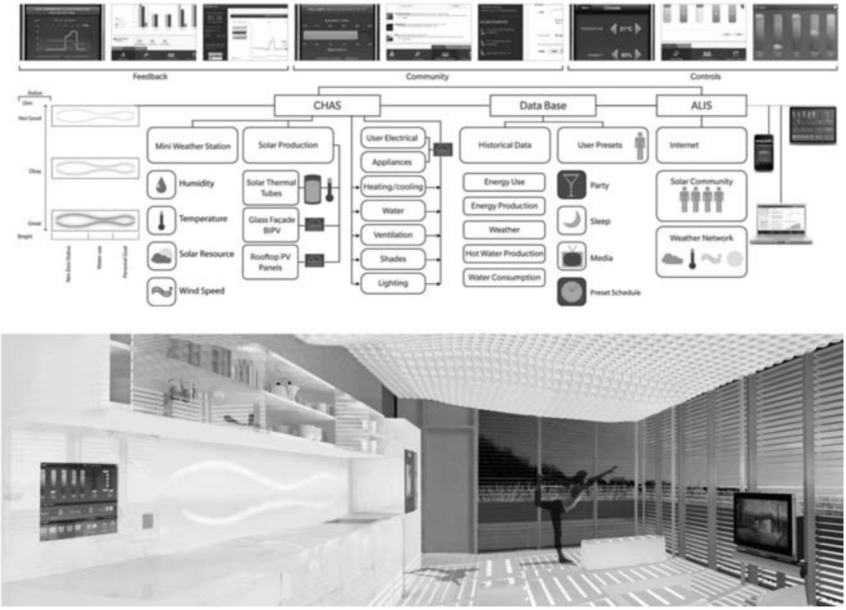

Figure 2: (above) Adaptive Living Interface System (ALIS) programming logistics, interior environments, interactive and ambient controls; (below) ALIS integrated into the North House interior environment. (Team North 2010)

technologies to result in a net-energy producing building design with a high window to wall ratio; (iii) ALIS: Adaptive Living Interface System, that combines a customized set of advanced controls with direct and ambient feedback systems intended to enhance and mediate individuals' relationships to the complex technologies and systems of the home, while fostering behavioral reinforcement of sustainable forms of occupation; and (iv) Holistic Solar Living: an ambition to develop and expand the potentials of the inhabitants' relationship to solar resources including a broad set of lifestyle enhancements, such as localized personal food production, daylighting opportunities, and robust links between interior and exterior environments[5].

As a result of the project framework, each team member, and each team decision was governed by a set of interrelated and linked concerns marrying performance and theoretical considerations. The commanding form and materiality of the project were shaped by an aggregate set of intensive conversations and performance considerations that drove spatial configurations and component selection. Each discipline helped to shape the final form, and within the team, it was rapidly understood that each iterative inflection from the original diagram of spatialized systems was authored by the team, and remained the responsibility of the whole group. No single decision was addressed independent of performance, and so, although time-consuming, group conversations regarding the merit of each inflection directed all of the work. Detailing, of course, was weighed equally relative to form and specifications were considered relative to intent. This method is a considerable departure from traditional, or even IDP processes where the feedback and balance of such complex parameters for decision making often reside within and reinforce the authority of a 'partner in charge', or author. The primary objectives developed during the initial workshop were not only to be valuable throughout project development, but also proved essential in clearly communicating the potential sponsors, donors and granting agencies across a range of media developed as a primary objective of broad dissemination both academic and popular.

STRUCTURING ADVANCEMENT TEAMS

In order to provide structure and locus for the work, a primary project office was procured at the University of Waterloo with proximity to networked devices and the fabrication shop (Figure 1, below left). Regular and revolving meetings took place in the center of the space, bringing professional peers, team collaborators, donors, and University administrators exposing the project to a wider public – including into the core of research work and design production. Despite the fact that team members were in some instances physically separated across the various locations of the collaborating institutions, the importance of a single physical locus for design refinement was critical. Where distances were constant, a variety of communications devices produced a virtual office nested within the physical space of production. The format of project critique familiar to the design studio model, with specific emphasis on actions, follow-up activities or the suggestion of lateral or parallel probes in the work was utilized on regular cycles in focused team groups to advance materials research, energy modeling, and design advancement. Design decisions and material evaluations were undertaken within these contexts, with student team members presenting proposals for concentrated review with design faculty and team members from other disciplines in order to ensure that a full spectrum of concerns were considered at each junction. Visiting professional engineers, industry partners, and manufacturer's representatives also provided feedback on the project, its detailing, and assemblies during these sessions.

An early team visit to the Toyota Motor Corporation production facilities in Cambridge, Ontario (intended to foster appreciation of Mass-Customization or Delayed Differentiation techniques within the project's potential modes of fabrication) introduced the concept of "Kaizen" – or continuous team performance improvement through the incremental implementation of all team member's initiatives to improve process and product. For example, the students' internalization of distributed social networking systems was legible, and constantly offered more senior team members a window into team organizational logics beyond those of our own experience - we would often witness several remote team members collaborating within compressed timeframes toward specific material solutions with virtual tools, yet still capable of maintaining constant informal contact as would those working in close physical proximity.

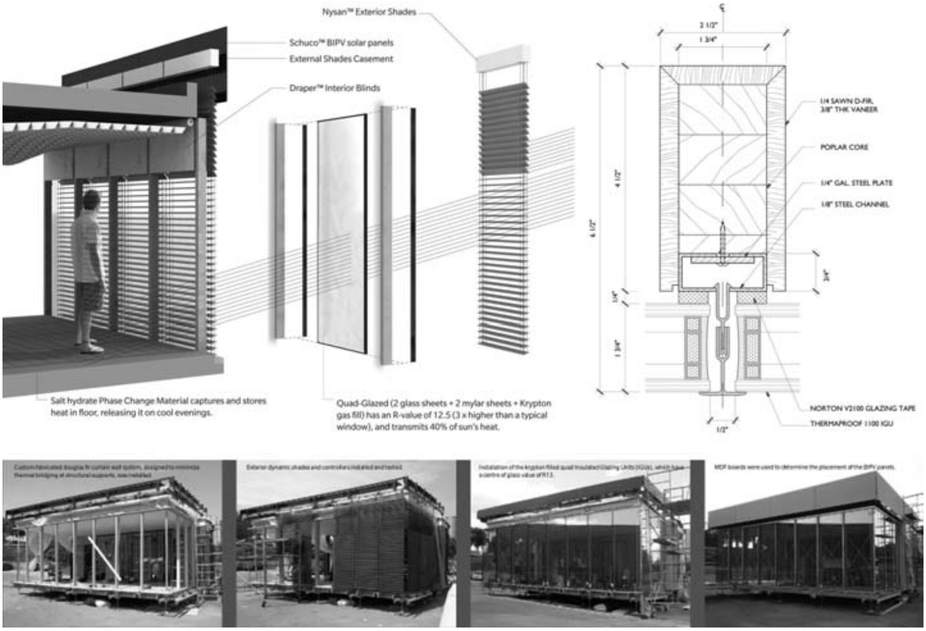

Figure 3: (above, left) Responsive Envelope System components; (above, right) Highly insulated wood curtainwall mullion detail; (below) responsive shading and glazing system during assembly. (Team North 2010)

EXPANDING DISCIPLINARY BOUNDARIES

In order to manage the complexities of the project, specific project component teams were developed to bring to bear a range of disciplinary perspectives on particular aspects of the project. These included teams that focused on glazing and active shading envelopes, structural assembly chassis and details, BIPV integration, HVAC systems, controls and sensor systems. However, each team was required to interface simultaneously with each interrelated team and system so that all components could be successfully integrated and so that incompatibilities and conflicts could be minimized in the built and operational prototype.

Of particular interest, was the development of the project's complex automated controls and human-digital interface systems. Architectural students and faculty found themselves consulting on the development of controls software and interface systems. This student team, consisting of graduate students from the architecture program, the school of interactive arts and technology, mechanical and systems engineering, computer science and sustainable systems programs, worked through an intensely collaborative process to develop advanced controls systems with a digital graphic user interface, web, and smart phone application. While this work was coordinated and executed in partnership with industry partners Vertech Solutions and Embedia Controls, it was interesting to note the former work experience that was brought to bear by student team members including mature students, a retired project manager from Research in Motion (RIM), and a student who had directed product development within the biomechanical industry. The architecture students found themselves being educated in engineering and computing discourses and had to learn to navigate through design discussions that typically do not occur within our school of architecture. It is hoped that this type of collaboration might become more common in architectural design programs, as sustainable and high performance architecture increasingly embraces advanced technologies and automated systems.

The Adaptive Living Interface System (ALIS) developed by the team responds to the project ambition of enabling occupants to relate to the suite of advanced technologies and mechanical systems that govern the performance of the house. This is achieved primarily through the architectural integration of ubiquitous computing technologies that provide feedback and ambient cues when user-activated changes affect energy performance-prioritized presets. The three components of the ALIS system consist of: building integrated touchscreen displays for setting of user preferences and automated systems; an iPhone application that provides statistical feedback on energy and water use related to costs, as well as links to online communities to foster further sustainable lifestyle patterns; and a pattern of solid state lighting integrated into one of the interior building surfaces that provides ambient and haptic feedback. The direct collaboration with systems engineers, interactivity designers and building controls has been a uniquely valuable experience for all involved and significantly transformed the resultant space of the house. (Figure 2, below)

The development of the building envelope introduced a broad range of technical and aesthetic variables into discussions that prioritized the design synthesis as a project goal. The goal of developing a 'responsive envelope' (Figure 3) as one that could mediate changing environmental conditions, rather than providing a static response to anticipated conditions, became a major focus within the subtle feedback on energy and water use.[6] (figure 2, above) Early energy modeling supported the project's challenge of conventional envelope best practices and had made the case for large areas of high performance glazing coupled with active shading systems that could support passive heat gain to phase change materials (salt hydrate packets) embedded within the interior assemblies of the building. The process of selecting individual IGU elements, coating for each face of this system, individual glazing tape types, spacer bar materials, mullion spacing and the like went through a rigorous process of digitally modeling each system and element configuration to evaluate its implications within the overall envelope system (quad glazing utilizing mylar films with selective UV coatings was eventually deployed). The final configuration of mullion spacing, wood curtainwall cross sections, fastener-less nylon glazing caps, exterior venetian blinds and interior shades were determined within a complex matrix of dimensional logics, performance evaluation, and proportional concerns. The resulting system has been designed to outperform anything currently available commercially within the local market. Digital tools were utilized to not only anticipate and evaluate energy and thermal performance of this system, but to evaluate carefully the appearance of these systems. Student teams undertook energy modeling, three-dimensional digital modeling and visualization activities in parallel constantly tracking the implications of performance with respect to appearance, and daylighting levels.[7]

PROTOTYPE TESTBEDS VS DESIGNBUILD

Across North American schools of Architecture, many initiatives are underway that prioritize new relationships between thinking and making – design and production as a means to transform the role of studio teaching in the education of an architect. Within the North House Project, it has been the synthetic approach to the implementation of collaborative structures and ways of working that has been of the most profound impact. This is perhaps most evident in the several ways in which students' relationship to making and building itself have been cultivated. Rather than the prioritization of one method over another, the project embraces several modes in parallel, as appropriate to team member skill sets, available resources and quality objectives.

During construction of the prototype building by MCM 2001 Inc., student team members were embedded at the factory where each component of the project was produced on the shop floor, fitted, tested and finished prior to being assembled on the prototype proper, an activity which also occurred on the site of the professional fabrication shop. Contrary to traditional models of project document, production and procurement, detailed drawings were produced in advance, during and after production. Each component of the construction went through several cycles of development, first informed by the inclusion of energy performance and digital modeling integration, then by the exigencies of the fabrication process and material realities. During the production of prototypes, (both by professional fabricators and team members), knowledge acquisition was understood to be transferred regardless of the hand's relation to the work. In this case, it is not the lessons derived through the researcher's direct physical relation to the creation of the artifact through their labor that is prioritized (as with design build programs of creative research), but rather, their contact with advanced processes that shape the project's delivery and its realization regardless of manufacturing format.

OUTCOMES

With respect to the research outcomes of the North House project, the benefits of an action research methodology and testbed utilization are multiple. First, the dedication to the project by its team members was undoubtedly amplified by the strategies achieved through participatory buy-in and responsibility for decisions and outcomes created by the process. Second, the range of unique technical solutions (building envelope, kinetic shading systems, system performance and ALIS occupant interface system were without question radically different in outcome and performance than had they been developed within traditional silos of disciplinary responsibility. Further, the complex synthesis between these systems and their tectonic resolution was indicative of the high level of commitment and responsibility that the lead students took on relative to the finished product and its performance. Although learning in action research would have occurred regardless of the project outcome, the project performed extremely well during the Solar Decathlon competition,[8] and has been since recognized by a range of awards, agency support and dissemination formats.[9] At the time of submission of this paper, fundraising efforts remain ongoing to reassemble the prototype in order to facilitate long term occupancy testing.

THE STRATUS PROJECT

As both an extension of, and departure from, the whole building performative and environmental demands of the North House project, the Stratus Project is an interior-environment modifying apparatus which aims to bring our attention to the immediate air-based environment and the conditions that produce it. Similar to the initiation of the North House project, Stratus began with intensive meetings around disciplinary positioning, and in particular, on the relation between the 'soft' architectural projects of the 1960's and 70's, and their relation to new formats of responsive environmental production enabled by recent advances in computational capacity and ubiquitous intelligent environments. Preliminary discussions between interested research participants involving students and faculty from Architecture, Mechanical Engineering, Industrial Design and Computer Science proposed to bring together two emerging areas of architectural concern – atmospheric design and responsive architecture – to develop a light and air-based architectural environment that utilizes new sensing technologies and distributed systems to harness energy and movement flows tempered through occupant-responsive feedback in defining envelopes of intimate and collective space. The work seeks to investigate how new forms of digital manufacture, embedded sensors and dynamic controls systems informed by user feedback and kinetic energy-producing surfaces might engender an environment based upon the prioritization and rendering legible of the often intangible aspects of architectural environments: temperature gradient, luminosity, airflow, humidity and atmospheric effect. (figure 4)

The project anticipated from its inception that it would be comprised of a distributed system of components, elements and operations that behave through controls-linked interdependence to perform in aggregate, and so the work began with two primary scalar streams of investigation; *network* and *cell*. The two streams of intensive work were developed first, in parallel, and then were combined into a prototype responsive system. Ambitions for these systems were defined in aggregate consensus by team members; (i) that the material form of the project would produce phenomenological effects sympathetic to the atmospheric ambitions of its theoretic underpinnings, (ii) that the system's spatial configuration would embody both gross motor reconfiguration in response to occupant presence and localized deformation in response to air quality sensation and human presence, (iii) that all formal characteristics of the system would be governed by the limits of manufacturing logistics and material properties rather than predetermined formal conceits and (iv) that visualization and simulation of the project would be prioritized in its development and in the context of a seed project to both develop didactic communications regarding the project's characteristics, and as a vehicle towards future project phases.

ITERATION | LATERAL MOVEMENT | PROTOTYPING

Several streams of research informed directly by physical prototyping in parallel with digital design processing informed the early development stages of the first of several anticipated iterations of the Stratus project. V1.0 investigated the potential of tensegrity-based structural systems relative

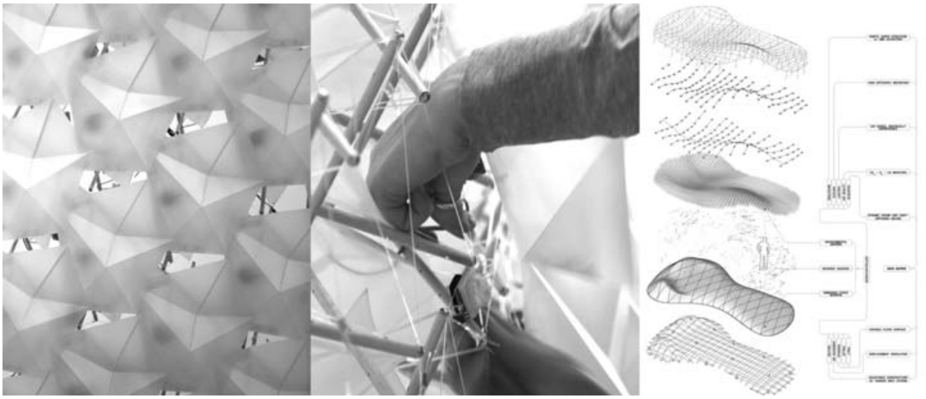

Figure 4: (right to left) Preliminary systems diagrams incorporating displacement ventilation raised floor assembly. Rigging the tensegrity framework. Die cut actuated cells assembled. (RVTR 2011)

to physical reconfiguration in space actuated via occupant sensing, the development of cellular baffles to control air movement, the incorporation of phase-change coated fabric membranes to maximize surficial area and absorption potential within the system, the development of low energy distributed micro fans to condition sensible temperature variation, and affect air extraction based upon 'contaminant' sensing of VOC's and CO2 levels. (figure 5) As with the North House project, the specific pre-existing research interests of the team shaped the development of the first prototype system, yet were tempered through team discussions and material and technological resistances as well as external constraints (budget, material embodied carbon values, limits of commercially available components for prototyping etc).

For the participants in the Stratus team, the value of a short period of intensive investigation into somewhat unfamiliar disciplinary territory has been of immense value in helping to not only identify clearly frictions illuminated through the physical prototyping process, but through the development of shared language and practices that juxtapose areas of assumed disciplinary familiarity relative to naivety. The advantages of the interdisciplinary discourse around this modest research project positioned within the context of equality prioritized by action research methods has again, as in the case of the development of the advanced systems of North House, produced unexpected outcomes, and a new appreciation for extra-disciplinary voices in the shaping of architectural research projects. Apparent disadvantages and frictions in development prototyping have become project leitmotivs as opposed to conditions to be overcome. The contributions of more junior team members in shaping the project have been significant relative to projects structured outside the tacit horizontality of action research structures, and through the undertaking of an intensive short first phase involving physical prototyping, a range of issues and questions have emerged in the near term of this undertaking that already prioritize a set of concerns and questions not clear in terms of their relevance at the on set of the project. At the time of this paper preparation, the first fully operational prototype is being completed for demonstration in a public context.

PROJECTIONS

The intention of this paper is to illuminate the potential for action research principles relative to the conception and structuring of architectural research projects, particularly in the context of full-scale testbed constructions, through the experience of recent projects – one completed and one in motion. While the development of practice based processes aimed at advancing environmentally responsive and sustainable building design such as IDP may engage mechanisms towards inclusive interdisciplinary research models, they remain structured in the realms of practice as opposed to the primarily academic domains of research inquiry. Further, we contend that central to the adoption of these practices in the development of research projects involving complex interrelations between environmental and occupant responsiveness, that the development of prototype testbeds is critical

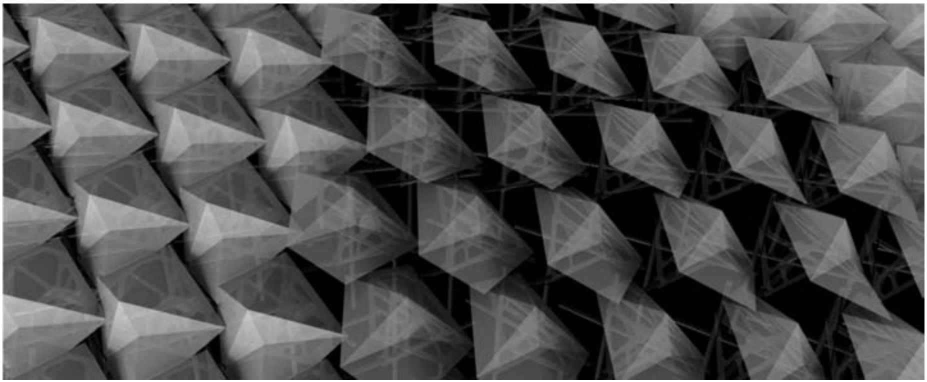

Figure 5: Stratus Project, breathing cells differentially actuated to facilitate responsive airflow. (RVTR 2011)

in advancing related research agendas. Implicit in the action research model is the value placed on structuring processes of knowledge transfer and exchange between participants as not only a byproduct, but a central aim of the research method. In the context of academic research, the links between this set of structures as both a catalyst to new models of research projects and new formats of learning may be instructive. Several fundamental and perhaps rhetorical questions remain with respect to the adoption of action research modes of inquiry as a model for architectural research; (i) Are we disciplinarily willing to accept the questions and interests of a broad constituency of team members as representative of societal concerns in structuring and defining research objectives? (ii) Does the implicit role of learning among team members prioritized by action research models have a place in serious architectural research? (iii) Will the extended timelines for research projects necessitated by the inclusionary nature and iterative processes dictated by action research models be accepted within the constructs of disciplinary research structures? (iv) Will funding agencies be willing to accept the nature of proposals that describe expanded teams and related costs in structuring grant conditions and budgets relative to existing humanities or scientific based models? The authors of this paper are hopeful that these questions are of value to colleagues and may contribute to emerging discussions surrounding the structuring of architectural research poised to engage the development of high performance sustainable buildings and systems that necessitate ever more complex teams, questions and objectives.

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ENDNOTES

[3] The overview of action research methods outlined in the paper's introduction is based on the structure of a literature review and synopsis of dominant action research perspectives authored by O'Brian in 2001 and cited above.

[4] All drawings and photographs of North House courtesy of *Team North* and RVTR. For a full project description, general project overview, please visit www.team-north.com For a complete listing of project credits and participants, see www.rvtr.com/rvtrWeb/ TEAM_NORTH_CREDITS.pdf

[5] For an extended discussion of the principles of holistic solar, see Velikov and Thun, "Contemporary Critical Regionalism and the Emerging North" 2008 *Conference Proceedings of the Society for the Study of Architecture in Canada*, and Velikov and Thun, "Complex Collaboration as a Lever for Design Research Innovation" *Deep Matters: 2008 AIA/ACSA Teacher's Seminar: Cranbrook Academy of Art, Bloomfield Hills, MI* (online proceedings), and for a description on the environmental performance outcomes of the North House project, see: Velikov and Thun, "Mass-Customized Prefabricated Solar Residential Prototypes for Northern Climate Applications " in *ISES RE2010 Renewable Energy 2010 Proceedings*, Yokohama: ISES, O-Ps-1-3.

[6] for a detailed discussion of the technical design and theoretical positioning of the ALIS system and its links to sustainable building usage through the lens of behavioural psychology, see Velikov and Bartram, "North House: Developing Intelligent Building Technology and User Interface in Energy Independent domestic Environments," *PLEA Annual Conference 2009 Proceedings*

[7] for a detailed discussion of North House envelope modelling and glazing system design and performance metrics, see Lee, I.Y.T. et al. (2010). "High Performance Facades for Heating and Cooling in Northern Climates", *International High Performance Buildings Conference*, West Lafayette, IN, July 12-15

[8] for a detailed description of system performance and interaction during the Solar Decathlon competition based on data-logger records, see Saeid, T. et al, (2010). "Compact Integrated HVAC System for a Net-Positive Energy House for a Northern Climate", International High Performance Buildings Conference, West Lafayette, IN: July 12-15

[9] The *North House* project has been exhibited as part of the 2008 Young Architects Award program at the Urban League in NYC, the 2009 Twenty+Change Canadian Design Awards program. It was awarded a 2010 Design Excellence Award from the Ontario Association of Architects, a 2010 R&D Award of Excellence from Architect Magazine, and a 2011 RAIC Award of Excellence for Innovation in Architecture.