

Thick Air

As increasing numbers of architecture schools introduce new degree programs based on postgraduate research, often engaging other disciplines, emerging technologies, materials and environmental concerns, this new species of architectural education demands an approach distinct from those that dominate professional programs. The authors present *The Stratus Project*—an ongoing body of design research investigating kinetic environment-responsive interior envelope systems, as a means of identifying a potential range of issues, models of inquiry and disciplinary influences for postgraduate research.

Since the middle of the last decade, architectural education has been in the midst of a broad and sweeping transformation, spurred by a concerted re-engagement with the profession. This interest in practice, as well as a concern with broader political, social and environmental issues, is coupled with the self-proclaimed “death of theory,” and a renewed interest in technical, process and material-related exploration within the field. As a result of a complex series of factors—including increased pressures on professional graduate degrees from accreditation boards that limit curricular experimentation, and the proliferation of new technology, tools and computational paradigms that provide potent media to explore disciplinary boundaries—many schools of architecture are initiating new, specialized post-professional degree programs in technical, material and computational research.¹

Some of the early pioneers of these programs include the well-known Design Research Lab (DRL) at the Architectural Association, MIT’s Media Lab, and the Centre for Architectural Structures and Technology (CAST) Lab at the University of Manitoba. More recently, numerous schools have initiated post-professional programs and labs in advanced technology-based research, including the programs at Rensselaer Polytechnic’s CASE Lab, Harvard’s GSD, the Bartlett at University College London, the ETH in Zurich, Stuttgart University’s ICD, the IaaC in Barcelona, and the University of

Michigan. Not intended as feeder programs directed towards PhD programs of study, these specialized degrees might indeed represent a new breed of architectural education, deviating significantly in both ambition and methodology from either professional Master of Architecture and Bachelor of Architecture degree programs or PhD studies in Building Technology. Lab-based as opposed to studio-based, declaring an interdisciplinary agenda, focusing heavily on invention and exploration through making and computation, geared toward the emerging generation of experimental hands-on scholar-practitioners and often accessing funding programs in technology and science that schools of architecture have not traditionally engaged in, these programs are actively expanding disciplinary methods, practices and discourses.

This is a timely moment to reflect upon the discipline’s trends and trajectories, considering the increasing interest in scientific (and scientific)² research within the architectural academy. In a pair of lectures published under the title *What is the Style of Matters of Concern?* sociologist and philosopher of science Bruno Latour argues, as he did in his influential *We Have Never Been Modern*, that the divide that the Enlightenment created between the symbolic order (the social and political order of humans) and the material world (the sciences) is essentially an artificial construct.³

Latour proposes a theory of knowledge, *matters of concern*, that works by continually navigating the flows of science and art, instead of trying to bridge a gap that does not exist, or attempting to reconcile the imagined breach between science and art through monstrous hybrids.⁴ This theory of knowledge aims to reinvent and reconstruct the “Art of Describing,” as practiced in the 16th and 17th centuries.⁵ *Matters of concern* operates by focusing first on things that *matter*, and then gathers into the ambit of the thing the continually shifting and diverse multiplicity of agents and mechanisms that bring it into being, promoting the development of multiple networks of understanding that support simultaneous and often contradictory realities.⁶

This epistemological construct can provide a fertile ground for the development of a robust new program of advanced design research. It suggests a research model that challenges post-professional programs to operate between the artificial divisions that have been entrenched within schools of architecture—such as the factions that often exist between history/theory and technology, or design and building science. It is a model distinct from those used in science, technology, engineering and mathematics by virtue of the expansive and interdependent nature of the questions posed the multi-dimensional nature of both the methodologies and expertise that must be synthetically engaged in its explorations, and the



1. The Stratus Project prototype v1.0, installed. (Photograph by authors.)



2. The Stratus Project prototype v1.0, installed. (Photograph by authors.)

non-conclusive status of its outcomes. The Stratus Project (Figure 1), while not the product of a post-professional program, is a design-research project developed by the authors that gathers into itself a broad range of discourses, methodologies, expertise and practices (historical and theoretical discourses, material investigations, computational research, digital fabrication technologies, spatial and aesthetic preoccupations) and might serve to inform new models and possibilities for architectural research, exploration and pedagogy.

The Matter of the Air

With the transition from the 20th century to the 21st, the subject of the cultural sciences thus becomes: making the air conditions explicit. – Peter Sloterdijk, *Terror From the Air*⁷

The air is a *matter* that matters. In our modern world comprised of exhaust, dust, smoke, pollen, volatile organic compounds, radio frequency waves, wireless signals, and noise, atmosphere's capacity to support the conditions of life can no longer be taken for granted, and the right to breathe can no longer be considered inalienable.⁸ Sloterdijk positions the atmosphere as contemporary society's fundamental object of design: from the specific

mechanics, aesthetics and politics surrounding the control of the condition of the air in both cities as well as enclosed spaces, to the last century's foremost invention in modern war—the attack on the conditions of life itself through strategically fabricated airborne compounds such as poison gas, radioactivity, and germs.⁹

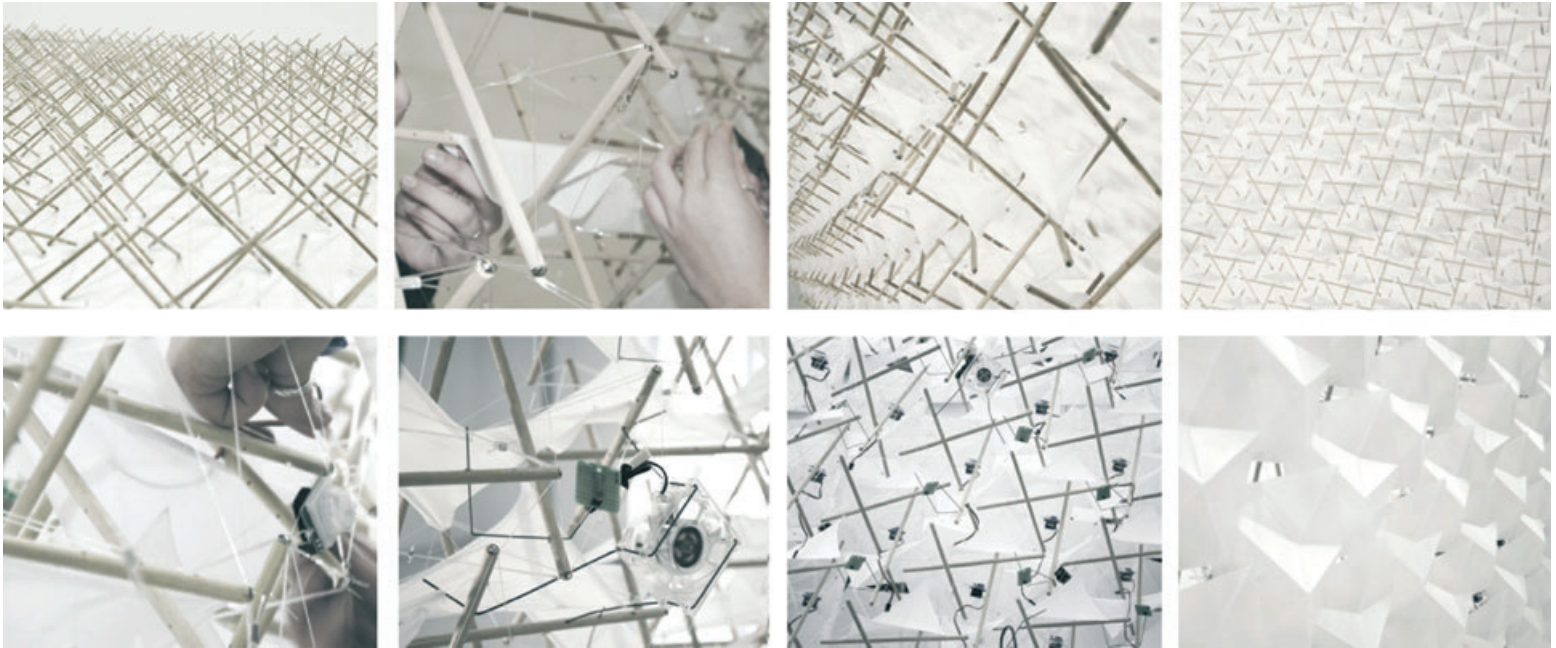
It can be argued that the control and regulation of the air environment is the *sine qua non* of buildings, which may essentially be understood as “an extension of our bodily heat control mechanisms—a collective skin or garment.”¹⁰ Within the traditions of architecture leading up to the late 19th century, this environmental control was primarily achieved through physical and material means: building orientation, spatial configuration relative to sun and wind, and material and formal elaborations of the building envelope that modified interior climate.¹¹

These traditional architectural strategies, however, could not produce the precise regulation of interior climates required by large-scale modern industry, where humidity control was a crucial factor in quality control and productivity.¹² Air conditioning, or man-made weather, was first developed for industrial applications, and was quickly taken up at the domestic scale for interior comfort control, with mass-market air conditioning

becoming an essential component in new North American buildings by the 1970's.¹³

The advent of air conditioning, and the challenge that it posed to the status of the building envelope, may have had as profound an effect on the development of architectural form as did the elevator in the previous century. Radical proposals from the 1950s and 1960s explored architectures that removed the building envelope altogether, such as the Air Architecture projects by Yves Klein and Werner Rugnau, Reyner Banham and Francois Dallegret's Environment Bubble, and Buckminster Fuller's Skylark House as well as his Dome over Manhattan proposal with Shoji Sadao. Yet this would not be only a formal or material question for designers, but also a question of the individual's now altered relationship to technologically mediated environments as extensions of themselves, which, combined with a contemporaneous rise in cybernetics and mobility, precipitated such projects as Archigram's Living Pods, Cushicle and Suitsaloon or Coop Himmelblau's Heart Space, Pneumatic Living Unit and Cloud, as well as the works of Cedric Price. The mounting anxiety over the social politics of air quality was perhaps most emphatically embodied in Ant Farm's 1970 Clean Air Pod.

These questions have re-emerged again within the discipline. R&Sie(n), Philippe Rahm, Sean Lally, and David Gissen have explored these issues in a



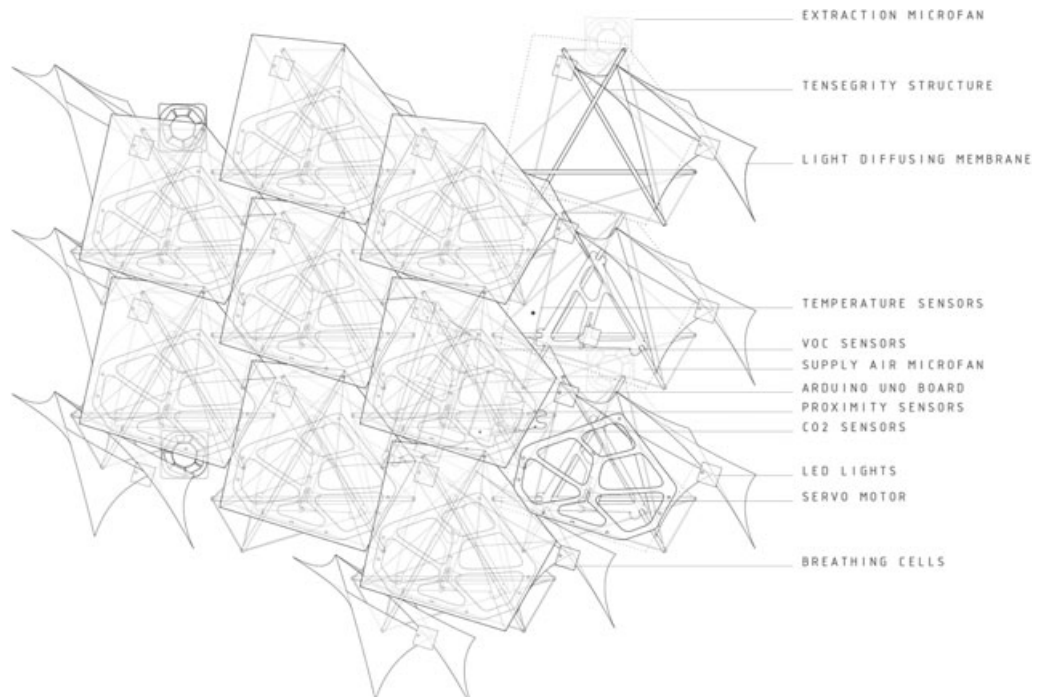
4. Plan view revealing the thick array of tensegrity weave, breathing cells, diffusing membranes, sensors, and actuators. (Photographs by authors.)

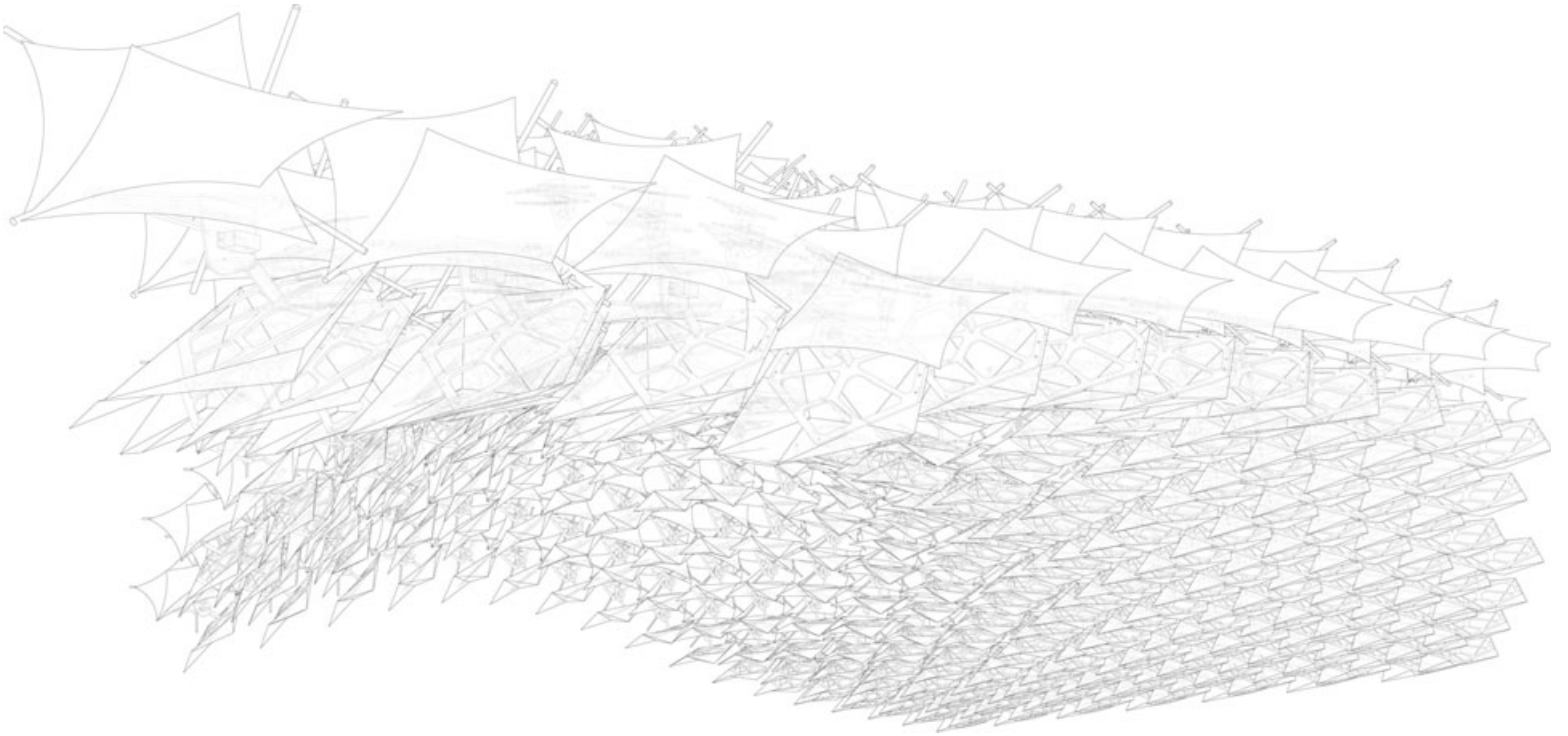
number of projects. Examples of contemporary installation work include HeHe's *Nouage Vert*, AnTe Liu's *Cloud* and Omar Khan's *Open Columns*. Diller, Scofidio + Renfro's *Blur Building* which, although intended by its authors to explore primarily the dialectics of seeing, also engages artificial weather and the politics of breathing. In these contemporary explorations of the biopolitics of atmosphere, issues range from the control of individual environments and bodies to the negotiations among the agencies of power that determine the complex trade offs associated with interventions into environments and ecologies existing over multiple political and jurisdictional boundaries.¹⁴

The Stratus Project

The Stratus Project situates itself critically within this disciplinary context, and develops models of kinetic, sensing and environment-responsive interior envelope systems that aim to attune our attention to the air-based environment and to the physical conditions that produce it (Figure 2). The work explores physical and technological systems and techniques towards the design of distributed and personalized atmospheres, while simultaneously developing communication with individuals to enhance their awareness and sense of agency within the atmospheric conditions that they inhabit: both those conditions that are sensate (temperature,

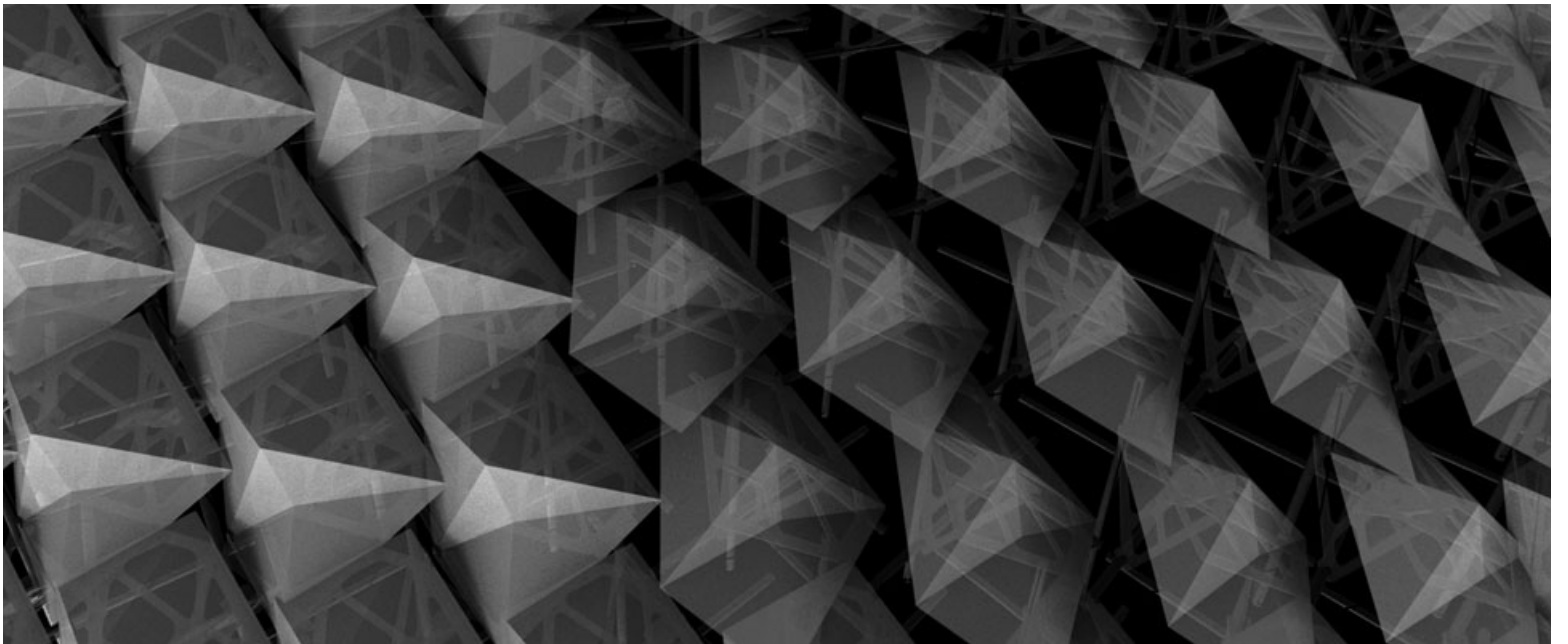
3. Sequence of Stratus prototype v1.0 assembly. (Courtesy of the authors.)





5. The flexible tensegrity structure allows for the surface to undulate and respond to occupant presence. (Courtesy of the authors.)

6. Digital model of breathing cell luminaries in operation. (Courtesy of the authors.)



```

temp = analogRead(tempPin);
float tempV = temp * 5.0;
tempV /= 1024.0;
float tempC = (tempV - 0.5)
* 100;
if (tempC >= 20) {
  sOne-slowmove (90, 1);
  sTwo-slowmove (90, 40);
  sThree-slowmove (90, 80);
  sFour-slowmove (90, 100);
  sFive-slowmove (90, 150);
  sSix-slowmove (90, 200);
}
if (tempC < 20) {
  sOne-slowmove (179, 200);
  sTwo-slowmove (179, 150);
  sThree-slowmove (179, 100);
  sFour-slowmove (179, 80);
  sFive-slowmove (179, 40);
  sSix-slowmove (179, 1);
}
Serial.println(tempC);
delay(1000);
}

Fans:
long unsigned int pause = 5000;

int tempPin = 0;
int fanPin = 3;

void setup() {
  Serial.begin(9600);
  pinMode(tempPin, INPUT);
  pinMode(fanPin, OUTPUT);
  digitalWrite(fanPin, LOW);
  Serial.println("calibrating sensor");
  for(int i = 0; i < calibrationTime; i++){
    Serial.print(i);
    delay(1000);
  }
  Serial.println(" done");
  Serial.println("SENSOR ACTIVE");
  delay(50);
}

void loop() {
  if(digitalRead(pirPin) == HIGH && check == false){
    fadeon();
    check = true;
    takeLowTime = true;
  }
}

boolean takeLowTime;

int pirPin = 3;
int ledPin = 9;

void setup(){
  Serial.begin(9600);
  pinMode(pirPin, INPUT);
  pinMode(ledPin, OUTPUT);
  digitalWrite(pirPin, LOW);
  Serial.println("calibrating sensor");
  for(int i = 0; i < calibrationTime; i++){
    Serial.print(i);
    delay(1000);
  }
  Serial.println(" done");
  Serial.println("SENSOR ACTIVE");
  delay(50);
}

void loop() {
  if(digitalRead(pirPin) == LOW && check == true){
    if(takeLowTime){
      lowIn = millis();
      //save the time of the transition from HIGH to LOW
      takeLowTime = false;
      //make sure this is only done at the start of a LOW phase
    }
    if(millis() - lowIn > pause){
      fadeoff();
      check = false;
    }
    delay(5);
  }
}

void fadeon() {
  for(int fadeValue = 0 ; fadeValue <= 255; fadeValue +=3) {
    analogWrite(ledPin, fadeValue);
    delay(60);
  }
}

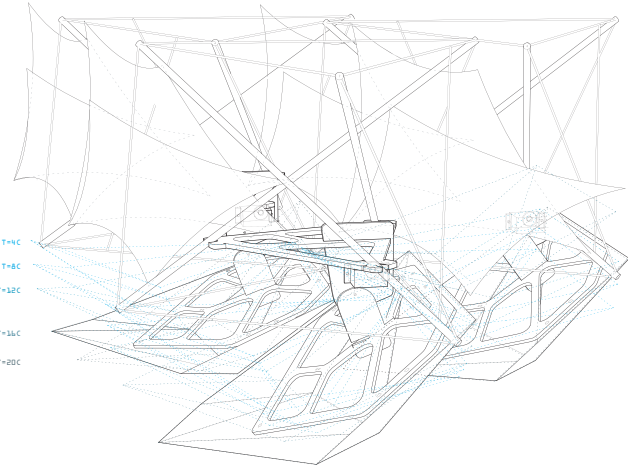
void fadeoff() {
  for(int fadeValue = 255 ; fadeValue >= 0 ; fadeValue -=3) {
    analogWrite(ledPin, fadeValue);
    //fadeSave = fadeValue;
    //fadeon();
    delay(60);
  }
  Cell motion;
}

#include <VarSpeedServo.h>

VarSpeedServo sOne;
VarSpeedServo sTwo;
VarSpeedServo sThree;
VarSpeedServo sFour;
VarSpeedServo sFive;
VarSpeedServo sSix;

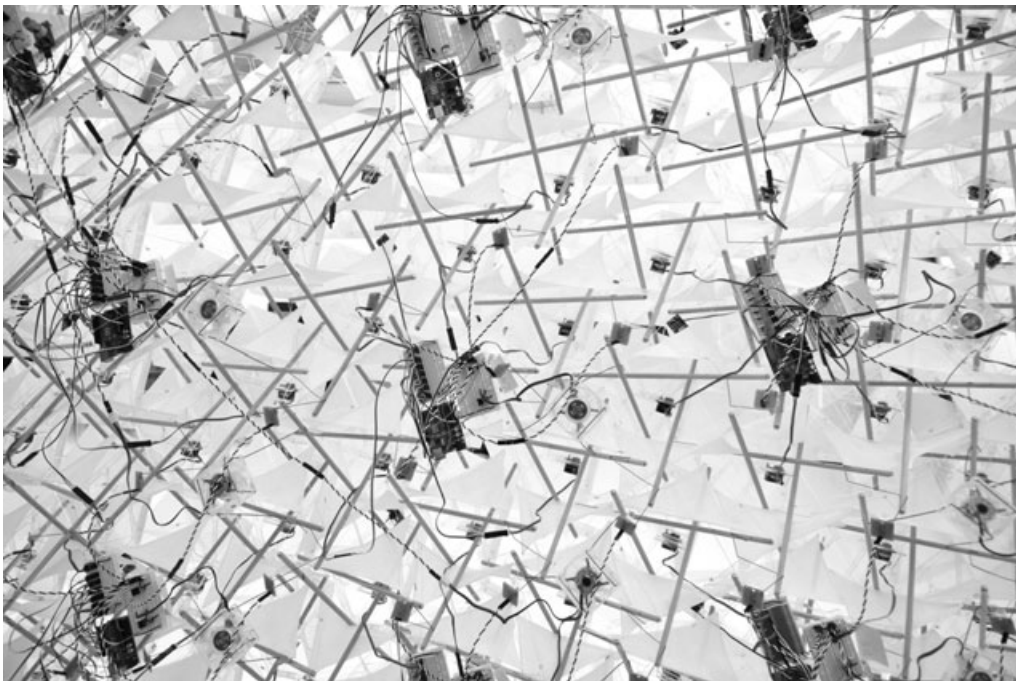
int tempPin = A0;
int tempI;

```



7. Axonometric of 3-cell structure demonstrating reaction to temperature change with Arduino code for cell actuation on the left. (Courtesy of the authors.)

8. Circuits and sensors wired into the prototype array. (Photographs by authors.)



light, sound, spatial and surficial configuration) and those that exist beyond our senses (radiation, energy and information flows, organic and inorganic pollutants). The instrumental potential of the research points to strategies for the design of healthier interior environments while reducing the energy demands that come from unnecessary baseline conditioning of large volumes of uninhabited space. Distributed, real-time feedback based air delivery also opens up possibilities of flexible spatial inhabitation and may operate within post-programmatic theories of architectural planning.¹⁵ The research aims to advance the development of responsive, or adaptive architectures—architectures that include real-time sensing, kinetic climate-adaptive components, smart materials, automation and the ability for user-interactive characteristics such as computational algorithms which operate under the principles of second-order cybernetics, wherein both user and system are capable of shaping an unlimited set of performance outcomes so that both “learn” over time.¹⁶

The Stratus Project is explored through full-scale operable prototype development, and the first



9. Breathing cells field closed, and in operation, with cooling fan deployed. (Photograph by authors.)

version, Stratus v1.0, takes the form of a thick suspended ceiling system installation and testbed (Figure 3). The system is composed of a layered array of distributed components, each of which has discreet as well as aggregate operations (Figure 4). Beneath this thickened stratum, an atmosphere defined by light and air is produced in response to a number of variables in the environment. Stratus v1.0 develops a responsive environment that senses movement, proximity, temperature, humidity, CO₂ and airborne pollutant levels, and reacts according to individuated occupancy triggers and processing algorithms.¹⁷ Unlike some the examples cited previously, that explored how man-made weather might eventually lead to the dissolution or elimination of the building envelope, the work of the Stratus Project is interested in exploring the very material, technological and design questions of the spheres of our existence (to borrow another term from Sloterdijk).¹⁸

Stratus v1.0 is constructed using a tensegrity-based structural system¹⁹ that is both lightweight and highly stable while allowing for both small and large-scale spatial deformations (Figure 5). This allows the perceptual and air volume of a space to be modified locally according to user requirements or for improved thermal or use-based performance.

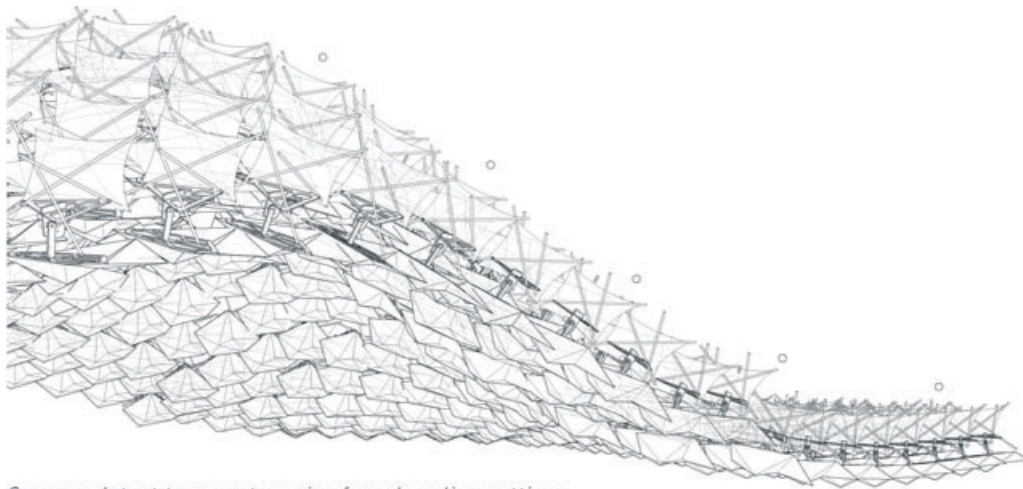
A tessellated array of die-cut and shaped translucent operable leaves, referred to as the “breathing cells,” is mounted on the underside of the structure (Figure 6). Groupings of cells are individually actuated through a simple arduino-controlled circuit and operate in connection with a distributed system of sensors, actuators, lights and microfans located within the tensegrity matrix (Figures 7 and 8). Dimmable solid-state lighting responds in a graduated mode to occupant presence, whereas conditioning responds to both occupancy and environmental conditions (Figures 9 and 10). In operation, the system often combines functionalities. For example, a higher than acceptable local temperature will cause the light diffusing cells to open and cooling microfans to operate above the occupant, while raised levels of CO₂ trigger extraction fans whose blue lights provide haptic indication of the conditions of the air.

The new envelope becomes a thick, sensing dermis, providing perceivable and sentient modification and response relative to breathers and their air-based medium (Figures 11–14). At the same time, it is fragile, soft and malleable, making the breather almost painfully aware of the thickness

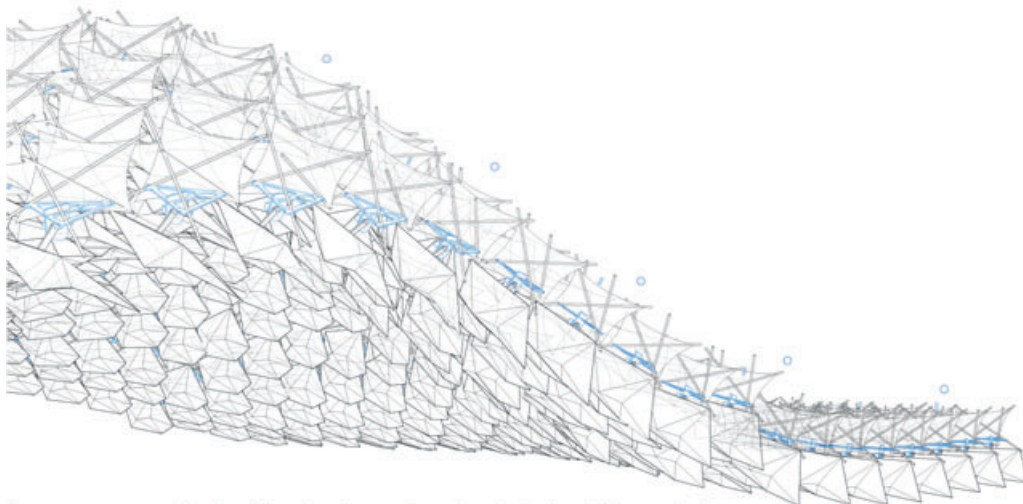
of the air and the work required to condition the air environment. (Figure 15).

The implications of the Stratus Project for architectural education do not lie in the technical, material or effectual properties of its physical manifestation, but rather in the methodological conception of the project. The real work of the Stratus Project has been the attempt to develop a dialogic method of inquiry and design based research that approaches, from the disciplinary position of architecture, questions that until recently have been given over to the realms of science and engineering. In reclaiming the territory of engineering systems design for architectural research, we transform the nature of the questions being asked of systems design from the purely and specifically instrumental to questions of complex ecologies of performance, perception, culture, aesthetics. Conducted in close collaboration with faculty, graduate researchers and students from the fields of architecture, engineering and computer science (and increasingly, as we move forward with the project, professional and industry partners), the project presents an attempt to develop a model of collaboration that refuses to recognize or accept a split, in Latour’s terms, between science and culture, offering a position simultaneously fixed in both realms as a platform for architectural research and an attempt to chart out a line of inquiry that may serve as a thought-provoking ground within the consideration of post-professional program development.²⁰

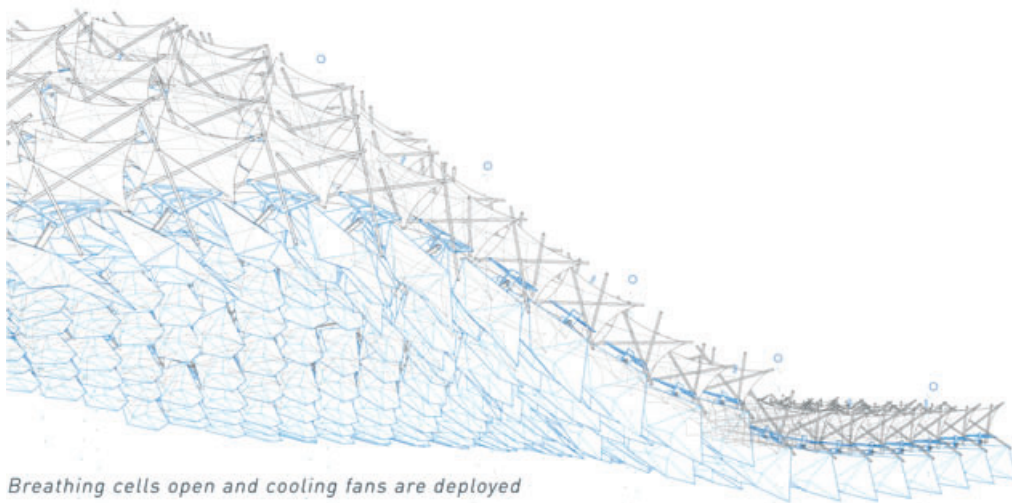
As architectural education charts the emerging ground of post-professional specialization, there is an increasing anxiety that these new programs will serve to further splinter architectural knowledge and discourse into isolated categories, and will continue to erode the synthetic and ecumenical tradition of the architectural discipline. If one accepts the merit of Latour’s proposal, that design is a “drawing together” of diverse and conflicting concerns, then we might imagine the development of post-



Sensors detect temperature rise from baseline settings



Sensors communicate with actuator motors to rotate breathing cells to open



Breathing cells open and cooling fans are deployed

10. Top to bottom: Sensors detect temperature rise from baseline settings; Sensors communicate with actuator motors to rotate breathing cells to open; Breathing cells open and cooling fans are deployed. (Courtesy of the authors.)

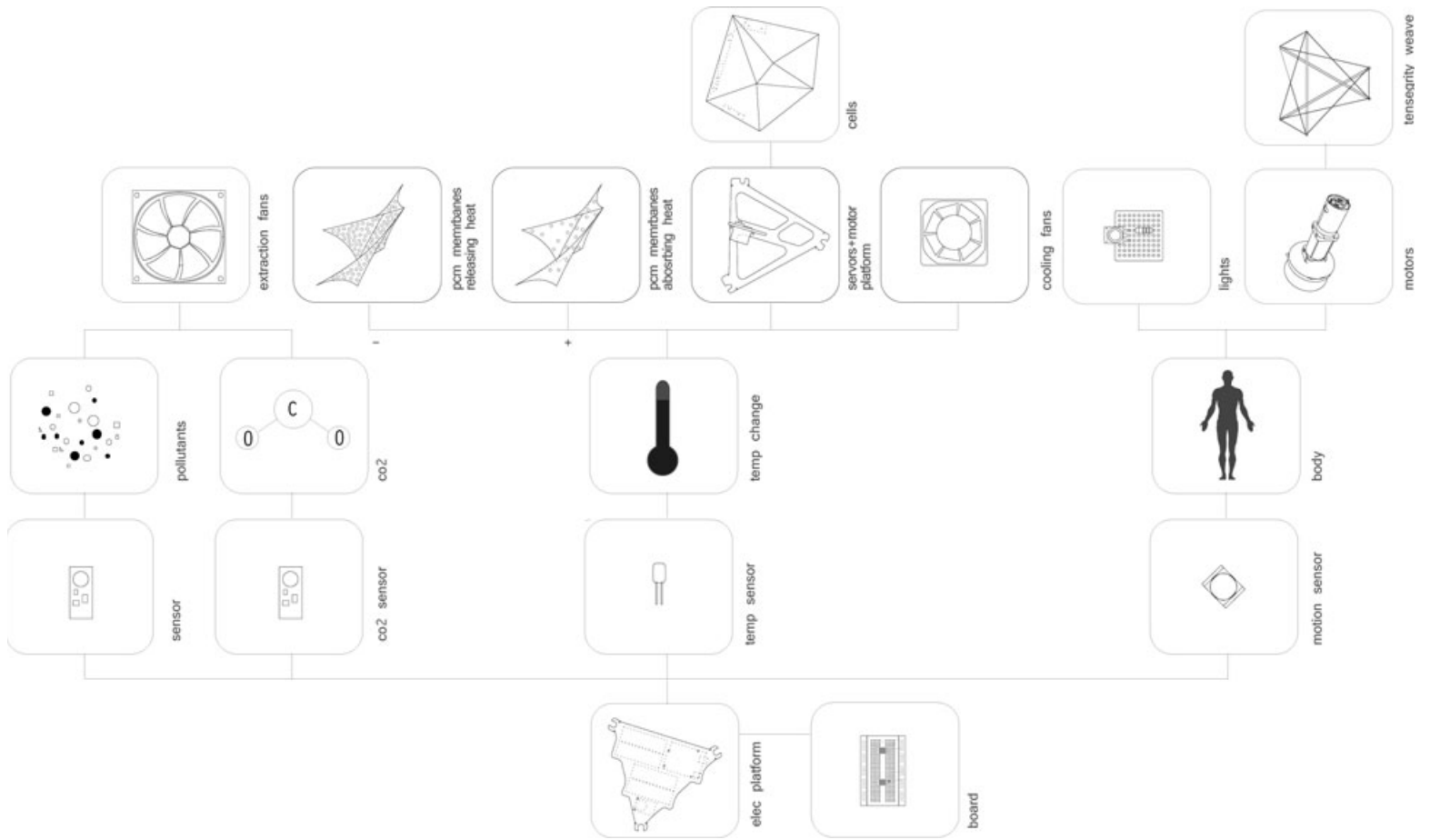
professional specializations as an opportunity for a depth of exploration not possible within the scope and mandate of professional programs, and as experimental grounds that foster new ways of drawing together as well as drawing forth.²¹ Freed from both the constraints of professional accreditation and the explicitly individual and specialized inquiry of doctoral studies, new post-professional streams may offer opportunity for potent disciplinary expansion.

Acknowledgments

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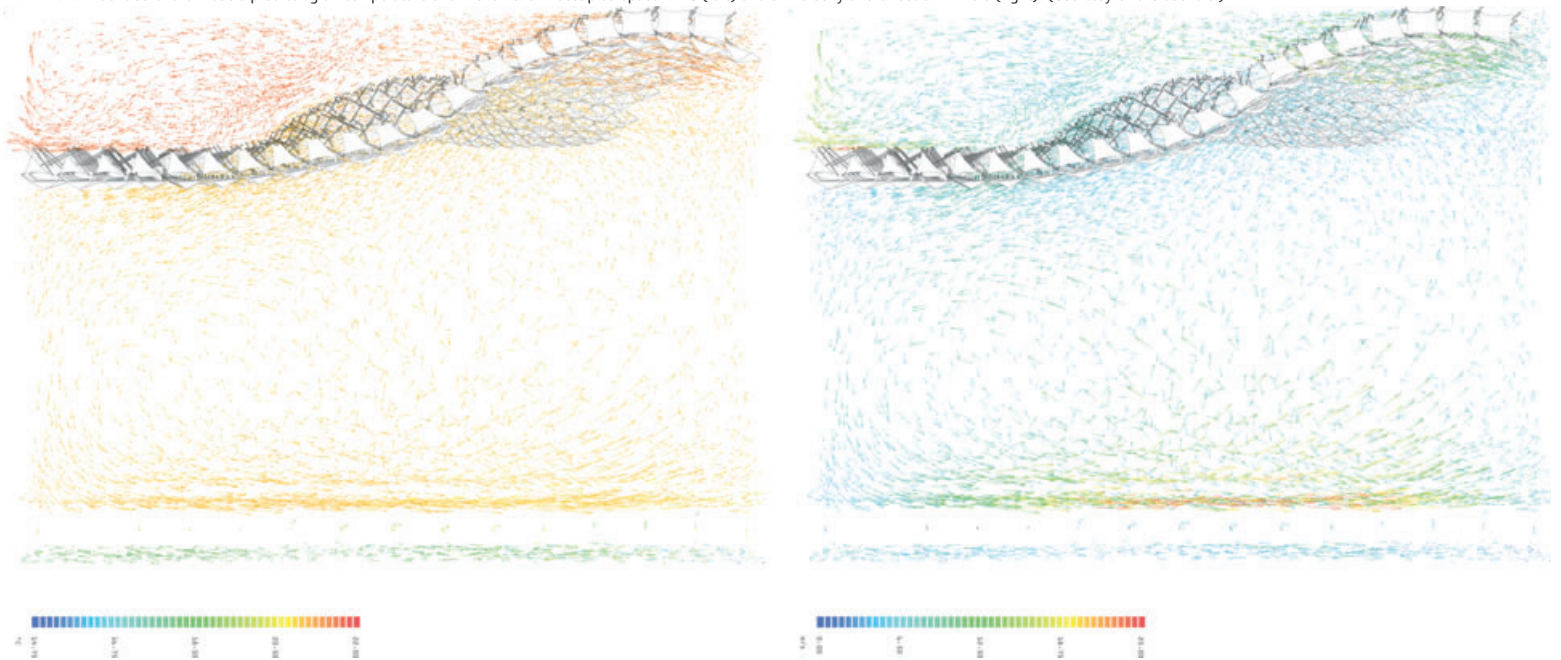
Notes

1. Post-professional programs in architecture are, with equal magnitude, being developed in urban design, history and theory of architecture and conservation. However, this article is specifically concerned with the programs in technology and material research specialization.
2. Amy Catania Kulper, "Scientism: The Breeding Ground for Current Architectural Trends, or Towards an Architectural Monoculture," in *Where Do you Stand? Proceedings of the 99th ACSA Annual Meeting*, Alberto P rez-G mez, Anne Cormier and Annie Pedret, eds. (Washington, DC: ACSA Press, 2011), pp. 21–28.
3. Bruno Latour, *What is the Style of Matters of Concern? Two Lectures on Empirical Philosophy* (Assen: Van Gorkum, 2008), p. 15.
4. *Ibid.*, 38.
5. *Ibid.*, 46.
6. *Ibid.*, 47. Bruno Latour, "Why Has Critique Run Out of Steam? From Matters of Fact to Matters of Concern," in *Critical Inquiry* (Winter, 2004), p. 246.

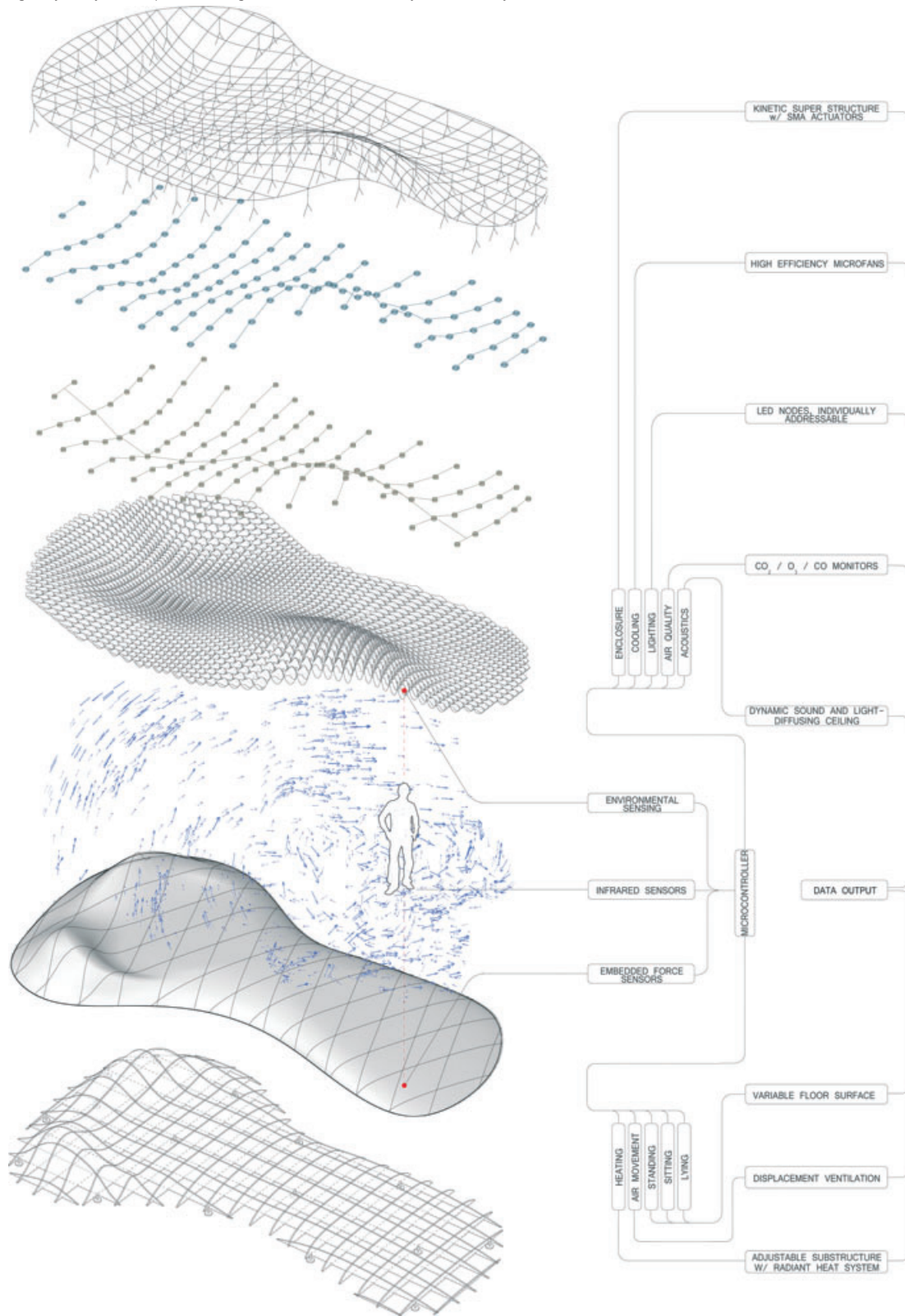


11. Sensing and response logics diagram with operative components. (Courtesy of the authors.)

12. ANSYS Fluent software models predicting air temperature and movement in occupied space in °C (left) and air velocity and direction in m/s (right). (Courtesy of the authors.)



13. Exploded axonometric drawing of layered system components and logic streams of related control systems. (Courtesy of the authors.)





14. Installed prototype, with breathing cells closed. (Photograph by authors.)

7. Peter Sloterdijk, *Terror from the Air*, trans. Amy Patton and Steve Corcoran (Los Angeles: *Semiotext(e)*), 2009), p. 84.

8. Kathy Velikov, Colin Ripley, and Geoffrey Thün, "Soft Goes Hard," in Neeraj Bhatia and Lola Sheppard, eds., *[Bracket 2]: goes soft* (Actar: Barcelona, forthcoming January 2012).

9. Sloterdijk, 2009, p. 15.

10. Marshall McLuhan, *Understanding Media: The Extensions of Man* (New York: McGraw Hill, 1954), p. 123.

11. See, for example, G.Z Brown, *Sun, Wind and Light* (John Wiley, 1985).

12. Gail Copper, *Air-Conditioning America* (Baltimore: Johns Hopkins University Press), pp. 7–28.

13. *Ibid.*, 166–70.

14. Gwynne Dyer, *Climate Wars* (Toronto: Vintage, 2008).

15. William Mitchell, *Me++: The Cyborg Self and the Networked City*. (Cambridge, MA: MIT Press, 2003), pp. 159–68.

16. See: Michelle Addington and Daniel Schodek, *Smart Materials and Technologies for the Architecture and Design Professions* (Oxford:

Elsevier Architectural Press, 2005); Philip Beesley, Sachiko Hirose, and Jim Ruxton, *Responsive Architectures: Subtle Technologies 06* (Cambridge: Riverside Architectural Press, 2006); Lucy Bullivant, *Responsive Environments: Architecture, Art and Design*, (London: Victoria and Albert Museum, 2006); Micheal Fox and Miles Kemp, *Interactive Architecture* (New York: Princeton Architectural Press, 2009); Thorsten Klooster, *Smart Surfaces and Their Application in Architecture and Design* (Berlin: Birkhauser, 2009); and Dubberly, H., P. Pangaro, and U. Haque, "What is Interaction? Are There Different Types?," *Interactions Magazine*, Jan/Feb 2009. <http://mags.acm.org/interactions/20090102/?pg=71#pg71> (accessed March 2011).

17. For a detailed technical description of system components and operation, see Kathy Velikov, Geoffrey Thün, Mary O'Malley, and Colin Ripley, "Toward Responsive Atmospheres: Prototype Exploration Through Material and Computational Systems," *ACADIA 2011 Annual Conference, Integration Through Computation*, Banff, Alberta, October 11–16, 2011: 326–33.

18. Peter Sloterdijk, "Foreword to the Theory of Spheres," in *Cosmograms*, M. Ohanian and J.C. Royoux, eds. (New York: Lukas and Sternberg, 2005).

19. The tensegrity structure is based on a cable-strut system developed by mathematicians Wang and Liu. See Wang Bin Bing, *Free-Standing Tension Structures: From Tensegrity Systems to Cable-Strut Systems*. (Oxford: Spon Press, 2004).

20. These concepts are central in the development of the new Master of Science in Material Systems at the University of Michigan Taubman College of Architecture and Urban Planning, which Kathy Velikov is coordinating in the Fall of 2012.

21. Bruno Latour, "A Cautious Promethea? A Few Steps Toward a Philosophy of Design (with Special Attention to Peter Sloterdijk)," 2008. http://www.unsworn.org/docs/Latour-A_Cautious_%20Promethea.pdf (accessed July 12, 2011).

15. Stratus prototype installed, delivering localized light and cooling. (Photograph by authors.)

