BIM in Aca-demia

Edited by Peggy Deamer
and Phillip G. Bernstein

Characterizing the Problem: Bioenergetic Information Modeling

Anna Dyson, Ted Ngai, and Jason Vollen

The culture of Building Information Modeling (BIM) is in its embryonic stage of development, yet it is rapidly subsuming many aspects of the building "life cycle" into its purview, from material sourcing through design development and, importantly, to the maintenance of the various future lives of the building. The prevalent dialogue on BIM tends to focus on Parametric Computing (PC) as a means to both streamline the building process and manage increasingly complex geometric problems. Digital information management platforms are often framed as a means for architects to regain control within the building industry that has been lost over the last half century, and they have also been highly valued as vehicles for problem solving through automated trade-off optimization.

While the merits of BIM and PC in these areas, both within the profession and the academy, continue to attract proponents, we are concerned that the socioeconomic values of "efficiency" may be tending toward BIM practices that reinforce certain systemic and relational paradigms in the design process, rather than allowing for what is potentially the most significant value of BIM and PC, a value that may in fact not be in solution finding, but in problem formation.

With access to ever more available computing power, the scientific community has developed the ability to attain great resolution for multiscalar stochastic modeling, leading to a new understanding of the relationship between material and bioclimatic flows in the environment. CASE (Center for Architecture Science and Ecology) believes that a radically different *characterization of the problem* is the significant promise of BIM, a characterization that is in sync with contemporary interpretations of material formation as the shaping and transformation of energy flows. The "Bioenergetic Information Model," rather than the "Building Information Model," proposes an inclusive basis to manage the complexity of fluctuating ambient energy flows and fluctuating programmatic demands as they concern the energy footprint of the building life cycle, which extends urbanistically and infrastructurally beyond the conventional understanding of a building.

This novel decision-making framework would associate the programmatic and climatic energy flows in and around buildings over time, and place the architect within a range of agents that shape a dynamically responsive built ecology. Yet, if considered within the context of continuously fluctuating ambient energy flows, along with dynamic demands, there are many established design models for successfully thriving in dynamic conditions. While nature takes advantage of local climatic conditions to diversify and thrive, building technologists create models that attempt to mitigate these same conditions. By assuming "fixed" models, or by attempting to impede energy flows instead of absorbing and transforming them, the models often designating "phenomena" as "antagonistic." As a discipline, we currently direct our emerging tools toward gross averages or singular instanced responses that give dubious results for accurate decision making, within a dynamic and highly variable context that is the life of a building.

The ability to translate recent advances in understanding the interactions of material phenomena across the atomic, molecular, microscopic, and macroscopic scales into new building products and systems requires a transformation in the methodologies of modeling, simulation, and design used by architects and engineers. Increasingly, the key environmental questions that need to be addressed in the development of new energy systems that fully capitalize on distributed natural sources of energy require the consideration of multiple interacting models and scales to represent the phenomena of interest.

For substantial increases in "efficiency" gains, we require the development of methods to link multiple models over multiple physical and temporal scales to support design simulations that can inform the design of dynamic, responsive building systems that incorporate new biocompatible models for systems behavior. In this way, within architectural and building-science research models, we need to explore a realignment of systems-integration strategies toward distributed regenerative principles, in order to develop effective strategies for the autonomous performance of built environments.

Regarding the degree to which tools both shift and determine the nature of the problem, at its most impressive, proponents of BIM contend that it has facilitated the resurgence of social synthesis into the design process, and that within the i-room (information room), there is increased potential for a range of agents to participate more fully on both the conception and the resolution of complex problems. The potential for Building Information Models to legibly accommodate and embody a broader range of design criteria than might have been feasible prior to its usage, has impressively coalesced with the possibility for flexibly reiterating information-heavy models. These models are capable of reverberating shifts throughout the weave of systems that are embodied with them.

The prospect of being able to incorporate a Building Information Model directly into an energy analysis tool has increasingly rendered the creation of a building energy model into an automated and formulaic process within practice. The obvious benefits typically offered are that BIM-integrated processes lead to a streamlining of efficiencies, and perhaps even more importantly, they ensure that certain assumptions relative to geometrical and material choices are coordinated and identical between users in different disciplines.

Typically, energy simulation modeling has been used to analyze and evaluate the environmental implications of architectural designs, which are then outfitted with the requisite lighting and mechanical systems. At best, this linear process might give an accurate enough reading of the grossly anticipated thermodynamic performance of various design schemes, so that the relative trade-offs can be considered in the final design strategy. The incorporation of energy modeling into BIM practices is significantly advantageous in this regard, as the direct linking of a BIM model to the energy modeling process will remove the problem of insufficient assumptions that might arise from having to reconstruct a model within the energy modeling software.

BIM-based energy modeling is seen as preferable to the first generation of energy modeling, whereby information is imported via a graphical user interface and "translated" into the new model, often with many details simplified in order to make the data-intensive simulations manageable. As a result, on a complex project, the potential for various interpretations of building information across the different engineering consultants could easily occur. A direct interoperable model whereby the information is directly "translated" removes the potential for inconsistent interpretations or simplifications as well as the time consuming process of having to manually duplicate design modifications by changing the geometry of the energy model. This removal of inconsistency is generally seen as a uniquely positive outcome, as it "improves efficiency" in the process.

However, if the ultimate objective of energy modeling is energy efficiency and responsiveness, one might realistically ask if these inconsistencies do not also allow some opportunity for validation of assumptions. Unfortunately, these same inconsistencies provide fuel for discussions and negotiations of the potential goals and outcomes of the project. If executed within any degree of accuracy, energy modeling is a complex activity requiring a significant level of experience-based judgment. The problem with beginning with assumptions that may include gross inconsistencies, rather than staged judgment, is that one may become so committed to a desired result that it often becomes challenging to disengage oneself from an assumed direction. This is especially the case if that direction has been entrenched in a schematic design process, given the time frames that BIM has shrunken and the boundaries that have been blurred between design development and construction documentation. The question is: What "efficiency" are we working toward? Is there less time for thoughtful analysis and development? Certainly, there is more coordination between changes. However, with BIM's high degree of transparency, BIM could either beneficially support the accumulating feedback of performance criteria or serve to channel out the "noise" when certain "design" directions have been set and are no longer flexible.

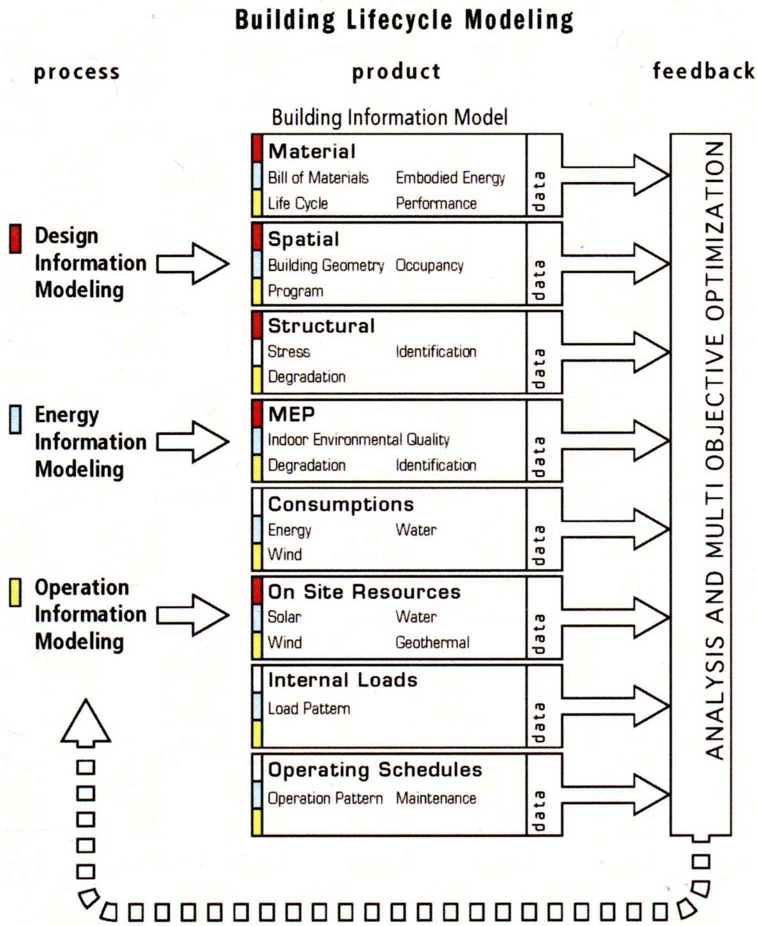
It is telling that within practice, a substantial amount of variation consistently arises between differing simulations of the same presumed model, as well as between the projected energy performance of a building and the actual performance of the building in post-occupancy evaluation.[1] Therefore, it is not clear that a completely integrated model at the inception of the project and throughout its development would lead to more accurate predictions within the design process. Total initial integration tends to remove opportunities for checks and balances from the interpretative process, as assumptions are carried directly through to more detailed analyses in the later stages of design, which previously might have been constructed from entirely different methods and/or programs than the earlier analysis.

It is this aspect of "totalizing" models, whereby one might have greater and greater opportunity to assume the interpretations of others on the team (typically engineering consultants on different systems) that is most concerning regarding the incorporation of BIM processes into schematic design projects in an educational setting. Certainly, the inculcation of awareness that an architectural design decision may have implications on the existence of multiple complex systems and converging frameworks is essential to the education of an architect today. Presumably, the addition of BIM to the curriculum could foster the ability to develop a kind of "peripheral vision" with respect to the complex interweaving of systemic relationships within buildings at the outset of one's architectural experience. However, the concern remains that values of efficiency and competency could predominate with normative solutions at the expense of resistances that are created by truly collaborative discourse with other fields, questions that generate critical discourse on the implications and assumptions behind various design strategies. Even worse, at a time when we are in desperate need of creative new solutions to both building design and building systems, how much does the rapid pace at which design development is expected to occur through BIM models actually reinforce conventional systemic solutions to complex energy problems?

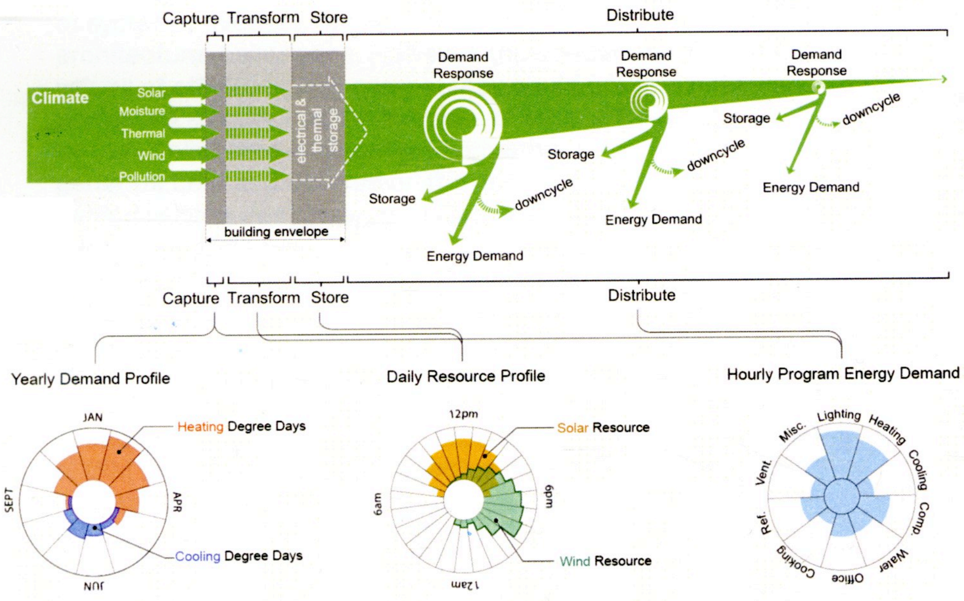
In an attempt to introduce understanding of complex relationships within the design process, might the incorporation of BIM into academic studios prolong the notable and ubiquitous absence of meaningful collaborative experiences between student architects and other students of engineering, policy, ecology, and so on? By its very nature BIM clearly does not have to be a projective tool that reinforces the assumptions of its users, however it could very well drift that way if the facilitated access to vast amounts of information can so easily be linked and inserted without judgment, thereby "streamlining" what was previously a dialogic process. The redeeming quality of a dialogic process is the intrinsic requirement of an exchange of knowledge through discussion and negotiation in order to evolve satisfactorily "complex" responses to complex problems.

As BIM makes certain things easier, some things might want to remain "difficult," such as the problem itself. As we, as a society, become increasingly aware of our grave energy and environmental situation, we are also becoming increasingly aware that there is no real way to "simplify" the problem of acquiring "clean" energy, particularly for buildings. A key that may help in tackling a problem rooted in complexity is to begin looking at solutions to similar problems. Viewed through this lens, the meaningful pathway toward the viable integration of bioclimatic information in a decision-making, BIM-based framework may come from complex systems other than of our own making.

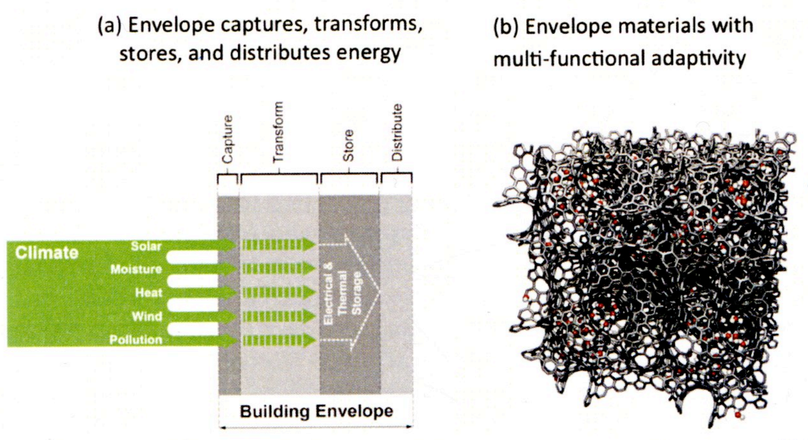
Biotic systems have evolved myriad strategies to metabolize the continuous flux of energetic resources in the environment, while the man-made built fabric continues to be burdened by systems that attempt to mitigate these environmental conditions without efficiently capitalizing on natural resources. We propose the development of new interoperable computational platforms for the simulation and animation of energy, power, air, and water systems.



Conventional information flows through building lifecycle modeling



Building envelope as complex transfer function—proposed model for BIM modeling to effectively match fluctuating bioclimatic energy resources with fluctuating programmatic patterns of building occupation.



Proposed Bioenergetic Information Modeling through multifunctional, adaptive material assemblies

The simulations will parallel the testing of concepts for integrated systemic responses to the complex interactions between the various flows, at multiple temporal and length scales, that are afforded by emerging synthetic multifunctional materials and sensors.

Ecological interactions across scales result in complex, dynamic, self-organized ecosystems that make optimum use of resources. Therefore, a compatible relationship between "built" and "natural" systems requires the development of "constructed ecologies," modeled on ecological processes and principles across a wide range of scales. Recent advances in the study of ecological energetics suggest new approaches that take on the complexity of interconnected resource and demand flows, rather than decoupling them, to develop a more adaptable and robust "building metabolism." If it is situated to facilitate concepts of "efficiency" and performance across the building life cycle and not just in producing an artifact, then BIM can be critical to our efforts in formulating a new systemic, multiscalar approach to distributed networked building systems and controls that effectively respond to fluctuating bioclimatic energy resources (e.g., solar and wind) and couple these to distributed systems, which capture, transform, use, store, and cascade electrical and thermal energy for specific applications. The monitoring and control of this interdependent energy cycling throughout multiple systems with distributed networked sensors would allow the system to adaptively self-organize and would result in the optimization of energy use, minimization of losses, and improvements in the quality of the conditioned environment.

Throughout the modern era, building typologies increasingly moved away from passively harnessing and directing natural energy flows and toward a model of escalating dependency on internally driven mechanical and electrical systems for environmental controls. Motivated by principals derived from the First Law of Thermodynamics, the development of building-envelope technologies tended toward the optimization of energy conservation by resisting the flow of energy into or out of building membranes. This approach neglects opportunities to optimally capture and transfer on-site energy resources by transforming their quality at the building-envelope membrane and has increased the energy consumption profiles of modern buildings (e.g., the increased energy consumption caused by ASHRAE standards for ventilation requirements, instituted to combat sick-building syndrome associated with tight building envelopes). In order to meet the challenge of efficiently metabolizing available bioclimatic resources to supply the primary energy requirements of buildings, we require decision frameworks that reframe the traditional conservation principals of the First Law with a transformational shift toward the development of building systems based on the Second Law of Thermodynamics.

The concept of entropy generation is applicable to various systems as entropy increases in time in closed systems; however, in open biotic systems, inputs such as food and energy cause these systems to self organize. Learning from these principles, designers can rethink buildings as open systems with the self organization of energy degradation.

Natural systems have evolved a web of metabolic pathways to make optimal use of exogenic energy degradation through the storage, distribution, and transformation of energy for purposeful endogenic tasks until the ability to do work is exhausted. Based on this analogue, the development of a BIM framework for a progressive network of systems is required—one that monitors the degradation of available energy, extracting as much work from each step as optimal by matching each stratum of quality to appropriate applications through the use of distributed networked sensors and controls. This framework would provide a scaffold for emerging materials and processes that can be progressively developed into a new generation of material sensors and controls as they become viable.

Ecosystems self-organize to systematically increase their ability to degrade incoming solar energy and, as such, they can be considered as the biotic, physical, and chemical components of non-equilibrium, self-organizing, dissipative systems that can serve as new models for the metabolism of natural energy flows throughout building systems. Just as ecosystems are most resilient when cross-scale interactions reinforce one another so that resilience can emerge redundantly at multiple scales, buildings can be most adaptive to fluctuating conditions when local responsiveness can be distributed throughout material systems. The application of these embedded, interscalar functions to building design and operation would result in more responsive, robust, and efficient buildings and be even further augmented if the sensing and control functions were embedded into the intelligence of the materials, themselves, and to integrated biotic components, as much as possible.

BIM frameworks could also be ideal in helping the building disciplines move toward the requisite mindset for acknowledging the degree of adaptability that is required for climate- and weather-specific adaptability in the behavior of buildings, not only of individual systems, but also of the building as a whole as it evolves with advances in information and technology. In the context of integrated building systems, adaptive management strategies—adopted from ecosystems management theory—allows for learning and altering of the system through control operations. The underlying assumption of adaptive management strategies is the recognition that current designs should, at best, be considered as temporary and transient solutions to conditions, which will necessarily need to adapt to changing circumstances and opportunities. Therefore, comprehensive monitoring and adaptive flexibility must be intrinsic to a distributed system that allows for reorganization through learning.

Through Peterson's framework for construction ecology, several components of adaptive management strategies foster ecological resilience and optimize distribution of energy in the development of building environmental control systems.

These include:

1. modeling of complex dynamics to build synthesis and embodied ecological consensus;

2. association of management strategies to the appropriate temporal and spatial scales;

3. maintenance and monitoring with a focus on statistical power and controls;

4. use of ecological consensus embodied in models to evaluate strategic alternatives;

5. communication of alternatives to social forums for cooperation and negotiation.

Within adaptive systems with distributed networked sensors/controllers, each distributed decision point will be interlinked giving the advantages of local control of energy degradation balanced by the "awareness" of the system performance as a whole. In this way, energy metabolism through degradation, distribution, and use, may begin to affect energy effectiveness, whereby the building becomes more effective in its energy management over time: building adaptive behavior management.

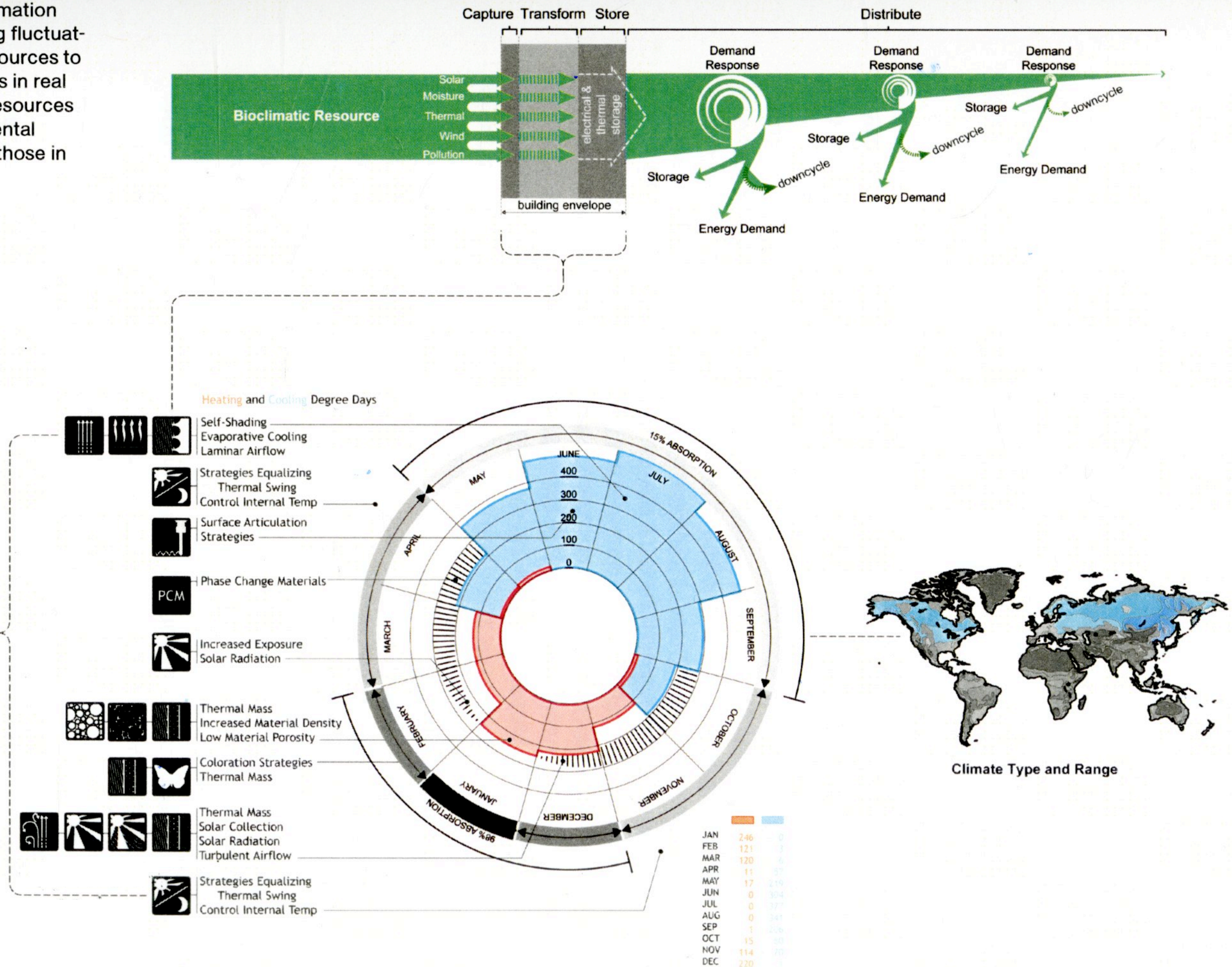
The decision points become the optimal place to investigate fluctuating resource and demand through the distributed networked sensor and control approach. Traditional Turing computing models that are currently used in building energy management are considered logical and deterministic, and therefore, do not meet the adaptive necessity that a dynamically changing networked system will require.

BIM will have to propel, not just keep pace, with evolving building hardware. Available networked models for building controls communicate through traditional building components; wires and chases that have existed for centuries and hardware and software that in most cases in one form or another have been around for decades, all require significant infrastructure. However, materials have been shown to act as a distributed network for stochastic computing, providing a parallel and robust platform for sensors and controls. Recent developments in biotechnology and materials science and engineering could provide newly viable opportunities for materials within the building matrix to act as distributed networked sensors and controllers.

The building industry is conservative, but the efficient and effective metabolism of natural energy flows throughout building systems is extremely complex in terms of matching the quality and quantity of the multiple resources to the requirements of building and users. This must happen synergistically, and it will need to happen through more intelligent and integrated degradation of energy flows in emerging material systems. Existing technologies can metabolize electrical and heat energy quite effectively down the gradient. However, this is only possible if the quality of the energy is continually transformed, beginning with the transmission through the building envelope through concentration (solar) and amplification with re-lamination (wind). If the focus of integrating building systems with adaptive management is placed on degrading or using energy available to each system with minimal entropy production, then it might be possible to stretch diffuse energy sources to cover the gamut of requirements. As emphasis is placed on the optimization as well as the minimization of energy dissipation, energy sources take advantage of as many different and diverse processes that are available. A Bioenergetic Information Modeling framework is necessary for this level of dynamism.

However, existing BIM paradigms are not conducive enough to continuous fluid dynamic inputs—"fluent" for example—to persist within the process beyond informing aspects within the stages of schematic design, or after the fact, to analyze the performance of constructs once they are formalized. The inherent conceptual and logistical complexity of linking systems that actively transform and redirect airflow and incident solar energy gain throughout multiple building systems has previously been the major impediment in the development of integrated systems that

Bioenergetic Information Modeling matching fluctuating bioclimatic resources to energy-use profiles in real time, comparing resources in extreme continental climate belts with those in hot arid climates



can capture and transport low quality energy flows to appropriately matching systems of consumption in real time. However, with the advent of powerful computational techniques that can stitch together simultaneous multiscale models, the incorporation of learning behavior at multiple dynamic systems can emerge. Unless they are captured and effectively transferred through a synergistic web of mutually reinforcing material systems, diffuse on-site energy flows will not reach their maximum potential to deliver the energy consumption requirements of commercial buildings.

Because of the huge investment needed for new buildings, innovative ideas must be rigorously investigated and proven before they are adopted in practice, and this context has not lent itself to addressing the complex task of optimally harnessing natural energy resources through integrated building systems. Bioclimatic flows fluctuate around a building. For instance, solar input varies with time of day, season, weather, and so on, and wind resources also vary within the same parameters, as well as height above the ground. Inside a building, energy and ventilation demands also vary with time of day and season (e.g., heating versus cooling), as well as occupancy (e.g., night, day, weekends, and meetings), lighting requirements, air quality, and equipment used. The physical scale varies, for example, from a small office to a large conference room to an entrance atrium to a whole floor or group of floors.

Coupling between the interior and exterior environments should be employed to best utilize available resources. Using bioclimatic resources may involve passive or active devices, like solar collectors, wind turbines, shading structures, and natural ventilation systems. Modulating interior conditions could use either active (e.g., traditional air conditioning/air handling units) and/or passive approaches (e.g., using the inertia of a responsive material to moderate temperature swings or toxics/air quality variations). Simulations of the interactions among all of these time varying quantities across various length scales is a huge undertaking, but developing such simulations is a needed task to estimate how important quantities, such as energy usage and local air quality, can be affected by different parameters, materials, inputs, demands, building types, usage patterns, and so on. In addition, a sophisticated, decentralized control system approach must be coupled to these simulations, so that optimum design and operation of buildings and multiple systems inherent in contemporary structures can be achieved.

For the foreseeable future, building design and energy management systems will be based on hardware and software.

While advances are being made toward distributed systems, a new mentality must be inculcated within the architectural design studio, one that allows for not only an understanding of the emerging complexity of integrated systems that on the one hand, may be easier for designers to conceptualize because of their increasing and inherent "performative interdependency," but also a required peripheral awareness among designers of the operative quality of integrated systems. It is precisely this tension—the increasing complexity and performance requirements, with a concomitant increasing need for radical integration of function within material systems—that necessitates the introduction of Bioenergetic Information Modeling into the design studio early in the architectural curriculum.

The awareness that one is ultimately "sculpting" energy flows through the formalization of architectural elements—flows that are constantly fluctuating as one's model or construct interacts with continuously fluctuating bioclimatic flows—is of critical importance to the future social relevancy of our discipline. On the other hand, if BIM is introduced to design studios within current paradigms, the question becomes whether or not it is ushering in greater opportunities for the types of innovations that are required within the building sector, or if it is cementing current paradigms by making the delivery of disparate systems even more "economically" efficient, along economic lines that ignore costs associated with basic thermodynamics within the life cycle of buildings.

1 Cathy Turner and Mark Frankel, *Energy Performance for LEED for New Construction Buildings*, New Buildings Institute, March 4, 2008.