Abstract

Fundamental principles in environmental performance for architectural design typically consist of integrating energy conservation laws with static material systems through analysis of macrostate metrics. Shifting our understanding of environmental performance fundamentals towards an integration of entropy laws with dynamic medium flows and cross-linked analysis of microstate conditions allows for emergent designs of self-sustaining architectural systems.

Such a shift is analogous to metabolic processes for attaining balance, equilibrium, and effective redistribution of various endothermic and exothermic system flows. This shift also allows for multivalent forms of energy to be engaged within the design of building systems, concurrently providing frameworks for emergent material compositions, and resulting in greater efficacy for environmental performance.

The research framework addresses four contrasting modes in environmental performance design methodology and suggests the integration of specific fundamental principles for emergent building technology innovation. These foundational considerations include entropy laws, micro-scale phenomena, spatiotemporal dynamism, and medium flows. The research of these modes incorporates examples of new interactive digital simulation visualizations to inform intuitive logic regarding energy behaviors in the architectural design process.

Introduction

The current state of building design for environmental performance is trending towards more holistic frameworks and conceptual thinking for influencing the efficacy of resultant designs. This concept of efficacy in design encompasses the qualitative aspects of environmental phenomena affecting human experience, human health, and even an extension outwards to ecological health. Energy performance in building design is no longer left for the engineers to solve as an afterthought of the architect's decisions for determinant spatial and material conditions. There is a movement towards integrated and distributed environmental controls embedded within the logic of architectural morphology and material compositions. Such integration begins to address contents of energy beyond the quantifiable metric, and blurs the historic separation of mechanical system functions from base building design concepts.

In order to address the momentum of this integration, shifts in design methodology inherently emerge. Four specific dichotomies in our design thinking with regards to energy flows and environmental performance are addressed in this research. These diametric topics include: entropy vs. energy, micro vs. macro, dynamic vs. static, and medium vs. matter. The intention of introducing these dualisms is not to exemplify binary tendencies in design thinking, but to exemplify the range of conditions available amidst such gradients.

Each of these comparisons exposes the lineage of building system design thinking weighted towards particular ends of such spectrums: energy, macro, static, and matter tend to prevail over entropy, micro, dynamic, and medium concepts. Energy is conceptualized solely in terms of first law of thermodynamics and conservation principles in our building system designs and simulation frameworks. Macro scale is historically favored by means of conceptualizing the building scale in relationship to the urban context, as well as considering global physiology as a means to act locally through built
environment design and performance. Static building systems are the prevalent form of response to temporally dynamic climatic, thermal, and anthropogenic patterns. And matter is the default point of reference for conceiving of energy flows within and through building systems.

The research within this paper suggests a necessity to shift our design methodology towards a re-centering of these gradients upon entropy, micro, dynamic, and medium informing our integrative design thinking for environmental building performance. The intentions and goals for such integrated methodology is to achieve emergent design innovation for building system concepts that are self-sustaining over long-term trajectories. Such methodology avoids prescriptive modes of energy efficient strategies and systems as post-analytical applications into designs, and preferences foundational fundamentals of thermodynamic spatiotemporal characteristics to embed such logic within inherent design processes and intuitive design thinking.

Entropy vs. Energy

Too often energy is deemed a quantifiable metric as an input to and expenditure within a building system, especially through diagnostic design process methods of post-analytical performance evaluation. Contemporary modes of integrating energy performance concepts in architectural design tend to be embedded in these reductive logics and result in didactic and appropriated design strategy solutions. Such design process methodology excludes the aspect of energy from early conceptual phase thinking as results in a lack of well-integrated postulations for efficacious building system performance.

In the 1930’s design theories of a similar vein were introduced by Fredrick Kiesler, who began to address the principles of anabolic and catabolic energies into correlation with technological environments. The pedagogical models presented by Kiesler presumed an analogical potential for sustaining and prolonging life through a balance between syntheses found in constructive metabolism with release of energy found in reductive metabolism.

The counter flows of anabolic and catabolic metabolisms alongside endothermic and exothermic processes are prevalent in the second law of thermodynamics. The laws of entropy within any given system define the potential ability of that system to perform work. The maximum entropy of any given system is an indicator of thermal equilibrium, and thus the inability to transfer energy into or out of the closed system naturally.

Situating entropy modeling at the forefront of our design thinking allows for conceptualization of efficacious redistribution of energy flows. Contrary to a first law of thermodynamic modeling process, which assumes a constant input to the system from some source external to system configuration – an entropy modeling process insists upon effective configuration of a closed system to ensure the consistent redistribution of energy and resistance to maximum entropy. This is comparable to conceiving of a Carnot engine, where any degraded form of energy is captured for re-use and redistributed to provide constant maintenance of system performance. Though the entropy laws of thermodynamics are indeed in accordance and compliant with the conservation laws, the second law of thermodynamics as a centering for design thinking shifts our focus towards understanding closed systems through an intention of resource rationing, recycling, and re-use. Establishing entropy as a fundamental design principle enables us to envision energy flows in terms of qualitative aspects as opposed to reductive bottom line values.

Traditional conceptions of energy in architectural design originated, in part, from the bioclimatic design theories of Victor Olgyay in the 1960’s. Such conceptual models postured energy as a component of climate, primarily through heliothermic planning notions, and interlinked this aspect alongside biology (human), technology (artifact), and architecture (building). The significance of Olgyay’s methodology as a contribution to the field of architecture resides in its integration of the climatological with the biological as a scientific premise to inform technological solutions for architectural application.
In addition, this frame of mind insists upon concurrently conceptualizing forms of energy in terms of potential, kinetic, chemical, and multivalent manifestations available within our building systems. An example of such dynamic states of energy conceived in terms of entropy is the reciprocal exchange of sorption and desorption physics within an elastopolymeric and humid air system (Fig. 1). In accordance with the Maxwell relation, the thermodynamic phenomena correlate with statistical mechanical functions within this system and provide for the inclusionary assumptions of energy as a multi-state condition. While this system is not a perpetual machine, which is fundamentally impossible in accordance with thermodynamic laws, it comes very close to representing the potentiality of cyclical and indefinite flows of energy.

The expansion of traditional qualifications of energy into multivalent forms that prevail in building system design allows for an extension of energy performance in architecture towards more efficacious realizations. Such efficacy is demonstrated by the integral aspects of qualitative and quantitative environmental phenomena in complete integration with human experience and socio-cultural interactions. Our baseline quantified metrics of delimitations of energy performance dating back to oil crisis system design thinking is no longer valid in paradigms where we see the direct and indirect costs in terms of both human and ecological health associated with such limited stances. It is imperative to indeed integrate the alternate aspects of these measureable and quantifiable metrics with the qualified conditions of human and ecological experiences that result from our design decisions. Fernandez-Galiano identifies the fundamental departure for thermodynamic concepts from antecedent laws of classical mechanics as specifically residing with the second law of thermodynamics and entropy. He expands and validates this point through the historical oppositions of quantitative and conservational principles rooted in mechanical views with the qualitative and evolutionary principles situated in thermodynamics. Shifting system performance measures to entropy metrics enables this translation of qualitative state and potentiality for efficacy of integrated systems’ energy forms.

### Micro vs. Macro

Contemporary systems’ concept thinking requires an understanding of multi-scalar relationships from global environmental dynamics to microcosm phenomena. Such interscalar connectivity constitutes a broadened peripheral vision within the architectural discipline, and is partially influenced by the emergence of sustainability theories over the past thirty years. These interscalar correlations for energy flows can influence our spatial concepts in architecture and require us to stretch our minds to elastic limits and envision the interconnectedness of our building microclimate upon broader environmental domains (Fig. 2).

Ecologists claim that the micro-biological conditions of the environment have much greater influence on any larger scale functioning of longevity and sustenance for life than any type of urban-scale network and its impact on fossil-fuel consumption and relative impact on green-house gases. In order to avoid favoring the
quantifiable impact of macro-scale conditions over qualitative efficacy of micro-scale conditions when engaging with a building design problem, situating a deep understanding of interscalar relationships within the research methods and design curriculum is necessary. For sustaining environmental equity and resource balance over long-term viability, we already comprehend the necessity for assessing global conditions and the reactionary mode of mobilizing local response. But our interscalar thinking must go beyond a basic form of logic justification for design thinking and approach and integrative methodology of multi-scalar physics to encourage holistic energy integration in system designs.

Furthermore, we must associate directly the micro-scale physis of any given system with its larger scale qualities and make specific correlations between these interscalar aspects in terms of the performance characteristics that result. For instance, with any given material, we are able to determine the molecular structure, whether a crystalline packing structure or a fibrous lignin morphology. This micro-scale composition immediately informs us as to the ability for phonon lattice vibrations to travel through the given material structure – either by means of conduction with a direct path of travel in the substance, or by means of a meandering route due to fibrous air pockets and a resultant means of resistance. In both cases, the micro-scale conditions of matter directly influence the energy flow conditions of particle-wave or particle-lattice vibrations. These micro-scale conditions then reciprocally inform the larger scale attributions of energy performance within a given system.

These interscalar relationships can be conceptualized between the building scale in terms of spatial form and geometry responsive to various thermodynamic criteria, the system scale in correspondence with morphological manifestations for metabolizing energy flows, and material scale conditions applicable to enable the intended modes of energy metabolisms (Fig.3). The spatial and material conditions may be designed as particular responses to very specific physics with intentions of metabolizing energy flows within building systems. The spatial conditions are most pronounced at the building scale, but also manifest at the system scale by way of component geometries. The material conditions formalize at a much smaller scale, but are critical for realizing the intended conceptualizations through localized thermodynamic and metabolic processes.

Our current building energy analysis simulations are not robust in terms of such interscalar correlations and degrees of resolution inherent at both the system and material scale. Emerging simulation frameworks
are allowing for interconnected inputs and outputs from multi-scalar analyses to result in depicting trends between our base building architectural designs, system designs, and material selection.

Form-giving processes integrated across various scales in design posit a significant role for the architect to intervene with artistic ideas to extend form beyond scientific positivism. The techne of the environmental ethos combines with the poesis of artistic pathos to allow for a synthesis of technics and art in architecture. The form of architecture tends to speak most closely to its aesthetic, which in turn is the phenotype of an ethic.

Dynamic vs. Static

A primary aspect of energy flow in our built environment is dependent upon the temporal nature of climate phenomena, both diurnally and seasonally. Another prevalent temporal aspect in building design is the socio-cultural pattern of use and related behaviors of occupants. The temporal component in building design is fundamentally necessary to establishing appropriate design responses for metabolizing energy in cyclical and integrated modes. However, our discipline has a long-standing tendency to design for static physical manifestations with building systems.

Compounding the complexity of temporal dynamics in architecture are the spatial intricacies of environmental flows, which by default we define primarily through heliothermic principles. Yet there are other spatiotemporal variables, such as airflow patterns, humidity in and around buildings that constitute integrated modes of spatiotemporal visualizations.

A unique interactive visualization tool developed by the author in Processing depicts dynamic thermal flows within building zones (Fig. 4). The diagrammatic representation includes envelope zones, core zone, and roof zone, depicting heating (red) vs. cooling (blue) loads simulated for hourly iterations over an annual timeframe. The random stills selected for representation here are indicative of the complex and contradictory thermal dynamic states within a given building due to varying external stimuli (solar path radiation), variations in internal use (equipment, lighting, people), and conditions of spatial geometry and building envelope materials.

Medium vs. Matter

Any energy process is dependent upon the type of medium and matter with which it manifests, interacts, and transfers through. In many ways, the energy...
variable in our built environment is invisible, and as such, difficult for architectural designers to comprehend within what is predominantly a discipline of visual thinkers.

We generally find an intuitive understanding of materials in architectural design thinking due to the emphasis on matter as a fundamental component of creating space, form, and phenomenological affects. It is also the case that architecture operates within a cultural realm, and our material logic is responsive to such cultural demands, whether imagined, perceived, or real. A fundamental understanding of matter is conceived through its micro-scale properties, genetic behaviors, and anatomical traits. The design of any environmental building technology that is culturally situated will tend to be embedded within a material logic responsive to particulars as opposed to mechanical solutions responsive to universals. The embedded logic of matter is coherently integrated with medium in our environment.

Environmental medium consists of sun (thermal), light (optical), wind (kinetic), water (solid, liquid, gas), and chemistry (atmospheric). Light (optical value) often serves as a primary metaphysical concept for spirituality in architecture, while sun (thermal value) and wind (thermal and kinetic value) serve as form-giving conditions to attain thermal properties of comfort desirable in passive design. The human body can also be considered as a medium. The combination of these mediums results in bioclimatic aspects that may be considered in architecture design processes.

Fig. 5. Medium and Matter: Molecular entropy and viscoelastic sorption (Maxwell relation).

The scientific basis of bioclimatic design informs the thermal functions of architectural systems in relation to the human body, thus establishing in part the physiology of architecture. The intersection of various mediums with architecture forms a complex nonlinear dynamical system. The medium in these nonlinear dynamical systems contains large quantities of solar energy, nutrients for photosynthesis, powerful wind forces, water sustenance, and chemicals for catalytic processes.

Conceiving of medium as resource in the manifestation of design processes propels architecture towards a state of low entropy. The intersection of medium with matter results in dynamic conditions and exposes the potentials and abilities for such intersections to perform work (Fig. 5).

Endeavoring to employ matter for the purpose of metabolizing medium through building system configurations constitutes emergent necessities of material functions and results in innovative material science frameworks. While permanence and stability are typically primary requisites for determining the potential of materials in building construction applications, an internal logic to the medium flow paradigm insists upon a notion of impermanence and instability.

Form often takes precedence over medium and matter in architectural design. The gothic flying buttresses were innovative responses to extensive vertical forces and subjected building materials to unanticipated forms. The gravitational force studies with string by Gaudi, improved innovative
experimental procedures for the design of catenary and funicular forms that were subsequently translated into material systems. Bioclimatic design is similarly informed in response to environmental forces (medium), but often such architectural forms are simply diagrams of a scientific positivism. Darwinian theories of plant morphologies as regional adaptations to environmental flows incorporate genotypic constraints with climate forces in an evolutionary timescale. Medium intersects with matter and the multivalent forms of energy flows within these processes inform dynamic state morphologies for system configurations. The conflux of spatiotemporal criteria with medium and matter shapes the formal conditions required for efficacious environmental performance in architecture.

**Conclusions and Future Work**

The framework of this emergent methodology presented within this paper is currently integrated into ongoing design research projects by the author in both singular (transdisciplinary) and collaborative (interdisciplinary) platforms. While there are not yet any steadfast conclusions with regards to the effectiveness of introducing these concepts into design processes, the expression of work resulting from such methodology is indicative of exemplary intuitive logic not accessible through prior methods.

These foundational concepts are being introduced within Environmental Control Systems building technology courses, and the tracking of design documentation resulting from such curriculum integration is currently being established. Future integration of these concepts will occur in design studio curriculum, including the implementation of the interactive simulation and visualization tools developed for this work. Additional simulation and visualization tools will be developed and expanded to incorporate cross-linking of the interscalar relationships of environmental performance and medium flows. This framework continues to inform numerous unique designs for environmental building technologies in various applications as well as concurrent emergent material innovations.

**Notes:**

3. While Kiesler referenced metabolic processes for analogies in design processes, his primary focus in technological design was on human kinesis and ergonomics of technology as opposed to environmental performance aspects.
4. Kiel Moe addresses this fundamental mode of conceptual thinking as a necessary aspect in contemporary architectural design practice in *Convergence: An Architectural Agenda for Energy* (New York, NY: Routledge, 2013). Moe argues that focusing our understanding on the potential benefits of maximizing and capitalizing on energy and its integration with material and building systems through a lens of second law of thermodynamics (entropy) would allow us to benefit from the qualitative aspects of such functions and behaviors rather than just quantities.
5. In this particular system, the Maxwell relation refers to the increase in entropy as the elastopolymers contract and the decrease in entropy as the elastopolymers expand.
7. This broadened multi-scalar lens is not conceptually new for the architectural discipline, however, as the Eames conceived of such corollary in their short *Powers of Ten* films (1968 and 1977).
9. Matter is physical substance defined by its chemical attributes and molecular structure inducing specific behavioral responses with variant medium.
10. Medium facilitates energy and is causation for qualitative and quantitative variations through interaction with matter. Medium influences the technique by which modes of expression manifest in design processes, and influences all impressions upon the senses.
A low entropy system is one in which greater quantities of thermal energy are available for conversion into mechanical work.

Form is the manifestation of shape, organization, arrangement, and composition as a result of the interactions between techne and poesis in design processes.