Complex Modelling of Open System Design for Sustainable Architecture

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Abstract. This paper argues a model of complex system design for sustainable architecture within a framework of entropy evolution. The spectrum of sustainable architecture consists of the efficient use of energy and material resource in life-cycle of buildings, the active involvement of the occupants in micro-climate control within buildings, and the natural environmental context. The interactions of the parameters compose a complex system of sustainable architectural design, of which the conventional linear and fragmented design technologies are insufficient to indicate holistic and ongoing environmental performance. The complexity theory of dissipative structure states a microscopic formulation of open system evolution, which provides a system design framework for the evolution of building environmental performance towards an optimization of sustainability in architecture.

Keywords: complex modelling, entropy evolution, sustainable design.

1 Introduction

The negative environmental impacts of building design imply that the technologies in building industry have been developed with incomplete concerns in both human and environmental dimensions. With the challenges of degenerated natural resources, degraded natural environment and increasing global population, the significance of sustainable development is raised globally. The concept of sustainability is identified as a systematic composition of social, ecological, economic, cultural and technological dimensions [7]. In other words, design for sustainability should be an integral participation of man, nature and technology.

The integrity of sustainability implies that sustainable design in architecture should aim to technologically implement the interactions of all the parameters for an optimised environmental performance of a building system, to achieve sustainable symbiosis of man and nature. Specifically, these parameters of system sustainability in buildings

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refers to the end-users' aspirations, the environmental context, energy and material use in buildings, which interact with each other in a complicated non-linear pattern. These interactions contribute a dynamic characteristic of system sustainability [15]. It means sustainable development must naturally change in response to shifts in any part of this dynamic interrelation. In brief, the complexity of system sustainability can be represented with spatial and temporal coordinates in a way that building environmental performance adapts and responds to the constraints of both man and nature through its life-cycle.

Most of current design strategies and technologies for sustainable architecture mainly focus on improving the energy performance of buildings [5] [6] [8] [22] [26]. Energy-efficiency as a popular approach is interpreted as a respect for the location, the users of the building and concerns of conservation of energy and resource, which encompasses all those sensibilities of solar and photovoltaic technologies, optimum orientation, diurnal zoning, and energy self-sufficiency as the hybrid or intermediate technologies. However, this mixture of fragmented techniques [22] is employed with a main focus on energy efficiency within buildings without predicable and controllable tools to indicate ongoing performance of the holistic building system in the context of its host environment, the natural ecosystem.

In this context, a radical concept of sustainable architecture is advocated [22], which pushes the generally acceptable identification of sustainable architecture further to a more interactive and even more ingenious adaptations to the host environment of the natural ecosystem. This strategy aims to design buildings climatically and culturally effective over time, to regional microclimates and materials and even to global scale. In brief, sustainable architecture is currently identified to re-imaging the interrelations between human beings and living ecosystems in a more positive manner.

One of the alternatives for positive interactions of buildings and nature is argued as restorative design [1] [9]. In this proposition, a building is designed to nourish and restore living systems in an analogy with the positive interrelation of sun with a tree. It means that buildings are designed as ecologically productive systems with positive contributions to the environment, to restore the environment without sacrificing natural resources and to increase the carrying capacity of the ecosystem. This proposition of positive interactions of buildings and nature is consistent with the concept of fitness of the environment proposed by McHarg [10]. From the basis of ecology and biology, McHarg argues, every organism or any system modifies the environment, and the environments adapt and evolve to accomplish the fittest of the organisms and the natural environment. This interdependence provides a positive model for sustainable symbiosis of man-made space and the natural environment.

With the identification of system sustainability, design for sustainable architecture is argued to establish positive interactions of man and nature through innovative technologies in buildings, towards a more general environmental symbiosis. A new design program for sustainable architecture is therefore expected. It is hypothesized as an integrated response to the full spectrum of sustainability with an optimized environmental performance evolving from non-linear interactions of all the parameters of system sustainability in architecture.

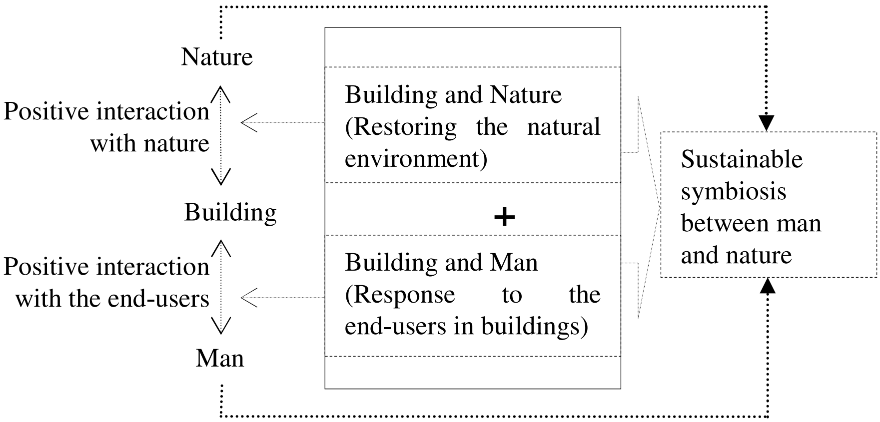

Fig. 1. An Interactive Design Strategy for System Sustainability of Architecture

2 A Paradigm of Entropy Evolution in Complex Open Systems

It is stated that one of the great misconceptions on sustainable design is that environmental consciousness is not dictated by sound science [23]. By applying the laws of science and taking nature as a workable model [2] [9] [14] [19] [22] [23] [28], the ecological principles of entropy, for example, the environment is to provide the products demanded by society, both predictable and sustainable.

A striking interpretation of the Second Law of Thermodynamics [12] [16] [17] [18] [20] states that entropy of an open system is the origin of order. Open system in thermodynamics science refers to a system open to energy, matter and information, in which the interactions of energy and matters as the thermodynamic parameters are non-linear. The status quo of an open system is far-from-equilibrium when various self-organising processes such as the distribution of energy and matter occur in the system. With complicated feedback loops, the open system at the state of far-from-equilibrium is highly sensitive and adaptive to external influences. It means any small change in the system triggers fluctuations, for example, remarkable space-time re-organisations and re-distributions of energy and matter in the system.

During the evolution of an open system, entropy is both physical and chemical potential in the spontaneous change of the system, due to the differences or gradients of temperature, pressure, concentration of the system, and between the system and the surrounding. By the dissipation of material and energetic fluxes as thermal changes, entropy is produced from both the internal system and the external environment, such as heat flow and mass flow across the system boundary.

Specifically, by the fluxes of energy and matter across the system, the system is evolving in a state of far-from-equilibrium thermodynamics, which means the entropy production of an open thermodynamic system increases dynamically. This thermodynamics of the open system will finish at the state of non-equilibrium, when entropy production from the system is compatible with the constraints imposed upon the boundary of the system, and when a highly ordered organization of energy and matter in the system arrives eventually. In brief, the interpretation of the Second Law of Thermodynamics in an open system implies a microscopic formulation of the evolutionary paradigm for positive design, which evolves to highly ordered organisation with positive-feedback loop. Entropy is an indicator of the evolution of an open system. The second law of thermodynamics of open system is described in the equation [20]:

$$dS/dt = \sum M_k S_k + Q/T + S_{gen} \quad (1)$$

- dS/dt, the rate of entropy change of an open thermodynamic system, divided by the dimension of time;
- $\sum M_k S_k$ = the net rate of entropy flow due to the flows of mass into and out of the system (where S_k = entropy per unit mass);
- Q/T = the rate of entropy flow due to the flow of heat across the system boundary;
- S_{gen} = the rate of internal generation of entropy within the system.

Table 1. The Second Law of Thermodynamics of Open Systems [12] [16] [17] [18] [20]

Phase	State of system	d_eS & - d_iS	dS	Entropy	Impact
I	Far-from- equilibrium	$d_eS/dt < - d_iS/dt$	$dS > 0$	Positive	Negative
II	Non-equilibrium	$d_eS/dt = - d_iS/dt$	$dS = 0$	Neutral	Balance
III	Order emergence	$d_eS/dt > - d_iS/dt$	$dS < 0$	Negative	Positive
Notes	$dS/dt = \sum M_k S_k + Q/T + S_{gen} \rightarrow dS/dt = d_eS/dt + d_iS/dt$ (2) $d_eS/dt = (\sum M_k S_k + Q/T)$: entropy change rate due to the external flux of energy and matter $d_iS/dt = S_{gen}$: entropy change rate due to internal entropy production				

Phase I: A far-from-equilibrium state, $dS/dt = d_eS/dt + d_iS/dt$, where $dS/dt > 0$, $d_iS/dt \geq 0$ and $d_eS/dt < -d_iS/dt$. At the far-from-equilibrium stage, entropy in the system is incorporated by the internal production within the system and external entropy flow from the surrounding; the rate of entropy in total is positive. This stage represents increasing entropy of the open thermodynamics system, and results in negative environmental impact.

Phase II: A non-equilibrium state, $dS/dt = d_eS/dt + d_iS/dt$, where $dS/dt = 0$, and $d_eS/dt = - d_iS/dt$. At the non-equilibrium state, the rate of internal generation of entropy within the system is compensated by the net rate of entropy flow due to the energy, heat, and materials fluxes into and out of the system. In consequence, the system finishes the thermodynamics change, and arrives at a highly-ordered organisation when entropy is balanced. This state is when order emerges from the system through the spontaneous and self-organising evolution of energy and matter fluxes.

Phase III: An order state after the evolution of the system, $dS/dt = d_eS/dt + d_iS/dt$, where $dS/dt < 0$, and $d_eS/dt > - d_iS/dt$. In this case, d_eS becomes sufficiently negative and exceed the magnitude of d_iS, resulting in certain stages of the evolution characterised by $dS/dt < 0$. It means that because of the entropy flow, order increases in the course of the evolution. This can be observed in biological evolution, where an irreversible evolution process of an open system, such as an organism, is associated with increasing complexity.

Nicolis & Prigogine [12] thus argue the nature of an open system is a dissipative structure far from thermodynamic equilibrium in order to survive; it is thermodynamically self-adaptive, open to both energy and matter; it exchanges with the host environment by continuous fluxes of neg-entropy from the universe, to which they return an even larger amount of positive entropy. In consequence, open systems evolve to higher and higher forms of order while isolated systems evolve to disorder.

In sum, by self-organizing and self-spontaneous thermodynamic change to fully take use of energy and matter fluxes across the system, an open system evolves through the steady growth of structure, organization and complexity to constitute new organizations of the system [17] [18] [21]. This evolutionary paradigm of entropy has been used to interpret the creation of the universe as an entropy production [12], the regenerative process in nature from chaos to order [13] [17], the evolution of an organic life [3] [4] [17] [21] [27], the model of origin-of-life [24] and the formation of matter's structure [12].

3 A Model of Open Systems Design for Building Environmental Performance

With the clarification of the concept of entropy, the implication of entropy in a complex open system to the built environment is a complex model of open system design for the evolution of system sustainability; and entropy is the indicator of the evolution of an open system. Specifically, by designing a building, or its subsystem, as an open system it is possible to facilitate non-linear interactions of all the parameters of system sustainability. In an entropy paradigm, the complex open system of a building or its subsystem, which is adaptive and responsive to the constraints from the host environment, evolves with positive feedback towards a highly ordered organisation, such as an optimised environmental performance of the building. In fact, an open system of a building or its subsystem refers to a virtual environmental system immersed with dynamic information which represents the non-linear interactions of all the parameters of system sustainability. These include the local climate context such as climate, soils, and topography, the end-users' demands and satisfactions of past performance and future prediction on the microclimate in the buildings, the available energy and material resources, the distribution and consumption of energy and material resources, the environmental impact of that use, such as energy waste and emission, or self-generated energy, and the available building technologies. These parameters can be translated and converted as elementary parameters of an open system in entropy paradigm, including the system, the boundary, the surrounding, the constraints, and the drivers:

- Operators of adaptive system: the end-users' aspirations of micro-climate control;
- The host environment: the constraints such as the conflicts between the local climate context and the end-users' demands and satisfactions;
- The adaptive system: a building or its subsystem, such as HVAC (heating, ventilation and air-conditioning) system;
- Dynamic fluxes of adaptive system: the information of the fluxes of energy and material resources across the boundary of a building system or its subsystem;
- Internal entropy production: the environmental impact such as emission and waste, and positive contributions of self-generated and self-contained energy, etc.

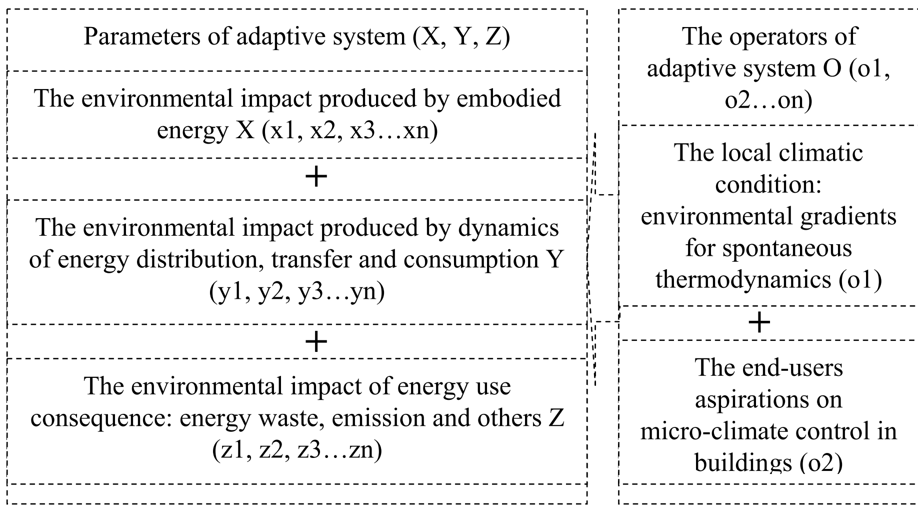

Fig. 2. Parametric Design of Adaptive Building Environmental Performance

These parameters follow the rule of the entropy evolution, adapting and evolving towards the positive outcome of a highly-ordered organisation of energy and material resources as sustainable environmental performance. A formula of parametric design for open system in buildings will be developed, which refers that the complication of energy and material resource distribution in a system or subsystem of buildings, will be controlled by and responded to the conflicts of end-users and the environmental condition as the constraints of the evolution of the open system of buildings or the subsystem.

$$dS/dt = dX/dt + dY/dt + dZ/dt + dO/dt \tag{3}$$

- dS/dt: entropy change rate
- dX/dt: entropy produced by the embodied energy in material flows
- dY/dt: entropy produced by the operational energy
- dZ/dt: entropy produced by energy waste and emission
- dO/dt: the operators of energy and material fluxes: the users and environmental context

This model composed with parameters and the rule will converge to control modelling for system sustainable design in buildings, by which the environmental performance of a building is manipulable and responsive to the accessible constraints with positive outcome. In this context, complex modelling represents a wide range of information on the physical characteristics of the building, to simulate and analyse alternative scenarios such as the critical constraint of local climate, a variety of demands from the end-users and dynamic fluxes of energy and material use in buildings, which can then be convert into a final design solution for sustainability.

In this composition of complex model, the relative information of the internal energy and material distributions in the system, which are used to create the microclimatic environment in the building, is connected to the information of the system's constraints of the conflicts between the end-users' demand and the local environmental context. Virtually, a building or its subsystem can be designed in a self-sufficient and self-organizing mechanics to organize energy capture, distribution and consumption. The interactions of all the parameters, including the active involvement of the end-users and the sensitive response to the local environmental context are thus established for an adaptive evolution within the timeframe of building's life-cycle. In this process, entropy is a sensitive indicator of the evolution of the adaptive system, indicating the state quo of the system. Once entropy is balanced neutrally, it means the positive outcome of non-equilibrium of the system arrives, and the constraints or conflicts of the system are resolved.

The complex model will be used to constitute building information modelling, which will provide sufficient informative feedback of ongoing building performance to facilitate the adaptation and evolution of system sustainability design in buildings. Through manipulable organisation of energy and material resources use in the building system, the design proposition is not only to reserve energy and resource use in life-cycle of buildings, but also produce positive ecological contribution to the environment as interactive design to restore the natural environment. In terms of the framework for entropy analysis of open thermodynamic system, the active thermodynamic fluxes of energy and resources will accelerate the ecological interactions of buildings with the host environment of the natural ecosystems. By these positive interactions, the research will reveal the harmonious relations of buildings to their surroundings are ecologically interactive. Therefore, buildings can be identified as part of productive ecosystem in nature, restoring the natural environment for sustainable symbiosis of man and nature.

4 Summary

The paper proposes a model of complex open system design for sustainable architecture within the framework of entropy evolution. This model is converged to complex modelling of building environmental performance for a manipulable organisation of energy and material resource used in the building system, with an active involvement of the end-users responding to the natural environment. By this complex modelling of open system as an alternative proposition for system sustainable design in architecture, the paper argues it is possible to attain an ideal sustainable environmental performance of a building, a highly-organised energy and material use in buildings. Hence, the harmonious relationship of man and nature can be established for the imperative of environmental sustainability. This paper is based on a work-in-progress PhD research project which will be developed by means of experimental simulation of an open organic system evolving to minimum entropy stage, in the forms of mathematical expression and control modelling in the next research stages.

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