A Generative Nervous System for the Planet

Professor John Frazer, AA Dipl, MA (Cambridge), FCSD, FRSA
School of Design, Faculty of Built Environment and Engineering
Queensland University of Technology, Brisbane, Australia
j.frazer@qut.edu.au

GU Yan, BSc, MSc (London), PhD Candidate
National ICT Australia (NICTA), Victoria Research Laboratory
Department of Electrical and Electronic Engineering, Faculty of Engineering
University of Melbourne, Melbourne, Australia
y.gu@pgrad.unimelb.edu.au

Abstract

Generative systems are now being proposed for addressing major ecological problems. The Complex Urban Systems Project (CUSP) founded in 2008 at the Queensland University of Technology, emphasises the ecological significance of the generative global networking of urban environments. It argues that the natural planetary systems for balancing global ecology are no longer able to respond sufficiently rapidly to the ecological damage caused by humankind and by dense urban conurbations in particular as evidenced by impacts such as climate change. The proposal of this research project is to provide a high speed generative nervous system for the planet by connecting major cities globally to interact directly with natural ecosystems to engender rapid ecological response. This would be achieved by active interactions of the global urban network with the natural ecosystem in the ecological principle of entropy. The key goal is to achieve ecologically positive cities by activating self-organising cities capable of full integration into natural eco-systems and to network the cities globally to provide the planet with a nervous system.

Introduction

The prevalent industrial pattern of design and development in the urban environment which is expanded and driven by fossil fuels has significant impacts on the global environment. Broadly speaking, the depletion of natural resources, the reduction of biological diversity, and the degradation of carrying capacity of the earth, global climate change and global warming are remarkable indications. In statistics [3], cities consume three quarters of global energy, responsible for at least three quarters of global pollution; approximately 64 per cent of the world's economic production, consumption and pollution are associated with cities. It has been summarised [27] that cities have become parasites in the landscape, immense organisms that drain the world in search of food and energy, relentless consumers and relentless polluters. The explosive urban growth in the use of energy and materials characterise in the twentieth century is warned with the global limits to space and resources [14]. Specifically, ecological footprint is defined to account for resources consumption and environmental degradation, and calculations show that only 1.5 hectares of ecologically productive land and about 0.5 hectares of productive ocean are available for every person on earth [26]. On other hand, it is expected by United

Nations Human Settlements Programme that in 1950 only 30 per cent of the world's population was urban; by 2008 more than 50 per cent are living in urban areas, and by 2030 60 per cent will live in cities.

With the challenges of degenerated natural resources, degraded natural environment and increasing global population, conventional industrial development which has been practiced for nearly two centuries is recognised inherently unsustainable [4]. A growing recognition is that long term economic and social vitality depend upon more efficient use of natural resources, coupled with improved human and environmental health [32]. This integrated concern from economic, social, and environmental perspectives campaigns for sustainable development globally. Further, the concept of sustainability is identified as a systematic composition of social, ecological, economic, cultural and technological dimensions [9]. In other words, design for environmental sustainability should be an integral participation of man, nature and technology.

A New Sustainable Strategy for Complex Urban System

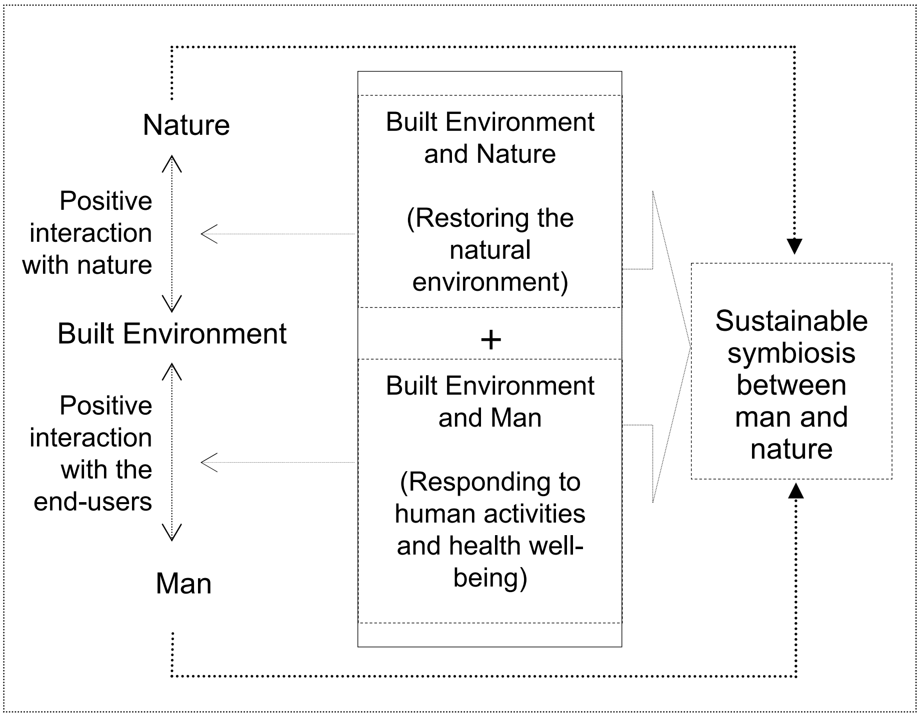
The integration of sustainability implies that sustainable design should aim to technologically implement the interactions of all the factors for an optimised environmental performance of the built environmental system, in order to achieve sustainable symbiosis of man and nature. Specifically, the factors of system sustainability in the environment can be identified as parameters of the end-users' aspirations such as climatic demand to satisfy human activates contained within spatial design, and the physical environmental context, including energy and material resource used in the built environment. All of these parameters interact with one another in complex non-linear patterns, which contribute a dynamic characteristic of system sustainability of the built environment [22]. In brief, sustainable development must naturally change in response to shifts in any part of this dynamic interrelation.

Currently, most design strategies and technologies for sustainable design in the built environment focus on improving the environmental performance of energy and resource use and reducing the environmental impact of that use [7] [8] [13] [33] [37]. These approaches are interpreted as a respect for the local contexts, the concerns for the end-users of the built environment and the conservation of energy and resource. However, the hybrid of fragmented techniques towards the vision of environmental sustainability is employed without predicable and controllable tools to indicate ongoing environmental performance of the holistic system, particularly ecological interactions with the natural ecosystem which is the host environment in essence.

In this context, a radical concept of sustainable architecture is advocated [33], pushing the generally acceptable identification of sustainable design to interactive and even ingeniously adaptive to the natural ecosystem. This advanced strategy aims to design environmental sustainability climatically and culturally effective over time, responding to regional microclimates and materials and even to global scale. In general, sustainable design urban environment is re-identified to imaging the interrelations between human beings and living ecosystems in an ecologically positive manner.

A significant component of this positive design is restorative design [1] [16]. It is argued to design urban environment to nourishing and restoring living ecosystems in an analogy with the positive interrelation of sun with a tree. By this restoration, cities 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 natural ecosystem. This proposition for positive interrelations of urban environment and nature is consistent with the concept of environmental fitness [17]. From the basis of ecology and biology, it is argued 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 ecological interdependence provides a positive model for sustainable symbiosis of man-made space and the natural environment.

Fig. 1: Positive Design for System Sustainability in Urban Environment



In sum, a holistic composition of positive design aims to bridge the gap of man and nature which are identified as two main components of system sustainability in urban environment. Positive design is proposed not only to satisfy human activities and aspirations including climatic demands and health well-being, but also to produce ecological contribute to the natural ecosystem. Through positive design, an ecological symbiosis of man and nature in urban environment will be established. With the identification of composition of system sustainability in urban environment, a new design program for sustainable design is thus expected which needs the assistance of relevant innovative technologies. It is hypothesized as an integrated response to the full spectrum of sustainability, the parameters of which evolve in a non-linear pattern towards an optimized environmental performance of the system.

A Design Framework of Entropy for Complex Urban System

It is argued that one of the great misconceptions on sustainable design is that the environmental consciousness is not dictated by sound science [34]; furthermore, science is argued [19] bound to play an increasingly important role to meet the challenge of understanding and reshaping the environment to achieve constructive modification of the environment with a less destructive coexistence with nature. By applying the laws of science and taking nature as a constructive model [2] [16] [21] [28] [33] [34] [39], the ecological principles of entropy, for example, it is possible to design a sustainable urban environment which is embedded by the demands of society.

In general terms of thermodynamic science, the built environment is considered as entropy result at high order. It is a highly ordered material environment constructed with a highly ordered power through energy use with energetic order, including refining, processing and purifying energy itself, provided from the low-ordered natural environment [10] [35]. Another generally acceptable thermodynamic interpretation argues that the consequence of energy and matter use in the environment is entropy, the inescapable negative environmental impact, including energy inefficiency and pollution emission [11] [18]. In particular, climate change is considered as entropic consequence, chaos in the built environment, mainly caused by fossil fuel use for greenhouse gas emission. In contrast to this collective sense of guilt accelerated by human technology to the point of endangering the survival of the species on the earth, on the other hand, entropy is interpreted as the nature's technique for balance [2]. This positive recognition regards entropy as spontaneous chemistry and physics thermodynamic change between man-made environment and nature due to the temperature and pressure differentiates, and other thermodynamic gradients.

Most strikingly, the latest interpretation of the Second Law of Thermodynamics states that entropy of an open system is the origin of order [19] [23] [24] [25] [29]. Through evolutionary thermodynamics, an open system evolves towards positive outcome, a highly ordered state with complex organisation, when order is generated from chaos. During the evolution, entropy functions as an informational indicator, representing the phase changes of microscopic configuration of the open system, such as thermodynamic distribution of energy and matter in the system. In short, this interpretation of entropy in an open thermodynamic system provides a microscopic configuration and formulation for positive design in the environment.

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 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.

In 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. In the dissipation of material and energetic fluxes as thermal changes between the open system and its host environment, entropy is produced by heat and mass fluxes across the system boundary and the open system itself.

In specific, an open thermodynamic system evolves through three phases: an initial positive entropy state with negative environmental impact, an entropy balance state with neutral environmental impact, and a negative entropy state with positive environmental impact. The evolutionary pattern of entropy in an open thermodynamic system can be specified as follows.

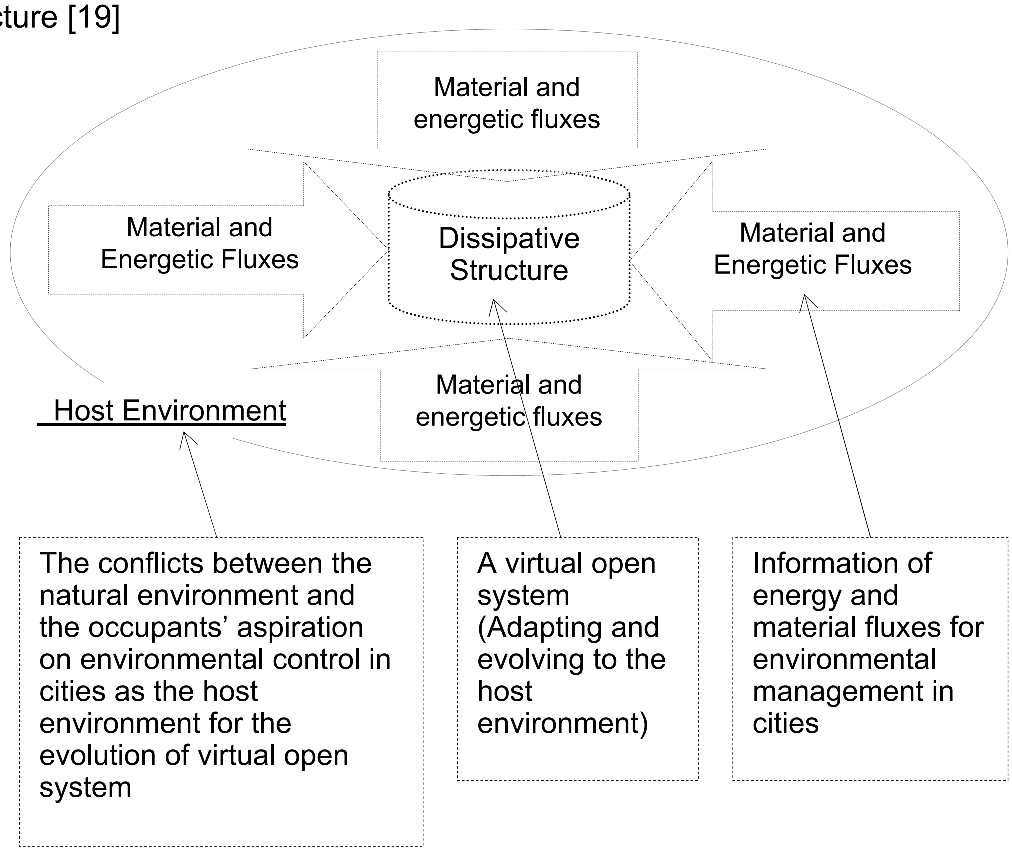
- Phase I: when the system is at a far-from-equilibrium state, entropy in the system is incorporated by the internal production within the system and external entropy flow from the surrounding; the rate of entropy in total is positive. This stage represents increasing entropy of the open thermodynamics system, and results in negative environmental impact. In other words, entropy production of the open system is compatible with the constraints imposed upon the boundary of the system.
- Phase II: when the system is at a 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 of energy and matter in the system. This state is when order emerges from the system through the spontaneous and self-organising evolution of energy and matter fluxes.
- Phase III: when the system is at a highly order state after the evolution of the system. In this case, 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.

It is thus argued that [12] [19] the nature of an open system such as living systems and biological organisms are open thermodynamically dissipative structure, which evolve towards organised complexity. This dissipative structure, with the work of physico-chemical processes of developmental mechanisms, evolves from 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 [23] [24] [25] [30]. This evolutionary paradigm of entropy has been used to interpret the creation of the universe as an entropy production [19], the regenerative process in nature from chaos to order [20] [24], the evolution of an organic life [5] [6] [24] [30] [38], the model of origin-of-life [36] and the formation of matter’s structure [19].

With the clarification of the concept of entropy, the implication of entropy in a complex open system to the built environment is a conceptual model for sustainable urban development. It is specified as a complex model of open system design for the evolution of system sustainability. The hypothesis is cities as open complex systems exchanging both energy and matter with the natural environment and evolving towards positive environmental impact in entropy evolution; thus cities work as ecological productive ecosystems to produce ecological contribution to the natural ecosystem. More specifically, by designing a city as an open system, it is possible to facilitate the non-linear interactions of all the parameters of system sustainability in the self-organising pattern. In an entropy paradigm, the complex open system of a city or cities network, is self-adaptive and self-spontaneous to the constraints in the host environment, and evolves with positive feedback towards a highly ordered organisation, such as an optimised environmental performance.

Fig.2: An Open System Model of Complex Urban System adapted from Dissipative Structure [19]



In general, it is argued [14] that the fundamental biophysical bases for an urban system like a city to survive indefinitely rely on its consistency with physical limits imposed by thermodynamics and the preservation of ecological surroundings and, consequently, of ecosystem services. In this paper, an open system of a city or cities network 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 urban environment, 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.

- Controller of open systems: the information of the end-users' aspirations such as micro-climate control;
- Host environment of open systems: the constraints such as the conflicts between the local physical context and the end-users' demands and satisfactions;
- Open system: a city or a city network;
- Dynamic fluxes of open systems: the information of the fluxes of energy and material resources across the boundary of the system;
- Internal entropy production: the irreversible environmental impact such as emission and waste, and positive contributions such as self-generated and self-contained energy and etc.

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.

Virtually, a city 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 identified as the constraints for the adaptive evolution of urban complex systems. 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.

This model composed with parameters and the rule will converge to control modelling for system sustainable design of complex urban systems, by which the environmental performance of the system is manipulable and responsive to the accessible constraints with positive outcome. In this context, control modelling represents a wide range of information on the physical characteristics of the system, 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, which can then be convert into a final design solution for sustainability. A differential equation of parametric design for open system of urban network will be developed, in which the rate of change of each variable is written down in terms of the present values of all the variables which influence the variable in question.

$$dS/dt = \text{Function}(x, y, z)/dt + \text{Controller}(\lambda)/dt \qquad (1\text{-}1)$$

- dS/dt: entropy change rate;

- Fucntion (X, Y, Z)/dt: entropy produced by the embodied energy in material flows, entropy produced by the operational energy, entropy produced by energy waste and emission in the open system,
- Controllers (λ)/dt: controller rate of energy and material fluxes controlled by the end-users and the environmental context.

In this composition of complex model, the relative information of the internal energy and material distributions in the system, which are used to create an optimised environmental performance in urban environment, is connected to the information of the system's constraints of the conflicts between the end-users' demand and the local environmental context. Within each individual system, conflicting constraints will yield a fitness design solution responding to individual environmental context and the human demands.

A Model of Generative Nervous System for Complex Urban Systems

Through manipulable information organisation of ecologically environmental performances of complex urban system, the urban system will not only reserve energy and resource use, but also produce positive ecological contribution to the surrounding environment restoring the natural ecosystem. 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 urban system with the natural ecosystems. By these positive interactions, the harmonious interrelation of urban environment to their surroundings is ecologically positive. Therefore, cities can be identified as part of productive ecosystem in nature, restoring the natural environment for sustainable symbiosis of man and nature. The constitution of control modelling of complex urban system will provide sufficient informative feedback of ongoing environmental performance to facilitate the adaptation and optimisation of environmental management of urban system for an efficient organisation [31]. By changing the constraints of the system and identifying the order of the system, through the analysis of informational feedback, a variety of design solutions for sustainability can be generated, which will be used to design forms and structures for the stabilities of complex urban systems.

This Complex Urban Systems Project (CUSP) founded in 2008 at the Queensland University of Technology aims to provide a high speed generative nervous system for the planet by connecting major cities globally to interact directly with natural ecosystems to engender rapid ecological response. By following the paradigm of open system in entropy evolution, cities will positively interact with the natural ecosystem by both internal ecosystem and external ecological interactions with the natural environment in the form of dynamic fluxes of energy and resources, which can be engaged by human active participations assisted with control modelling techniques. Therefore, urban environment is activated with capabilities of self-organising and adaptation for a full integration into natural eco-systems and to network the cities globally to provide the planet with a nervous system to achieve ecologically positive cities.

CUSP aims to establish the beginnings of a digital sustainability network which will research and develop a new approach of Generative Urban Systems. We posit that this project will contribute to the development of environmentally sustainable cities by expanding ecological and urban assessment capabilities and harnessing real–time sensing technologies. It will also contribute to an expanded awareness of innovative approaches to reducing the environmental impact of urbanisation. The end product will further demonstrate methods of retooling cities in alternative approaches to designing for a zero carbon emission strategy. This differs from restorative or regenerative design, which is about producing a clean energy, water and air, and is essentially remedial and focussed on resource autonomy – and is not net positive.

Conclusion

This paper proposes a generative model of complex open system for sustainable urban design within the framework of entropy evolution. This model is converged to control modelling of ecologically environmental performance of complex urban system, with an interactive involvement of the end-users and a responsive engagement to the natural environment. By employing control modelling technique to identify the constraints of the system adaptive and responsive to the local context, and to design a desired order of the systems, the paper argues it is possible to attain an ideal sustainable environmental performance of complex urban system, a highly-organised energy and material use. Hence, the harmonious relationship of man and nature can be established for the imperative of environmental sustainability.

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