# Sustainable Human–Building Ecosystems


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# SUSTAINABLE HUMAN–BUILDING ECOSYSTEMS

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# Preface

Welcome to the First International Symposium on Sustainable Human–Building Ecosystems!

For decades, a significant amount of research effort has been directed towards developing engineering, economic, and policy approaches to better design and maintain energy efficient buildings. Until recently, many have realized that occupant behavior is another missing piece of the equation. As the research community is quickly growing, we need a venue where researchers can share cutting edge findings in the integration of human behavioral, social and economic sciences with building design, engineering and metrology for better understanding building energy performance, environmental impacts and occupant comfort.

We received over 60 abstracts and 25 high quality papers have been accepted and included in the proceedings. The abstracts and final papers were peer-reviewed. The proceedings cover a wide range of topics, generally classified into three subject areas, namely, occupant behavior modeling and analysis, thermal comfort prediction and analysis, and innovative design, planning and policies for building energy efficiency. The proceedings also include a keynote presentation paper on human ecology and building science.

On behalf of the organizing committee, we would like to thank the School of Architecture at Carnegie Mellon University for hosting the symposium, our sponsors Autodesk Inc. and Cristal Global Engineering for their generous financial support, and reviewers for their great contribution to the review process.  We also want to recognize the Predictive Modeling Network for Sustainable Human-Building Ecosystems (SHBE), a Research Coordination Network (RCN) for Science, Engineering and Education for Sustainability (SEES) funded by US National Science Foundation (NSF) for establishing the foundation for this symposium, and contributions from the participants of Annex 66: Definition and Simulation of Occupant Behavior in Buildings under the auspices of the International Energy Agency's (IEA) Energy in Buildings and Communities (EBC) Programme.

# Contents

# Human Ecology and Building Science: A Necessary Synthesis

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## INTRODUCTION

Buildings represent a major class of interventions by people in the environment, resulting in resource depletion, environmental emissions, and waste generation. To date, building-related interventions, together with those involving industry and transportation, have comprised the planet's capacity to support the sustenance of future generations. This circumstance has raised the awareness regarding the importance of sustainability in the building sector. However, as in many other environmentally relevant domains, the theory (how the built environment should be) and practice (how the built environment actually is) have not converged. If we are to take the idea of sustainable buildings seriously, we need to approach it critically in the context of the complex and consequential relationships involving people, buildings, and environment. Why do we erect buildings? How can we measure their effectiveness in meeting people's requirements? How can we assess their ecological implications?

To address these questions this paper offers a broad and critical framework. Toward this end, section 2 of the paper entails a brief introduction to "Human Ecology" as a fruitful conceptual framework for the discussion of interrelationships between people and their surrounding built environment. Section 3 is dedicated to a number of essential background or boundary conditions necessary for a meaningful discussion of sustainability in the building sector. These include, amongst other topics, population growth and "life style". Section 4 is concerned with the indoor environmental (especially thermal) requirements of building users. Section 5 addresses people's passive and active influences on buildings' indoor climate and environmental performance. Section 6 summarizes the paper's conclusions.

## HUMAN ECOLOGY

As a discipline, ecology deals with the relationships between organisms and their surrounding world. Accordingly, human ecology may be simply defined as the ecology of the Homo sapiens. There are multiple traditions in human ecology. For the purpose of the present discussion, we consider the "Vienna School of Human Ecology" (Knötig ,1992a, 1992b; Mahdavi, 1996a) and focus on a couple of its essential concepts. Construction and operation of buildings and related artifacts may be viewed as an integral part of the totality of largely regulatory operations initiated by human beings as they interact with their surrounding world. Human ecology offers a useful way of thinking about these interactions via a number of high-level yet versatile concepts. Thereby, a central pair of concepts involves:

- **i.** the human beings' *ecological potency*;
- **ii.** the surrounding world's *ecological valency* (Knötig, 1992a; Mahdavi, 1996b).

*Ecological potency* refers to the human repertoire of means to deal (cope, interact) with the surrounding world. *Ecological valency* denotes the totality of that surrounding world's characteristics (resources, possibilities, opportunities, challenges, risks, hazards, etc.) as it relates to, confronts, or accommodates people's *ecological potency*. Coined initially by Uexküll (1920), the concept of *ecological valency* is akin to the Gibson's concept of *affordance* (Gibson, 1977, 1979).

Given this conceptual framework, the main consideration in human ecology pertaints to the complex and dynamic relationships between the ecological potency of human beings and the ecological valency of their surrounding world. We can thus broadly characterize the entire building construction and operation endeavor in human ecological terms: Buildings are mainly constructed and maintained with the (implicit or explicit) intention to favorably influence the relationship between people's ecological potency and the ecological valency of their surrounding world. Such an intention expresses itself, for example, in the "shelter function" of the vernacular architecture (Mahdavi, 1996c, 1989). In contemporary building delivery processes, this intention is often expressed explicitly and formally, for example when desirable indoor environmental conditions are specifically defined and are expected to be maintained in the course of building operation. Provision of desirable conditions for the building users, or in other words, maintaining a high degree of "habitability", may be thus seen as the central utility of buildings. The challenge is to realize habitability with a minimum on resource depletion and environmental impact.

Human ecology's concepts are also relevant to the evaluation of the habitability of the built environment. Specifically, a second pair of concepts should be mentioned, which concerns distinct aspects of the relationships between people and their surroundings. Thereby a high-level distinction is made between the *material-energetic* and *information-related* aspects of these relationships (Knötig, 1992a; Mahdavi, 1996a, 1992). These two aspects can be assigned to every entity, state, and process. The *material-energetic* aspect refers to the assumption that nothing exists unless some amount of matter or energy is involved. The information-related aspect refers to the assumption that matter and energy have a certain distribution in space and time, which can be represented in terms of a structure. An information content can be correlated with this structure.

To measure the habitability of the built environment we cannot disregard people's subjective experiences and opinions. Subjective evaluation processes of the built environment arguably involve both material-energetic and the information-related aspects of the relationships between inhabitants and the built environment. A common approach to "operationalize" such evaluation processes in planning and operating involves the use of "psycho-physical" scales. The idea is that exposure to various levels of physical (material-energetic) stimuli translates – in a more or less predictable way – into corresponding subjective experiences. For example, exposure to increasing levels of sound intensity is said to result in an experience of increased loudness and associated stress (annoyance). But it would be highly problematic to postulate a deterministic relationship between measurable environmental factors and occupants' evaluation of environmental conditions (Mahdavi, 2011a, 1996a, 1996b).

People's evaluation of exposure situations may be easier to describe and predict in when the material-energetic aspect of the environmental relationships dominates. In extreme cases of high-intensity exposure, the necessity for protective regulations is self-evident due to the obvious health hazards for the involved individuals (e.g., irreversible physical damage to the organism). It is, thus, not surprising that most efforts toward predicting the outcome of evaluation processes have focused on the identification of a measurable material-energetic scale (such as sound pressure level) to which subjective judgments (such as the degree of annoyance) are expected to correlate. However, the relevance of internal information processing for the degree of expressed dissatisfaction associated with various energetic levels of exposure has been demonstrated in experimental psycho-acoustic experiments (see section 4.3 for a further discussion of this point).

## BOUNDARY CONDITIONS

**Motivation.** We will address the immediate implications of the human factor for the built environment (i.e., human requirements and behavior) in sections 4 and 5 of this paper. But it is important that we consider a number of broader questions pertaining to the environmental implications of social development and human activity (Mahdavi, 2012): *i)* How important is the antecedent consideration of population growth, lifestyle development, as well as agricultural and industrial production for the effectiveness of sustainable building efforts? *ii)* How do the relative resource needs and environmental loads associated with building activity compare to other domains of human activity and production such as industry and transportation? *iii)* To which extent can contextual factors such as urban planning decisions and mobility solutions affect and constrain the energy and environmental performance of individual buildings? *iv)* How should we account for the impact of user behavior (including the rebound effect) on the energy and environmental performance of buildings?

**Population and life style.** United nation's data (medium growth scenario) projecta for 2050 alone for India and China a combined population number of three billions. Likewise, the population of Africa – slightly over 200 millions around 1950 – is projected to approach two billion by 2050. The topic of population growth containment appears thorny and difficult politically. But even if population growth is seen as an inevitable and unalterable process, at least the implications for resources, environment, as well as ecological and social systems should be frankly discussed, rather than evaded. In human ecological parlance, the ecological valency of an ecosystem can sustainably support only a finite number of people of a given ecological potency. Transgressing that limit invariably results in an ecological degradation of the environment.

The ecological strain resulting from population increase is aggravated by a parallel process involving the improvement of living standards – at least for some populations – around the world. For instance, the global primary energy consumption of China is projected to increase – from the value in 2008 – about 230% to reach roughly 200 exajoules by the year 2035 (EIA, 2012). Moreover, whereas in the last twenty years per capita energy use has been stagnating (albeit at a very high level) in countries such as United States and Germany, both per capita energy use and Gross National Income (GNI) have been increasing in China, India, and Brazil (Databank, 2012). In fact, the Gross National Product (GNP) of China and India is projected to increase within a period of 40 years (2009 – 2049) roughly by a factor of 6 and 9 respectively. Lest these assertions are misunderstood: Rise in people's standard of living is necessary, crucial, and desirable socially and ethically. However, even though not a necessity, per capita improvement in living standard is typically mirrored in per capita increase in resource depletion and environmental impact. The environmental ramifications of such developments can be easily exemplified. Human ecologically speaking, rise in indicators such as GNP and GNI can be interpreted as a population's increased ecological potency. A precarious implication