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Stamatina Th. Rassia
Panos M. Pardalos *Editors*

Sustainable Environmental Design in Architecture

Impacts on Health

Foreword by Dr. Nick V. Baker

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Aims and Scope

Optimization has been expanding in all directions at an astonishing rate during the last few decades. New algorithmic and theoretical techniques have been developed, the diffusion into other disciplines has proceeded at a rapid pace, and our knowledge of all aspects of the field has grown evenmore profound. At the same time, one of the most striking trends in optimization is the constantly increasing emphasis on the interdisciplinary nature of the field. Optimization has been a basic tool in all areas of applied mathematics, engineering, medicine, economics, and other sciences.

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Editors

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Editors
Stamatina Th. Rassia
University of Cambridge
Department of Architecture
1-5 Scroope Terrace
Cambridge CB2 1PX
UK
mrassia@gmail.com

Panos M. Pardalos
Department of Industrial and Systems Engineering
University of Florida
303 Weil Hall
Gainesville, FL 32611
USA
pardalos@ufl.edu

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Foreword

Sustainability

Writing a foreword to such a broad and important range of topics appearing in this book is a daunting task and perhaps reflects the difficulty that faces society in understanding the breadth of the problem of sustainability. Ever since Brundtland wrote those words "act locally, think globally," we have been grappling with the "grain size" of sustainability – how widely to cast the limits of our concern, both geographically and intellectually. The problem is, perhaps, that we have no instinctive response for thinking globally – our survival behaviour has always had a local field of action. We are fundamentally selfish creatures, and this has stood us in good stead. Even when we scale up our unit of survival, we form groups whose survival will enhance our own chances. This is reflected in most of the major world conflicts, where although the causes have often been "intellectualised" as religious or ideological, they are in fact largely between the "haves" and "have nots." They are not concerned with world averages, but local acquisition and consumption.

Here in one volume, we have topics ranging from the minutiae of the sizing of rooms in hospitals, to the philosophical discussion of "proper design" and its historical precedent. Is it a useful exercise? Will it give us any pointers to a sustainable future?

To digress a moment, I remember being shocked and slightly dismayed, when, during a discussion about publication and making a name for oneself in science, our university tutor told us that there are as many scientists alive today, as have ever lived. He cited the exponential increase in the shelf space needed for journals in the library, as evidence. This was 40 years ago and since then scientific development has continued unabated. So if we have the might of this burgeoning scientific army, ready to hurl itself at the problem, why is it so difficult to find a solution? For what it is worth, I offer a couple of reasons. The first is about behaviour, and the second communication.

Behaviour and Communication

It is increasingly common to read in field studies how the potential for the performance of, for example, a low-energy building, is dominated not by technical issues, but by the behaviour of the occupants. And the impact of behaviour is not limited to buildings; it operates on other human activities too. The scale of the problem is wide, ranging from the decision to leave the light on in an unoccupied room in our home "because it is more convenient" to the decision to fly to a conference halfway round the world to present a 10 min paper (on sustainability?). In spite of our clear knowledge that the energy being used in the unoccupied room is utterly pointless, and that by standing up in front of 60 delegates (sleepy after a heavy lunch) and reading out a script which they already have in the conference papers is not going to make a major contribution to the world of science, we go on doing both. It seems that we have an instinctive need for action and influence, resulting in consumption and ultimately environmental impact, and no amount of rational argument against such behaviour will prevail. We desperately need to understand this aspect of human behaviour better.

As the papers presented here show, there is now a growing interest in behavioural studies. How humans behave in real contexts and how it impacts on sustainability is becoming a subject for scientific enquiry. This welcome trend is relatively new. Having been in building physics for about 25 years, I remember well when sustainable design (though it had not yet achieved that rather optimistic title) was largely concerned with test cells and computer models. When venturing into the real world of a test house, scientists would populate them with simulated occupants, little devices that emitted heat and water vapour to order. Human beings were much too messy and unpredictable.

And although Fanger's work, which has dominated our understanding of human thermal comfort, involved actual human subjects, they were incarcerated in a climate chamber, in standard clothing and instructed what to do. Meanwhile, environmental psychology was practised in the darkened laboratories, with subjects in headphones and wired up to sensors and data loggers. How people behaved in the real world (and influenced it) seemed to attract little interest, although this kind of study applied to the non-human world of animals and plants, was commonplace.

By identifying *communication* as the second reason, I mean that although there is a wealth of deep scientific knowledge in a wide range of topics, it has tended to be constrained by its field, rather than the problem to which it is applied. We have already touched on the fact that there is no shortage of scientific activity. Rather, it is the links between the scientific disciplines that need to be developed.

Cross-disciplinary Behavioural Studies and Sustainability

These links rely on cross-disciplinary communication and it is in publications of this kind that researchers can become aware of the different contributions, and hopefully be stimulated into cooperative effort. The common thread in the papers

presented here jumps out at you. It is human behaviour. In every paper, be it concerned with beauty of urban space, or the application of passive technologies to housing, the impact on and by human behaviour in the built environment is an underlying theme. And here we see the bringing together disciplines as diverse as philosophy, politics, physiology, information technology and building physics. Maybe these links will create a whole that is greater than the sum of the parts. And in doing so, will draw attention to the vital role that human behaviour plays in our quest for sustainability.

It has become almost a mantra to say that the quest for sustainability must not compromise human health and well-being, and this is a second common thread in the papers. It is reassuring then to read of strong evidence that occupant health and well-being do not correlate with energy use. It seems that the effort to engineer the perfect environment, usually at a high cost in energy and plant, has not led to higher satisfaction, and many passive design solutions are preferred in spite of wider variations of indoor conditions. This welcome news focuses attention on the design of the built environment, and again, on understanding the behaviour of the people who occupy it.

Cambridge, UK

Nick V. Baker
University of Cambridge
Department of Architecture
The Martin Centre
1–5 Scroope Terrace
Cambridge CB21 PX
United Kingdom

Preface

All fine architectural values are human values,
else not valuable.

Frank Lloyd Wright (1867–1959)

The book *Sustainable Environmental Design in Architecture: Impacts on Health* presents recent research in architecture and engineering as well as interdisciplinary applications of sustainability.

Over the last few decades, studies on sustainable design and human sciences have stimulated interdisciplinary work across multiple fields of research and practice. Architects, engineers, mathematicians, environmental researchers, as well as medical scientists are focusing their work in a variety of interrelated aspects of sustainability.

With this publication, we provide a forum for the presentation of new ideas for designing space by applying new methods and cross-disciplinary approaches. Eminent researchers with international backgrounds present their latest results.

The book is devoted to indoor and urban design impacts on human comfort, remote sensing, modelling and assessment of multi-scale design dynamics, as well as new results from diverse areas of research spanning from architecture and engineering to neuroscience and public health.

We would like to express our special thanks to all the authors of the chapters contributed in this book.

It is our honour that Dr. Nick V. Baker from the University of Cambridge has written the Foreword of this book.

We would like to thank Jui-Hong (Vic) Chien for his help in the process of bringing the manuscript of this book into the Springer style.

Last but not least, we wish to acknowledge the superb assistance that the staff of Springer, New York, has provided in the preparation of this publication.

University of Cambridge, UK — Stamatina Th. Rassia
University of Florida, USA — Panos M. Pardalos

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Contributors

Philomena M. Bluyssen TNO Environment and Geosciences, Delft, Netherlands
philo.bluyssen@tno.nl

Rex Britter MIT SENSEable City Lab, 02139 Cambridge, MA, USA
rb11@eng.cam.ac.uk

Lia Chatzidiakou The Bartlett School of Graduate Studies, University College London, London, UK
e.chatzidiakou@ucl.ac.uk

Dickson Despommier Department of Environmental Health Sciences and Department of Microbiology, Columbia University, New York, NY, USA
ddd1@columbia.edu

John P. Eberhard FAIA, Gaithersburg, MD, USA
jpeber@aol.com

Eve A. Edelstein Innovative Design Science, Academy of Neuroscience for Architecture, San Diego, CA, USA
neuroarchitecture@gmail.com

Igor Esau G.C. Rieber Climate Institute of the Nansen Environmental and Remote Sensing Center and Bjerknes Centre for Climate Research, Bergen, Norway
igor.ezau@nersc.no

William Fawcett Department of Architecture, The Martin Centre for Architectural and Urban Studies, Cambridge University, Cambridge, UK
wf223@cam.ac.uk

Eduardo de Oliveira Fernandes IDMEC-FEUP, Universidade do Porto, Porto, Portugal
eof@fe.up.pt

Matthew French Department of Architecture, University of Cambridge, Cambridge, United Kingdom
emailformatthew@gmail.com

William French Head of Communications, Embassy of Switzerland in the United Kingdom
William.French@eda.admin.ch

John Gardner Centre for Biomedicine and Society, King's College London, United Kingdom
gardnerjohnyg@gmail.com

Elissa Gerfen Cancer Control Program, Lombardi Comprehensive Cancer Center, Georgetown University Medical Center, Washington, DC, USA
egerfen@georgetown.edu

Antonios Kounadis Academy of Athens, Athens, Greece
kounadis@bioacademy.gr

Pierre Lefèvre La Hayette 5 pré au Renard, Jouy LE Moutier 95 280, France
pierre.lefevre6@wanadoo.fr

Eduardo Macagno University of California San Diego La Jolla, Academy of Neuroscience for Architecture San Diego, CA, USA
emacagno@ucsd.edu

Shweta Manchanda Taubman College of Architecture and Urban Planning, University of Michigan, Ann Arbor, MI, USA
shweta@manchanda.net

Salome Meyer Counsellor, Political and Legal Affairs, Embassy of Switzerland in the United Kingdom
Salome.Meyer@eda.admin.ch

Nikolaos Makris Structures and Applied Mechanics, University of Patras, Patras, Greece
nmakris@upatras.gr

Birgit Müller Hochschule für Technik und Wirtschaft Berlin, Berlin, Germany
birgit.mueller@htw-berlin.de

Dejan Mumovic The Bartlett School of Graduate Studies, University College London, London, UK
d.mumovic@ucl.ac.uk

Maike Neuhaus Cancer Prevention Research Centre, School of Population Health, The University of Queensland, Herston 4006, QLD, Australia
m.neuhaus@uq.edu.au

Mohammad Yousef Nili Architecture and Urban Planning, Shahid Beheshti University, Evin, 19839 63113 Tehran, Iran
m-nili@sbu.ac.ir

Neville Owen Behavioural Epidemiology Laboratory, Baker IDI Heart and Diabetes Institute, Melbourne, VIC 3004, Australia
neville.owen@bakeridi.edu.au

Ayub Pathan The Bartlett School of Graduate Studies, University College London, London, UK
a.pathan@ucl.ac.uk

Carlo Ratti MIT SENSEable City Lab, 02139 Cambridge, MA, USA
ratti@mit.edu

Bernd Resch MIT SENSEable City Lab, 02139 Cambridge, MA, USA
berno@mit.edu

Claude-Alain Roulet LESO-PB, École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland
claude.roulet@epfl.ch; claude.roulet@apples.ch

Leo de Ruijssher Delft Technical University the Netherlands, Delft, Netherlands
L.deruijsscher@tudelft.nl

Mojtaba Samimi Raz Mehr Mehraz Solarch Studio, 19336 44543 Tehran, Iran
m_samimi@solarchvision.com

Sana Seifi Raz Mehr Mehraz Solarch Studio, 19336 44543 Tehran, Iran
s_seifi@solarchvision.com

McKane E. Sharff Cancer Control Program, Lombardi Comprehensive Cancer Center, Georgetown University Medical Center, Washington, DC, USA
mes225@georgetown.edu

Athanassios Stamos NTUA, School of Civil Engineering, Zografos, Greece
stamthan@central.ntua.gr

Koen Steemers The Martin Centre for Architectural and Urban Studies, Department of Architecture, University of Cambridge, Cambridge, UK
kas11@cam.ac.uk

Alex Summerfield UCL Energy Institute, University College London, London, UK
a.summerfield@ucl.ac.uk

Takemi Sugiyama Behavioural Epidemiology Laboratory, Baker IDI Heart and Diabetes Institute, Melbourne, VIC 3004, Australia
takemi.sugiyama@bakeridi.edu.au

Kenneth P. Tercyak Cancer Control Program, Lombardi Comprehensive Cancer Center, Georgetown University Medical Center, Washington, DC, USA
tercyakk@georgetown.edu

Ioannis Tzouvadakis NTUA, School of Civil Engineering, Zografos, Greece
itzouvad@central.ntua.gr

Dimitra Vassilaki NTUA, School of Civil Engineering, Zografos, Greece
dimitra.vassilaki@gmail.com

Part I
Public Health and Neuroscience for Architecture and Sustainability

Chapter 1
Sustainability and Neuroscience

John P. Eberhard

As other chapters in this book will have made clear, sustainability, for humans, is the potential for long-term maintenance of well-being, which has environmental, economic, and social dimensions. Or, as the Brundtland Commission of the United Nations indicated on March 20, 1987, "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." This chapter will suggest that how our brains and minds formulate concepts of sustainability is a question for study by neuroscience.

Ecological economist Herman Daly in proposing that sustainable development seems to simultaneously involve environmental degradation once asked, "what use is a sawmill without a forest?" In the same vein, one might ask what does sustainability mean without a mind to understand the concept. At the same time a sufficiently affluent social context is needed for this concern to be made manifest – people who are living from day to day on the edge of survival do not have the luxury to entertain a concept requiring an obligation to future generations.

Sustainability, as a concept, can be understood as a feel-good buzzword with little or no substance. Many architects and social activists seem to share a conceptual framework, which allows them to continue on their normal course of action with a token reference to how concerned they are with sustainability. The so-called green architecture movement seems to be populated with such architects. The advocates of green architecture claim a common objective of reducing the impact of the built environment by

- Efficiently using energy, water, and other resources
- Protecting occupant health and improving employee productivity
- Reducing waste, pollution, and environmental degradation

J.P. Eberhard (✉)
FAIA, Gaithersburg, MD, USA
e-mail: jpeber@aol.com

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However, most architects seem to seek LEED certification so that their clients can get significantly higher rents, sale prices, and/or occupancy rates as well as lower capitalization rates potentially reflecting lower investment risk. This is not evil or even wrong, but it seems shallow. It falls into the same conceptual trap as believing that one is "conservative" as contrasted to "liberal" by supporting a particular political party.

A more substantive concept of sustainability could be called a "dialogue" of values formed by the mind. This approach can be compared to such concepts as "liberty" or "justice" … ideas that have been explored by philosophers for many centuries. In exploring the breadth of our minds, Antonio Damasio (1994) writes:

> There is no doubt that the human mind is special – special in its immense capacity to feel pleasure and pain; to be aware of the pain and pleasure of others; in its ability to love and to pardon; in its prodigious memory, in its ability to symbolize and narrate; in its gift of language and syntax; in its power to understand the universe and create new universes; in the speed and ease with which it processes and integrates disparate information so that problems can be solved. (pp 189)

The degree of human progress toward sustainability depends on the involvement of all levels and contexts of society. The United Nations declared a decade of "education" for sustainability (2005–2014) with the aim of "challenging us all to adopt new behaviors and practices to secure our future." Education is an exercise of the mind. From the time we learn to know our mother to the time we understand the concept of justice as related to decisions of the highest courts we are progressing through a process of education.

Returning to Damasio, he says:

> One of the main traits of civilized human behavior is thinking in terms of the future. Our baggage of accumulated knowledge and our ability to compare past and present have opened the possibility of "minding" the future, predicting it, anticipating it in simulated form, attempting to shape it in as beneficial a manner as possible. We trade instantaneous gratification and defer immediate pleasure for a better future, and we make immediate sacrifices on the same basis. (pp 146)

Finally, we need to return to Vitruvius, the ancient architectural wise man, who coined the concepts of commodity, firmness, and delight for well-designed buildings. By commodity he meant functional effectiveness of the design. By firmness he meant its structural strength and integrity. And, by delight he meant "beauty" in the generally understood sense of that word. With neuroscience we can add an understanding of how spaces in buildings provide sensory perceptions such as:

- Images in the visual cortex that link to the amygdala to produce a sense of harmony, pleasure, and satisfaction
- Sounds recorded by the auditory cortex that are harmonious, melodious, or joyful
- Odors that the olfactory sensors report as pleasant
- Touch sensations experienced by actual contact with the body or simply imagined by the mind that include the smoothness of marble or the warmth of sunlit spaces

1.1 Studies of Neurogenesis

Most of the work done by neuroscientists seeking to understand how enriched environments affect the brain has been done with animals (especially rodents). Brains of animals in stimulating environments (such as cages with toys, ladders, tunnels, and running wheels) have shown an increase in the number of synapses, and the dendrite arbors upon which these synapses reside are more complex.

Research done with humans suggests that lack of stimulation in a developing child (such as the plight of orphaned infants in Rumania) delays and impairs cognitive development. Research has also shown that stimulation associated with acquiring higher levels of education (and the associated social stimulation from others who are also students) results in greater resilience to the effects of aging and dementia (called "cognitive reserve" by neuroscientists). Recent research at the Salk Institute on a process called neurogenesis has shown that enriched environments increase the formation of neurons (especially in the hippocampus) in humans as well as animals. A question that might be addressed by the neuroscience community is how neurogenesis could be infused with an awareness of sustainability.

1.2 Human Behavior in the Face of Crises

Creating an awareness of sustainability could (and largely does) depend on how well one's attention to the concept of a crisis can be engendered. Sustainability disasters are understood to be crisis events that are largely the outcome of human decisions and actions. This would include the increased loss of forests, the decrease in available drinking water, etc., that have no concrete, attention-grabbing event to mark the onset or the final dissipation. With most environmental disasters we can only speculate on the likely outcomes. There is no clearly defined point at which the danger is unequivocally perceived to have worsened or passed.

Human error is normal in crisis situations because of the inherent limitations of the human brain/mind/nervous system to recognize and respond (Aronoff and Kaplan 1995). For example, if there is an impending collision of automobiles, the drivers first have to be aware of that possibility, they then have to fully turn their attention to the situation they are facing, and then (most importantly) they need to recognize and understand the nature of the crisis in order to take evasive action. Each of these brain functions is limited by the cognitive ability of the persons involved. And, each of them will have differing stored memories that enable them to recognize and understand what is happening.

The crises created by natural disasters have changed little over the centuries. Tornadoes, hurricanes, floods, and droughts strike with regularity. However, our ability to become aware of these events, give them our undivided attention, and understand what is happening has improved considerably. Early detection allows time for evasive actions that may control the damage. These crises may be severe, but unlike sustainability crises they do not drag on for years amid uncertainties

about how great the risks may be, who is affected, who should be held responsible, and what actions to take.

If we turn our attention to the impending crisis of sustainability for the earth's population, we need to conceptually deal with each stage:

- We need to be "aware" that there is a crisis pending. And this awareness needs to enter the consciousness of many people in responsible positions … not just a dedicated few.
- We will then need to turn the attention of world leaders to this situation in a way that engages them in serious study (their education).
- And, then we need to have the concepts available to enable world leaders to recognize and understand the causes and consequences of the situation and to take actions needed to avert disaster.

It is one thing to read and write papers and books about these matters, but it is more difficult to enter the minds of world leaders with concepts that they can and will store in their cerebral cortex. We need to provide the neurogenesis that binds recognition and understanding of the crisis of sustainability to the networks of the brain that produce action.

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Chapter 2
Behavioral Science Perspectives on Designing the Environment to Promote Child Health

McKane E. Sharff, Elissa Gerfen, and Kenneth P. Tercyak

Most of the 13,000 child deaths each day are due to the dangers present in the environments in which they live, learn, play and grow.

(World Health Organization (WHO), 2002)

Abstract In general, there is a need for large, well-integrated studies that both assess environmental characteristics and measure health outcomes in children. Results from these studies would demonstrate to policymakers the positive impact of thoughtful community design and comprehensive multilevel interventions on child health outcomes. This is essential for both the design of new health-promoting communities and the revitalization of existing communities.

2.1 The Built Environment

In addition to the over three million children that die each year due to a disease related to the environment (Gavidia et al. 2009), countless more suffer from accidents, injuries, and illnesses that are environmentally influenced. These outcomes greatly impact children's quality of life, with lasting consequences for future health and development, family dynamics, and community sustainability. Children, like all humans, have a right to health (Cummins and Jackson 2001) and their position in society as minor, developing, dependent individuals necessitates that others recognize the threats to child health, strive to understand how these threats interact and impact health, and work to revitalize and reshape current systems and spaces,

M.E. Sharff • E. Gerfen • K.P. Tercyak (✉)
Cancer Control Program, Lombardi Comprehensive Cancer Center,
Georgetown University Medical Center, Washington, DC, USA
e-mail: mes225@georgetown.edu

S.Th. Rassia and P.M. Pardalos (eds.), *Sustainable Environmental Design in Architecture: Impacts on Health*, Springer Optimization and Its Applications 56,
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and build new environments and interventions that effectively promote child health. Such efforts require collaboration across disciplines and strong and sustained commitments from multiple stakeholders at various levels of society to make child health a priority now and for future generations.

To this end, this chapter sets out to broadly explore a variety of well-recognized, environmentally based health issues and offer multilevel solutions and preventative measures that can be employed to enhance child health. In order to better elucidate how factors at various levels of the individual and society impact the health of a child, we review an ecological model of health behavior that places the child at the center of multiple levels of influence, with specific domains within each. We then review the epistemology of social and behavioral research in epidemiology first put forward by Sallis and colleagues (Sallis et al. 2000), and later expanded for use with research with children by Tercyak and colleagues (Tercyak et al. 2006). These phases help define the progression of evidence-based research, illustrating ways that this research can help determine and define the connections among various factors in the built environment that affect a child's health and can subsequently be used to inform future design and interventions.

The well-recognized and alarming obesity epidemic among children in the USA is further used as an example of how social and behavioral research can be employed to explore and explicate how factors and interventions at various levels of influence within the ecological model can be used to address this pressing child health issue.

Finally, we offer suggestions for continued and effective measurement of environmental and intervention-related impact on child health. We end with a call for continued and sustained collaboration and partnership among those that design and build environments and interventions to improve child health, those that create policies and laws that protect children, those that raise and care for children, and those that explore and measure the behavioral and health impact of these multilevel efforts benefiting children's health and well-being.

2.2 The Obesity Epidemic

One of the most pressing public health issues at hand is the growing prevalence of obesity throughout the societies of Western and non-Western nations around the world (Sallis et al. 2009). According to the US Centers for Disease Control and Prevention, obesity has reached an epidemic status; one-fifth of children in the USA are overweight or obese (Ogden et al. 2010). As a major preventable cause of death, swift action must be taken to reduce obesity rates (Cummins and Jackson 2001). The built environment can play a role in shaping the everyday decisions that people make and contribute to the problem of obesity by providing an environment that simultaneously encourages high caloric intake and low energy output (Hill et al. 2003). At the same time, the built environment affects availability-based consumption of foods from fast-food restaurants (vs. more nutritional options at supermarkets) (Morland et al. 2002). The increase in suburban sprawl over the past few decades, marked by low accessibility to safe spaces in which to be active and larger distances

between buildings (Ewing et al. 2003), has led to a higher reliance on motor vehicle transportation as opposed to opportunities for physical activity, such as walking or biking (Saelens et al. 2003). This is evidenced by aspects of the built environment that promote sedentary behavior and are linked with obesity, such as design elements of neighborhoods (i.e., cul-de-sacs and low street connectivity) (Berrigan and Troiano 2002) and heavy traffic (Timperio et al. 2010).

Just as there are elements of the built environment that contribute to sedentary lifestyles among children, there are also aspects that can encourage physical activity and healthy eating behaviors. Thus, the built environment may be a risk factor or a protective factor to children's health. For instance, proximity to parks and recreational facilities has been shown to correlate well with increased physical activity and decreased risk for obesity (Giles-Corti and Donovan 2002). Ewing and colleagues (2004) observed a positive association between miles of sidewalks and numbers of children who traveled to school either by walking or riding a bike (Ewing et al. 2004). Jago and colleagues (2007) show a positive correlation between proximity to small grocery stores and consumption of low-fat vegetables (Jago et al. 2007). Findings such as these demonstrate that there are aspects of the built environment that can be altered to aid in the prevention of obesity vis-à-vis facilitation of physical activity and promotion of nutritional eating. We further address the issue of obesity and multilevel approaches to prevention and control later in this chapter.

2.3 Environmental Health

Obesity is one among many child health issues with an environmental risk component that are well worth noting. The World Health Organization's Healthy Environments for Children Alliance (HECA) has compiled information identifying the primary sources of environmental risks to children's health worldwide, as well as examples of how to reduce potentially harmful exposures (Centers for Disease Control and Prevention (CDC) 2006; World Health Organization (WHO) 2010). In Table 2.1, we highlight some of these risks and preventative measures at various levels of intervention and oversight, adding some of our own recommendations as well.

The environmental risks to child health presented here contribute greatly to child mortality and morbidity worldwide. As stated earlier, all children have a right to health and we have a responsibility to use knowledge and resources to ensure and maintain child health globally. The preventative measures discussed herein provide some suggestions for approaches that can be taken at home, at school, in the community, and by governmental and nongovernmental organizations to combat environmentally influenced health risks. However, without an overarching understanding of how factors within each level impact and interact with each other to influence child health overall, it remains challenging to understand the complex and multifaceted ways in which the environment contributes to child health. A model that illustrates these interactions and contributions is useful in understanding child health behaviors, health-related risk and protective factors, and for the development interventions that will promote child health.

Table 2.1 Approaches to reducing environmental risks: From individuals to society

Sources of environmental risk	At home	At school	In the community	Government
Accidents and injuries	Review and ensure use of home safety and safety equipment (e.g., seatbelts, safety helmets, smoke alarms, gates, fences) Parents should learn first aid and have basic supplies available	Classroom teachers can instruct children about safety and self-protection Provide safe transportation to school, bicycle safety and pedestrian safety awareness training	Create child safety education centers Community fundraising and support for local emergency personnel and first responders	Change engineering and structural building and development requirements (e.g., installations of road signs) Enforce stronger penalties for driving while under the influence
Air pollution	Children should avoid direct and secondhand exposure to tobacco smoke Family members who smoke should stop smoking, or only smoke outdoors and away from children	Create smoke-free school zones Respect public air quality announcements during school activities Teachers should never smoke on school property	Promote the purchase of unleaded gasoline and good vehicle maintenance Encourage the use of mass transportation system	Implement laws and regulations to raise awareness (e.g., The Clean Air Act of 1990, which requires the setting of regulations for pollutants) Air pollution control regulations should be enforced in cities, especially ending leaded gasoline consumption
Chemicals	Avoid purchasing repackaged or unsafely packaged chemicals Store chemicals in secured locations and out of the reach of children	Teachers should inform children about chemical exposure as part of raising awareness School administrators must review the safe use and storage of chemicals in the school	Community organizations and leaders should join forces to improve local handling of hazardous chemicals Engage in advocacy efforts for policy changes and awareness-raising of decision-makers	Invest in research on effects of chemical exposure on children's health Provide more consistent risk assessment and toxicity testing for chemicals and children (e.g., Consumer Product Safety Improvement Act of 2008)

Table 2.1 (continued)

Sources of environmental risk	At home	At school	In the community	Government
Pesticides	Reduce or eliminate use of pesticides in and outside the home and carefully follow directions Avoid use of pesticides and repellents on infants and young children	Seek alternatives to pesticides for controlling pests in and around food storage Apply pesticides only when children are not present	Advocate for pesticide reduction and safe practices Establish poison control centers	Develop food safety and pesticides regulations Provide funding for research on risk assessments based on child-specific vulnerabilities
Vector-borne diseases	Eliminate and control potential mosquito breeding grounds (standing water, garbage) Use insecticide impregnated mosquito nets and screen doors	Inform children how vector-borne diseases are transmitted Teach children about breeding sites	Record incidence and other information on vector-borne diseases Provide immediate and effective treatment	Invest in infrastructure to reduce breeding grounds Support media campaigns to increase awareness

Note: Tabled material adapted from the WHO Healthy Environments for Children Alliance Issue Briefs Series, and the authors opinions (CDC 2006; WHO 2010)

2.4 Ecological Models of Children's Health and Health-Related Risk and Protective Factors

Ecological models focus on the interactions between people and their environments. These models emphasize multilevel influences on behavior that can be observed at the individual, social and cultural, organizational, community, and policy levels (Glanz and Bishop 2010). In these models, the environment is conceived of as anything outside of the individual. The environment includes not only the physical environment, but also social and built environments (Sallis and Owen 2002). This understanding is parallel to the definition put forth by the US Department of Health and Human Service (2000) in its Healthy People 2010 initiative: "In its broadest sense, environmental health comprises those aspects of human health, disease, and injury that are determined or influenced by factors in the environment. This includes not only the study of the direct pathological effects of various chemical, physical, and biological agents, but also the effects on health of the broad physical and social environment, which includes housing, urban development, land-use and transportation, industry, and agriculture" (Chap. 8, p. 3) (US Department of Health and Human Services 2000).

Environmental influences on disease and behavior have long been recognized in public health. In public health, the host-agent-environment model has been used to explain population level change in disease rates that may be attributed to changes at any of the three levels in the model (McLeroy et al. 1988). B.F. Skinner, an influential American psychologist, was a strong proponent of environmental influences on behavior. His research designed specific environments and tools to shape and measure individual environmentally controlled actions. In the later part of the twentieth century, Albert Bandura purposed the Social Cognitive Theory in which aspects of both the environment and personal factors were seen as influencing individual behavior (Bandura 1986; Sallis and Owen 2002). Contemporary ecological models and theories of health behavior are informed by these early conceptual traditions.

In the 1970s, Urie Bronfenbrenner proposed an ecological model for human development in which he described nested levels of influence on behavior, and highlighted interactions between and among them (Bronfenbrenner 1979). In this model, the environment is divided into micro-, meso-, exo-, and macrosystems of influence that affect and interact with individual development. McLeroy and colleagues (1988) purposed an ecological model for health promotion that drew upon Bronfenbrenner's model and the works of others. In that model, behavior is conceived of as being determined by five levels of influence, each of which can be assessed and addressed to improve health behavior. The five levels are: (1) intrapersonal factors (including characteristics and developmental history of the individual); (2) interpersonal processes and primary groups (such as social networks and support systems); (3) institutional factors; (4) community factors; and (5) public policy.

A social-ecological approach to health has been employed to conceptualize various health behaviors including physical activity, child abuse, and eating behavior (Belsky 1980; Booth et al. 2005). Within this perspective, environments