Environmental Issues for Architecture

DAVID LEE SMITH

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PREFACE

Since the beginning of time, living species have had to find ways to adapt to the natural environment. While some adaptation can be achieved physiologically or the need for it can be reduced through migration, many species, particularly humans, have also developed physical structures to help adjust the natural conditions to form an environment that can not only support life but also provide comfort. These constructions are the beginning of architecture, but for building to achieve this status, it must also embrace an emotional expression of intention or, as some would say, a sense of poetry.

Over time, designs intended merely as a way of providing functional adaptation to the natural environment often acquired an aesthetic quality that transcended their initial purpose. At times, perhaps when the intentions of these designs were no longer understood, the designs were applied to conditions for which they were not applicable or no longer relevant. As such, these designs acquired an intrinsic value in terms of their compositional or artistic expression rather than their functional potential.

With the development of modern technology, reliance on direct architectural intervention became less critical. The developing architectural form often was possible only because technology could not only adjust the natural environmental conditions but could also correct for the additional imposition of the architecture. The assumption was that technology made anything possible, and the intention of architectural design was no longer focused on environmental adaptation. For this reason, many designers felt that they were free to pursue poetic expression while relying on others to develop technological methods that could support this freedom. Unfortunately, this practice has given rise to a serious disconnect from the basic intentions of design.

The unfortunate result is that today architecture often seems to be part of our environmental problems rather than part of the necessary solution. Architectural design should be able to contribute to the solution of our environmental problems in a manner that is both effective and poetic. But for this to happen, architectural designers must be aware of the basic concepts and principles of the various environmental issues that are critical to sustaining life on this planet. While we as designers can embrace technology and utilize it to enhance our efforts, we must begin by understanding what is intended rather than focus on what is possible, particularly in terms of utilizing technology. Based on this belief, the title selected for this textbook was *Environmental Issues for Architecture*, for we must understand these issues if we are to realize the environmental contributions that can be achieved through effective architectural design. At the same time, we need to be knowledgeable about technology so that we can successfully integrate its potential into design. Architecture can then achieve its purpose and enhance the physical design.

As an architectural educator, it is important that I avoid the temptation of prescribing specific solutions to complex problems. Instead, my challenge in lectures and in the studio is to attempt to instill in my students an awareness of the critical issues that must be addressed, an understanding of the concepts and principles that underlie these issues, and a commitment to work to resolve them through responsible design. In this vein, I have written this book with the hope that it might inspire future designers to appreciate the potential that environmental issues have for architecture and to support that inspiration with the understanding and skill that can help them achieve this potential.

This intention was the basis for a conference held many years ago in Boston for architecture faculty teaching technology. The gathering started with a keynote address by Jerrold Zacharias, a professor of physics at MIT. He began his presentation by swinging one of two disks that hung behind a projection screen located above a huge chalkboard. As this disk swung back and forth, the second disk began moving in what appeared to be a somewhat erratic manner. Professor Zacharias began to compare the two motions and then suggested that we could analyze them mathematically in order to figure out what was causing the erratic movement. He then proceeded to fill the chalkboard with mathematical equations and finally exclaimed, "Now we know what's happening!"

As a nonengineer with a somewhat lazy mathematical mind, I had pretty much ignored his presentation, thinking instead about the wonderful things that I could do in Boston, but I continued to pay enough attention to be amazed that Professor Zacharias could fill the chalkboard and solve the problematic equation just before running out of space. I was also astonished that so many in the audience, who like me were teachers in architectural schools, seemed not only to be able to follow the presentation but apparently even relished the mathematical experience.

After Professor Zacharias's announcement that we now understood the conditions of the swinging disks, much of the audience, whom I assumed had an engineering background, initially seemed to agree. But then after a few moments of silence, it became apparent that while the equation had been solved, what was causing the two disks to move was still not clear. And then, at the right moment of bewilderment, Professor Zacharias raised the screen; there, to the amazement of the audience, was the explanation—a simple double pendulum with a stick connecting the two.

Professor Zacharias then talked about pendulums and vibrating strings, explaining that a guitar string is plucked and, depending on the type and length of the string, different pitches of sound can be produced. He then explained that with a violin, the desire is to sustain numerous repeated plucks of the strings; this is why a bow is used. Rosin is put on the bow, and as the bow is pulled across the strings, the rosin grabs a string and pulls it. Since the rosin cannot "hold on," as the bow is pulled across the string, a series of repeated plucks is established.

Once again, the audience seemed to understand. But again, Professor Zacharias would not let it rest. He said, "That's not the issue. The problem is that most of us didn't understand that there was a problem!"

While not necessarily problems, the various issues addressed in this book need to be understood in context with architectural design. In an attempt to help you grasp the connections between environmental issues and architecture, the discussion of each issue includes a short historic review to help you make connections with the general development of architecture that have occurred over time, especially since the Industrial Revolution. In addition, the order in which the various issues are organized is somewhat different from the traditional way in which environmental concerns are presented in most textbooks on environmental technology. While it is true that thermal issues are very important and have a major impact on design, this book begins with discussions of lighting and acoustics. This tends to parallel somewhat the way we actually experience space—through seeing and hearing. The expectation is that this order of presentation will further help you realize that *Environmental Issues for Architecture* can contribute to the foundations for architectural design. But since there is more than one way to approach design and since each issue is presented somewhat independently, you may consider each environmental issue in any order that makes sense to you.

ACKNOWLEDGMENTS

While the preparation of this book was essentially an individual effort, it was achieved with the help of many people to whom I am deeply indebted. Without their support, which has been provided in various ways, this publication would not have been possible.

Since this book covers material that I have taught for more than 40 years, I am most indebted to the many students who have taken my courses covering the various environmental technology topics. Not only did they provide the initial motivation to organize my lecture presentations of the different topics, but their requests to review my personal notes encouraged me to clarify and expand them as handouts that could help make connections between the assigned readings and class presentations. These handouts of my notes provided the initial draft of this book, although they have been expanded and, I trust, refined. So again, thanks to all of my students.

My knowledge of the various environmental issues is based in part on the work of many different authors who have effectively presented this material in their own books. While I have attempted to take a slightly different approach in this textbook, trying to emphasize the material from an architectural design point of view, my grasp of the material would not have been possible without my exposure to their publications, most of which are listed at the end of the chapters. I also want to acknowledge my association with the many members of the Society of Building Science Educators (SBSE). Through various gatherings and sharing of teaching materials, but especially through the ongoing dialogue on a broad range of important issues related to teaching on environmental controls and architectural design, the SBSE has been a great support and has encouraged me to pursue this effort.

I must also give thanks to my teaching colleagues. While my interaction with all of them has supported me over the years, I must give special recognition to my teaching buddy, my longtime officemate, and one of my dearest and closest friends, Richard Stevens. Dick is a mathematician and engineer who taught structures at the University of Cincinnati for many years, but his personal design sensitivity and aesthetic appreciation always emphasized the connection between technical considerations and architectural design.

I am also especially grateful to my colleagues Patrick Snadon and Jim Postell, both of whom strongly encouraged me to pursue the effort necessary to prepare this book.

Patrick, who is an accomplished historian of architecture and interior design and author of *The Domestic Architecture of Benjamin Henry Latrobe*, agreed to read an early draft of Chapter 8, which covers the history of thermal control. While he made many helpful critical comments, most importantly Patrick suggested that I take it further, although rather than focus on history, I decided to incorporate historical discussions related to each of the issues addressed in this comprehensive book on the full range of environmental concerns.

Jim persuaded me to follow up on Patrick's suggestion. Jim and I have taught together for many years in our foundation design studio in the School of Architecture and Interior Design, and building upon this association, we have also partnered on several actual design projects. Having recently completed an interesting and informative textbook, *Furniture Design*, Jim gave me the confidence to write this book, and he made it possible by connecting me with Paul Drougas at John Wiley & Sons. I also want to thank Paul and his colleagues at Wiley, especially Donna Conte, for their help and guidance in this effort.

I must also thank Donald Mouch, who was my graduate assistant as I began rewriting my notes. Not only did he relieve me of some of the work associated with my teaching, Donald also reviewed the early drafts of several chapters, providing helpful input that ultimately encouraged my rewriting; I trust it has helped clarify my presentation.

I must also give credit to my former teacher, mentor, and employer—Sidney J. Greenleaf. Sid introduced me to the environmental technologies as my professor when I was in graduate school. His classes instilled in me an understanding of the basic principles underlying the performance of these technologies and an appreciation of how this can inform architectural design. But more importantly, as my employer for a few years, he trusted in my understanding and ability, which provided me with an extraordinary opportunity to be involved in a critical way in a number of very interesting projects. This work forced me to expand my own explorations and gave me a wealth of experience in a relatively short time. Sid was also instrumental in making it possible for me to teach a course on climatological design at the Harvard Graduate School of Design (GSD) shortly after my graduation and then made contacts for me at the University of Cincinnati, where I have spent most of my teaching career.

I am also extremely indebted to my family, especially my dear wife, Susan, who not only encouraged me to complete this book, but supported me with love and understanding as I struggled with the difficult task of rewriting during the past year. I could not have succeeded without her understanding and compassion, not only in preparing this book and teaching and practicing architecture for many years but, more importantly, in achieving a life of happiness and fulfillment.

CHAPTER

1 INTRODUCTION

INTRODUCTION

This book presents basic information about the major environmental issues that impact on architectural design and attempts to do so in a manner that can guide and support the design process. These presentations are not intended merely to cover "required" information before they must be addressed, which for too many design projects done in school is during preparation of the presentation drawings. Unfortunately, the inclusion of environmental considerations often tends to be merely applied "window dressing" intended to make a project appear more "architectural." While there are legitimate reasons why an expansion of items addressed occurs at presentation time, an understanding of environmental issues, particularly in terms of concepts and principles, must be present at the beginning of the design process so that it can inform the initial schematic explorations. A response to the critical environmental issues must be at the core of any effective design, not merely an applied accommodation added later.

With an increased understanding of the basic concepts and principles of the different environmental topics, we should be better able to grasp the connection between these critical issues and effective architectural design. Although the presentation of these issues might at times be mathematical, these issues are definitely not external to effective design, nor should they be considered only as corrective measures that allow one to do something illogical in terms of design. In fact, an understanding of these principles is fundamental to design.

Unfortunately, the obvious significance to design of some of the material covered in this book might not become fully apparent until later in your studies or perhaps not until later in your design careers. But as with most of what we study, if we understand the underlying principles, these explorations of environmental issues will continue to be of value as we progress in our studies and throughout our professional careers.

ENVIRONMENTAL AESTHETICS

Nature can only be mastered by obeying its laws.

Roger Bacon (Thirteenth-century English philosopher and scientist)

Esthetic judgment constitutes the quintessential level of human consciousness.

James M. Fitch (Architectural historian and theorist)

The commitment of environmental designers (interior designers, architects, landscape architects, and urban designers) to the enhancement of the human experience can best be realized through designs that are both aesthetically pleasing and socially meaningful. In this effort, perhaps the most confusing task is to assign the proper significance to each concern so that the resulting design responds appropriately to the imposed conditions. To accomplish this effectively, designers must have an understanding of science and technology in addition to sensitivity for composition and form.

Science is much more than a body of knowledge. It is a way of thinking. This is central to its success. Science invites us to let the facts in, even when they don't conform to our preconceptions. It counsels us to carry alternative hypotheses in our heads and see which best match the facts. It urges on us a fine balance between no-holds-barred openness to new ideas, however heretical, and the most rigorous skeptical scrutiny of everything—new ideas and established wisdom.[1]

Carl Sagan (Renowned American scientist)

Many erroneously believe that science is based primarily on complex mathematical computations, and because of this, there is often a tendency to assume that science is imbued with a notion of certainty. On the other hand, art is generally considered to be nonspecific and nonscientific. As a result, designers often tend to avoid specific limitations, especially if they are expressed through the use of numbers, as if the acceptance of specificity might imply that they are not really concerned with the poetry of design or, even worse, that they are not really creative.

Calculations, the use of mathematical formulas, are merely a way to model certain aspects of the physical world. Math is a language that provides a simple way of expressing ideas, but many designers are uncomfortable with the mathematical language and cannot appropriately appreciate or effectively use a mathematical model. While rejection of mathematics is unfortunate, since it deprives designers of an effective means of modeling certain conditions, it is untenable if it encourages designers to concomitantly reject science or to go as far, as some do, as to exclaim, "Don't confuse me with the facts!"

Science is the ever-unfinished task of searching for facts, establishing relationships between things, and deciphering laws according to which things appear to occur. The main intention of science is to extract from the chaos and flux of phenomena a consistent, regular structure—that is, to find order. Similarly, effective environmental design should be committed to the discovery of pattern, structure, and order and to giving them viable expression in physical form.

Today there is some confusion over what is or should be the basic intentions of environmental design. This confusion is probably the result of various changes that began developing as long as 150 years ago with the general industrialization of the construction field. This industrialization has tended to separate the design process from what James Marston Fitch called "the healthy democratic base of popular participation."[2] As a result, the designer is now typically isolated from the consumer, increasing the "prevalence of the abstract, the formal, and the platitudinous in architectural design."[3] It is becoming increasingly clear that an attitude within many segments of the various design professions is "one of complacent laissez faire whose esthetic expression is a genial eclecticism. The result is a body of work as antipopular and aristocratic in its general impact as anything ordered by Frederick the Great or Louis XV."[4]

While many of the prominent voices in the design field seem to be consumed by a theoretical dialogue on stylistic intentions and priorities, the traditional leadership role that environmental designers have traditionally contributed has been significantly reduced. In fact, in many situations, oblivious to their fundamental responsibility to ensure that environmental development is nurturing and sustainable, the work of many designers continues to degrade rather than enhance the natural environment. At a time when the design professions should be actively involved in supporting rational, sustainable development, continued infatuation with a narrow set of design parameters might reasonably be interpreted as equivalent to rearranging the deck chairs on the *Titanic*.

Rather than narrowing our options, design professionals should be pursuing ways both to maintain traditional involvement in environmental design and to increase the level of participation through an expansion of professional services. We should take the opportunity to build upon the problem-solving methodology of the design field and substantially extend its realm of engagement. We should reinterpret the basic notion of what constitutes environmental design practice, and sustainable development provides a means to accomplish this.

The ultimate and quintessential role of environmental design is the interpretation of ideas through physical form for human habitation, and designing is the actual act of interpretation. The idea of the designer as a creative individual operating intuitively and independently in this effort of interpretation, although romantic, is unsubstantiated by fact and is a notion that inhibits realization of the architectural potential. While designing is obviously a critical responsibility of professional practice, there are numerous activities with which designers have regularly been involved and upon which designing relies. Just in

[1] Carl Sagan, *The Demon-Haunted World: Science as a Candle in the Dark* (Ballantine Books, New York, 1966), p. 27.

[2] James Marston Fitch, *American Building: The Environmental Forces That Shape It* (Houghton Mifflin Company, Boston, 1972), p. 316.

[3] Ibid., p. 317.

[4] Ibid., p. 318.

terms of traditional architectural practice, these usually include promoting and selling architectural services; educating the public, clients, and future professionals; preparing a project brief; developing contract documents; selecting contractors and determining costs; and inspecting construction progress. In addition to these activities, there are a number of allied services that are frequently associated with architectural practice.

Although these various activities collectively constitute the overwhelming portion of architectural practice, a presumption remains, even among many practicing architects, that designing is the most dominant aspect of professional architectural services. In reality, designing accounts for only around 10% of the actual effort expended in fulfilling the demands of most architectural practices! While the actual act of interpretation is critical, all efforts necessary to accomplish this interpretation are essential and crucial to the architectural endeavor, not merely the interpretation itself.

Regrettably, a distinction is sometimes made between the value and importance of "designing" and the "nondesign" efforts of contemporary environmental practice. This establishes an unfortunate hierarchy within the design professions that is extremely divisive and can undermine collaboration, which is essential for effective design that is responsive to the multiplicity of concerns in our complex world. While distinctions in the areas of involvement will remain, any assumed hierarchy will continue to be extremely disruptive to the environmental design professions. To remain effective, we can no longer indulge ourselves with a biased, myopic view of what is actually an extremely diverse responsibility that demands multiple skills and abilities.

Too many recent "prestigious" buildings have been designed in response to a rather narrow value system. While some of these buildings are clearly attractive, too often they are void of functional meaning or any significant social connotation. Only with an understanding of the technological propriety, tempered by a process of socialization, can the environmental design professions move from their recent role of "agent and spokesman for the elite"[5] to achieve more meaningful contact with and support for the popular community.

An understanding of technological propriety can only come from a sound theoretical scientific foundation. As Gary Stevens stated in *The Reasoning Architect*:

> *. . . although architecture is usually thought to be the product of acts of inspired creation, it is also the product of acts of inspired reason; to demonstrate that science and mathematics are portions of our intellectual culture that cannot be set apart from architecture and left to the engineers to worry about, but are the concern of all of us.*[6]

> *A distinction is often made also between art and craft. These dichotomies are in fact quite recent, about 200 years old, but as long as we do not take the boundary as hard-and-fast, and admit into each parts of the other, they are useful distinctions if only because scientists and artists do see themselves as carrying out quite different sorts of activities.*
>
> *Though they may be different, it does not necessarily lead to the conclusion that they are opposed. The two can be unified in the one individual or pursuit.*[7]

It is unfortunate, and perhaps even harmful, that in our society, art and science have come to be seen as opposites and antagonistic to one another. Perhaps this tension between the two cultures of art and science is most evident in the environmental design disciplines—that is, in architecture, broadly defined to include physical design extending from consideration of interior space to the urban environment. This confrontation between art and science is especially disturbing since effective environmental design depends on a collaboration of the two.

The wide-ranging criticism of science in architecture is based on the notion that science demands that design be predicated on the application of a set of operational rules that are devoid of any concern for humanistic values. But this criticism is founded on a fundamental confusion about the meaning of humanism and the nature of science. As expressed by Jacob Bronowski:

> *The scholar who dismisses science may speak in fun, but his fun is not quite a laughing matter. To think of science as a set of special tricks, to see the scientist as the manipulator of outlandish skills— this is the root of the poison that flourishes in the comic strip. There is no more threatening and no more degrading doctrine than the fancy that somehow we may shelve the responsibility for making the decisions of our society by passing it to a few scientists armoured with a special magic. [This is a] picture of a slave society, and should make us shiver whenever we hear a [person] of*

[5]Ibid., p. 319.

[6]Gary Stevens, *The Reasoning Architect: Mathematics and Science in Design* (McGraw-Hill Companies, New York, 1990), p. 3.

[7]Ibid., p. 11.

sensibility dismiss science as someone else's concern. The world today is made, it is powered by science; and for any [individual] to abdicate an interest in science is to walk with open eyes towards slavery.[8]

Gary Stevens said:

[T]he fundamental fallacy . . . is in regarding creativity and reasoning as two watertight compartments of the human intellectual makeup. Since architecture is clearly a creative activity, it [is assumed to follow] that architecture cannot be about reasoning, and from this it is a straightforward step to conclude that it must not be about reasoning. The critique perpetuates the wholly wrong idea that creativity in architecture is the domain of design and design alone and that all the other components of architectural knowledge are just so many dry facts that are sometimes handy to the architect but preferably left to the consultant. The result of such attitudes, among other consequences, is that architects are doing less and less in the construction process, as the masters of all these dry facts chip away slowly but steadily at the architect's role.[9]

Only with an appreciation for human values and a committed sensitivity for nature, including both an understanding of its technological potential and an awareness of its ecological fragility, can we hope to achieve environmental design of significance and quality. But confusing any attempt of designers to address environmental concerns appropriately is their apparent failure to grasp the proper meaning of certain common terms: *visual*, *aesthetic*, and *taste*.

To address environmental concerns appropriately as we fulfill our commitment to design, we must grasp the proper meaning of *aesthetics* and *taste*, recognizing that they are based on more than personal choice and opinion.

Aesthetic Judgment

Aesthetic judgment deals with the issue of "beauty" as distinct from "moral" or "useful" issues, but "beauty" is not limited merely to visual concerns. Unfortunately, James Fitch's claim that "esthetic judgment constitutes the quintessential level of human consciousness"[10] is confusing since it seems to be directly opposed to his stand against the obsession that many in the environmental design professions had, and still have, with visual aesthetics. However, any confusion that comes from this pithy comment derives from a narrow interpretation of aesthetic judgment and beauty. Since beauty entails a combination of qualities that pleases the aesthetic senses, "esthetic" judgment, as expressed by Fitch, is based on an interrelationship between all the physical senses, not just the visual. Aesthetic judgment also depends on personal interpretation of these sensations.

Assuming that aesthetic judgment is based only on visual phenomena leads to a serious misconception of the multidimensional aspect of aesthetic theory. "Far from being narrowly based upon any single sense of perception like vision, our response to a building derives from our body's total response to and perception of the environmental conditions which that building affords."[11] There are many examples of building types where the aesthetic judgment is clearly based on nonvisual concerns as well, and sometime perhaps instead of visual concerns. Even in the most beautiful symphonic hall, a building type that is primarily intended for the appreciation of auditory sensations, one cannot be truly aesthetically pleased if the acoustics are inadequate. In a ballet theater, one cannot be satisfied if one is unable to see the performance properly. There are also situations in which external issues impose on aesthetic judgment. For example, while an owner might recognize that a building incorporates certain positive physical qualities, if the costs far exceed expectations and/or the capacity to pay, it is questionable if there would be substantial appreciation, aesthetic or otherwise, of the structure.

It is inappropriate to attempt to qualify environmental design merely from visual phenomena. While we can, of course, analyze a building in terms of its compositional aspects, we should not confuse this with a comprehensive investigation of its overall aesthetic quality. Although we can derive information on certain nonvisual aspects of a structure from visual observation, we should not confuse issues.

An exploration of the broad issue of aesthetic judgment begins to clarify that there is an important distinction between architecture as object and architecture as experience. As object, architecture tends to exist external to us, and can be observed and interpreted dispassionately and objectively. It is beyond us. It exists for itself. However, as experience, the architectural object has significance only in that it provides the basis for a perceptual experience. It becomes part of us, and the actual physical substance of the object is not of paramount importance. Rather, it is only the effects of the object that are truly significant.

[8] Jacob Bronowski, *Science and Human Values* (Harper & Row, New York, 1965), p. 16.

[9] Stevens, *The Reasoning Architect*, p. 17.

[10] Fitch, *American Building*, p. 309.

[11] Stevens, *The Reasoning Architect*, p. 5.

Of course, the physical reality is important, but this importance is derived primarily from what it implies rather than what it might be physically. Its value and strength exist in its expressed ideas and in its meaning.

The distinction between architecture as object and architecture as experience is similar to the distinction between what can be referred to as "design from outside" and "design from within." While it would be desirable to further explore and clarify these differences, this is beyond the scope of this book; however, hopefully we can agree that the human-caused modification of the physical environment that we call architecture must be considered in terms of a complex composite structure formed of numerous distinct, yet interacting, elements including, but not limited to, its visual characteristics.

Aesthetic Taste

Taste deals with the value system on which we establish our aesthetic judgments. These judgments are based on established values that are developed by and representative of a culture. Since they are statements of cultural consciousness, aesthetic criteria are relative and are dependent on a particular culture. So, while there are specific individual responses that must be considered, aesthetic judgment is greatly affected by its particular social and cultural background. "Esthetic standards are expressions of social agreement, of a common outlook or attitude towards [a] particular aspect of human experience."[12] These standards may, and probably will, vary not only according to the society, but even within a society, according to the particular group or class, establishing a differentiation between what is called *popular taste* and *high style*.

While there is a sharp distinction between popular taste and high style, there is also an extremely important relationship between the two and a joint subordination of them to the exigencies of society as a whole. In certain situations, the connection between the two is complete. As Fitch mentioned, with handicraft methods of production, the aesthetic standards were constantly disciplined by the production method itself. Initially, the designer, producer, and consumer were one and the same, and there was no such thing as bad taste. With early societies basically isolated from other communities, there were no comparative values applied externally to an object, and it was on this basis that the unique aspects of primitive art evolved.

As society progressed from the primitive stage, a distinction between popular taste and high style started to emerge. It became more apparent and ultimately, following the Industrial Revolution, with an increase in automation, popular taste and high style tended to become totally separated and, at times, even in direct opposition to one another. Today, such opposition is often a conscious positioning by those choosing to suggest that their value set, which is obviously assumed to be high style, is different from and superior to that which is generally accepted.

Perception of the Physical Environment

In his book *American Building: The Environmental Forces That Shape It*, James Marston Fitch wrote about our perceptual experience. He suggested that while there might be a dominance of visual sensations or significance for our thermal experiences, our spatial perceptions are strongly influenced by all of our senses. Fitch listed six senses upon which our environmental perceptions are based: visual, auditory, olfactory, tactile, gustatory (taste), and proprioceptive (interactive). While the first five are reasonably understood, the proprioceptive or interactive sense is not commonly recognized. According to Fitch, this sense is activated by stimuli produced within the organism by movement of its own tissues. As intriguing and provocative as this sixth sense might be, another interpretation of the phenomena of perception was provided by Pierre von Meiss:

> *Be warned: for a person who has the use of all his senses, the experience of architecture is primarily visual and kinaesthetic [using the sense of movement of the parts of the body]. . . .*That does not mean that you are allowed to be deaf and insensitive to smell and touch. *That would be to deny oneself the fullness of sensations. Isn't it sometimes a failure on a single one of these points which are deemed to be of secondary importance which destroys all visual qualities? Aesthetic experiencing of the environment is a matter of all our senses and there are even some situations where hearing, smell, and tactility are more important than vision; they are experienced with extraordinary intensity. As designers we must never forget that! Let us try to imagine the echo in the spaces that we are designing, the smells that will be given off by the materials or the activities that will take place there, the tactile experience that they will arouse.*[13]

While Fitch considered perception to be based on the five senses augmented by the proprioceptive or interactive sense, von Meiss reduced the number of basic senses by dropping the sense of taste and added the kinaesthetic

[12] Fitch, *American Building*, p. 31.

[13] Pierre von Meiss, *Elements of Architecture* [Van Nostrand Reinhold (International), London, 1990], p. 15.

sense as his special augmentation. More likely, our perceptions of the physical world are the result of the five physical senses of sight, sound, touch, smell, and taste, modified by our prior experiences, our expectations, and our intellectual capacity. Further, in agreement with both Fitch and von Meiss, our perceptions of the physical environment are established by the interaction of *all* of our senses. As Fitch said: "Far from being narrowly based upon any single sense of perception such as vision, our response to a building derives from our body's *total* response to and perception of the environmental conditions the building affords."[14]

As an extension of his classification of the senses, Fitch distinguished seven factors or areas upon which our environmental perceptions of the physical environment are based. He identified these as the thermal, atmospheric, aqueous, luminous, sonic, world of objects, and spatio-gravitational. (For a further explanation of this, refer to the first chapter in Fitch's book.) While Fitch's division is helpful, especially since he used these to organize his book, assigning a chapter to each, in the discussion of environmental issues, the presentation is not generally organized on the basis of our perceptual experience. Rather, we usually organize the issues by the standard engineering subdivisions. These include HVAC (heating, ventilating, and air conditioning) or ECS (environmental control systems), lighting, and acoustics, plus the additional areas of plumbing, fire safety, electrical service, communications, movement systems, and others. This book uses these classifications, although the order in which they are arranged is somewhat different. Rather than begin with thermal issues and ECS, the discussion starts with lighting and then acoustics, and then addresses thermal issues, although there is no need to read the chapters in this order. The other issues are addressed afterward.

This arrangement aligns more closely with how we utilize our various sensations in developing spatial perception and, because of this, how we generally begin to develop an architectural design. In our discussion of the various environmental issues, we will explore basic physical phenomena and address how architectural design can be a means of addressing these, and since early design explorations tend to be more spatial than fully experiential, it makes sense to begin with lighting and acoustics since these issues most closely relate to how we predominantly develop our sense of space.

However the discussions of the various environmental issues are arranged, we should realize that our perceptual experiences are the result of all of our senses, although we tend to rely on each in different ways. Obviously, spatial perception is highly dependent on vision, followed perhaps by hearing, but it is also affected by thermal and atmospheric conditions. Olfactory senses also can have an effect that can be quite powerful, but generally this is because odors tend to trigger recollection of previous experiences, and often these do have spatial connotations. The tangible experience of touch can also influence how we experience space since it provides information on both the texture and substance of the materials, and these attributes are connected with issues of quality. However, it is usually sufficient to observe a texture or surface that we have touched previously to reconstruct the experience and then incorporate this in forming our perception. As for taste, although it is involved in assessing atmospheric conditions, we usually do not lick the space. However, as with touch, we might have actually had a taste. As infants, we probably did rely on taste as we initially explored our world, and these memories still have an impact on our interpretations.

THE INTENTIONS FOR ENVIRONMENTAL DESIGN

[The] ultimate task of architecture is to act in favor of human beings—to interpose itself between people and the natural environment in which they find themselves. . . . The successful interposition between people and their natural environment furnishes the material basis of all great architecture. To wrest the objective conditions for our optimal development and well-being from a Nature that only seldom provides them, to satisfy our physiological and psychological requirements at optimal levels— this, beyond question is the objective basis of any architecture that is both beautiful and good.[15]

James Marston Fitch

The main intention of environmental design, which includes urban design, architecture, interior design, and those other fields that deal with design of the physical environment, is the ordering of the physical environment to serve humankind. In order to serve humankind effectively, environmental design must be fundamentally scientific. Going beyond a dictionary definition,[16] science can

[14] Fitch, *American Building: The Environmental Forces That Shape It* (Oxford University Press, 1999), p. 4.

[15] Ibid., p. 3.

[16] *Webster* defines "science" as "1.) a branch of knowledge or study dealing with a body of facts or truths systematically arranged and showing the operation of general laws, 2.) systematic knowledge of the physical or

be explained as the ever-unfinished task of searching to discover facts, establishing relationships between things, and deciphering the laws according to which things occur.

The ultimate intention of environmental design is to achieve an environment that can support the fullest measure of human endeavor without the imposition of excessive external stress or, at the other extreme, the deprivation of necessary minimal sensory stimuli. To achieve this goal, designers must rely on science, although unfortunately, some design professions are unprepared to do this. Many designers do not adequately understand certain critical factors that significantly impact on the environment and, therefore, are unable to respond to them properly.

According to Fitch, this isolation from critical information is partially the consequence of the spread of industrialization and the resulting isolation of "design from the healthy democratic base of popular participation."[17] With increasing industrialization, the traditional connection between users and designers was set aside. The result of this division was the "increasing prevalence of the abstract, the formal, and the platitudinous in architectural and urban design."[18] It is probably fair to say that the aesthetic concern that has been the motivating force in the design of most of the recent prestigious buildings is an aesthetic void of any significant "functional-democratic connotations."[19] This has resulted in "a body of work as antipopular and aristocratic in its general impact as anything ordered by Frederick the Great or Louis XIV."[20] The environmental design professions must go beyond their current role as agents for the elite to provide meaningful professional service to the popular community. This demands that designers go through a process of socialization evolved from a broad theoretical foundation gained from a scientific education.

Some time ago, Dr. Jacob Bronowski presented an address to the Royal Institute of British Architects entitled "Architecture as a Science and Architecture as an Art." In this talk, Bronowski stated that "the architect bears the same responsibility for making science as well as art visible and familiar, and for having each influence and enter into the other. Architecture remains the cross-roads of new science and new art. If the architect is willing to make them one, by learning to live naturally in both, there will at last be fine modern buildings, and citizens wise enough to see that they survive."[21] Or as Fitch stated: "Modern architectural problems can no more be solved by carpentry than can spacecraft be built by village blacksmiths."[22]

To be effective, environmental design must maintain or establish a symbiotic relationship between the physical structure and its occupancy. In this sense, occupancy includes both a human component and an operational component. As environmental designers, we can expect to achieve an appropriate and effective design expression only if we have a proper understanding of the technical issues that relate to environmental issues.

In *An Outline of Philosophy*, while commenting on mathematical modeling of the physical world, Bertrand Russell wrote, "Physics is mathematical not because we know so much about the physical world, but because we know so little; it is only its mathematical properties that we can discover."[23] Paraphrasing this comment to address the problems that face architecture today, we might suggest that architecture is evaluated on the basis of visual aesthetics, not because we know so much about design, but because we know so little. It is only the composition of form that we can readily observe and, therefore, attempt to control.

Another interpretation derived from Bertrand Russell's quotation is that, in general, we tend to be more attentive to those issues that are initially most apparent to us, not necessarily those issues that are most significant. Since we tend to deal first with obvious issues, we frequently avoid or miss those that are more difficult and may be more significant. As designers, we should recognize this and attempt to avoid the trap. We must be able to consider objectively all issues that impact on our task, not just the ones that we think of first or those in which we are interested. If we are to establish our design standards on a relatively firm factual base, we need to develop a more systematic and detailed investigation of the actual relationship between humankind and the physical environment.[24]

We should also recognize that we bring to the design task a great deal of valid understanding based on our prior experience. We should use this understanding or preconditioning, which some might choose to refer to as *common sense*, and build upon it. While our prior conceptions can guide us when we undertake the study of a new issue, they should not interfere with our expanding into new areas of understanding. We must be careful to keep our preconditioning from limiting our willingness to acquire new,

material world gained through observation and experimentation, . . . 4.) systematic knowledge in general, 5.) knowledge, as of facts or principles; knowledge gained by systematic study, . . . 7.) skill, esp. reflecting a precise application of facts or principles; proficiency" (*Webster's Encyclopedic Unabridged Dictionary*, Gramercy Books, New York, 1996).

[17]Fitch, *American Building*, p. 354.

[18]Ibid., p. 355.

[19]Ibid., p. 356.

[20]Ibid., p. 356.

[21]Jacob Bronowski, "Architecture as a Science and Architecture as an Art," *R.I.B.A. Journal* (March 1955), pp. 183–189.

[22]Fitch, *American Building*, p. 357.

[23]Bertrand Russell, *An Outline of Philosophy* (Blackwell, Oxford, 1993), p. 125.

[24]Ibid., p. 24.

sometimes conflicting, information and formulating new concepts and ideas. In fact, they might give some relevance to these new concepts and ideas.

As designers, our ultimate concern should be the experiential reality of the physical environment that results from all of our senses.

Other Thoughts

The term *primitive* refers to being at the beginning, being original. According to Amos Rapoport, "Primitive building . . . refers to that produced by societies [which are] defined as primitive by anthropologists."[25] While these buildings might appear to us as rather elementary, "they are, in fact, built by people using their intelligence, ability . . . and resources to their fullest extent. The term primitive, therefore, does not refer to the builders' intentions or abilities, but rather to the society in which they build."[26] That is, a primitive building can be very sophisticated, especially from the vantage point of the builder!

According to the anthropologist Robert Redfield, *primitive* refers to a culture that is isolated and self-contained, if not in terms of other primitive cultures, then in terms of some higher culture. Primitive cultures have no knowledge of an outside higher culture. They are limited to their own devices. In the primitive society, there is a diffused knowledge of everything by everybody. In a primitive culture, there are prescribed ways of doing or not doing everything.

The term *vernacular* is distinct from primitive. Vernacular refers to a culture that coexists in association with a higher culture. Therefore, vernacular is related to *folk* and *peasant*, terms that clearly imply a distinction of cultural levels. In a sense, vernacular carries the connotation of *popular taste*.

In vernacular design, models are used as the basis of design, but these models are individually modified. They are not copied directly, as is done in primitive design. As mentioned before, in primitive design, individual adjustments of the prototype are not available. But while there is an important distinction between primitive design and vernacular design, this distinction is not as significant as that between vernacular design and high-style design. In vernacular design there is a "lack of theoretical or aesthetic pretensions; [and] working with the site and micro-climate; respect for other people and . . . the total environment, [human] made as well as natural; and working within an idiom and allowing variations only within a given order"[27] is the acceptable standard. In high-style design, aesthetic pretensions tend to dominate, and concern for the environment is subjugated to the more ethereal concerns of the designer. Another distinction between vernacular and high-style design is that vernacular design has an additive and open-ended nature, whereas high-style design is basically closed and complete. Vernacular buildings can readily accept change and adapt to variations. This tends to contribute to the particular charm of such buildings. High-style buildings, on the other hand, cannot change or adapt without being conceptually modified.

With vernacular design, tradition is a regulator that helps establish the aesthetic norm. But today, the regulatory nature of tradition has basically disappeared, especially in the United States. It has been supplanted by stylistic pretensions that are not, unfortunately, generally concerned with adaptation to the natural environment. Even with all of the rhetoric concerning the need to change our ways and become better stewards of the environment, our actions tend to continue to impose on nature rather than work with it. While there are obviously many who are dedicated and committed, the majority seem unwilling to take even modest steps that could help in the near term, so it is our responsibility to lead as best we can.

Needs and Means

In vernacular design, the major intention is to achieve an honest solution to the fundamental requirements expected of the building. The designer, who is also usually the builder and the user, does not impose contradictory and extraneous considerations on the design. Rather, the designer attempts to accomplish a natural symbiosis with nature. In simpler times this natural symbiosis of vernacular design was easily achieved, generally through an intuitive process that resulted in a positive response to imposed requirements. This process should not be thought of in terms of blind trial and error. It was a logical process that depended on an understanding of the demands expected of the proposed building and the means available to meet these demands, as well as on a wealth of prior experience.

With the unbelievable expansion of knowledge that has occurred since the beginning of the twentieth century, an expansion considered to double every 15 years,[28] and with the increase in expectations and demands of our contemporary society, the intuitive design process cannot sustain effective architectural development. Today the architectural design process must be consciously rational

[25]Amos Rapoport, *House Form and Culture* (Prentice-Hall, Englewood Cliffs, NJ, 1969), p. 3.

[26]Ibid., p. 3.

[27]Ibid., p. 5.

[28]This would mean a more than 60-fold increase in knowledge since 1900.

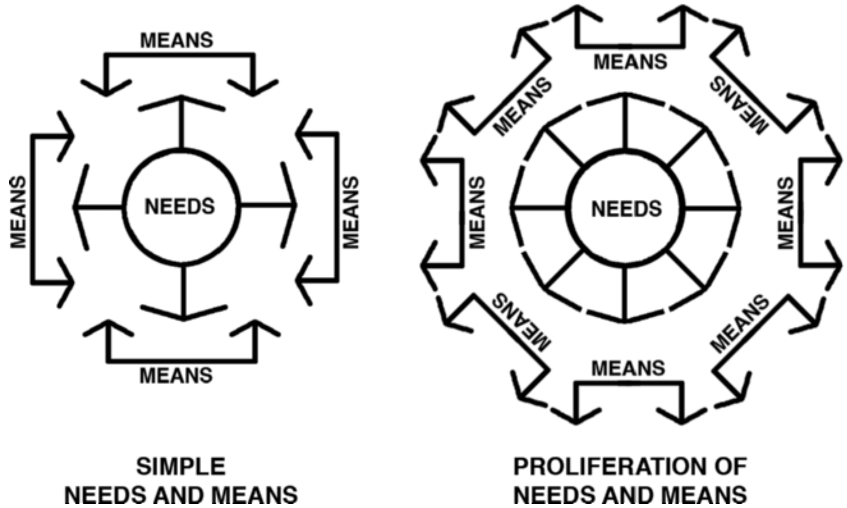

Figure 1.1 DIAGRAM OF NEEDS AND MEANS
James Marston Fitch stated that design should be the process of balancing the outward-pressing needs with the inward-pressing means that are available. While this balance was readily achieved in simpler times with limited needs and means, the increased complexity of needs and the expansion of the various means that are now possible have led to an explosion of possibilities and design chaos.

and scientific. In *American Building,* Fitch presented this thesis—the requirement for a rational and scientific design method. He suggested that prior to the general proliferation of design requirements and potentials that resulted from the industrial/technological revolution of the last 150-plus years, the building profession was disciplined and ordered by what Fitch called a "clear and comprehensible reference frame of needs and means."

As shown in the left-hand diagram in Figure 1.1, the needs that a building was to address, which were outward-pressing requirements, were relatively simple and basic, and they were readily defined. Also the means by which it was possible to respond to these needs, which were inward-pressing limitations, were easily identified and offered minimal opportunities for choice. Today, however, as indicated in the right-hand diagram, the balanced interface of needs and means has been exploded with the increase in both technological capability and programmatic demands. Without a balanced interface, chaos reigns supreme and the adaptation of the physical environment in humankind's favor, the primary objective of environmental design, cannot be achieved effectively.

Things have become more complex, and the challenge for environmental design is to embrace this complexity. We must develop a clear understanding of both sides of the needs–means interface and use this to reestablish a sustainable future where needs and means are again brought into balance, as indicated in Figure 1.2.

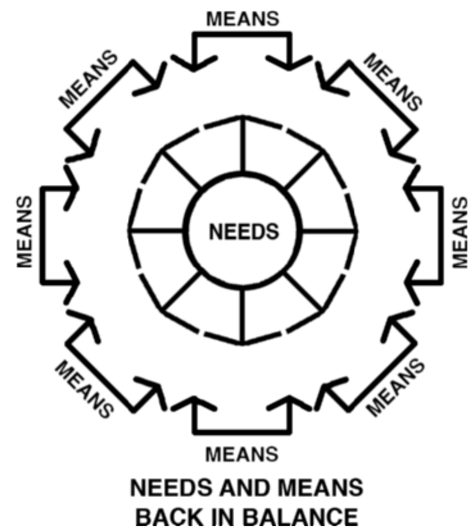

Figure 1.2 DIAGRAM OF NEEDS AND MEANS BACK IN BALANCE
With a clear understanding of the needs that environmental design must address and a solid grasp of not just what is possible but, more importantly, what is appropriate to address these complex needs, a balance between the two can be reestablished.

CONCLUSION

The aim of environmental design is to achieve a nurturing environment that can support the fullest measure of human endeavor without imposing excessive external stress. The aim is to establish what Fitch called the *third environment*, in which there is a symbiotic relationship between the physical environment and the occupancy. If a designer's standards for judgment are to be firmly based, with more substantiation than is currently provided, the designer needs to understand the fields of physiology, psychology, anthropology, history, economics, and others. Architecture needs to have a broad knowledge base and a well-developed understanding of humankind's actual physical and emotional relationship with the environment.

Let us begin by learning more about the environmental issues that impact on architecture.

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CHAPTER

2 LIGHTING PRINCIPLES

VISUAL PHENOMENA

Visual phenomena obviously deal with what is sensed by the eye; however, even in the area of design, they are not limited to issues of composition. Rather, visual experience relates to the broader issue of visual communication that extends well beyond mere visual sensation and enters into the realms of perception and conception that depend on interpretation of information gained through the visual senses. Visual communication is probably the major means by which information is transferred, although as we mature, verbal communication tends to supplant the dominance of visual data. However, even then, much of the verbal information is acquired through the visual senses—that is, through reading.

While we understand that our visual sensations allow us to discern the physical composition of the environment, we should recognize that these sensations also provide us with considerable data that convey important additional information about the environment. For example, we can often identify the function or purpose of a space from what we see, even when the space is devoid of people and furniture, or we can recognize the appropriate paths by which one may easily move through a space. We can even perceive the acoustical qualities and perhaps the thermal qualities of a space, and we can determine certain characteristics of the enclosing materials, such as whether they are soft or hard or whether they are smooth or rough. For instance, irregular light and dark areas on a surface are indicative of a rough surface texture, with the amount of irregularity of the light related to the relative degree of surface roughness.

Such interpretations of visual data are based on an understanding acquired from prior experience. Since individuals are unlikely to share similar previous experiences, common visual experiences do not typically result in identical interpretations. Each individual's interpretation of a particular visual condition is the result of the actual visual sensations of that condition combined with his/her own preconditioning. While we should be aware of the lack of uniformity in individual past histories and how these differences might affect spatial interpretations, we should also recognize that people often share many common experiences, especially with those within their own culture.

Understanding that people rely extensively on their previous experiences, we should realize that it is possible to establish visual statements that might suggest conditions that do not physically exist. For example, in this age of synthetic materials, the visual message of a rough-textured surface may be derived from a surface that is actually smooth, such as contact paper or plastic laminate (i.e., Formica), or an actual rough or irregular surface, such as one that might result from a poor finishing job of a gypsum board ceiling, can be rendered as a smooth, flat surface if the lighting is bilateral and eliminates all shadows. This is an important factor: as designers, we can manipulate the visual message to make it either consistent with or somewhat independent of the actual physical reality.

The complex processes used in visual communication are obviously very significant in establishing appreciation or lack of it for the physical environment. However, while not intending to diminish the significance that visual sensations have in formulating our spatial experiences, we might question the appropriateness of overemphasizing the importance of the visual qualities of design to the almost total exclusion of all other environmental qualities. We might also wonder about the current proclivity that certain design professionals seem to have for supplanting direct spatial experience with abstract, conjectural verbal commentary, sometimes referred to as *talkitecture*, which often seems to have very little connection with the actual physical realities.

As designers, it is important to understand visual perception and use this in the design process. The visual experience is a significant part of spatial perception, and understanding how this experience is formed should inform how a design intention might develop in terms of the placement, configuration, texture, and color of those objects that define the physical environment, not just in connection with the design of the lighting system. While the principles of composition are critical to this task, unless the visualization process is also considered in the development of a physical design, it is unlikely that the intended spatial perceptions will be achieved.

Reality or Illusion

When we "see" an object, unless it is actually emitting enough electromagnetic radiation that lies within the visible spectrum, what we actually sense is light that is reflected off the object, not light that actually comes from the object. That is, contrary to our normal way of thinking, we really do not see the object since we cannot sense any visible radiant energy that it emits. What we sense is actually the "negative" or the electromagnetic radiation that the object rejects, and we use this sensation to achieve our perception of the object. The image of the object received on the retina is also inverted since it is turned upside down in passing through the lens of the eye.

In terms of color perception, the visual process is similarly convoluted. When we see an object and assign a color to it, we are really identifying the object by the color that it does not possess. Since the object absorbs certain colors and rejects others, the color of the object that we sense is actually the color that it rejects or reflects. That is, the color we call an object is that which it is not. As if this were not confusing enough, let us consider what happens when we observe something through glass.

Looking through glass is also not what it at first appears to be. The general theory suggests that when we look through glass, we really see only a reproduction of the original visual image that impinges on the glass since the specific light rays that are reflected off the object that we "see" do not actually pass through the glass. Rather, these rays are absorbed by the glass, which, in turn, emits new light rays. This sets up a chain reaction, somewhat like the movement of billiard balls. So again, we actually see a reproduction and not the real thing, but for all practical purposes, there really is no difference in terms of our experience. Of course, if the visual sensation is a construct that is not based on a physical reality, perhaps this also does not make much difference in our experience. Interestingly, in addition to establishing this magical experience of sight, the absorption and reemission of radiation in glass, or in any transparent medium, is what also causes the light to bend as it moves from one density to another (see Figure 2.1).

We are told that the cause for this bending of light is that the speed of light is reduced as light enters glass; but the speed of light is supposedly one of the fundamental constants of the universe, so how can it change? The more complete explanation is that the actual speed of light remains constant, but the absorption and reemission of the radiation in a transparent medium requires time, and this adjusts the apparent or effective speed of light. This delay in

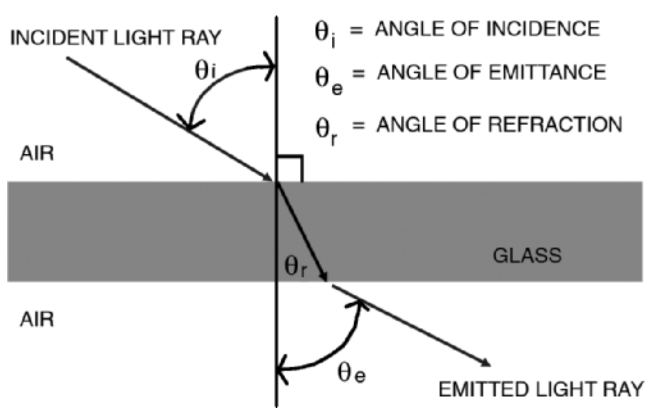

Figure 2.1 REFRACTION OF LIGHT

Light bends as it passes obliquely between the interface of two media of different densities. The light rays bend toward normal when the density increases and away from normal as it decreases, with the amount of the angular change related to the coefficient of refraction of the medium through which it passes.

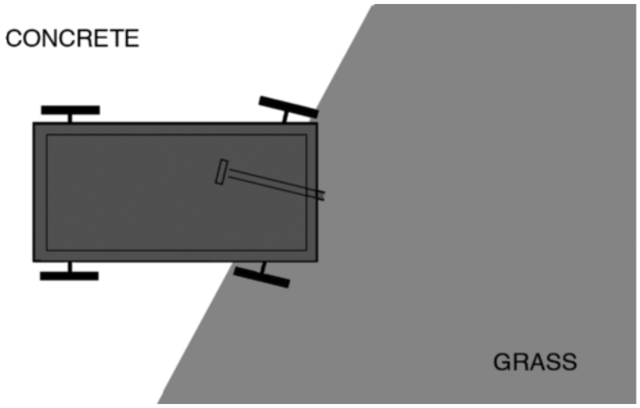

Figure 2.2 ANALOGY OF BENDING BY REFRACTION
Refraction of light is similar to what happens with a wagon moving across a paved surface onto grass. Assuming it comes at an angle, when one front wheel runs onto the grass, its speed is reduced while the other front wheel continues at a higher speed, which forces the wagon to turn.

Figure 2.3 PERPENDICULAR LINES
Which of the images includes two lines of equal length? Interestingly, by comparing the two images with a square that has side dimensions equal to that of the vertical line, which is obviously equal in both images, we not only get verification of which image has lines of the same length, we also perceive the results in a way that mere measurement of the line length does not provide.

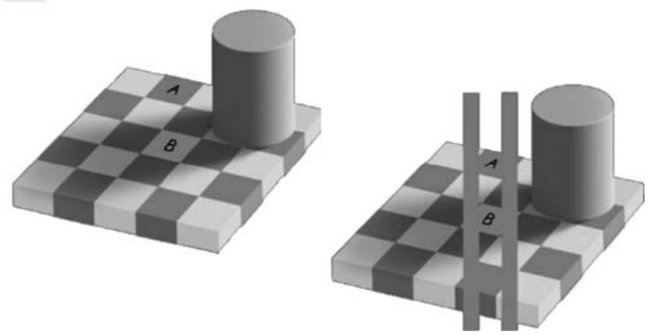

Figure 2.4 CHANGING SHADOWS
Are all of the light gray squares the same shade? While there might be some variation among the shades of the light or dark squares, clearly the light and dark squares are different from each other—or are they?

passing through the transparent medium causes the light to bend, assuming that it enters at an oblique angle. The light bends when it enters and again when it leaves the glass because of the difference in the effective speed that occurs between the light rays at the interfacing planes of the denser glass and the air.

This bending is analogous to what occurs when a wagon rolls obliquely across a smooth concrete area onto grass. As diagrammed in Figure 2.2, as the first front wheel of the wagon leaves the smooth paved area, it slows down and the wagon turns slightly. The amount of turning is dependent on the difference between the speed of the wheel on the paved surface and on the grass and on the length of time that the first wheel is on the grass while the second wheel is still on the pavement, which is related to the angle of approach.

Even when not looking through glass, vision still relies on a similar reproductive process. The eye has an exterior covering called the *cornea*, a lens that focuses the entering light upon the retina and is itself filled with a transparent fluid called *vitreous humor*. As a result, the light rays that the eye initially receives do not actually strike the retina, so all visual perceptions are based on reproduced electromagnetic radiation. Since we do not see objects directly but rather experience energy fields that are merely influenced by the objects, it seems reasonable that, as designers, our major concern should be focused on the energy fields as the source of visual stimuli rather than on the physical objects themselves. We should be predominantly concerned about how the physical elements of a design affect the energy fields that are experienced instead of being obsessed with the tangible reality of the design. That is, if our primary concern is for a perceptual experience, our regard for the physical reality should be in terms of how it determines the energy fields, especially in terms of lighting, upon which perceptual experience is established rather than on the physical reality itself. Or to say it otherwise, it is important to understand that the way an object is illuminated has a critical impact on how it is visually perceived. Recognizing this, perhaps rather than continue to assume that the purpose of lighting is merely to render the environment in a way that supports the perception of its actual reality, our intention might be to use lighting as a way to modify the appearance of physical reality and thereby create an illusion.

Perception also depends on interpretation, and there are a number of intriguing examples of how what we think we see is not substantiated by actual conditions. Figures 2.3 to 2.5 show several classic optical illusions.

Which of the perpendicular lines in Figure 2.3 are the same length—those in the left image or in the right image? Since the vertical line in the left image is clearly longer than the horizontal line, the equal lines must be in the right image, and these lines do appear to be the same length. However, since the vertical lines in both images are of the same length, by placing a square with sides of this length around each image, we can clearly show that the left image includes equal-length lines.

In Figure 2.4, the image on the left shows a checkerboard on which a shadow is cast by a cylinder. As we

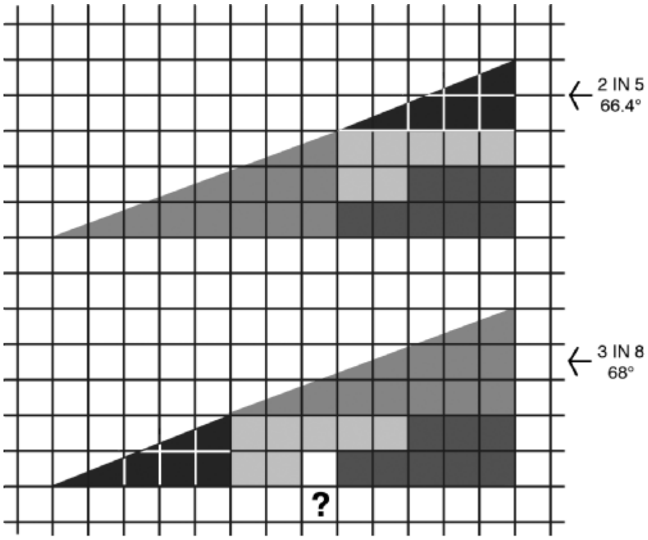

Figure 2.5 THE 7% RULE
Things are not always as they appear. While both of the larger triangles are comprised of two different-sized smaller triangles and two L-shaped blocks, when they are arranged differently, there is an extra grid square in the bottom 13×5 triangle. How is this possible?

Figure 2.6 LA GIOCONDA
The Mona Lisa presents an image that is quite familiar, although sometimes what we assume we see is not actually what we do see.

observe the various squares in the shadow of the cylinder, the A and B squares are clearly different colors, with the A square darker gray and the B square lighter gray. We perceive this, in part, since we know that the squares alternate on a checkerboard, but also because we accept that the lighter gray should be darker in the shadow of the cylinder. However, as we can readily observe in the image on the right, which has added dark gray bands to link the A and B squares, these two squares are the same gray.

Figure 2.5 contains two triangles on a grid. Each of these triangles contains the same four subcomponents, but these components are arranged differently in the two triangles. Interestingly, in the lower triangle, even though the same four components are used, there seems to be an extra square in the grid that is not covered by the rearranged components. How could this be possible, especially since these two triangles were actually developed by physically rearranging the different components?

The clue to solving the puzzle is provided at the right of the image. The top component of the upper triangle is itself a triangle. This smaller triangle has a base that extends for five grids and a height that is two grids, which, based on trigonometry, means that the slope of the hypotenuse of this smaller triangle is 66.4°. The upper triangle also includes another subtriangle, with a base of eight grids and a height of three grids, which relates to a slope of 68°.

The nontriangular subcomponents together include a total of 15 units of the grid. In the top composite triangle, they overlap and fill three five-unit rows, which is a total of 15 squares in the grid. In the bottom composite triangle they are allocated to two rows or 8 units, which means that the 15 units cannot cover all 16 grid units. The "extra" square in the grid is not the result of changing the way the L-shaped blocks are arranged but of the different slopes of the subtriangles.

What we do not observe is that, since the hypotenuses of the two subtriangles in each figure are not at the same slope, the hypotenuse of each of the two larger triangles is not a straight line. This is not apparent to the eye, partly because of what is sometimes referred to as the *7% rule*, which states that when similar dimensions or angles have less than a 7% divergence, the difference is generally not perceived since our desire for order attempts to equalize conditions.

Another example of our tendency to perceive what we believe is there is provided by Figure 2.6. This image appears to be an inverted copy of the Mona Lisa by Leonardo da Vinci. While most people easily recognize this famous painting, few realize that the image has a serious flaw, but it is not because it is upside down. In fact, being inverted tends to conceal the flaw, which is that the eyes and the mouth in the image are inverted with respect to the overall orientation of the image.

Whether reality or illusion, environmental design is concerned with establishing a physical environment that is perceived primarily through the visual sensations derived from the impact of the various spatial definers (e.g., walls, floors, and ceilings) on the visual field. The way these spatial definers are illuminated clearly influences the way they are seen, and this, in turn, impacts on the spatial perception. While this is a cue that the design of the electric lighting system is important, we should understand that it actually has perhaps more to do with spatial design and how the physical components should be arranged so that they are seen in a way that will produce the intended spatial experience. Unfortunately, many designers do not adequately understand the processes by which we see, even though the visual experience is clearly the dominant force of architectural design.

As James Marston Fitch said:

The paradox is that, despite contemporary architects' obsession with the visible aspects of their work, they often have little knowledge or understanding of the visual performance field. This is expressed in many ways. For all the new means at their disposal, their use of color—either as pigment or as light—is both more timid and less expert than in many previous periods. For all their extravagant use of glass, they seldom recognize the basic optical fact that glass is only transparent under certain objective conditions. For all their wide use of [electric], non-daylit illumination, all too many buildings are poorly lit with improper fixtures for the task.

The field of lighting design has changed tremendously since the first energy crisis of 1973. All facets of technology have improved, including more efficient lamps, improved fixtures, and various controls to reduce waste. Laws, codes, standards, and basic operational economics have reduced the luminous power density of most buildings substantially. However, notwithstanding these changes and increased knowledge of insolation and orientation, many new buildings still display serious malfunction, expressed in glare, overheating, and faulty integration of natural and [electric] light sources. In short, the architect pays at once too much and too little attention to the visual world— too much to its formal superstructures, far too little to its experiential foundations.[1]

Too often it seems that designers, having only a limited understanding of visual perception, are incapable of realizing the potential of light and using it as an important part of the design palette. Instead, they increasingly turn to excessive spatial contortions as the way to develop spatial interest and excitement or, unwilling to take this tack, merely accept that spaces will be rather mundane and dull. If some designers do not seem to understand the basic principles of visual perception, then perhaps failure to recognize the tremendous significance that nonvisual stimuli can have on our perception of the physical environment is to be expected, but hopefully not accepted.

[1]James Marston Fitch with William Bobenhausen, *American Building: The Environmental Forces That Shape It* (Oxford University Press, New York, 1999), pp. 103–104.

BASIC PRINCIPLES OF LIGHTING

Over the last 40 years, considerable effort has been expended on determining the appropriate criteria for effective interior lighting. Prior to the Arab oil embargo in the early 1970s, the general tendency of the lighting profession was to continually increase levels of illumination. While several voices were questioning the logic of this approach to lighting design, the overwhelming momentum in the lighting industry was for higher and higher lighting levels to support greater and greater levels of visual performance. The Illuminating Engineering Society of North America (IESNA), which is the main professional organization in the lighting field, was calling for performance efficiencies[2] of 99%. According to the IESNA, this necessitated illumination levels of more than 100 foot-candles for general office work and more than twice that, 250 to 500 foot-candles, for detailed tasks such as drafting. Fortunately, in response to the general awareness of our energy limitations, the IESNA considerably reduced the recommended levels of illumination.

Four Factors That Affect Vision

While lighting levels have been reduced from those promoted by the IES prior to the 1970s, there is currently no clear agreement as to the amount of lighting that might be appropriate for various tasks. However, there is a general consensus that vision is improved when there is an increase in various factors:

1. Level of illumination
2. Contrast between a visual object and its background
3. Size of a visual object
4. Time of exposure

Level of Illumination: Up to certain levels of illumination, providing more light for a visual task generally improves vision. With an increase of illumination there is an increase in visual stimulation, which usually supports improved vision. However, with excessive levels of illumination, adaptation might actually result in a reduction

[2]Performance efficiencies are based on the percentage of correct responses given by subjects as to the orientation of a specified form. Often the subjects are asked to identify the location (i.e., top, right, bottom, etc.) of an opening in what is referred to as a Landolt Ring, a small C-shaped figure that has a line thickness equal to one-fifth of the diameter of the circular shape. The width of the opening in the ring is also equal to one-fifth of the diameter.

of actual stimulation of the retina, resulting in decreased vision. For most visual tasks that are not highly demanding, 10–20 foot-candles of illumination, which correlates with 100–200 lux, is all that is actually required for adequate vision. While vision does tend to improve with higher illumination levels, there are data that suggest that above 30 foot-candles there is a diminishing benefit provided by increased levels of illumination and that above 120 foot-candles visual effectiveness might actually decline, especially if the illumination is not appropriately controlled.

Contrast Between a Visual Object and Its Background: Contrast is perhaps the single most important factor in visual acuity, especially when the outline or silhouette of the object provides the primary source of information. While providing an appropriate contrast is important, for ease of vision the average level of brightness within the visual field should be relatively in balance. Average brightness is what is provided within a particular portion of the field of vision to which our eyes adapt. For example, rather than the contrast between the letters in this book and the paper on which they are printed, which is critical to being able to distinguish the letters, the average brightness of this page of print is based on the combined effect of the black letters and the exposed white paper.

Any major difference in average brightness between adjacent surfaces should be avoided. This has often been stated in terms of ratios between the visual task and the surround, with recommendations that the ratio between brightness levels should not exceed 3:1 within the near surround, which is within the area of visual attention. It is also suggested that the task brightness be at a higher level than the background brightness, although this is not as critical as maintaining the 3:1 ratio. Within the total field of vision, the recommended maximum ratio should be 10:1, again with the task preferably at the higher level.

While contrast is effective in defining an object, contrast in brightness can also establish emphasis since the eye is naturally attracted to a level of luminance (brightness) that is significantly higher than the average brightness within the field of vision. A 10:1 ratio of brightness between two different surfaces will be clearly noticeable, with the brighter surface usually interpreted as being about twice as bright. A brightness ratio of 100:1 will produce a perceived emphasis on the brighter surface.

Size of a Visual Object: As the size of the visual image increases, the visual task becomes easier. With a reduction in the size of the task, the illumination level, the contrast, and/or the exposure time would have to increase in order to maintain comparable vision.

Time of Exposure: As the time available for a visual task increases, it generally becomes easier to discern things. With a reduction in the available time, the illumination level, the contrast, or the size would have to increase in order to maintain comparable vision, but additional time cannot always resolve inadequate illumination, contrast, and/or object size.

While we need to be aware of the interaction among these four factors, perhaps the most important thing to realize is that once minimal levels of illumination have been provided, improved visibility and visual comfort can often be more readily achieved by adjusting the contrast, increasing the size of the visual image, or expanding the time available for the task rather than by increasing the illumination level. For example, an original intention in suggesting increased illumination levels for the work environment was to enable effective reading of a fifth carbon copy generated by a manual typewriter. Today typewriters are hardly ever used, but if they are, they are probably electric rather than manual, and if we were intent on producing carbon copies, an electric typewriter will produce a stronger imprint and better copies. But rather than carbon paper, reproductions are now generated by photocopiers, and if the copy is not clear, it makes more sense to fix the copy machine than increase the level of illumination.

Although not one of the four basic factors of lighting control, another important aspect of visual perception is that in normal conditions the major plane of sight is horizontal. That is, we tend to look straight ahead, not up or down, and because of this, vertical surfaces comprise the most significant portion of the visual field. In most spaces, the walls are generally the dominant surfaces and, as a result, are the primary surfaces upon which spatial perceptions are based. This is especially true in normal-sized spaces. In large spaces, the ceiling and floor tend to become more visually dominant.

Sometimes lighting is identified as being either *natural* or *artificial*. Although there are differences between light emitted from the sun and light electrically generated, particularly in terms of wavelength composition, the significant distinction is the source of the light rather than the light itself. That is, light is a form of energy, particularly electromagnetic radiation with a wavelength between 380 and 760 nanometers. As a form of energy, it exists, and since it does, regardless of the manner in which it is generated, there is no such thing as artificial light. There is daylight and electric light, and sometimes even gas light, but whatever its source, light is light.

It is dubious whether the notion of artificial light is ever appropriate, but perhaps it is legitimate for light that is represented in a graphic manner or maybe when a sensation of light is experienced mentally independent of physical sensation. When light exists, it is real even though the characteristics of the light might differ.

PURPOSE OF ARCHITECTURAL LIGHTING

In addition to understanding these basic principles of lighting, it is also important to recognize that architectural lighting has a twofold purpose: spatial and task. Spatial lighting generally deals with visual ambiance, while task lighting deals with visual performance, and although at times these two roles of lighting continue to be handled together, they are distinct.

The role of spatial lighting is to define and enhance the spatial qualities of the physical environment. These qualities might be derived from the actual physical characteristics of the space, or they might not; in the latter case, the lighting system would attempt to modify the real physical configuration in order to achieve an intended effect. While spatial lighting basically involves illumination of the spatial definers, task lighting generally deals with lighting an implied surface on which a visual task is to be performed. This implied surface is assumed to be a horizontal illumination plane, often referred to as a *work plane*. This plane is usually set at 30 inches above the floor, which is the typical height of a desktop. The role of task lighting is to make a visual activity possible without imposing unnecessary effort. Of course, if the visual activity is to experience an aspect of the space, such as might occur in a building lobby or along a stair, then task lighting might be spatial lighting; however, normally the task is assumed to be something like reading or drafting, which requires illumination on the horizontal work plane.

As shown in Figure 2.7, in the early days of electric lighting, the electric lamps were often left exposed. While these exposed lamps could produce an interesting delineation of a space, the brightness of the lights could be a problem, especially when the lighting level was increased to provide better task lighting. In order to avoid this, indirect lighting was frequently used. The bright light sources were concealed from view, with the emitted light intentionally bounced off a room surface, usually the ceiling, to be reflected down to the illumination plane. As a result, with both of these early lighting methods, exposed lamps that outlined a space and indirect lighting, spatial lighting was often the means of providing task light. As the design of lighting fixtures improved, emphasis was placed on developing adequate light on the illumination plane, with spatial lighting often provided merely from the reflected task lighting, somewhat the reverse of indirect lighting. Unfortunately, the distinction between the two roles of lighting was not generally considered in the lighting design, and the approach was to light all areas to achieve the lighting level for the intended visual task level, letting the resulting reflected light serve as the source for spatial lighting. With expanding awareness of the fragility of our natural environment and the negative effects of excessive energy consumption, the approach to lighting design is changing. Lighting all areas to task levels is being supplanted with a more focused approach to task lighting. These higher levels of illumination are now more typically provided only for those areas where the tasks are actually performed, with reasonable general levels of illumination now often achieved through intentional spatial lighting.

Figure 2.7 PLUM STREET TEMPLE
This image of Plum Street Temple, located in Cincinnati, Ohio, and designed in 1866 by James Keyes Wilson, shows exposed incandescent lights that tend to outline the physical structure. This space, which is the home of American Reform Judaism, was originally illuminated by gas but was electrified around 1900.

Whatever the motivation is, task lighting and spatial lighting should be approached distinctly in order to achieve the desired results. The lighting of a lecture hall in which digital presentations are shown is an example of a condition where the two should be handled separately. For example, taking notes demands an adjustable lighting system that can illuminate the tablet-arm surfaces so that students can see their notes during a presentation. In order not to affect the slides, this task lighting on the table arms should not spill off and illuminate the enclosing surfaces of the room, especially the screen. The spatial lighting system would be the system used to illuminate these surfaces. If there is a chalkboard on the front wall, the system for task lighting might also be part of the spatial lighting system.

If the enclosing surfaces of a space, such as the lecture hall, are illuminated, the space will appear to be brightly lit, even though there might not be adequate light for a particular task on the implied illumination plane. On the other hand, if there is proper illumination on the horizontal work plane that does not spill over onto the walls, the space might be perceived as not being adequately lit, although for the particular task, it is. But while these two purposes of lighting are different, spatial lighting can affect our expectations, which, in turn, can affect our visual performance.

Nela Park in Cleveland, Ohio, is the home of General Electric's Lighting and Electrical Institute. It began with the formation of the National Electric Lamp Association, primarily due to the efforts of Franklin S. Terry, from the Sunbeam Incandescent Lamp Company of Chicago, and Burton Gad Tremaine, who had business connections with the Fostoria Incandescent Lamp Company in Ohio. In the early days of electric lighting, without standardization, it was difficult for the various competing companies to gain a share of the lighting market, especially when contending with the major player in the lighting industry, the General Electric Company.

While we all know that Thomas Alva Edison was instrumental in the development of electric lighting, we might not realize that another sign of his innovative genius was his ability to form various companies to produce and support his invention. In 1889, Edison consolidated all of his companies under the Edison General Electric Company. Then in 1892, through a merger with the Thomson Houston Company, the General Electric Company was formed. Charles A. Coffin became the president of this new company, continuing in this position until 1913.

Coffin believed in competition, supposedly having different parts of GE compete against each other to improve the company's overall performance. His penchant for competition was well known, so the leaders of the smaller lighting companies came up with the audacious idea of approaching Coffin with a proposal that he endorse the formation of an association to standardize lighting components that would provide a more level field for broader competition. Coffin agreed, and the National Electric Lamp Association (NELA) was formed in 1901, with GE providing 75% of the financial backing although remaining a silent partner. While NELA essentially operated as an independent agency of the lighting industry, standardizing things and engaging in research, as a result of a U.S. government antitrust investigation, the major position of GE and the nonindependence of NELA were exposed. As a result, GE acquired the remaining 25% of NELA and converted it into its own research arm.

General Electric's Lighting and Electrical Institute at Nela Park provides resources and education support. This facility includes several demonstration lighting installations that dynamically adjust to show different lighting applications. While these demonstrations are quite effective in showing the different results that can be achieved, they also clearly show that work plane illumination and effective spatial lighting are best accomplished by different but coordinated lighting designs for each purpose.

Intentions of Lighting Design

William M. C. Lam, architect and lighting consultant, has been concerned with the architectural intentions of lighting design. He has presented his ideas in numerous publications, specifically in a series of articles entitled "Lighting for Architecture," originally published in *Architectural Record* and then reissued in *Environmental Control*, an Architectural Record Book edited by Robert E. Fischer. In a more recent publication, *Perception and Lighting as Formgivers for Architecture*, Lam again presented his ideas along with a number of well-documented case studies. Lam classified lighting according to six different objectives, one of them dealing with task lighting and five, with spatial lighting.

1. Light to see by: enough light for the purpose
2. The light you see: lighting for mood or atmosphere
3. The light you see: lighting for emphasis or to direct movement
4. The light you see: lighting to express intended use
5. The light you see: lighting to complement structure
6. The light you see: lighting to modify the appearance of space

Lam categorized lighting systems by the character of the lighting or the objective that the lighting achieves. While each of his six lighting categories has a particular emphasis, there is often an overlap among them. For example, the lighting design for a church that creates a mood conducive for a religious space might also establish a sense of movement toward the altar (see Figure 2.8). While *Perception and Lighting as Formgivers for Architecture* concentrates on electrical illumination, the lighting categories apply equally to day lighting.

In a slightly reordered manner, Figures 2.9 to 2.15 and associated commentary expand on the effects that Lam's various categories of lighting might have on one another.

Enough Light for the Purpose

While increasing lighting levels can improve vision, rather than merely increase light levels, it is usually more appropriate to provide a suitable level of illumination, in an appropriate manner, and to adjust other factors to enhance visual perception. Rather than rely on changes in lighting, the more practical approach to improve visual performance often involves altering the task. The return on increased lighting levels continually declines, and if excessive, it is also probable that higher lighting levels might actually reduce visibility (see Figure 2.9).