The conventional contemporary process of lighting design

Today, the process of design has become fragmented and compartmentalized, so that the original design concept, no matter how strong, is almost inevitably subjected to sequential erosion. Decisions are typically made one at a time—first planning, then structure, then mechanical systems, then lighting, then detailing, then finishes—with each stage in the decision-making process more or less isolated from and constrained by its predecessors. Irreversible decisions made in the early phases of such a linear, sequential process inevitably restrict the range of options which are open to the design team in subsequent stages. Some designers seem to believe that no joint decisions are possible—that each design phase must be a separate layer. The results of this line-of-least-resistance approach are usually boringly repetitive, wasteful, and frequently even confusing. All too often, the resulting luminous environment shows little or no variation throughout a project, even though the activities and needs in different areas may be quite different. In terms of effectively meeting the biological and activity needs for environmental information discussed in the previous chapters, far too many new working buildings fail miserably; responsibility for the generally low quality of these luminous environments can be attributed at least in part to the typical sequential, compartmentalized process of design. Let us run briefly through a typical design sequence.

Our hypothetical architect begins his or her design with no further consideration of artificial lighting than to make brief programmatic statements such as “downlighting” or “recessed fluorescent lighting, 70 footcandles.” Late in the design development stage, or at the beginning of contract documentation, lighting design proper begins. The electrical engineer is given responsibility for the lighting, and follows the “lumen method” throughout the building except for a few, special spaces such as the lobby or the executive floor which receive more attention and thought. The steps in the lumen method are as follows:

1. From the IES Handbook, from government codes, or from the client’s specifications, determine the required average level of horizontal footcandles for the project. A single level may be specified for the entire building, or various levels may be
established for different types of space: office, classroom, corridor, etc.

2. Select a lighting fixture or fixtures suitable for mounting in the preselected ceiling system, which uses the most economical lamps available and has the highest fixture efficiency in terms of producing illumination on the horizontal plane at desk level. The shape of the fixture relative to that of the room is usually considered to be of secondary importance, if it is considered at all. Some consideration is given to quality of the lighting system by limiting direct glare; generally, however, low-brightness fixtures will not be selected if they cost more per footcandle delivered on the work plane.

3. Calculate the number of fixtures required to achieve the average illumination level or levels determined in step 1.

4. Find a layout for the required number of fixtures which distributes the light uniformly over the room as measured at the work plane.

**Conventional “qualitative” criteria and their limitations**

Some variations on this standard procedure do take place. Additional qualitative restrictions may be imposed by the government or by the client. Such requirements are frequently stated in terms of maximum permissible brightness ratios. The deficiencies of brightness ratios as indices of quality have already been pointed out: they simply fail to take into account the desirability of seeing the source in question, which is an important determinant of the viewer’s reaction.

Although brightness restrictions are not sufficiently stringent to eliminate undesirable visual noise such as glaring patterns of meaningless light fixtures, they are often too restrictive to allow desirable, relevant high-brightness elements such as pleasant window views. Brightness restrictions have been misused to eliminate windows from school designs, and to lower the transmission value of window glass to such a degree that even sunny days appear dull and gloomy from inside the building. Abstract numerical criteria such as these cannot distinguish between objects we like to look at and those we do not; as a result, people are deprived of desirable and biologically necessary information in the name of their own comfort.

The Visual Comfort Probability Index (VCP) is representative of another type of qualitative restriction which may be imposed on a lighting design. Indices such as VCP attempt to rate various arrangements of fixtures according to the proportion of viewers who would find the arrangement in question tolerable from the point of view of glare. Incorporation of VCP requirements into design criteria has the unfortunate side effect of restricting fixture options to those which have been listed by the manufacturer as meeting VCP minima for the contemplated fixture arrangement, room size, and proportions. Since only regular arrangements are listed, the designer’s options are quite restricted from the start. We have seen that optimal luminous
environments are likely to call for irregular fixture layouts and selectively illuminated room surfaces, or for low general illumination combined with supplementary local lighting on demanding tasks. Faced with glare limits stated in terms of VCP, however, a designer trying to achieve the optimum luminous environment is handicapped by the necessity of using rated fixtures in regular patterns. Indirect lighting cannot be considered, since there are no published tables from which the designer could derive meaningful VCP ratings for the illuminated room surfaces which serve as sources of light. The only alternative involves the expense of carrying out either complicated calculations or a full-scale testing program for each design option—an operation for which the average designer has neither the requisite funds, experience, nor equipment.

Much better results can be achieved if the design team and building committee use mock-ups or even realistic model studies of alternative designs—including those which can be assigned VCP ratings—as the means for evaluation of design options for the luminous environment.

When VCP criteria are specified, the typical VCP objective is 70 percent, which means simply that 70 percent of the occupants of the space are expected to find glare conditions acceptable. This is an objective which can be attained under most circumstances by the use of moderately good lenses in recessed fluorescent fixtures. In view of how much money and energy is involved, this seems a singularly low objective: 95 percent satisfaction is not too difficult to achieve and seems a more appropriate standard of performance in this age of technical sophistication, yet such high standards are never set because most commercially available fixtures in conventional arrangements would fail to qualify.

It must be pointed out, in closing, that the VCP method only rates glare, which is just one aspect of the luminous environment, albeit an important aspect. There is nothing in the VCP rating system which guarantees that people will find environments with a good VCP rating either comfortable or pleasant. Similar criticism applies to the British discomfort glare rating system developed by Hopkinson.

Recently, a new “qualitative” measure has been introduced into the conventional design process: Equivalent Sphere Illumination, or ESI. ESI measures the degree to which a particular lighting installation approaches the effectiveness of sphere lighting. When light comes from a uniformly illuminated sphere surrounding the task there is very little loss of contrast due to veiling reflections, because only a very small amount of the total incident light is delivered at the mirror angle. The ESI rating of a lighting installation indicates the footcandle level of illumination from a spherical source which would be required to produce an equivalent degree of accuracy in the performance of visual tasks as the lighting installation being evaluated. Although ESI represents an improvement over the use of raw footcandle measurements, because the ESI approach makes a gesture toward the quality of the luminous environment, the use of ESI footcandles in no way alters the invalidity of the premises on which the conventional design process is based. In fact, the use of ESI criteria raises a number of additional questions which have yet to be resolved:

- ESI relates to only one very limited aspect of the quality of the luminous environment,
having to do with the legibility of written or printed matter of a certain size located flat on a desk directly in front of the reader. There is no guarantee, however, that this “most difficult task” will be either important or distributed throughout a space, nor is there any guarantee that, even if important and evenly distributed, the task will be performed in the manner specified: flat rather than inclined, directly in front of the reader rather than to one side, from a desk chair rather than a drafting stool or a lounge chair, etc. Since the geometry of the situation is critical to the determination of ESI, the stringency of the control conditions throws the validity and usefulness of the entire process into question.

- In all spaces ESI varies with the location and orientation of the task. Usually an average ESI value is calculated. This presumes that the visual tasks are distributed at random in the space. Yet there is no method available which the designer can use to make a meaningful comparative evaluation of two alternative designs with different distributions of ESI. For example, one cannot compare directly the “quality” of two spaces, one with a very low ESI in only 10 percent of the area (perhaps in an area where desks are unlikely to be placed) and a high ESI elsewhere, and another space in which the minimum ESI is higher but the minimum obtains throughout 75 percent of the space, including the most likely work positions. Without comparative techniques, the value of ESI as a meaningful working tool for the designer is greatly reduced.

- There are only a few instruments currently available for the measurement of ESI. This makes such measurements costly and difficult to obtain. ESI-based design therefore must rely heavily on meaningless patterns of fixtures which have been prerated by manufacturers, or on similar fixtures in comparable arrangements. This precludes the use of irregular fixture layouts which might respond better to the nature and distribution of tasks within a space, as well as effectively prohibiting the use of room surfaces as major sources of indirect light since these, being unique, have no listed ESI ratings. In short, ESI criteria restrict the objectives of design as well as the means available to the designer. This is exactly the same problem which is inherent in the use of VCP minima as design standards.
Although the use of ESI footcandle criteria as design objectives or code requirements is by no means a panaces, the underlying concept of ESI—that the quality of light is an important determinant of how well we see—is a valuable one. Since the relationship between task visibility and illumination levels is quite complex, however, illumination-level criteria of any sort should only be used as cross-checks on a design, not as the sole means of evaluation. There are several other interchangeable qualitative criteria related to ESI which can also be used as cross-checks: among these are the Lighting Effectiveness Factor, or LEF, which measures how effective the footcandles produced by a particular lighting installation are in relation to those produced by spherical illumination, and the Contrast Rendition Factor, or CRF, which measures the capability of a lighting installation to render contrast between detail and background of a task, as compared with that of a uniformly illuminated spherical source. LEF is calculated by dividing ESI by the level of illumination on a task, while CRF depends on a number of variables such as the location and size of light sources in relation to the task and the nature of the light distribution in the space, which also involves reflected light from room surfaces. The CRF can be greater than 1.00 because certain lighting configurations deliver even less illumination from the mirror angle than an evenly illuminated spherical source.

Variations on the conventional design process

In the design of flexible modular buildings such as speculative office structures, another variation of the lumen method may be employed. After required illumination levels have been determined by the usual procedure, fixture selection may be based on the worst possible condition: a small office with dark walls. Once a fixture and spacing have been found which can deliver the required amount of light under these worst possible conditions, the design is repeated throughout the entire building, from glass line to core, often producing more than twice the specified levels of illumination in the larger spaces. No consideration is given to the fact that most of the small offices will probably be on the perimeter, where daylight is quite sufficient for many tasks much of the time, and that the executives who usually inhabit small offices are likely to prefer to use a desk lamp. No allowance is made for the fact that the area around the core is usually devoted exclusively to circulation, which requires only minimal lighting for orientation and physical safety.

Because initial rather than operating costs tend to dominate decisions in the design of speculative structures, switching hardware and equipment such as multilevel fluorescent ballasts are generally omitted, despite the fact that such equipment would make it possible to adjust the luminous environment to suit specific activities in specific locations, conserving energy and lowering operating costs while improving the luminous environment in the process.

The objectives of, justifications for, and fallacies behind the conventional process of lighting design

When the conventional design process and the conventional design methodologies are considered in an objective light, it is hardly
surprising that most conventional lighting designs fail to satisfy many of the needs of their users and do little to reinforce the specific character of an architectural design. How could they, when there was never any attempt to define the full range of needs; to ascertain the probable set of activities, their frequency, their probable locations, and priorities; to discover what furniture arrangements would be likely and what useful daylight contribution could be assumed? In the search for “quality,” there is rarely an attempt to articulate the desirable, only an attempt to avoid or mitigate the intolerable.

The long-established conventional design method, which has become standard practice largely due to the influence of the Illuminating Engineering Society, is based on a number of false premises:

1. That the exact light levels listed in recommended standards have a clear-cut relationship to health and/or productivity.
2. That failure to provide the recommended levels of illumination everywhere would result in complaints if not in catastrophe.
3. That the “most difficult tasks,” selected by IES committees as the standard on which quantitative recommendations are based, are in fact “common”.
4. That, whether common or not, they are sufficiently critical to warrant their use as a basis for general criteria.
5. That these “most difficult tasks” may take place anywhere and/or everywhere in any space.
6. That “quality” of the luminous environment is something to mention, but not something for which quantity should be sacrificed.

An expert panel assembled in 1967 by the author at Saratoga totally rejected these assumptions, which have been used by the lighting and power industries to justify a design process with an inherent bias toward ever-increasing and wasteful light levels. The conference resulted in the following conclusions:2

1. Low levels of illumination cause no organic eye damage. According to available medical evidence, insufficient illumination no more causes organic harm to the eyes than indistinct sound damages the ears. Considerations of comfort and performance would therefore set the criteria for lighting.
2. A comfortable, pleasing, relevant environment is as important as visual performance in determining the conditions of good lighting.
3. In place of the footcandle—commonly used, but inadequate, since it is a measure of only the quantity of light—the development of a performance index which correlates with both quality and quantity was recommended.

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4. Quality, rather than quantity, is the key to good lighting. A small improvement in the quality of the luminous environment produces better visual performance than a large increase in intensity. Increases in illumination operate under a law of diminishing returns.

5. Since visibility is satisfactory over a wide range of illumination, and since varied tasks, fluctuating daylight, and balance of quality and quantity of light all influence the determination of good lighting, rooms with uniform task distribution do not demand uniform lighting. If a major part of the area meets the intensity criteria during most frequent use, the lighting is likely to be satisfactory.

6. For rooms with nonuniform task distribution, the British practice of a moderate level of general lighting, combined with local supplementary light on work requiring performance of unusually difficult or specialized tasks, was endorsed in preference to systems of uniform lighting.

7. In addition, the current practice of specifying an all-time minimum lighting level for an entire room, based on the possibility that a critical visual task might be performed once in a while somewhere in that room, was rejected. Instead it was agreed that the probability of the occurrence of such a task and its duration should be realistically analyzed in advance and spaces should be lighted for critical visual tasks only if such tasks are unquestionably the predominant tasks to be performed in such a space.

But if many of the conventional premises are fallacious, what can be substituted for them as the grounds for more realistic, more productive design process and design objectives for the luminous environment? To answer this question, we must examine further the relationship between different qualities and quantities of light, the ability to see, productivity at work, and health.

Regardless of which specific criteria are utilized during the course of design, the basic objective must always be to provide optimal luminous conditions for as many as possible of the expected activities in a space and to satisfy biological information needs by using a moderate amount of light as effectively as possible. Unusually difficult or specialized visual tasks are best provided for by local lighting or by visual aids designed to suit the particular task in question. A generally high illumination level throughout a space makes sense only when the special tasks which demand those levels are also distributed throughout the space. The conventional justifications for the "more is better" approach to lighting design can no longer be defended—there
is no evidence which suggests that indefinitely increasing illumination levels lead to corresponding increases in comfort, productivity, or health. But let us examine briefly the limited evidence which is available concerning the relation between light levels, comfort, productivity, and health.

**Task visibility as a factor affecting productivity**

Let us consider for a minute the simplistic argument which is often advanced, “The brighter things are, the better we will be able to see them.” We know that this is not necessarily the case. While acknowledging the importance of adequate illumination levels as a factor affecting the quality of vision, the discussion in the preceding chapter brought out a number of other, equally important factors. How well we see is influenced by the experience and attention of the viewer, by the presence or absence of a positive focus or distraction, by the strength of competing visual noise, by the attributes of the background as they influence the ease of distinguishing figure from background, by constancies in our interpretation of visual stimuli, by the size and object characteristics of the subject of attention, by the directional qualities and color temperature of the light, by the pattern of sources, etc.

Is it true, then, that there is a clear link between increasing the quantity of illumination, higher task visibility, and improved productivity? There is little evidence which suggests that increased illumination levels alone lead to increased productivity, unless the initial levels were grossly and obviously inadequate. Increasing task visibility only affects productivity positively when task visibility is a limiting factor, which is rarely the case today.

We know that familiarity with the task is a factor—that unfamiliar tasks require more light and a better control of focus and distraction. A good activity environment creates a natural focus on the task, while providing alternative foci which may serve as visual rest centers during periods of inactivity or relaxation. All these factors play a role in determining productivity, yet they are very difficult to incorporate meaningfully into testing procedures which evaluate the effect on productivity of changing the luminous environment.

When increased light levels have been accompanied by increases in productivity, it seems that the productivity increase can be attributed just as easily to a perceptible improvement in the quality of the overall luminous environment as to the increased lighting levels.

I know of no experiments which have been performed which, in analyzing typical school and office activities, distinguish successfully between the influence of task visibility and the influence of other factors such as attitude, mood, mental speed, comfort, motor limitation, concentration, etc., as determinants of productivity. The exception may be in the task of viewing chalkboards, when low light levels combined with veiling reflections and fixed seat locations sometimes make it impossible to read the writing on the board. However, very large increases in light levels must be made if they are to be as effective as a minor change in other, related physical conditions, such as decreasing viewing distance, increasing the size of the writing, eliminating glare sources, or improving the directional qualities of the light.

As lighting levels across the country have been reduced in
response to the energy crisis, there has been substantial evidence of *increases* in comfort and productivity as a result of the *decrease* in light levels. People are finding out for themselves that if they turn off their lights (at least, some of their lights) they can see just as well—if not better—and more comfortably.

In industrial work, where productivity is obviously affected by visibility, especially in critical tasks such as electronics assembly, watchmaking, and product inspection, optical aids or specialized local lighting fixtures are usually used to increase the perceived size of the task or to highlight its essential characteristics by controlling the direction, color, polarization, focus, and contrast of the illumination. These demonstrate clearly the importance of factors other than simple quantity which affect the quality of task performance. It is far more effective to increase light levels in a small "task" area than to raise levels indiscriminately by the same amount throughout a space.

**Motivation and productivity**

While several instances of increased productivity due to increased task visibility have been reported, these findings are somewhat suspect in that the researchers usually fail to perform at the same time essential control experiments such as testing the *effect* of reducing light levels. The importance of such control experiments was demonstrated conclusively by the Hawthorne experiments performed by Professor Elton Mayo of the Harvard Graduate School of Business in the late 1920s. In these experiments, Mayo measured the performance of workers under various conditions, and discovered that while productivity increased with increased lighting, it continued to increase when light levels were subsequently reduced. Mayo’s studies do not prove that increased lighting cannot improve productivity, but they do demonstrate that productivity increases may be attributable to the feeling that management cares about working conditions in general, as evidenced by their alteration of the luminous environment. The Hawthorne studies and work by Adams in Britain seem to suggest that *any* change indicating attention paid to workers by management may produce an attitude change in workers which may subsequently affect productivity in a positive way. I would hypothesize that task performance increases are more frequently brought about by improvements in the overall luminous environment which satisfy biological information needs, producing feelings of comfort and pleasure, than by improvements restricted to increasing task visibility. Thus, investment in better colors, carpeting, or a more pleasant environment by using modest levels of well-designed indirect or local lighting may well increase productivity more than an equal investment in increasing footcandle levels.

**Comfort and productivity**

In order to understand the relationship between visual comfort and productivity, we need to remember the discussion of “What Do We Look At?” Even in factory production work, the eyes are not glued continuously to the task at hand. They are constantly scanning the environment for the information which one consciously wants or unconsciously needs to know. Therefore, elements such as distracting foci, patterns of bright sources, and glare have a bearing on comfort and productivity. User surveys by Manning and Wells and Langdon

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3 These experiments, conducted at the Hawthorne Plant of the Western Electric Company by Professor Mayo, are reported in detail in F. J. Roethlisberger and W. J. Dickson, *Management and the Worker*, Harvard, Cambridge, Mass., 1966.


in British office buildings show almost no complaints about the quantity of light (although the measured levels were generally below those recommended by the British Illuminating Engineering Society and a mere fraction of the levels required by current United States practice). On the contrary, the complaints which the researchers noted were mostly concerned with discomfort glare—typically a symptom of photometric glut rather than famine.

**Discomfort glare**

The volume of valuable work done by Hopkinson and others on discomfort glare suggests a stronger relationship between feelings of comfort and the overall design of an environment than between comfort and the absolute quantity of light in it.

Traditional lighting research has tried to evaluate the relative comfort and discomfort of various environments by attempting to define the borderline between comfort and discomfort in terms of abstract mathematical indices. The basis of this rather negativistic approach is that if one could define the limits of discomfort, and then surpass them, one would have comfortable spaces. The conceptual poverty of the idea is rather disappointing; in effect, it says that the way to design good spaces is to avoid the positively objectionable. That seems a rather unambitious objective! Lighting technology has made it possible for us to go far beyond the borderline of discomfort, and lighting expenditures are sufficiently high that we ought to try for something a little better. In formulating new criteria for the luminous environment, we should concentrate on defining situations which give maximum comfort and pleasure, rather than looking for arbitrary borderlines which define the edge of pain. We should be able to design environments consistently which are so far from the threshold of discomfort that the tolerance of individuals should be unimportant. If we are still arguing over the threshold, we have not yet addressed the real problem.

After extensive study, Hopkinson concluded that:

Discomfort due to glare is not only a subject of complaint, but it is reasonable to suppose that it affects the general efficiency of the worker as a result of a build-up of annoyance, frustration and irritation in people who are subject over a long time to what amounts to a minor emotional affront. It has been shown, however, that the effect on human "efficiency" is very difficult to measure, in much the same way as the effect of noise in a building is more important because of the distress which it causes than because of the actual reduction of the efficiency of working.  

**Illumination levels and physical safety**

If we cannot justify high footcandle requirements on the grounds that they contribute positively to environmental comfort, motivation, or productivity, can we still justify them on the grounds of physical safety? We know that lighting for orientation and physical security satisfies an important biological need, but how much light is actually required to satisfy this need?

In the normal course of lighting design, considerations of physical safety play a minor role, because almost any lighting which suffices for other purposes will be adequate to assure physical safety. In good design practice, spaces express their use clearly and consistently: materials,
forms, focal points, junctions, stairs, and other circulation elements are well-defined and comprehensible. Under such conditions, it is very unlikely that a safety hazard will exist except when misdirected or improperly shielded sources create disability glare conditions. Safety deserves particular consideration in interior situations where very low light levels are consciously sought, such as nightclubs, and at potentially dangerous exterior locations such as stairs, level changes, or on rough terrain. At night, a minimum of 1/10 footcandle from any direction is normally sufficient to prevent a person from stumbling or falling, unless the visual information is misleading or faulty—for instance, if there are confusing shadows—or if disability glare conditions exist. The average horizontal illumination level, which is the conventional method for specifying minimum exterior light levels for safety, is not as important as the minimum illumination level from any direction, especially at critical points. Levels as low as 1/10 footcandle have been measured by the author in a number of well-known buildings and streets, and the users of these spaces showed no signs that they found either orientation or movement to be a problem.

One dangerous situation which should be avoided whenever possible involves disability glare from strong daylight sources such as a window at the end of a long corridor. This effect is aggravated if the corridor is finished with dark or specular materials, which increase the contrast between the corridor surfaces and the window. In such situations the brightness balance should be improved, either by increasing illumination of the corridor surfaces, increasing the reflectance of the corridor surfaces, or by controlling the source, direction, and distribution of daylight. The best solution consists of light-colored walls and ceiling, well illuminated. It should always be remembered that even outdoors, where the overall brightness balance of full daylight is fairly good, a dangerous situation will exist whenever one’s line of sight must be toward the sun.

**Illumination levels and health**

Eye health is sometimes advanced as a justification for high levels of illumination, with the implication that low levels of illumination will damage the eyes themselves. Dr. David G. Cogan, director of Ophthalmology of the Massachusetts Eye and Ear Infirmary, states conclusively that “There is no generally acceptable evidence that poor illumination results in organic harm to the eyes, any more than indistinct sounds damage the ears or foul smells damage the nose.”

Eye strain may indeed result from the effort of trying to overcome a difficult seeing condition, but eye strain is only a temporary discomfort and does no damage to the eye. The need for wearing glasses arises only from organic causes, not from inadequate illumination levels. Eye strain can be caused by glare—too much light of the wrong kind—as well as by inadequate illumination, but eye damage can only be caused by overexposure to light.

In 1976 William Lam Associates was commissioned by the Canadian Federal Government to conduct an assessment of the effects of light on human health. During this project our staff reviewed the existing literature and interviewed many experts in the field, and were unable to find any scientific evidence whatsoever that low light levels had any negative effects on human health.
Summary

Most of the conventional arguments advanced in support of continuously increasing levels of illumination seem untenable, once levels of 10 to 20 footcandles have been achieved. Improvements in task visibility will only call forth increases in productivity if task visibility is a major constraint on productivity at the outset. Under most circumstances comfort and motivation play equally if not more important roles in determining productivity. So far as we can tell, low levels of illumination have nothing to do with general health, as long as they are adequate for safety. The arrangement of the light sources is often more important for safety than the actual levels provided, since the arrangement can indicate movement patterns and highlight potential danger points, or it can be misleading, or it can create glare conditions, interfering with the perception of information required for orientation and safety.

There is little or no conclusive evidence which relates comfort to high levels of illumination. Most work on comfort has been concerned with the measurement and analysis of disability and discomfort glare conditions. Yet we all know from personal experience that feelings of comfort are affected by what we look at—by everything in the visual field—even in factory work. Therefore, the overall luminous environment must be regarded as the critical, and in many spaces the only, determinant of the sensation of visual comfort.

We are comfortable when the objects we see give us the information we consciously want or instinctively need to know. We are comfortable when the things we see please or interest or reassure us, and when the things we do not want to see are hidden from view. The key factor in assessing the qualities of a specific luminous environment is relevance; that is relevance of the available visual information to the activity and biological needs of the users.

Therefore, in setting new criteria for design, we need to eliminate negative elements such as sources of discomfort glare, distracting elements, and situations which by comparison (conscious or unconscious) will be perceived as gloomy. But in addition, we need to accentuate the positive aspects of the luminous environment, by providing lighting natural and relevant to activities and expectations, giving orientation clues, creating a focus on activities, and providing interesting visual rest centers, without simultaneously introducing glare or unwanted distractions.

Whenever a cheerful and bright space is expected during the day (lobbies, classroom, office, lab, library, etc.), large areas of walls or ceilings must be illuminated to balance daytime brightness (either visible simultaneously or remembered). Sufficient illumination of these surfaces to balance (but not necessarily equal) daylight levels will generally result in sufficient illumination for casual activities throughout most of the room. Such “environmental lighting” plus supplementary local illumination, controlled by the user for more demanding activities or in darker portions of the room (e.g., in study carrels shadowed by enclosure), is likely to produce the greatest comfort both for those using the local lighting and for others in the space—and at lowest cost. High levels of illumination for an entire space are justifiable only if critical tasks appear throughout the space and if the geometry of lighting, optimal for one occupant, is not detrimental to others in the form of glare.
A new process of design

Anyone who understands the perception process, acknowledges the existence of biological needs for environmental information, and recognizes the importance of optimum lighting geometries and qualities, will agree that the best, most relevant luminous environments are those which have been tailored to the unique requirements of the activities which they house, without compromising the general qualities required for the satisfaction of biological needs. The standard design process fostered by the IES which was described at the beginning of this chapter is obviously unsuited to produce such a high-quality fit between needs and luminous environment, nor was it ever intended to produce such a fit. A new, more integrated and comprehensive design process will be required if we are to make the creation of successful, relevant spaces the real objective of design. A closer cooperation will be required among all the members of the design team at all stages of the design process, with more emphasis on the formulation and achievement of perceptual rather than numerical objectives.

Hopefully, it is indicative of a new positive trend that in setting performance criteria for luminous environments, the advisory committee to the State University Construction Fund of New York agreed that the development and implementation of a new design process would be far more important than any numerical criteria, and recommended a design process which would bring designers and client agency together to go through the logical steps of problem definition and schematic design prior to the selection of any specific fixtures or the computation of illumination levels. The new design process recommended in the SUCF report\(^{13}\) begins with the listing of activities, subactivities, biological needs, and their relative priorities, rather than with the selection of hardware or the blind listing of minimum levels of illumination to be achieved.

A lighting concept should be derived from the set of programmed activities and biological information needs, so that the definition of the luminous environment will complement and reinforce the general architectural concepts; then— and only then— should details and hardware be selected to execute the concept. This is the diametric opposite of the typical “engineered” approach, which starts with the selection of light fixtures and then, taking them as givens, places them in patterns to achieve predetermined illumination levels.

In theory, it might seem that detailed programming of activities and corresponding lighting needs for each space would logically lead to buildings consisting of sets of individually designed spaces, each perfect for its programmed set of activities. In practice, however, several factors make such an eclectic “tight-fit” solution unrealistic and undesirable in most buildings. Regardless of specific activity needs, people have important biological needs for orientation, order, and continuity, which demand that there should be common denominators and reference points in related spaces. Satisfaction of these important needs constrains the freedom of the designer to respond solely to the activity needs of each space. In addition, very few spaces are used for only a single purpose—one activity which would define one optimal lighting configuration. In most spaces, a number of activities take place, and an appropriate luminous environment must be either highly complex, with localized effects, or

flexible, with a range of possible effects controlled by combinations of
switching and dimming.

Only when the illumination needs of a project are truly
specialized and localized, as they are in a performing arts center, for
instance, are the added time and expense required by a totally ad hoc
approach justifiable. Very specialized, focused activities such as
theater demand equally specialized luminous environments. Multiple
activities which are not localized, on the other hand, call for flexible
environments which are sufficiently neutral and adaptable so that the
users can create foci on specific activities as they desire.

With the rare exception of certain special-use spaces, the
illumination required to provide for most biological and activity needs
can best be provided by the simple expedient of illuminating room
surfaces and furnishings, which in turn illuminate the work surfaces.
This is the condition one usually seeks when working out of doors:
not the direct light of the sun, but rather the even illumination of the
sky vault, supplemented by light reflected from the surrounding
landscape.

In an interior space, the visible surfaces and the way in which
they are illuminated are the design. They define space and its
perceived meaning. They convey the intent of the designer or betray
the lack thereof. Every element of a successful, relevant visual
environment—activity areas, equipment, circulation, structure,
mechanical services, etc.—should be carefully and clearly interrelated,
articulated, and defined. Special activity areas may call for special
lighting solutions. This approach produces easily comprehensible
complexity and consistency without dullness, because elements which
one expects to be consistent are in fact treated consistently, while
those which are really different are expressed as such.

During the phase of concept development, the lighting designer
should probe the possibilities with other members of the team to see
whether alternative structural or mechanical systems are feasible
which, in combination with a lighting proposal, would lead to a better
luminous environment. Constraints of partitioning flexibility, acoustic
separation, energy conservation, and cost must all be considered, as
well as many other factors, but these should never be taken as a priori
givens which cannot be altered in the search for a better overall
solution.

Almost every localized design decision can be expected to have
extensive repercussions on the rest of the design. For instance, the
limited ceiling height which normally is inevitable with a
disorganized two-way layout of air ducts dictates the use of recessed
downlights which must be closely spaced to achieve an even
distribution of light at the work plane. An increase in ceiling height,
which may be possible either by coordinating the ductwork with
structural elements or by consolidating bulky service elements into
discrete service channels, can dramatically increase the lighting
options. As another example, the selection of red brick walls and a
dark wood ceiling for an office building practically guarantees
inefficient lighting and uncomfortable, gloomy spaces unless light-
colored furniture is introduced and the principal work lighting is
localized to create positive foci. The advantages of having at least
some of the walls in small rooms light-colored should always be
considered—in such rooms, the walls rather than the ceiling tend to
dominate the field of vision and it is the brightness of the walls which
largely determines whether the space feels cheerful or gloomy. In large spaces with low ceilings, light walls make less of a contribution to the perception of a bright, cheerful space because they occupy less of the visual field. In such spaces, therefore, darker wall materials have a less negative effect than in smaller, higher spaces.

Every design element, from structure to finishes, affects the quality of the luminous environment, and it is the responsibility of every member of the design team to make decisions keeping this in mind. This requires a great deal of communication, and a common awareness of the principles of perception involved; of the effect of varying wall, ceiling, and floor reflectances upon the efficiency, light distribution, and perceived brightness of various lighting systems; and of the pros and cons of various light sources and light-control media—including the building itself. All design options must be evaluated in terms of the detailed objectives for the luminous environment.

The responses of the lighting designer to various design proposals should never be a simple "yes" or "no"; rather, recommendations and criticism should be phrased in terms of options and tradeoffs, seeking always to maximize the opportunities inherent in an architectural design. For such purposes, the author has found various simple graphic presentation techniques helpful in communicating options and alternatives to those members of the design team who may be unable to visualize different luminous environments when described in numerical or verbal terms. Although a full discussion of such techniques is not possible within the scope of this book, readers may find useful the samples of presentation material and design tools presented in the context of the case studies which form the second half of this book.

Alternatives to the conventional design process

The case studies which follow illustrate the application of the principles of perception to the integration of architectural and lighting design. The various design processes employed by the author are explained, and examples of written programs, schematic diagrams, models, and mock-ups have been included so that the reader can see the actual working tools employed by the design team.

The kind of integrated design process required to produce good luminous environments is understandably more complex than one which aims only at the achievement of minimum footcandle levels, and since not all elements of the design process and not all process aids are used in every project, they will be discussed here. Ideally, all steps and aids would have been used in each project presented, but differences in timing, complexity, personnel, and design budget make that impossible. Design process aids serve to facilitate and deepen the communication between all parties involved. Here, despite the dicta of Mies, more is always more.

The chart printed inside the back cover of this book presents in summary form the design processes and process aids which were used in the case study projects, as well as indicating the formgiving effects of lighting considerations in each case.

Lectures and field trips

It has been my experience that most clients and members of design teams initially have a total misconception about lighting, in terms of
both objectives and alternatives. Even while paying lip service to quality, they find it difficult to abandon traditional footcandle levels as the real objective of design. A lecture or field trip which brings home to all project personnel the principles of perception, the relevance of quality versus quantity, and what can be achieved, will always pay off in the end. If this is not done, the necessary reeducation must be done on an individual basis, in fits and spurts throughout the duration of the project.

A lecture on the principles of perception and lighting as formgivers for architecture can be supplemented with a field trip to illustrate specific principles and to show what is possible and what should be avoided. Any field trip will be much more effective if preceded by a formal lecture or discussion which teaches the participants what to look for and gives them a common terminology for further discussion of objectives and alternatives. Examples of the principles of perception can be found anywhere, once one knows how to look for them. Nevertheless, field trips are most productive when someone with considerable familiarity with perception is present to give guidance in what to observe and to explain the needs and processes involved.

Field trips can be particularly valuable when the design team is proposing or exploring unfamiliar types of luminous environments. Those without design training may be unable to visualize unfamiliar types of environments, and therefore may be afraid to accept and support them. A brief visit to an outstanding example of the type of environment under consideration will do more than any amount of persuasive argument in convincing all members of the design team of the importance of total synthesis and coordination in the visual environment. Once they have been shown what is in fact possible and more important, desirable, even the most recalcitrant people have been known to cooperate rather than resist in making the design tradeoffs required to achieve a good luminous environment. The principal objective of a field trip is to give everyone involved in the design process an opportunity to put himself in the place of the future users of the space, so that each specialist will apply his or her talents to the creation of an optimum environment rather than to a narrow-minded defense of his or her particular specialty, preconceptions, and habits of professional practice.

All persons who will play important decision-making roles should participate in the introductory lecture and field trip so that an early and irrevocable consensus is established as to the nature of the environment which will be the goal of the ensuing design process. Failure to include an important client or a key member of the professional team in these early phases of the design process has torpedoed a number of very promising projects on which the author has worked. A lack of understanding on the part of one important person who does not share the team's common frame of reference can throw an insurmountable roadblock into the path of design development. When this happens, a field trip to reestablish consensus should always be considered, since the cost of the field trip will certainly be insignificant compared with the price of delays, compromises, and backtracking in the design process.
Programming

Once the actual process of design begins, the programming stage is obviously critical. Rather than producing a list of footcandle levels to be achieved in the various types of rooms, the design team should list in the program the activities and biological needs, as well as their implications for the luminous environment, for each space or class of spaces weighted by importance, frequency, sequence, locality, etc. This type of listing can be used to generate performance criteria for each luminous environment, detailing its required characteristics and degree of flexibility. A suitable hardware system can then be selected on the basis of these criteria. Such a process can be extremely tedious and time-consuming. However, the exercise of having gone through such a systematic, detailed process of conceptualization once is invaluable. An experienced designer goes through the process almost unconsciously in the design of every space, and is able to sum up the activities, the biological needs, and their respective environmental implications in simple summary statements of objectives and design concepts. A verbal summarization of a detailed activities program and its corresponding design objectives is much more valuable and productive than any amount of simplistic numerical criteria. There is a great difference between summarizing a complex program in words and the unfortunate general practice of singling out one aspect of one “most difficult” task as the basis for lighting criteria. The verbal program statement for the Washington subway system presented here is an excellent example of this kind of summary.

VERBAL PROGRAM STATEMENT FOR THE LUMINOUS ENVIRONMENT OF THE WASHINGTON SUBWAY SYSTEM

DESIGN OBJECTIVES

The lighting design of the Washington Metropolitan Area Rapid Transit System has been developed as an integral part of the total architectural concept with the purpose of creating an image consistent with the concepts of optimum comfort and pleasantness. Comfort implies freedom from visual noise such as disorderly, irrelevant patterns of overly bright lighting fixtures. The provision of a restful background maximizes the impact of positive experiences such as focusing on objects of interest: signs or light patterns which aid orientation and tell us facts which we want to know, consciously or unconsciously. A background free from visual noise also contributes to the pure pleasure of just looking around.

Orientation

Patterns of lights and illuminated signs should be designed to improve the clarity of circulation routes, structural elements, and sequences of architectural spaces. If the design is carried out well the passenger should unconsciously receive all the visual information needed to tell him where he is and how to reach his destination.

It is important to realize that passenger safety may be endangered less by excessively low lighting levels than by confusing circulation patterns, especially under crowded conditions. Special types of lighting will serve the dual purposes of enhancing the appearance of the spaces and improving safety and traffic flow.

Entrance Areas

The important functional elements marking the entrances to the system should, if possible, be standardized and be given a strong lighting expression. The combination of a distinctive symbol, ticket office kiosk, and stairway should be instantly recognizable, not only in the setting of an isolated park, but also against a brightly-lit commercial background. The image would be strengthened if all lighting in the immediate area were to come directly from these elements, without the daytime or nighttime clutter of other lighting standards and fixtures.

The system symbol should be distinctive wherever seen and should be the strongest design element in its immediate vicinity, thereby attracting traffic to the turnstiles. An illuminated station name, map and symbol will strengthen this image, as will a pattern of lamps which make the ticket office a chandelier, setting the office apart from the signs and advertising. The ceiling of the office should read as a bright plane of distinctive shape (i.e., round).

The stair-escalator enclosure if properly highlighted can also contribute to identifying the system.
From Entrance to Platform

After passing through the turnstiles, passengers should be able to find the desired platform without confusion. In the passageways leading to the platforms, therefore, maps and directional signs should be visually dominant. Highlighted advertising and art would reduce monotony along the way during the off-hours, but the reassuring directional signs should always remain predominant.

At the approaches to the platforms, blinking signs indicating the imminent arrival of a specific train might tell the passenger whether to rush or to saunter, while adding to the kinetic quality of the experience.

The Platform

At the selected platform one should find the atmosphere relaxing, free from glare and obtrusive patterns of lighting hardware. The architecture of the space should be revealed, but not so strongly that one cannot turn away. Murals and advertising posters should supplement the visual interest of the architectural details.

The platform edges should be clearly visible, perhaps emphasized by white edging. (To attempt to emphasize the edge with a glaring overhead light fixture would call more attention to the fixture than to the edge, defeating the purpose.) The approach of the train will be heralded audibly, of course, but the arrival would be dramatized and passengers would be alerted for rapid boarding if the platform edge and tracks were brilliantly highlighted momentarily as the train made its grand entrance and took over the stage.

The Train

Achieving a comfortable visual environment in the train itself requires the same approach as in the stations: bathing of light over the wall and ceiling surfaces, no glare, no annoying reflections from shiny ceiling surfaces, all contributing to a lighting quality equal to that of the best jet aircraft. There should be enough light to read by, but not so much as to destroy privacy. Remember the close quarters and the face-to-face seating.

The lighted maps should be dominant. One likes to be sure of the stops. The route one is on should be underscored, and the approaching station marked with a bright light. If feasible economically, perhaps the lighted spot could move along the route, which would be both fun and relaxing to watch, alleviating the need to peer out of the window at each station—often a difficult task in a crowded train.

Advertising, if required economically, should display lighted information against dark backgrounds if backlit. Spaces between the advertisements should be masked with opaque panels. Otherwise, the car would become too bright and glaring, with the advertisements dominant rather than incidental background messages. An alternate means of advertising without dominance would be to use opaque advertising panels seen under light reflected from the car surfaces.

Illuminated destination-identification panels at the front of each car and over each door would be desirable for the boarding passengers.

UNDERGROUND STATIONS

To counteract the effect of subterranean gloom in the stations during daylight hours, the spaces must appear bright, cheerful, and airy. Such an atmosphere can be achieved by brightly illuminating walls and ceiling surfaces. (Although a high level of light directed to the floor or walls would produce adequate brightness on a white ceiling, the ceiling surfaces of the underground stations will be of unpainted concrete, and even high levels of light on the floor would not dispel the feeling of gloom which would strike the passenger entering a seemingly dark station interior from the bright sunshine outdoors.) The most efficient way to achieve bright walls and ceilings is to light them directly. Whenever it is appropriate therefore, an indirect lighting system shall be integrated with the structure and furnishings in such a way as to conceal the light sources themselves from view. Not only will such an indirect system be cheaper, in terms of both first cost and maintenance cost, than separate direct fixtures lighting the floor surfaces, but it will also minimize visual noise from discordant lighting patterns—a common problem in most subway stations. Wherever lighted graphics, kiosks, and direct light sources are used as aids for orientation or for special decorative effects, these effects will be enhanced by the general indirect system, rather than drowned out by it. At night, when the rider’s frame of reference and adaptation level is to the dark night sky and to the relatively dim street lighting of the outdoor night environment, the brightness levels of the interior station surfaces can be reduced to a fraction of daytime levels without making the stations seem dark. While maximum brightness on walls and ceiling is no longer instinctively demanded at night, bright enclosing surfaces are still desirable in subterranean spaces to minimize feelings of claustrophobia. If the lighting is harsh or glaring, the fault will be much more apparent at night.

If these objectives of bright, cheerful spaces are achieved, there will automatically be enough light to see by.

SURFACE STATIONS

Consistent with the overall objectives stated above, the lighting for the surface stations shall be such that the shape and extent of the platform and canopies are defined without the light sources becoming either overbearing or inconsistent with the architectural elements. Because of the limited area of enveloping architectural surfaces around the platforms of the surface stations, direct sources shall be used wherever possible and the types of light sources used should provide the maximum feeling of ambient brightness together with a sense of activity and cheerfulness, by creating a chandelier-type sparkle. Where appropriate, the disposition of an array of fixtures should be such that it is an aid to orientation. Disturbance of the neighborhood through glare and unpleasant light spillage shall be avoided.

EXTERIOR SPACES

The lighting of exterior spaces shall be so organized that pedestrians and drivers alike are made aware of the organization of the area by providing for the maximum clarity and amount of visual information, and also for the safety and amenity of its users. The disposition of the lighting system for the supporting facilities such as the car parks, bus loading areas, etc., shall not cause annoyance to the neighborhood by glare and unpleasant light spillage; but rather should be so organized that it is a natural lead-in to the station mezzanine.
Schematic design: diagrams and models

Once the programming stage is well in hand and the actual physical form of a project begins to take shape, options can be explored through the use of schematic diagrams. We use freehand color-coded plans for this purpose and, wherever possible, building sections and details are always diagrammed to show the location of light sources and the incidence of the light which they produce. Fig. 99 is an example of this sort of conceptual diagramming. Such diagrams are particularly useful for communicating why the reflections of certain surfaces—particularly those which will serve as sources of indirect light or which form major elements in the visual field—are more critical than others. As the design develops, the freehand color-coded diagrams can be transferred to standardized tape-and-symbol codes on sepias of the architectural drawings, which can be more easily reproduced for distribution to the various members of the design team. Samples of this sort of symbolic lighting plan are presented in Figs. A3–2 and A3–3. To represent individual fixtures of different types we use precut adhesive press-on symbols (developed for use in the design of printed circuits).

As an example of the sort of freehand schematic diagrams which are used for concept exploration and design development, a series of the diagrammatic sections which were used to develop the lighting for the underground stations of the Washington subway system is presented in Fig. 100. Since the plan of the tubular stations was so simple and consistent, and could be described in words, only section diagrams were required for this particular project. Objectives of the conceptual program for the WMATA stations included illumination of the ceiling vault to minimize feelings of claustrophobia, the minimization of visual noise, and the provision of maximum guidance for orientation and circulation. The use of schematic diagrams enabled the design team to explore the implications of a number of alternative designs and to converge on the best combination in a very short period of time.

Schematic tools can be developed as the need arises. Unlike the design of the underground stations, the design for the surface stations of the Washington transit system obviously had to be developed both in section and plan. Having developed concepts which worked for the first few sites, the designers were still faced with the problem of applying those concepts to 33 sites which vary substantially in terms of terrain, site size and shape, the amount of parking provided, the layout and configuration of access roads, etc. A hierarchy of standard luminaires and pole heights had been worked out to provide maximum orientation information: paired globes at entrances, low single clear globes for pedestrian pathways, multiple sources in simple rectangular hoods on higher poles oriented away from surrounding residential areas to illuminate the parking lots, etc. The team used various types of map pins stuck in the site plans to represent the different types of luminaire as a means of exploring the legibility of the resulting patterns in terms of the optical guidance which they would provide for the users, and to ensure that the various designs for the different stations were mutually consistent. For each type of luminaire, the light distribution at ground level was calculated using a computer program and the resulting distributions were transferred as shaded patterns onto transparent film. These reproducible film
templates were overlaid on the site plans by the designers to explore options for the design of each station and to determine fixture spacing, eliminating much tedious calculation. Examples of the template and map-pin techniques are presented in Figs. H6–6, 20, 21, and 22.

**Illuminated models and mock-ups**

Illuminated models and mock-ups are extremely valuable for exploring design concepts, communicating them to clients, and making measurements of light levels and distributions. Unfortunately, many designers use models only for presentation of the finished design to the client. Such models are usually too expensive and are executed too late in the design process to make them of any value in actually refining the design or exploring alternatives. Inexpensive study models are one of the most economical means of generating productive discussion within the design team itself, especially when some team members may be trained to think only in terms of numbers and not in terms of visual relationships.

There are various types of useful lighting models. Room models (Figs. G2–5, 6) enable one to visualize and measure the luminous environment in a room which is to be illuminated by daylight, by artificial sources, or by a combination of both. The materials of which the model is built should have the same reflectances as the materials to be used in the actual design. The scale of the model should be whatever is convenient to build and to look at.

Finding light sources of the proper scale for a model may be difficult, but this is rarely a critical problem since it is always possible to make allowances for scale inaccuracies when viewing the model or making quantitative measurements. For example, when viewing the illuminated models of the Washington subway stations (Figs. 101–103; see also Case Study H6), we assumed that in the real stations the brightness gradients in the immediate vicinity of the sources would not include the hot spot which could not be avoided in the model because of the exaggerated scale size of the neon tubes used and the impossibility of achieving in a model the same quality of control over light distribution which can be expected from a full-size fixture. The scale error was minimized in this instance by taping out part of the oversize lamp, but it was still noticeable.

In making quantitative measurements, the following assumption should be made: in the model, the ratios of generated light (expressed in lumens per real square foot of model floor area) to measured illumination (in footcandles) and to brightness (in footlamberts) will be the same as the corresponding ratios in the full-size space. For instance, if 500 lumens in a 2-square-foot model (250 lumens per square foot) produce an average horizontal illumination of 100 footcandles on the floor and an average wall brightness of 75 footlamberts, then a 200-square-foot room with the same proportions and surface reflectances would require $500 \times 100 = 50,000$ lumens (250 lumens per square foot) introduced in an identical manner to produce identical average measurements.

If a model is placed outdoors under the real sky, assuming that correct reflectances have been used for all visible surfaces and correct transmission properties have been used for all windows and skylights, no scale corrections need to be made in the evaluation of
a daylighting design, because in a scale model the reduction in the area illuminated is offset by the simultaneous and proportional reduction of the size of the daylight sources (the openings in the model).

Room models may be evaluated most conveniently and realistically via the medium of projected color slides, which minimizes visual noise from surrounding, out-of-scale elements in the visual environment, thereby maximizing the perceptual credibility of the model scene.

Even though a model may have been built only to evaluate a lighting effect or to make measurements, it is essential that it be furnished as realistically as possible if it will be shown to observers or clients who are not designers. Because visual perception is a gestalt process, a poorly executed or furnished model can destroy the credibility of both the model and the design team in the eyes of the client.

**Component models**

When a design involves repetitive elements such as ceiling coffers which are to be used as indirect light fixtures, a component model may be useful in demonstrating the appearance of a single module and can be used to generate quantitative data concerning light distribution characteristics and efficiencies which can be extrapolated for various larger spaces. Such models can be executed in very little time, and the subsequent extrapolations are not difficult. To simulate the appearance of larger areas, the component model can be placed between mirrors.

Engineers frequently oppose design proposals involving integrated lighting systems, in which the “luminaire” is a system of ceiling coffers and room surfaces (so that the room itself acts as a light fixture) because they are unable to calculate the illumination levels which such a system will produce. There are indeed no cookbook formulas and tables which can be consulted to determine the performance of such a system, but illuminated models can be built and measured to find the required data. One must remember, though, that the exact quantity of illumination is relatively unimportant, compared with the appearance and relevance of the final luminous environment.

When lighting is to be integrated into architectural elements such as walls, handrails, kiosks, bollards, or furnishings, component models make it easy to test and evaluate the concept and to refine the details. Illuminated models of hardware can also be built to evaluate the appearance, efficiency, and light distribution characteristics of novel fixture designs. These models can be built from such simple materials as reflective mylar, cardboard, and tracing paper, combined with commercially available fixtures and lamps (for an example, see Fig. C5–12).

**Renderings**

The rendering has always been an important graphic tool of the designer, but most contemporary renderings do not accurately convey what the luminous environment will actually look like. With some care and thought about where the light will come from and how it will affect the relative brightness of the various visible surfaces, a realistic
rendering is not too difficult to produce and can be almost as effective as model photographs in forecasting the actual appearance of a project as built. Compare Figs. 104 and 101, a rendering and a model photograph of one of the stations in the Washington subway system.

Renderings have the additional advantage that proposed furnishings can usually be more easily and convincingly sketched than modeled. Since renderings are produced for other purposes, they ought to be used to illustrate the planned lighting scheme as well.

Mock-ups

When no similar design exists, or when no comparable examples are available within a convenient distance for all involved in final decisions, a room mock-up can be invaluable, even though it may be necessary to substitute plywood for concrete, etc. On a major project where hundreds of thousands of dollars may have been invested in developing a design, the price tag of a well-detailed mock-up or of a field trip clear across the country will be insignificant compared to the costs of a major redesign or of having to start over again from scratch.

Because all perceptions are holistic, mock-ups even more than models must be realistically furnished as well as technically accurate in lighting details. They must be visually isolated from adjacent areas, particularly if these areas are unrelated to the design under study; otherwise, those who visit and evaluate the mock-up will be unable to ignore these unrelated and distracting elements in the visual field. When unfurnished and empty, a mock-up just like an actual building usually appears dull and gloomy, because the viewer subconsciously expects an interior environment to be complete and furnished, and frustration of this unconscious expectancy generates a negative response. Two identical spaces with identical lighting, one empty and one fully furnished, will elicit quite different responses from the same observers. Furnishings provide natural foci, obviously intentional points of interest, without which the eye roams about, seeking something else to look at that is worthwhile. Without normal furnishings and decorative elements, the attention of the viewer is drawn to features which in a furnished room would go unnoticed, such as uneven illumination of a wall, air grilles, minor defects in workmanship, etc. Omission of furnishings from a mock-up can easily lead to a totally erroneous and misleading negative evaluation.

Though the cost of a mock-up can often be justified for lighting purposes alone, they are valuable for many other purposes as well: the testing of unconventional air-distribution systems, the evaluation of the visual qualities of structural forms and surface finishes, detailing, etc. There are always many unexpected benefits from building full-scale room lighting mock-ups.

Evaluation of mock-ups must be done with great care so that any variances from reality are made explicit to all concerned. For instance, measurements of illumination levels made in a small, enclosed room mock-up, in which reflected light from the walls is an important component of the measured levels, will not give an accurate prediction of light levels in a space of different proportions or with different reflectances even though the lighting scheme may be identical. Though this should be obvious to anyone who understands the principles of perception and interreflection involved, far too often mock-ups are
viewed, measured, and evaluated without proper explanation of the differences between mock-up and reality.

The author has experienced all too many occasions when improper use of a mock-up led to serious misjudgment: library stack lighting evaluated with only a 4-foot length illuminated; rooms evaluated for pleasantness of lighting when unfinished, unfurnished, windowless, and with the temperature at 100° F; an on-site mock-up evaluated with the room temperature at 10° F and the lamps operating at about 5 percent of their normal output (since the fixtures had not been equipped with low temperature ballasts), mock-ups with the wrong room and furniture reflectances, etc.

When the construction of a realistic mock-up is impossible for cost or other reasons, the mock-up design should be modified as far as possible to compensate for the unavoidable distortions. It would have been prohibitively expensive, for instance, to build a full-scale 500-foot-long mock-up of an entire subway station, so we built only a 16-foot length of the station using the actual materials (Fig. 105). The mock-up was furnished with the end of a real train, graphics pylons, and other equipment. In a long tubular space such as one of these subway stations which is illuminated from strip fixtures running along the long axis (between the tracks and concealed along the outside edges of the platforms), however, much of the light which falls on any point of the walls and ceiling comes from secondary reflections from other surfaces, not from the sources themselves. In a 16-foot length of a 50-foot-diameter tube, the proportions of the space are significantly different from those of a 500-foot-long section of the same tube from the point of view of how they interreflect light. In a short tube much of the light is lost out the open ends, which in a longer section would fall on other surfaces of the tube and contribute to its illumination. To correct for this relative inefficiency in the mock-up, we increased the number of fixtures per running foot of station over the number called for in the actual design until the ceiling vault reached the correct luminance. The use of mirrors on both end walls of the mock-up would have increased both the realism of the mock-up and the efficiency of the fixture utilization, but this expensive refinement was deemed unnecessary since the clients were able to evaluate the overall effect from the very realistic scale model (Fig. 101).

There are, however, times when building a mock-up can cause more harm than good. It is unwise to build a mock-up where it can be seen by the client before the design team is satisfied with every detail, especially if the design is unconventional. If the client’s first experience with a space is of a mock-up full of errors, omissions, and outdated details in incongruous combinations, the initial impression is likely to be very negative, and this kind of impression can be almost impossible to erase. The design of at least one major project was seriously compromised because this general rule was violated. The mock-up (Fig. 106) was built in the project field office, and was used regularly for meetings during a lengthy period of experimentation and refinement of the design. Obsolete details were left in place next to their successors, so that the viewer was left with an indelible impression of visual chaos and overall lack of coordination. Still worse, neither the enclosing walls nor the proper furnishings were ever installed. It is virtually impossible to convey to a client the image of a building system free from visual noise when visual noise in the spaces surrounding the mock-up is not screened off.
While it was possible for the designers to use this mock-up to measure light levels and distribution from which they could calculate the anticipated illumination levels in the finished building, it was almost impossible for inexperienced observers to imagine what the finished space would be like. In the space they saw before their eyes, much of the light was lost to the dark, unrelated surroundings, rather than being reflected back by light-colored walls—a key part of the design which was never installed in the mock-up.

Properly executed mock-ups were built for the Hyatt Regency Houston Hotel, the MacMillan-Bloedel Building in Vancouver, and the Santa Clara County Civic Building (respectively Case Studies C9, E8, and E5). These mock-ups—properly furnished, consistent in detailing, and realistic in materials and finishes—were eminently suitable as communication devices which could be shown to people outside the design team without fear of producing misconceptions.

When making mock-ups of perimeter rooms in which daylight will play an important role in the overall lighting scheme, the mock-up should always be built to produce a similar daylight effect, whether real or as accurately simulated as possible. If for some reason this is impossible, then the room should be evaluated only for nighttime conditions, and only at night. Because an observer adapted to daylight conditions expects daytime levels of brightness and a view through windows during daylight hours, he or she cannot realistically evaluate a mock-up which should include a daylight component and view, but does not. For the same reason, one cannot evaluate a nighttime effect during daylight hours.

Mock-ups of modular elements comprising less than a full room are used primarily for the gathering of data about illumination levels. For this purpose they are no more accurate than models, unless the type of lamps to be used are not available in a scaled-down version.

**Fixture mock-ups**

The construction of fixture mock-ups is unnecessary as long as standard catalog models are to be used. However, any special fixture designs should be tested for appearance and light distribution before being manufactured in quantity. Unless a special design incorporates critical optics or reflectors, cardboard construction which can be done in the designer’s office will usually be adequate for the purpose. Like room models, fixture mock-ups are most valuable when used to refine the design.

**Job site mock-ups**

Full-scale room mock-ups can often be built at the job site for little if any extra cost. All that is required is for the contract documents to call for the completion of a small part of the building in advance. The minimal extra costs involved usually disappear in the competitive bidding process. If no models or mock-ups have been built during the design process, it is always worthwhile to test out the final design in all its details in time to make changes and improvements before the start of the full-blown construction process. Even if models and mock-ups have already been built, the design can always be refined further. Contractor errors can be discovered before they have been repeated thousands of times; usually, the contractor as well as the design team will benefit, since unanticipated problems and cost-saving alternatives
may also be brought to light by this simple expedient. Furthermore, final decisions on detailing, colors, and finishes can best be made using actual samples of the real materials, juxtaposed in the correct relationship to each other under the illumination in which they will actually be seen and used.

Cost-benefit studies

Of the various measures of performance commonly used, there is none more familiar than costs. Traditionally, cost criteria have been set as the primary—and sometimes the only—explicit constraint to be met by a design. Because it is relatively easy to state cost controls in precise terms, there has been a tendency to overemphasize cost per delivered footcandle as a measure of performance.

There are two principal ways of looking at costs in relation to design decisions. First, costs can be used as an absolute constraint: “For x amount of expenditure, what is the best possible environment which we can create?” Second, costs can be used as a measure of relative performance: to evaluate the relative merits of different design solutions if all solutions meet the design criteria equally well. Whenever possible, we prefer to use costs as a measure of relative performance, not as an absolute constraint to which the design must conform.

Cost-benefit studies should conform to the following common-sense but often ignored principles:

- **It is not valid to compare the costs of apples and oranges.** Costs being compared must always be carefully evaluated according to the relative “benefits” to be derived from alternative luminous environments. These must be put on some sort of comparable footing.

- **It is not valid to compare the costs of only certain individual components such as lamps or light fixtures.** Comparisons of both initial and operating costs must incorporate cost changes for all elements of the building which will be affected by the lighting decision in question. These may include costs of structure, mechanical components, operating costs of heating and air conditioning, painting, maintenance, moving of partitions, etc. A large percentage cost difference between two lamps may be an absolutely insignificant part of the total project budget, and therefore should not be taken as a basis for judgments which affect the user value of the entire project.

- **It is totally worthless to compare only costs per footcandle, since the footcandle per se is not a valid index of benefits.** The reader should understand by now that footcandle levels are only one dimension of a total luminous
environment, and a relatively unimportant
dimension at that, once quite low levels
have been achieved.

With all the perceptual subtleties inherent in the evaluation of
alternative luminous environments, the most realistic way to judge
their relative merits is to present the client not with numbers but with
full-scale mock-ups of the alternatives, with their corresponding price
tags. This was done during the design of the MacMillan-Bloedel
Building; the mock-ups are shown in Figs. E8–10 and E8–11. The
type of judgment involved in the ranking of alternative luminous
environments is in principle no different than choosing between cars
or chairs of varying qualities and prices. Weighing the benefits of
various alternatives can be facilitated by a checklist tabulation against
the programmed objectives and their relative priorities. A weighted
judgment based on an evaluation of all factors is much more likely to
be sound than a judgment based solely on an exact measurement of
only one of the many factors involved, such as horizontal
footcandles—the touchstone of the conventional design process.

Summary: new objectives and design implications

In terms of both methodology and objectives, the conventional
contemporary process of lighting design is highly unsatisfactory. The
tools at the disposal of the designer are often conceptually deficient,
the design process is poorly structured to maximize communication
between members of the design team, and the objectives themselves
are frequently irrelevant and sometimes even counterproductive. There
is little attention to energy conservation in terms of both operating
procedures and hardware development. There is little recognition of
the complexities and subtleties of human perception and of the
desirability of using light and lighting equipment to do more than just
deliver footcandles—to provide orientation and guidance information,
to minimize visual noise, to satisfy biological information needs, etc.

There is a great need for new design processes and tools, more
communication between the members of the design team, more
relevant objectives, and simpler and more visual working tools. The
creation of successful, relevant, comfortable, well-integrated, and
consistent luminous environments must once again be reinstated as
the overriding objective of lighting design. We need to do more with
less, to fight against wasteful and counterproductive levels of
illumination promoted by the power and lighting industry. We need
to add positive objectives such as the creation of positive focus,
sparkle, orientation, and guidance, and lighting for biological needs, to
the conventional objectives of eliminating glare, providing adequate
task lighting, etc. To this end, a number of design recommendations
based on the principles of perception outlined in the previous
chapters are summarized in the following rules of thumb.
Some rules of thumb for good design

1. A clear design intent should be evident in all elements of the visual field. Visual perception is a gestalt experience: clear synthesis of related elements and architectural systems facilitates their comprehension, and establishes a consistent background of visual relationships which can be modulated in a meaningful way to provide subtle but extremely valuable orientation and guidance information.

2. When structure is to be illuminated directly, the resulting gradients of light should emphasize its salient characteristics—the module, the shape, and the material—in a consistent and complementary fashion. When structural elements cannot be positively and consistently illuminated, the designer should not light them directly at all, but should rather rely on reflected light from other directly illuminated surfaces to light the structure.

3. In general, one should illuminate continuous planar elements such as walls evenly, or with even gradients, so that they appear continuous. When an expression of the continuity of a flat surface is not regarded as an important design feature, the surface can be illuminated unevenly without appearing unnatural or distorted—for instance, when a decorative element such as a painting or plant hung on the wall is to be highlighted, or when the wall receives spill light from lamps which clearly relate to furnishings or which are used as wall brackets to define entrances, or when a definite rhythm of light gradients is clearly related to rhythms of panel joints, structural beams or coffers, etc.

4. To conform with expectations, use light sources of relatively low color temperature at low levels of illumination, and sources of higher color temperature at higher levels of illumination. For interior lighting, warm colored sources such as incandescent and warm white fluorescent are preferable.

5. Because of adaptation and time orientation, a given amount of artificial lighting in interior spaces will appear much brighter at night than during the day. To conserve energy, provide switching and dimming controls so that illumination may be reduced at night to the relatively low levels which are expected and required for nighttime activities.

6. Whenever possible, design glazing to satisfy the basic biological needs for a view of outdoor conditions and contact with sunlight. In general, the principal function of windows should be to satisfy these important biological needs, rather than to provide task lighting for activity needs which can usually be more easily and economically provided by artificial lighting. Fenestration should be planned in conjunction with artificial lighting, so that the two complement each other. In most buildings, artificial lighting at the perimeter should be placed on separate circuits with easily accessible switches so that it can be turned off when daylight provides adequate illumination.

7. The shape and placement of exterior windows should be derived primarily from the nature of the view. Avoid clerestories through which nothing can be seen, unless they are used to bring sunlight into interior portions of a building which would otherwise have no contact with exterior conditions. In high buildings the portion of windows above eye height is of little use from the point of satisfying biological needs, and usually introduces substantial sky glare. Since the response to unpleasant sky glare is typically to draw the draperies, which cuts off the desirable portions of the view at the same time as the offending portions, it is advisable to restrict window height to less than, say, 7 feet. Alternatively, if full height windows are to be used, provide a means by which the upper portion of the window can be screened selectively—blinds, for instance, rather than or in addition to draperies.

8. To eliminate sources of visual noise, it is better to use large-scale elements such as deep window reveals for sunshading so that the resulting areas of uninterrupted view are sufficiently large to be comprehensible. If this is not possible, go to the other extreme, using very fine mesh screen, draperies, or blinds which overlay an even texture on the view rather than

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adding a competing pattern, creating a figure-background conflict.

9. There is no unique and perceptually “correct” method for the illumination of three-dimensional objects. As long as the nature and location of the sources of light are evident, almost any approach which reveals the desired information characteristics of the objects can be used without causing confusion.

10. Because of simultaneous contrast and adaptation, objects with identical luminance levels appear brighter when seen against a darker background. This fundamental principle is particularly useful in the design of relevant foci for the luminous environment. When, for reasons of preservation, illumination levels on a painting must be kept low, for instance, the painting alone should be illuminated against a relatively dark background, and both direct sunlight and views of objects illuminated by direct sunlight should be excluded from the space, so that the eye will adapt successfully to the low illumination levels in the display space. Remember that for the eye to detect a noticeable difference in brightness, the luminance of the focal object should be at least twice that of its immediate surroundings. To create a real sense of focus, a brightness ratio of at least 10 to 1 is usually necessary.

11. Judgments of an environment as orderly or chaotic are always made with reference to background and context. Irregular arrangements of architectural elements such as lighting equipment, partitions, and furnishings seem more orderly and less distracting when seen against plain backgrounds. Partitions which are higher than eye level will be perceived against the context of the ceiling structure, and should therefore be carefully related to the visual organization of the ceiling structure. Irregular or directionless office landscape partitioning should be kept at or below eye level, unless the ceiling is directionless and visually neutral.

12. Emphasize potentially dangerous edges in circulation paths by changes in material, the use of color, or definitive shadows, particularly when illumination levels must be low for some reason.

13. To maximize the signal-to-noise ratio of backlit graphics, use signs in which the letters are brighter than the background. Avoid backlit signs in which opaque lettering is superimposed on an illuminated translucent background.

14. The various elements of the visual environment have an inherent hierarchy of attractiveness to the focus selector, which is influenced in part by their relative (not their absolute) brightness. Where directional graphics are important, avoid placing competing, distracting patterns of informationless light fixtures near the graphic elements.

15. To avoid the “black hole” effect in windows at night from interior spaces, cover them with drapery or, better still, illuminate elements of the exterior environment which you would like to see—landscape, sculpture, etc. The latter solution increases feelings of security by reducing the unknown and therefore potentially threatening aspects of the exterior environment.

16. Do not try to backlight draperies in an attempt to simulate the effect of daylight. The human mind is too keen to be taken in by such tricks. For similar reasons, a backlit Kodachrome mural of a landscape cannot create a successful illusion of an exterior view in an interior or an underground space.

17. Grazing light always highlights any irregularities in the surface upon which it falls. It can be used to bring out the texture of a wall, as a positive design element, or, if used incautiously, it can emphasize every defect in workmanship. When a wall is to be illuminated with grazing light, therefore, be sure that it has a desirable and appropriate texture—use naked joints for brickwork (Fig. 109), or lay the units up with deliberate irregularity. Use rough textured concrete forms, or accentuate joint lines and tie holes when using plywood formwork. If a wall which will be illuminated by grazing light is intended to be perfectly smooth and regular, on the other hand, specify that it should be constructed under illumination conditions similar to the final design. When designing smooth walls which are likely to be imperfect for reasons of workmanship, try to plan the arrangement of likely trouble spots such as joints in
drywall construction so that their visibility will be minimized—orient them parallel to the direction of the incident illumination rather than perpendicular to it, or hide them with elements such as tack strips, bumper rails, picture-hanging slots, etc.

18. Avoid creating a focus in the luminous environment on unpleasant, undesirable or distracting elements. It is just as important to decide what not to light as it is to decide what to light. Obviously, a design methodology which aims only at providing more than some specified minimum level of illumination throughout a space has a built-in bias against this sort of selective illumination.

19. Wherever possible, avoid creating figure/background conflicts, such as those caused by striped or “checkerboard” lighting configurations where illuminated areas of ceilings are approximately equal in size and shape to adjacent unlighted areas.

20. Avoid the use of very low (i.e., 10 percent or less) transmission glass when the glazed area will be regularly compared with clear or unglazed openings such as open windows or doors. Under these conditions, low-transmission glass will always make the exterior seem gloomy by comparison.

21. Avoid materials such as translucent walls and glass blocks, unless they serve a definite decorative purpose—stained glass, for instance. Avoid translucent skylights which take on the informationless character of featureless fluorescent diffusers, destroying potential contact with biologically desirable sunlight and exterior conditions. Use clear skylights of relatively small area for desirable architectural definition and to introduce elements of direct sunlight into interior spaces. If the skylights themselves would appear too small in proportion to the room, use pyramidal skylight wells to increase their apparent size without increasing the solar heat load or the projected area in which the direct sunlight may interfere with activities.

22. In the interests of minimizing visual noise, avoid using light-control devices such as louvers in skylights and artificial lighting details if such devices are not really necessary. Such elements, in and of themselves, are of little visual interest, and they should be used only when the same purpose cannot be accomplished through careful integration of the lighting hardware with other architectural elements. Light sources may be effectively baffled using elements such as the edges of ceilings, beams, valances, cabinets, etc. Fixtures can be concealed in bollards, handrails, recessed slots, and in the flanges of major structural elements. Under most circumstances, the use of simple, understandable, unobtrusive control devices such as the low brightness “black cone” in direct lighting fixtures is preferable to the use of louvers of more complex shape, unless the light fixture in its designed context is intended to serve as a true positive focal element, a piece of sculpture in its own right. Since baffles and louvers used to control light distribution are typically very close to the sources themselves, they can very easily become the brightest elements in the visual field, achieving an entirely unwarranted and inappropriate prominence.