Introduction

In any given project, the real design process is always influenced by many factors: among them are timing, design budget, the attitude toward teamwork of the various persons involved, and the complexity of the problem. The quality of the design process is always reflected in the quality of the finished product. A lighting designer may be involved in the overall design process at a number of levels. He or she may be reduced to making the best of a series of prior decisions over which he or she had no control or influence. Better, lighting input may lead to modification of structure, mechanical systems, and other elements of the finished building to achieve a more successful, appropriate, comprehensible luminous environment. Ideally, lighting considerations and perception principles become principal formgivers in an integrated team design process.
In the following case studies, examples of each level of involvement are presented. The case studies demonstrate how the perceptual requirements of different activities may affect all aspects of design, and how similar activity needs may imply different design forms under different circumstances. The use of various tools in the design process is discussed at some length, as are a number of design failures and their causes.

The case studies have been grouped into various categories to simplify discussion and to demonstrate that the application of perception principles is never simple, but is affected by every nuance of other decisions. There are many ways in which the case studies might have been grouped. The cross-fertilization of concepts and their gradual refinement would have been most easily traced in a chronological presentation. Arrangement by building types was considered, but was rejected on the grounds that it would not necessarily bring out the most important common organizational features of related projects. To clarify these features, therefore, projects have been grouped by complexity of program and of the corresponding design process, starting with single interior spaces and buildings dominated by a single space, graduating in complexity to growth systems, clusters of spaces, and finally to entire complexes of buildings.

The first category of projects includes spaces in which the lighting design primarily responds to the activities housed. This category is further subdivided into two groups: BUILDINGS DOMINATED BY A SINGLE MAJOR SPACE and SINGLE SPACES DEFINED BY MODULAR ELEMENTS.

The third group, SEQUENCES OF MAJOR SPACES IN A SINGLE STRUCTURE, demonstrates how the design of individual spaces may be affected by the design of other spaces in the same structure, even though they may have quite different uses.

In the fourth group, SEQUENCES OF SPACES ORGANIZED ALONG FIXED CORRIDORS, projects are presented in which the existence of a system of fixed corridors was used as a strong organizing principle for the entire design, reinforced and expanded through lighting.

The fifth major group, SEQUENCES OF SPACES WITHOUT FIXED CORRIDORS: ARTICULATED SYSTEMS FITTED TO PREDETERMINED EXTERIOR FORMS, contains projects for which the design team developed integrated building systems—systems which include lighting, mechanical, and structural components—which would allow a wide range of spatial subdivision. The structural, mechanical, and lighting systems of projects in this group were given a strong exposed expression.

In the sixth group, SEQUENCES OF SPACES WITHOUT FIXED CORRIDORS: FLAT-Ceiling SYSTEMS FITTED TO PREDETERMINED EXTERIOR FORMS, programatically similar projects are presented in which structural and mechanical systems were hidden above a "homogenized" uniform suspended ceiling plane with a regular pattern of recessed light fixtures.

The seventh group, GROWTH SYSTEMS, is one of the most interesting. It includes projects varying in size from single buildings to entire building complexes, each of which was largely the result of the development of a flexible, articulated, integrated module incorporating structure, mechanical channels, and lighting systems.
With these basic three-dimensional building blocks, expansion of projects in any direction, in small or large increments, is always possible as desired—hence the title "growth systems." The special characteristics of these structures make them particularly suitable for infill projects.

Combinations of spaces and groups of spaces, which taken as individual buildings would fall into one or more of the preceding groups, have been consolidated into the eighth group, BUILDING COMPLEXES. Special attention is paid to the problem of providing adequate orientation in complexes which are linked below grade.

All the case studies have been selected from projects in which the author was personally involved, so that the design process and initial intent could be presented as well as the final results. For most projects, the statement of programmatic objectives given in the case study is verbal, as it was during the actual design process. The reader can judge whether or not the stated conceptual objectives were realized in the projects as built. In many instances, comments and criticism have been included to point out where mistakes and compromises eroded the initial design concepts.

As an index for the reader who is particularly interested in one specific building type, combination of integrated building systems, lighting strategy, etc., the chart printed inside the back cover summarizes the salient characteristics of all the case studies, listed chronologically.

CASE STUDIES GROUPS

A BUILDINGS DOMINATED BY A SINGLE MAJOR SPACE
B SINGLE SPACES DEFINED BY MODULAR ELEMENTS
C SEQUENCES OF MAJOR SPACES IN A SINGLE STRUCTURE
D SEQUENCES OF SPACES ORGANIZED ALONG FIXED CORRIDORS
E SEQUENCES OF SPACES WITHOUT FIXED CORRIDORS: ARTICULATED SYSTEMS FITTED TO PREDETERMINED EXTERIOR FORMS
F SEQUENCES OF SPACES WITHOUT FIXED CORRIDORS: FLAT-CEILING SYSTEMS FITTED TO PREDETERMINED EXTERIOR FORMS
G GROWTH SYSTEMS
H BUILDING COMPLEXES: SEQUENCES OF MAJOR MASSES
The design of the luminous environment for the buildings in this first group of case studies responded primarily to the needs for visual information inherent in the principal space or space type around which each is organized. We know that the luminous environment for any space must relate to the activity and biological needs of its users, and that a good visual environment is one in which all visual information is relevant—visual noise is at a minimum. This happens when the illumination for each activity comes from an environment that simultaneously serves other needs, either activity or biological—an environment which appears relevant, in which constancies are not upset and everything appears “natural” for each specific activity at each specific time. If a space houses only a single activity, then design is easy: provide optimum illumination for that activity. A theater during the performance, for instance, is almost totally focused, the
information needs of the audience being entirely related to the stage activities. In fact, however, a pure single need for visual information almost never exists. Even in the theater, for instance, the audience needs to know how to escape in case of fire—hence, the competing EXIT sign, the aisle lights, etc.

Then comes intermission, and the needs of the audience shift to relaxation, social stimulation, perhaps the sense of "event," orientation within the space and to others in the building, reading of programs, notices of future attractions, etc. When activities with very different needs take place sequentially, as in the theater or a classroom, then the luminous environment must be adaptable to those changing needs. A theater must appear very different during the performance than during the intermission.

If, on the other hand, many activities with very different needs take place simultaneously but in different rooms or areas of a room, it may be necessary for the user to move within the space that is provided for the various specific activities in order to find optimal luminous conditions for each activity. Where simultaneity of varied activities prohibits the responsive adjustment of the entire luminous environment to meet local needs, provision of a variety of different lighting conditions in different areas of the space may be the only feasible solution.

Only if all activities must take place simultaneously and in fixed locations—so that the luminous environment cannot be readjusted and the occupants cannot move to a new place for each new activity—is it appropriate to provide a luminous environment with a high overall level of neutral general illumination, giving a satisfactory condition at all locations for all activities with a minimum of visual noise and maximizing the occupants' ability to focus at will. Where local lighting of critical tasks is feasible, however, it is generally more economical to combine local lighting on demanding tasks with a much lower level of general illumination appropriate to and adequate for less critical activities elsewhere in the space.

Effective illumination of spaces defined by the shape of the room is simple, effective, and economical when it can be easily accomplished from totally concealed sources, or when the room definition can be combined with the creation of a desired local focus. A study illuminated by a single desk lamp which simultaneously illuminates the ceiling and walls is a good example of this type of lighting.
The Newburyport Institution for Savings (1) was built in 1870 and is considered an important part of the town’s architectural heritage. Before calling on a lighting consultant, the owners had rejected proposals for “improving” the illumination via the usual engineered array of pendent direct/indirect fluorescent fixtures, unrelated to either existing forms or materials, which would have satisfied only a few of the many needs. The visual noise inherent in such a system would have destroyed the character of the space.

In a bank, the general lighting design should create a pleasant, cheerful environment which fosters communication between staff and customers, provides well for clerical activities, and conveys an image of a progressive institution with a sense of human values.

Design
The location of counters and screen walls in relation to the walls and ceiling made illumination of the latter surfaces from the former the obvious solution. Details (2,3) were developed to minimize the presence of the sources and the amount of necessary construction. The indirect lighting was supplemented by neutral, recessed incandescent downlights. While downlights alone could have supplied all of the required desk-top illumination, the darker walls and ceiling would have rendered the space more gloomy on overcast days and more glaring at night.
When lighting design began, this room within a science building (1) was characterized by its rounded brick walls that flowed out into the adjacent lobby. While the auditorium floor rakes downward, its ceiling plane was extended throughout the adjacent spaces at a constant height with no change of materials, to express the continuity of the spaces.

**Design**

The wood-screen ceiling (3) seemed an appropriate means to express the continuity of the lobby and the auditorium, while allowing the necessary variations in acoustic treatment, air conditioning, and lighting. Its detailing began with the placement of downlighting fixtures so that they would articulate junctions in the ceiling rather than penetrate it arbitrarily. Bands of slats containing the fixed lighting were fastened permanently in position, while panels of slats between were left removable for access.

Two separate sets of baffled downlights were arranged: the first to illuminate the perimeter walls defining the space and the second to illuminate the seating area without spilling onto the walls (4). During projection, only the latter are used, dimmed (5).

**Critique**

At the stage end, the ceiling was to have been held back from the front wall so that chalkboard lighting would be totally concealed (above and behind the front edge of the ceiling). Unfortunately, this detail was omitted and the resulting visible recessed lights (7) are an unnecessary distracting blemish.

Had the illuminated walls been contained entirely within the auditorium rather than allowed to flow continuously into the lobby, the edge-slot technique would have been used rather than the recessed wall-washer units within the ceiling screen.

Note that the lobby (8) is intentionally illuminated unevenly, with walls and entrance points highlighted to provide desirable orientation and a pleasantly focused environment.

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3 Ceiling structure (which would normally be invisible) is revealed by the photographer's strobe.
The primary needs for illumination in a church are biological. Architect Harry Weese's concept was to create a warm, restful, lofty space with a focus on the side-lighted area at the front.

From the exterior, this complex of buildings appears as two powerful roof shapes sitting on a base of brick walls. The major interior spaces are also dominated by the roof shape. Thus, the obvious illumination scheme for the space was to balance the brightly daylighted chancel by highlighting the lofty wood surfaces of the roof—not uniformly, but in a manner that would emphasize the shape of the space and the "seating" of the roof structure on the brick base.

The brick ledge around the nave offered a natural place for locating fluorescent lamps with which to crosslight the vault (7a), and the decking was raised somewhat to increase the lamp-to-decking distance, to minimize any "hot spots" above the fixtures (4). Note that wide spaces such as this are primarily crosslighted. Only the ceiling near the lamps receives more light perpendicular to its surface from the adjacent lamps than from those on the opposite side. The lighting at the ledge is continued wherever the ledge-roof relationship remains constant. But at the chancel, the brick screen and altar are emphasized via skylights during the day and in several possible ways at night (5,8).

Architecturally neutral incandescent "cans" at the apex (7b) can be used to supplement the indirect lighting system. More important, they can be used instead of the glowing ceiling—at night, when there is no need to balance the brightness of the daylighted chancel, or when a more dramatic, dark space is desired, e.g., for a candlelight service.

Note that with these room proportions, only one row of cans at the apex is required to illuminate the floor area uniformly. If, however, the architectural decision had been made to place the fixtures lower, more fixtures on a tighter spacing would have been required (7c). Fixture spacing to achieve a uniform distribution of light is a function of the mounting height and beam spread characteristics of the fixtures chosen; size of lamp can be subsequently selected to provide the desired illumination levels.

Equal consideration was given to supporting spaces such as classrooms, social hall, offices, etc. These are illuminated in a manner similar to the main church and chapel, varied according to their own geometry and activity needs (6).
7 Schematic lighting sections:
(a) Continuous indirect fixtures on top of the perimeter walls crosslight the vault surfaces evenly.
(b) By locating the downlights high in the space the team was able to achieve very even illumination with good glare control. If the fixtures had been located lower in the space, as in (c), more fixtures would have been required to achieve the same uniformity of lighting and a great deal of unpleasant visual noise would have been introduced into the space by the pendant hardware.
The central dome has always been an important part of the exterior image of MIT. The interior space immediately under the dome was originally the library, an important space (although never a visual focus or an important traffic junction because of its third-floor location). In the 1940s, the grand space was remodeled for "better" and more efficient lighting. In the process the space was completely obscured with a visually noisy, dingy, luminous plastic ceiling and its arbitrary supporting structure (6). When the library was converted into the James Madison Barker Engineering Library, the architects and consultants had the opportunity to retrieve the original assets, a grand space with fine details of the period still intact (2).

Design
To provide unobtrusive, complementary general lighting, the shape of the dome was emphasized by cross lighting from within (made possible by the presence of a surrounding attic). Walls and columns were painted white in order to minimize the dominance of the dome and to maximize utilization of reflected light. Additional illumination for specific activities was provided by local carrel lighting, with angled louvers (5, 7) to minimize reflected glare, and by local highlighting of the publication racks. These illuminated racks were also conceived as an important source of diffused general lighting. Supplementary local lighting was provided for the reading chairs.
5 Local carrel lighting: Section AA shows a carrel of conventional design in which the unshielded fluorescent tube causes bad ceiling reflections (adding a lens does little to improve the situation). Section BB shows the location and orientation of the cross-luvers which were installed in the carrels at the Barker Library to minimize this problem.
Harry Weese’s extension (1) to the original Saarinen building maintained the cornice line and materials of the older building. The interior space, however, is of a totally different character, though similar materials and overall dimensions were used.

**Design**

Instead of giving interest to the large expanse of ceiling by the “attractions” of arbitrary circular lighting indentations (4), as Saarinen had done, the shape of the total space in the Weese addition was emphasized by “floating” the ceiling free from the surrounding structure and highlighting the walls. The space was further articulated by raising and illuminating the central area of ceiling adjacent to the featured mural wall (5), which was emphasized by means of a skylight supplemented by integral incandescent fixtures. The core, containing serving lines, meeting rooms, coatrooms, etc., was outlined by edge-slot lighting (2). Note that no louvers are visible—the wall disappears into the slot, with the lamps out of sight from normal viewing positions.
As at Columbus Baptist, it was desired that the auxiliary spaces of Calvary Church, such as classrooms, should be related in character to the main church. In this project, the lighting design of the main church could not be separated from that of the auxiliary spaces, since all lie under one continuous, unifying spiral of walls and roof.

**Design**

The most obvious way to illuminate such spaces was with fluorescent lamps from the tops of perimeter walls in a manner similar to Columbus Baptist (Case Study A3). However, this method was not used for several reasons. First, there was no way to conceal the fixtures on top of the wall, which slopes as it changes height. Dark louvers could have controlled the glare but would themselves have been conspicuous. Second, the distance between the top of the wall and the decking was too close to permit even illumination without hot spots. Third, the beams were spaced irregularly and close together, so that lamps of varying lengths would have been required to produce light gradients in a consistent relationship with the irregular structure.

Therefore, bowl fixtures, using quartz rather than fluorescent lamps, were placed low on each wall facet to get good light distribution over the ceiling (4). The quartz-lamp fixtures were selected because of the precise optical control possible. Only minimum light is spilled on the wall adjacent to the fixtures. A tradeoff between low initial cost and relatively high operating cost is acceptable in a church with limited operating hours.
The Indiana University Opera Hall (1) is one of the few single-purpose opera houses in the United States, and home of the country's only opera school. Evans Woollen's design manages to accommodate most of the extensive supporting school facilities above grade, without obscuring the drum of the hall itself, achieving both good working conditions and a clear public image for the hall.

**Design**

Definition of the shape of the round drum both from within and without was the starting point of the lighting design. Within the main hall (3), ceiling slots were created to accomplish this end. The slots were interrupted to accommodate structure; the resulting lighting appears natural rather than uneven in this context. The wall-washing effect was given maximum impact by painting the walls in rich colors (6). Most of the supplementary downlighting required to cover the areas out of reach from the wall slots could be done in an inconspicuous, glare-free manner from a concentrated area located in the rear of the main ceiling, out of sight for most of the audience (5). The great height of the hall made this possible.

On the lobby side, illumination of the drum was to have been from slots created by floating the ceiling. However, the pattern of structure made this detail too expensive; instead, recessed wall-washers were used (9).

Architect Woollen was against extensive 'acoustic clouds'—surfaces to reflect sound—that would have obscured the upper space of the hall and appeared mechanistic. Therefore, the necessary sound reflectors above the audience were developed as structurally uncluttered disk chandeliers (5), and the chandelier pattern was developed according to the acoustic density requirements.

The chandeliers consist of clear incandescent lamps which project through convex clear Plexiglas disks (sprayed gold on the upper surface). These act as sound reflectors. To aid relamping and to allow adjustment of the vertical composition of the disks for acoustic or visual reasons, the reflectors were suspended on retractable lamp cords.

To avoid visual noise from window framing of the projection booths in the rear wall of the hall, the glazing was deeply recessed and the holes shaped to have sculptural significance (7). This sculptural treatment was repeated at the check room (8), air outlets, etc., when possible.

On the exterior, floodlamps to illuminate the Calder stable (10) were housed in tubes chamfered to get maximum distribution of light on the sculpture with a minimum of glare.
St. Thomas Aquinas Church differs from Columbus Baptist in that the identity of the church comes at least as much from the forms of the stepped wall as from the roof. On the interior, daylight is better balanced throughout the church. Therefore, artificial illumination is used only for nighttime illumination and to supplement the natural lighting on dark days.

**Design**

Consistent with the vertical windows, incandescent lamps were arranged vertically within the window recesses. Though hidden from view during the service, they are seen as decorative patterns of clear lamps by people leaving the church or viewing it from the exterior. Highlighting of the altar at night (3), from reflector lamps concealed behind a beam, is consistent with the normal direction of daylight (4).
CASE STUDIES GROUP B

SINGLE SPACES
DEFINED BY
MODULAR ELEMENTS
Orchestra Hall is the dominant single space buried within the shell of a multistoried building on Michigan Avenue (2). Proposals had been made for bringing the Burnham-designed hall (1904) up to date, with air conditioning, more comfortable seats, modern elevators, modified acoustics, etc., that would have created a totally new "movie theater" space. A change in management led to a new look at the problem.

The new team saw the problem not as that of creating a new space but instead as one of restoring and enhancing what they believed was a superb original concept which had been eroded over the years through poor decorating and maintenance (4).

**Design**

Walls and ceilings of the hall were painted in a solid beige (replacing a tricolor scheme), and new red seats and carpeting were installed. Acoustically, the volume of the hall was increased without changing the visual volume by replacing a number of solid panels with visually solid but acoustically transparent, perforated material.

For the new scheme (1), the major portion of the original lighting system seemed excellent and was restored. This system had defined the shape of the hall with exposed carbon filament lamps projecting in bands through gilded plaster friezes and clustered on balcony fronts. Substitution of inside-frosted and bottom-sil-
The negative aspects of the original scheme, however, were eliminated during the restoration. Where they interfered with the view of the audience behind, white glass “drums” under balconies were replaced by neutral low-brightness recessed fixtures. Drums which formed a positive pattern over the row of boxes and presented no glare problems were replaced by fixtures with a positive sparkle (clear lamps in prismatic glass enclosures).

Like the main hall, the reception room seemed like a once-elegant room that had become dull because of poor redecoration and maintenance. The chandeliers and wall brackets needed merely to be fitted with clear lamps, cleaned, and regilded. The sparkle was then amplified and the space unified by replacing the small scattered mirrors with extensive, panel-size mirrors (5).

Spaces, such as the entrance lobby and upper foyer, that had no positive character were made neutral by recessed downlighting (6, 7). For occasions when the hall surfaces should appear neutral and unlit, low-brightness downlights were placed in the ceiling over the orchestra seats. Similarly, the stage lighting was supplemented from sources concealed behind the proscenium and in the rear wall (3). Small quartz lamps in specially designed fixtures were concealed in valances between the organ pipe balconies, to minimize glare and to eliminate hot spots on the rear wall of the stage.

**Note on Details**

The 70-year-old original scheme for relamping ceiling, hall, and stage lighting was ingenious. The fixtures were not permanently attached to the structure, so that the lampholders could be retracted, relamped from above, and dropped back into place through holes in the ceiling.
This factory building was to be similar to others previously built at Cummins by Weese and Saarinen. The initial design called for the same combination of steel trusses, skylights, and a "spaghetti" of ductwork radiating from a central mechanical room (5).

In a factory of this kind, most of the floor space is occupied by materials in temporary storage between production operations. Lighting needs are primarily biological. Factory environments are usually more chaotic and gloomy than necessary (2,3). An uplight component from typical industrial lighting fixtures can help, as will skylights above (illuminating the structure and ductwork which in turn reflect light to the ceiling); however, if the ceiling is chaotic and cluttered, the net effect can be negative.

For several reasons, indirect lighting of wall and ceiling surfaces was a very efficient method of getting the kind of bright, cheerful space that would provide the needed illumination for storage and movement of materials and for most manufacturing operations. The considerable depth of structure (10 feet) permitted a generous fixture-to-ceiling distance, reducing the hot-spot effect
4 Sections showing alternatives explored by the team in the search for an integrated systems solution.

5 Initial design—no integration of systems

6 Final integrated systems design.
generated by fixtures mounted too close to the surfaces which they illuminate. The indirect system was supplemented with down-lighting in local areas as required. Indirect lighting is excellent for storage areas because rows of storage need not be located in relationship to light fixtures, and shelving shadows are minimized. Recent experience in designing the IBM building (Case Study E2) gave the team added incentive to see if an integrated system could be developed.

Design
The greatest contributor to potential "visual noise" from the ceiling was the layout of the air-conditioning ductwork. The opportunity and challenge were rearranging ductwork to relate to the structure and to baffle the indirect light sources. A "fishbone" layout with several smaller fan units (rather than a single fan system) proved to be an economical, satisfactory approach, and the shape of the ducts was refined to provide a uniform mounting and shielding condition for the indirect fluorescent lighting. The ducts were supported within triangular delta trusses (4). The additional cost of the trusses was offset by savings in duct and fixture support, and by their doubling as catwalks.

Thus, the ceiling (7) is not perceived as an endless plane penetrated at random by arbitrarily placed lighting fixtures, but rather is articulated by the integrated structural/mechanical/lighting system whose clarity satisfies the biological needs for the under-
standing of structure, orientation (definable "bays"), etc. Work illumination and orientation were also improved by highlighting of the perimeter walls with skylights using integral fluorescent fixtures for night use, and by downlight accents in local areas that benefit from increased illumination, shadows, and reflections (B). The changing daylight of the skylights and a narrow horizontal band of view windows provide desirable contact with the exterior.

When closed cubicles within the space were necessary to keep out dust, noise, etc., they were related to the larger space by the sloping skylight and low-brightness downlighting (9) which not only reduces glare for the cubicle occupants but also keeps views of the cubicle fixtures from dominating and contributing visual noise to the surrounding major space.

The engine test-cell building contiguous to the large loft type structure contains test cells along a series of fixed spines containing the observation-control stations (12). These were illuminated in a nonindustrial manner: indirect lighting of the ceiling plus local lighting of the instrument panels (11). The space is properly focused; unlike earlier test cells at Cummins, none of the light sources in the test cells are visible to observers (10). A similar relation between viewer and activity to be illuminated led to a similar solution at the handball courts designed for Johns Hopkins University in conjunction with Meyer, Ayers, and Saint (13-15).
10 View from test cell toward control booth showing lights positioned to be invisible to the observer in the booth (the spotlights in each corner are used as work lights).

11 View into test cell.

12

13

14 Spectators' gallery at the Johns Hopkins Athletic Center, Baltimore, Maryland (Meyer, Ayers and Saint/Architects; William Lam Associates/Lighting Consultants).

15 Handball court at the Johns Hopkins Athletic Center.
In creating a totally new interior space within an existing structure, architect Lundy decided to define the space by an obviously non-structural lining of wood screening. Elegant organic forms were created by the pattern of wood strips radiating from columns and pilasters.

The lighting objective was the provision of an elegant environment in keeping with the prestigious location and product line. The display of a limited number of products could easily be accomplished in discrete self-illuminated displays. For the customer, flattering lighting at the full-length mirrors was essential.

**Design**

Direct lighting onto the dark wood-slat screening was avoided as much as possible in order not to illuminate the messy hardware and spaces between and beyond. Downlighting through holes or around the edges of the screens was considered desirable (2,3). The tour de force came with the elimination of the usual clutter of uncoordinated mirrors (in typical shoe stores). By making the mirrors radiate in plan from the semi-circular pilasters and follow their curving profile in elevation, the pilasters were made to appear as full-round “columns,” thus expanding the space and making the mirrors positive contributors to the spatial organization (5). Floating the mirrors free from the walls then allowed concealment of light sources that illuminate the infill walls and provide reflected light onto persons standing in front of the mirror.

**Critique**

The lamps were centered between wall and mirror, rather than placed as designed for maximum glare shielding and uniformity in illumination of the wall (4).
4 As built, the lamps are not so well concealed as they would have been if located at the front of the pocket as intended.
The general scheme of this pavilion library for a Montreal suburb was the winner of a competition. Lighting design capitalized on the planned ceiling structure. Perimeter skylights (3) were used instead of clerestory windows, reducing glare and giving the ceiling structure the appearance of floating free from the walls of the library. Thus sunlight is brought into the space in a way which improves the environment without interfering with the activities of the readers.

**Design**

Since the size and layout of the room made it possible to handle all air-conditioning requirements from the perimeter walls, the exposed waffle ceiling could be uninterrupted. Low-brightness direct/indirect louvered fixtures\(^1\) utilizing the twelve-inch-square panel lamp were used within each 6 x 6 foot cell to provide direct lighting with a minimum of direct glare, while the glowing ceiling coffers reduce shadows and define the ceiling plane.

The original design, which called for the use of clerestory windows, was changed to use clear edge skylights in order to get the desirable dynamic quality of daylight without the attendant problems of glare control from clerestory windows (4). At night and on dark days, incandescent lamps substitute for daylight. The main desk area is given prominence by skylights with decorative Plexiglas baffles.

On the lower level, as a compromise to initial cost, exposed incandescent lamps were centered in each coffer (5). Comfort and operating cost, while clearly not as good, were still judged acceptable.

\(^1\)Previously developed for the office segment of the Cummins Engine plant, Case Study E3.
Coordination of lighting and structure for the Eden Library began before the first diagrammatic sketch. The problem: how to serve the activity needs within an environment that would be warm and Gothic, in harmony with the existing campus. The architect, William Wenzler, hoped to achieve this character with maximum use of brick (the predominant campus material) and wood.

Objectives were to provide adequate but comfortable illumination for stacks and reading-work areas. Stacks were to run in either direction and reading-work areas were to be distributed freely and interchangeably. The goal: a cheerful yet low-key luminous environment.

Design

In order to avoid gloom and to minimize glare, a starting premise was that a wood ceiling, if used, would have to be either illuminated indirectly or used as louvers, since freely distributed stacks meant that frequent white walls were not available to use as sources of indirect illumination. The desire for a Gothic expression suggested a Gothic structure. The total concept, developed on the back of the classic napkin, was that of concrete "trees" (sculptured concrete structures being a specialty of the architect) with an infill of wood louvers that would conceal the services and provide pleasant overall illumination from a warm, glowing plane (5). This was a modification of the scheme used in Place Bonaventure (Case Study C5).

Since such dark louvers are relatively inefficient, the large-scale louver ceiling module was developed around the then highly promoted new 12-inch-square fluorescent lamp and low-brightness louver designed to fit the lamp precisely (thereby yielding maximum efficiency with low brightness). The lamp and louver provide local downlighting, and the upward component, reflected by the white painted slab and ductwork above, illuminates the surrounding unoccupied cells of the wood grid. Supplied from flexible cables, these units can be moved in minutes without tools to accommodate changes in the placement of stacks, work tables, etc. Interchangeable panels with recessed incandescent wall washers were placed to illuminate perimeter brick walls. The structural "trees" (4) contain concealed light sources within the branches which illuminate the trees themselves and the surrounding slab.

Critique

The final result is highly satisfying; the space is defined by glowing wood louvers, with local high-lighting related to use and furniture layout. This was a good "rustic" solution for the program.
However, edging the louvered service zones with deeper members to screen the mechanical services from view could have produced a more definitive, more refined appearance for a negligible increase in cost.

Unfortunately, because of unanticipated manufacturing difficulties the price of the fluorescent panel lamps went up sharply, rather than following the usual downward trend that goes with increasing production and amortization of development and tooling costs.
When a number of major spaces occur within a building, the design of each should be influenced by the design of the others. Even if common denominators are not advantageous for practical reasons, such as ease of construction, reduced cost of common details, materials, etc., there are good biological reasons for maximizing the design consistency, unless differences are dictated by real needs and are substantial rather than arbitrary, merely for the sake of "variety" (design without underlying concept). One may ask "Why bother with consistency if the related spaces cannot be seen at the same time?" It must be remembered, however, that "seeing" involves the brain and not only the eye. Seeing is inseparable from association with remembered mental images.

There are many possible solutions for the design of any individual space. With a sequence of spaces, only tentative conclusions should be reached for any one space until the solution for all begins to emerge. Ideally a design which may seem arbitrary in any single space will exhibit an appropriate relevance to all associated spaces when seen as part of a sequence.
The building committee for the Loyola-Notre Dame Library expressed a strong desire for "an arrangement that is direct, logical and easily understood and an environment that is friendly, intimate, warm and pleasant." In response to this and other programmatic objectives, the design team came up with a simple, comprehensible concept for this roughly square building: four rectangular perimeter spaces arranged in a pinwheel around a major central space (4). Both central and perimeter spaces were programmed to accommodate a mix of stacks and reading areas which could be changed at will, though the majority of stacks were to be concentrated in the central zone while most offices and reading areas were to be located in the perimeter spaces.

Architectural development and lighting design reinforced the clarity of this organizing concept. Although the roughly square plan form might have suggested the use of a uniform field of square ceiling coffers and light fixtures throughout the entire floor, the pinwheel arrangement and the expressed desire for maximum orientation led to the clear differentiation of the central and perimeter zones through the use of different lighting and ceiling systems (5). Since service and circulation cores were located in two of the perimeter areas, the logical approach to mechanical distribution was to run the major mechanical services above a suspended ceiling in the perimeter zone. This concentration of service elements opened up the possibility of a full-height ceiling in the center zone with only local mechanical distribution elements concealed in the ceiling depth (2).

The stack arrangement in the perimeter zone—consistently perpendicular to the exterior walls—suggested the use of a directional metal-slat ceiling oriented parallel to the lines of the stacks, with integral recessed single-lamp low-brightness fluorescent fixtures. Because of the pinwheel plan, the design team was able to treat each of the four perimeter spaces as a separate entity, thus avoiding the most common problem inherent in the nature of a directional ceiling texture: that of turning the corner. The 8-inch-wide luminaires, which replace two of the metal slats, were selected because of their high efficiency and very low brightness. The design team judged these to be more valuable characteristics than the attributes of narrower fixtures, which blend into the ceiling only when switched off (compare with Fig. 23, Case Study C5). Even when switched on, the larger low-brightness fixtures are relatively unobtrusive in the context of the linear ceiling texture, producing far less visual noise than the brighter single-slat-width fixtures (3).

Light-bronze-colored slats were chosen to produce an ambiance of intimacy and warmth. In general, dark-colored ceilings which extend over large areas appear depressing and gloomy during the day, even though desks, furniture, and bookcases may be adequately illuminated. However, at Loyola this effect is minimized because the areas of dark ceiling are fairly small, and each is surrounded by windows, illuminated walls at corners (6) and cores, and the bright central space in which square fixtures are located in each coffer of a large-scale waffle ceiling. Table tops are light-colored. Most of the visual field is therefore quite bright,
which compensates for the relatively dark ceiling overhead. Windows were designed primarily for the view rather than for the daylight, although reading areas near windows were planned to utilize the available daylight illumination; the incandescent lighting provided in these areas is intended for nighttime use only.

In the central area (8), every coffer is illuminated to avoid producing a visually noisy checkerboard pattern of alternating light and dark coffers (compare with Fig. 49). Wrap-around plastic diffusers were used in the 2 x 2 foot fluorescent fixtures, rather than diffusers with opaque sides, to eliminate shadow lines which would otherwise interrupt the light gradients which define the shape of the coffers (7). Air supply and return were handled through slots concealed in the light fixtures. Two 40-watt U-shaped lamps in each fixture illuminate the diffusers uniformly but generate more light than required except in isolated reading areas. The
use of two-level ballasts was recommended, so that each fixture could be operated at either full output or half output. Hardware such as the two-level ballast makes it possible to tailor the luminous environment at will to the specific requirements and locations of the activities in a space, conserving energy while maintaining the designated patterns and order of the visual field. However, the project proved too small to make the manufacture of special ballasts a financially attractive proposition; therefore, light levels were adjusted by using two different types of ballasts, installed in an arrangement dictated by the furniture layout. This compromise makes it more difficult to adapt the luminous environment to changing use patterns, since the ballast must be replaced to change the output of any fixture. However, our request for multilevel ballasts on this and several subsequent projects has led the ballast industry to offer several types of multilevel ballast as standard catalog items.
The architectural concept of this student center was very formal: in plan (2), nine squares separated by corridor/service bands; in section, layers of major rooms surrounding a skylighted well (5) with ceremonial stairs.

The environmental needs in a student center are primarily biological. Objectives are therefore the creation of pleasant, cheerful spaces suitable for circulation, lounging, conversation, eating, drinking, etc. Activity needs such as serious reading, studying, and office work take place in a few selected locations in the public spaces and in designated student offices which should be given special treatment.

Design
The strong plan organization (eight squares surrounding the central square skylight well and separated from it by service bands) suggested strongly that this organization be reinforced by the lighting design. Consequently, the eight squares were illuminated indirectly from their perimeter beams (from integrally cast recessed coves). The wash of light on the exposed concrete-grid ceiling effectively balances the brightness of windows. Downlight "can" fixtures provide supplementary light during the day and when used alone can provide a subdued alternative at night. While this lighting is suitable for the dining rooms, in the lounges (4) additional local lighting for reading was provided by portable lamps, creating a more intimate scale. In the bookstore, lighting tracks were provided to supplement the general indirect lighting system.

In the ballroom (6), where the major walls are solid, perimeter walls could be illuminated from behind benches as well as from coves and downlights overhead. The desired combinations are selected by dimming. It was decided not to create any additional decorative "chandeliers" effects since the adjacent skylight/chandelier/stair system in the central well would be visible from all floors.

Critique
The lamps in the skylight/chandelier (3) are hard to reach, and were to have been operated at reduced voltage and at night only for a very long life, so that relamping would have been required only at intervals of several years. Unfortunately, a false economy was achieved by elimination of the dimmer, thereby reducing lamp life and increasing relamping costs considerably.
Principal characteristics of the Walters Gallery addition are the diagonal shapes of the main spaces and the daylighted enclosing screen walls on the street side.

With the diagonal spaces, large-scale expressive horizontal structure would have conflicted more than usual with the works displayed on the walls. Therefore, a "homogenized" neutral ceiling was sought. Starting with the need for an accessible ceiling, the design team was faced immediately with the problem of finding a ceiling material whose inherent visual geometries would not conflict with the diagonal plan forms of the perimeter galleries. The use of a conventional rectangular material such as acoustic ceiling tile would have made it impossible to avoid the usual nasty little irregular triangular bits of cut tile whenever the ceiling intersected a diagonal wall. In addition, the ceiling had to accommodate runs of lighting track parallel to every major wall; with a rectangular tile ceiling, a number of runs would have had to cross the tiles on the diagonal.

The problem was solved with a continuous plane of bronze-colored metal ceiling slats that appear as a continuous texture meeting both principal walls at the same angle. The lighting tracks, which needed to be parallel to the walls, were placed above the ceiling slats. Stems of the movable light fixtures penetrate between the slats (easily removable for rearrangement of lighting and servicing of air conditioning). Thus hidden lighting tracks could be placed anywhere needed for display without introducing any additional, conflicting, strongly directional linear elements into the room (3, 4, 5).

On the office and library level, the slatted ceiling is white rather than bronze, with lighting introduced through the slats as in the galleries and from fluorescent wall washers around the "floating" edges of the ceiling.
Buildings consisting of a few major spaces on a single floor are generally less affected by mechanical distribution requirements than are more complex structures. Since the required ductwork can be placed in the basement and run up vertically within the walls, uninterrupted ceilings are possible in galleries and corridors. In such cases, a continuous waffle-slab ceiling can work well as natural centering or louvoring for lighting.

At Huntington, lighting design began with the assumption that the principal focus should be on the exhibits hung on the walls and on pole-supported panels inserted between the floor and the concrete ribs above. In order to minimize the visual competition from the ceiling, the waffles were used as a subtle organizing texture and centering for the fixtures rather than as lighting baffles. Point outlets for track-type fixtures were located in cells adjacent to the permanent walls and expected panel positions. They were circuited so that each wall and panel area could be switched or dimmed independently. Outlets in every cell throughout would have been both more costly and more flexible than required, unless the cell size were much larger.

In a few carefully selected areas, the waffles were used as louvers. For instance, in two axial areas which would be natural places for sculpture, the possibility of diffused light from "artificial skylights" was created by having outlets in every cell, fitted with clear or bottom-silvered lamps. Sculpture is highlighted from spot lamps in adjacent cells (3).

The design uses controlled daylight to give vitality to the spaces. The scoop-type clerestories (4) introduce a constantly varying mix of daylight and incandescent light. During the day it is very apparent that some walls are bathed in daylight, others by incandescent. The color mismatch might seem unnatural in a photograph, but goes unnoticed in the understandable context of the gallery itself. The frequent visitor probably welcomes the opportunity to "live with" the works under the range of conditions he would have at home. The view window to the lovely surrounding countryside (the focal point in a major gallery space) is welcomed by most as a pleasant diversion.
rather than competition to the art on display. The opportunity to shift attention to a distant focus is restful for the eyes.

The auditorium (5) was treated very differently, reflecting its different construction and purpose. The steps in the side walls were emphasized by recessed lights; the stage rear, by lighting concealed behind the front edge of a "floating" ceiling.

Having programmed probable positions for sculpture in the garden and terrace, outlet points and fixtures were placed at suitable positions on walls and in the ground to provide adaptable outdoor lighting (6).

At the time when the photographs were taken, baffles in the fixtures for control of spill light had not yet been installed, and some undesirable spills can be seen on the edges of the coffers.
Place Bonaventure, as most people who have been to Expo now know, is not what its name suggests—neither a public square with a monument in the center, nor a great plaza, serving as a platform for a typical arrangement of office towers, high-rise apartment buildings or great halls for the celebration of the arts. Place Bonaventure has no real plaza at all. One of the largest buildings in the world and relatively low in comparison to surrounding office and hotel towers, it is a dense monolith which almost completely covers its 6-acre site. As a building type it has no counterpart anywhere.

Designed by Montreal architects Affleck Desbarats Dimakopulos Lebensold & Sise, this $80-million complex has been constructed primarily to provide space at many scales for the exhibition and sale of products, and supplementary space to shelter and feed those involved in viewing and buying. Its great showrooms serve the international businessman, and the shopping concourse accommodates the local worker on his way to the subway. Built on air rights above the Canadian National railroad tracks, the massive building is shaped by a complicated circulation network which accommodates underground truck routes, parking, a subway station, and sheltered pedestrian passageways, all of which link with corresponding systems which are being developed as an integral part of Montreal’s 200-acre urban core. The complexity of these interrelated functions constituted a major architectural challenge. As a prototype for the dense, multi-use urban complex of the future, Place Bonaventure’s brilliant and unusual parti deserves careful study.

Place Bonaventure’s lack of an actual place, and its dense monolithic shape can be explained by an analysis of the program requirements. The owner’s essential demand was for the type of space which should be artificially lit. Merchandise displayed in exhibition and shopping areas is shown to best advantage under carefully controlled lighting conditions and daylight can be a positive handicap. The provision of vast interior spaces became a practical answer. Only the hotel, auxiliary office spaces for the display areas, and principal public elevator lobbies required perimeter locations to provide daylight and views. This meant horizontal circulation had precedence over vertical circulation for eminently functional reasons. The vertical distance to be travelled by elevators was minimized as was the area of perimeter wall and windows. These fundamental considerations made the conventional tower plaza solution infeasible.

Public enjoyment of the little outdoor open space which the Place Bonaventure complex affords is limited to users of the restaurants which are centered in the rooftop hotel garden shown in the hotel level plan or to future patrons of the small terrace café which is planned for the southern end of the west plaza shown in the shopping-level plan. This plaza’s principal purpose is to serve as an appropriately imposing drive-in entrance to the lower hotel lobby which is connected by express elevators to the main hotel lobby on the roof. The plaza also conceals parking facilities for about 1,000 cars.1

The design process

The project size, its complexity, and particularly the short time cycle between schematic design and occupancy (3 years) might have led to the all-too-frequent design approach which requires little design coordination—a ho-

1"Place Bonaventure, A Unique Urban Complex," The Architectural Record, December 1967, pp. 139–140.
mogenized approach of quickly erected steel loft spaces covered by a suspended ceiling that can conceal any arrangement of services.

Instead, Place Bonaventure represents a commitment to excellence through articulation and integration, despite the time limitations, by means of an unprecedented team effort. All relevant design disciplines worked closely together from concept to execution along with the builder (who, fortunately, was also the owner). Only the quality of the decision-making process and project management could have made possible the consistency of concept in the design and execution of the many integrated, articulated systems and the hundreds of details throughout the building.

The Place Bonaventure character comes from the consistent expression of concepts so clear that they can be expressed in words. The close designer/builder collaboration also meant that all forms were greatly influenced by the actual construction process used. It was not uncommon for structural details to be modified a day before the concrete was poured because of some problem in forming, etc. Since the lighting vocabulary was in concept rather than hardware, on such occasions the lighting was easily redesigned on the spot. The themes were few, the variations many.

Even in single buildings—a shopping center, an exhibition hall, a merchandise mart, an office building, a hotel, etc.—the integration of structural, mechanical, and lighting systems is not easy. When such diverse structures were brought together within a single building envelope with a desire for consistency of details, the difficulties were considerably multiplied. Clarity of design concepts was essential to the achievement of a successful, sophisticated building, especially in view of the extremely tight schedule.

Architectural and lighting concepts

In a typical urban place, buildings of widely varying functions are given a common identity by their relationship to the connecting outdoor space. Since such a relationship is not possible in a series of “buildings” within a common shell, the common denominators must necessarily be limited to those which can only be perceived sequentially.

The concepts which unified Place Bonaventure were as follows: The building was to be masculine, of urban rather than building scale. Public spaces and paths were to be treated as “streets and plazas” rather than as “corridors and lobbies.” Positively defined cores at the corners would contain common facilities such as elevators, washrooms, emergency stairs, etc. The decision to wash the exterior of these cores with light required that they be treated architecturally as “tubes” with punctured openings. The common material was to be concrete in a range of textures. On all levels, the concrete itself was to be formed to conceal light sources, creating glowing lanterns—large lanterns, such as the structural concrete “trees” of Concordia Hall, the floating stairs, the hotel skylights, the hotel entrance canopy, and smaller-scale elements, such as telephone booths (5), step lights, lanterns, bollards, and posts. For sparkle, a vocabulary was built around a common element of clear incandescent lamps baffled with sheets of bronze glass, used for wall brackets (21), room-scale chandeliers, and artificial “skylights.” Globes were considered too “feminine.” Because of the great size of each level, the provision of clear information for orientation was particularly important. Sign requirements were taken as form determinants (sign chandeliers (6,8,10,20), wide transoms and door frames).

On the concourse level, the principal focus and source of the interior “street” lighting was to come from shop windows and signs. However, when shops are unlit or have no display windows,
7 Half-inch-scale study model of artificial "skylight" shown in Fig. 8 below.
column-mounted lanterns fill in and give continuity. As the most consistently available element, columns were kept sacrosanct for this purpose.

Orientation clues are important in such a large enclosed area without normally available orientation information such as exterior building forms, direction of sunlight, etc. Graphic chandeliers of positive rather than apologetic scale were created to display the needed information. The well leading to the Metro station (7,8) was emphasized as a sharply outlined “skylight.” Similar concrete ceiling areas elsewhere on this level were intentionally left unlit, except insofar as they received a soft glow from the windows, column brackets, and “chandeliers” that define the “ed-dies” in the main corridor. As on other floors, exterior walls of the cores were washed with light. Entry points, etc., were highlighted from neutral downlights. A model was used to test the effect of lighting and signing. It verified the effect of the single, main “skylight” above the metro well but led to a change from a uniform band of standardized signs to a more lively, random, bazaar-like scheme.

Objectives and assumptions regarding Concordia Hall, the major space in the complex, were as follows: for the staging of shows the space should appear neutral (i.e., the pattern of lighting should not compete with displays). The ceiling should provide an integral catwalk system from which any amount of totally adjustable lighting could be directed to any display that is not self-illuminated. Neutral “house” lighting should be kept to a minimum. As a place for assembly and receptions, a positive, distinctive Place Bonaventure character was required for the space. A positive space might also be desired for some shows. Lighting (and overhead mechanical and electrical services) should be flexible, without sacrificing the permanent character of the building.

**Design development**

Since lighting coordination started from the beginning of design development, it was possible to develop an integrated structural/mechanical/lighting/display system within a few days.

The original schematic post-and-beam structure would have implied a wasteful structural depth with a hung ceiling to cover the usual disarray of service elements. Extensive perforation of the structure itself to accommodate mechanical runs would have been necessary. A tree-type structure (13,16,17,18) was evolved in order to create clean architectural surfaces which might be positive-ly illuminated to express the maximum volume and to transfer the loads of 25 x 25 foot bays overhead to the 50 x 75 foot bays of the Hall, while still providing the necessary two-way distribution of mechanical services from the corner cores. The trees were braced with a permanent ceiling catwalk system of concrete waffles pierced with an extensive distribution of portholes for lighting, drop cords, hanging displays, and air distribution.

The lighting system incorporated incandescent fixtures in portholes as neutral house lights. The perimeter walls and trees which create the character of the space were defined by decorative patterns of exposed incandescent point sources. More efficient linear sources (such as fluorescent) were avoided because they would have interrupted the structural continuity of the trees for those persons looking up. Continuous high-capacity lighting track was provided along rows of portholes in the ceiling for flexibility.

In circulation spaces within the merchandise mart, cores were given typical treatment (wall washers). Display windows were to dominate corridors with minimum competition, to create the proper focus on the merchandise. Light spill from the displays is quite sufficient to illuminate corridors (9). Supplementary per-
12 Cardboard mock-up, concrete lantern.

13 Services diagram (reflected ceiling plan) of the Concordia Hall tree structure.

14

15 Study model of Concordia Hall.

16

17 Photo overlaid/Michael Drummond
permanent corridor lighting was provided from each door header, and graphic chandeliers were located to define and give orientation at each circulation junction (10).

Walking through other merchandise marts revealed visual chaos as characteristic. Dominant ceilings, varied arbitrarily in materials and lighting over the course of several tenant changes, produce confusion and disorder. A consultant on merchandise marts advised "have an inviolate ceiling."

The design team did propose a unifying concrete-grid system with flexible service space above and provisions for an unlimited amount of lighting flexibility. This ceiling would have been "inviolate" in that very few tenants would have bothered to apply a second ceiling over an existing attractive, exposed structural ceiling. Unfortunately, this scheme had to be abandoned because of the method of financing. It would have been economical if the owner were to have completed all construction, leasing totally finished spaces. However, to reduce the initial capital investment required, the decision was made to lease unfinished spaces that would be air conditioned and finished entirely by tenants at their expense.

The metal-slat ceiling selected as the building standard (23, 24) does help unify the commercial areas, creating a quality that can be maintained over the years and through tenant changes. Unfortunately, the lighting effects are not controlled by management, but the system does encourage some standardization in the form of lighting track and slat-width fixtures.

The hotel variation on the general theme began with an entrance canopy with clear lamps set in concrete coffers and decorative sign chandeliers. Column-mounted brackets at concourse level were repeated closely spaced around the elevator core at hotel level (which is not one of the corner cores). In the lobby, bays of concrete-baffled clear skylights were edged with chandeliers. Long hotel corridors were interrupted by skylit wells (27). The decorative lamp theme was extended to the mirror lighting in each suite (22). Bridges (25) linking the central activity pavilion to the perimeter bedroom zone were illuminated from handrails in such a way as to avoid reflections that would interfere with viewing the garden at night. Unfortunately, heat- (and light-) reducing glass was used in windows looking out onto the garden, which, though they reduce solar heat gain, also reduce the visibility of the garden at night.

To create a ballroom which could be both neutral for meetings and elegant for special functions, a design incorporating neutral downlights, adjustable accent lights, and reflecting chandeliers was developed. Fully collapsible, easily removed chandeliers were conceived to meet the programmed requirement that the full ceiling height be available for projection. However, in the final version (19) the adjustable features2 had to be abandoned and the chandeliers reduced considerably in scale.

The hotel garden features ponds, fountains, and trees. Several forms of concrete lanterns (11, 14, 15) were designed to provide low-level pavement illumination. Where possible, the sparkling incandescent lamps of these lanterns were placed to reflect in the ponds.

Comment

By 1973 the owner (operator of a supermarket chain) had replaced the original vocabulary on the concourse level with uniformly distributed and domineering patterns of fluorescent fixtures, much to the detriment of the space.

2Later accomplished at the Hyatt Regency at O'Hare Airport, Chicago (Case Study C7).
Clear incandescent lamps set the theme at Place Bonaventure
The atrium of the San Francisco Hyatt demonstrates dramatically the effectiveness of a minimal area of clear skylighting in creating the ambience of a pleasant, outdoor public plaza when used with plantings of the proper scale and outdoor materials such as tile pavers and concrete. The highlighted metal sculpture gives a strong focus to the space, while the concrete trellises above the sunken lounges create pockets of space with a more intimate atmosphere at the floor of the cavernous lobby.

The lighting scheme for the lobby consists only of the lighted sculpture, trellises, and trees, complemented and set off by a single band of decorative clear lamps around the perimeter which draws the line between the surrounding commercial space and the lobby proper. The upper surfaces of the atrium are washed with a soft glow of indirect illumination from the handrail-lit balconies.

At the stand-up bar (6) the design team indulged in a bit of perceptual trickery, using the polished metal sides of the hood over the bar to mirror the glittering ceiling around them, so that the ceiling appears to extend in an unbroken plane over the bar.
HYATT REGENCY O'HARE HOTEL
Chicago, Illinois

John Portman & Associates (architect); John Street (project architect); Sasaki Dawson Denney Associates (landscape architect); William Lam Associates, Inc. (lighting consultants); Thomas P. Hughes, AID (interior design and public space planning consultant); Morris Harrison & Associates (electrical engineers); Brit Alderman, Jr. (mechanical engineer); J. A. Jones Construction Co. (general contractor). Cost: $30,000,000. Schematic design started 1969.

The distinction of this hotel comes from its atrium — extraordinarily vital both spatially and socially.

On the basis of biological needs, it was predicted that this vast interior space would be greatly enhanced by the introduction of sunlight to emphasize the spatial volume in a continuously varying manner (with much more variation than would be possible with only a single oculus). During the day, a ring of skylights high above the lobby creates the desired, striking effect. On overcast days, the space is not quite as appealing, just like any outdoor space, but the sparkle of moving elevators, the illuminated trees, the myriad of highlights, and the minimum of visible overcast sky all combine to reduce the effect of inclement weather.

The skylighting is valuable not because of the amount of light introduced but because of the specific characteristics which the daylight brings to the space. The directional light defines surfaces
and volumes dramatically, which become secondary sources illuminating the rest of the lobby. The decision to expose the Polaris Lounge structure to view from the lobby and to use clear glazing for connecting it to the perimeter mass (2) was a late design change. The original scheme called for a luminous plastic ceiling over the entire court with the Polaris Lounge totally separated from interior view. Had the original scheme been executed, a feeling of “permanent overcast” and of interior rather than outdoor space would have resulted, because of the diffuse quality of the light and the glaring nature of the translucent material. On the contrary, the daylight design along with the use of exterior materials and generous planting gives this vast interior space the feel and vitality of an exterior space. The presence of real rather than “artificial” sunlight is biologically important and gives subconscious pleasure to the users of the space. Openings were created in the lobby floor to serve as skylights for the reception level below (17), to establish some contact with outside conditions for this otherwise subterranean space.

At night, too, the space was treated as an exterior. As the sky darkens, so do the skylights, with no attempt to replace the daylight artificially. The lobby lighting becomes totally different as the daylight fades and lighting becomes more intimate, with concealed lighting from handrails, uplighted trees, the glitter of exposed clear lamps, some low floor lamps, and candlelight (4).

While any of the other major spaces might have been no different if located in another building, the common denominators that they share in concept and details give them a natural, perceptible relationship, subtly increasing the impact of each and all.

Positive emphasis of the daytime-nighttime reversal is exemplified by the swimming-pool design, which shifts at dusk from sky dominance (5) to low focus (7). At night, the effect is created by umbrella-chandeliers (with clear lamps visible from close up) and underwater lighting.

In gourmet dining areas, daytime focus is on a daylighted pool. By night, the focus is on illuminated fountain/chandeliers (with clear lamps). The captivating effect of the pool itself is reinforced by application of the perception principle that biological instincts are aroused by water about to spill (18). The attraction is much greater than if the water level were 6 inches below the edge.

Hotel ballrooms are a challenging design problem. They must be suitable for a range of activities (from business meetings and banquets to fashion shows, balls, weddings, etc.) and usable as full rooms or subdivisible into a variety of spaces. Lighting therefore must provide totally different environments for all these possibilities. Any single design arrangement sufficiently flexible to provide for all these activities and conditions cannot be anything but a compromise. Any design effect can be varied by dimming, but the variability of effect is maximized when the relative focus (or the pattern of foci) is variable as well as
the intensity.

It was necessary to develop for the ballroom a ceiling system with integral lighting which could be used to create a number of different ambiances. The first and most basic function was to provide neutral downlighting throughout the entire space, with ceiling and light fixtures as inconspicuous as possible (19). Wall lighting which can be modified as required is essential to the creation of a really flexible space—while some walls were to be treated with a decorative chandelier effect, others would have to serve at times as neutral, highlighted backgrounds for displays, etc. In addition, the basic lighting system had to provide focal lighting at potential "head table" locations, and at all potential locations of staged activities. Beyond these more functional requirements, the lighting had to provide a rich decorative effect, preferably with a distinctive character which would identify each individual ballroom. Any chandeliers had to look balanced and appropriate with either the subdivided or the whole room. A successful system would permit the easy creation of appropriate combinations of decorative and unobtrusive functional lighting to suit all possible events.

The ballroom ceiling is made up of Plexiglas cubes, some of which enclose fixed downlights for neutral house lighting, while others house adjustable fixtures which can be used to accent head tables and impromptu stages. Perimeter cubes were left open on the outer face to house wall washers. A similar ceiling system was developed for the function rooms (23). A pool and fountain (24) provide a dramatic entry to the complex of function rooms and the lower lobby.

The decorative chandelier effect was accomplished by a large, room-scaled sculpture of reflecting plastic balls (22) that can be lowered and illuminated from neutral sources, and raised to disappear above the ceiling plane when a business-like environ-
ment is desired or when a room is subdivided. Various degrees of intimacy can be attained depending on the height of the chandelier and the relative brightness of chandelier and other areas.

Screens of reflecting plastic balls and mirrors also line some of the walls and can broaden the decorative effect when desired. Unlike traditional internally illuminated chandeliers and wall brackets, these reflecting sculptures and curtains do not look unnatural when not illuminated.

The reflecting chandeliers, mirrored walls of the ballrooms, and patterns of clear lamps of the lobby and pool were repeated with variation in the bar (20), the executive health club game room (10), and the nightclub. The glowing red fabric of the nightclub ceiling was intentionally illuminated unevenly from the perimeter with hot spots related to the spacing of louvers. A ceiling with similar variation of luminance in an accidental, unplanned pattern would appear unevenly lighted, rather than giving evidence of a coordinating design intent.

The problem of lighting rooftop restaurants such as the Polaris Lounge is to enliven the atmosphere during dull days while interfering as little as possible with the view at night. The mirrored inside walls of the Polaris Lounge add to the view both day and night. The glowing ceiling, dimmed at night (21), reflects high in the windows but does not impede the downward view to the Chicago skyline. The guest tower roofs were outlined to give a close exterior view and reference point to those in the lounge, as well as to add to the exterior image of the entire hotel. The dramatic impact of the Polaris lobby was maximized by the use of a single light source (and focus) day or night—the skylight/chandelier (11).
The typical college arts center is usually built as a cluster of separate masses, each with its own structural system, connected by corridors for services and public circulation.

At Beloit (1), the integrated design process began with a field trip conducted for the design team to instill in the individual members an appreciation of what could be accomplished with an articulated approach which would integrate structural, mechanical, and lighting elements into an expressive architectural solution—as opposed to the homogenized solutions which might otherwise have been proposed. The investment of time and expense seemed to have been extremely worthwhile, to judge from the interdisciplinary cooperation which followed throughout the course of the project.

The initial schematic plans led to a tentative exploration of a tree-type structural approach, but this line of exploration was abandoned for several reasons. Primary among these reasons was a shift in the architect’s concept from formal, rectangular spaces toward informal, irregular polygonal spaces as the most appropriate to accommodate the variety of spaces in the program.

Therefore, the approach shifted from a highly articulated structure to a totally neutral one. The very tight budget suggested that all spaces be created within concrete lofts hung on a regular column grid. The desire for partitioning flexibility with good acoustic separation between the subdivided spaces led to the selection of a flat slab, lightened with tubular inserts. Against this hard, flat ceiling, partitions can easily be placed and sealed in any configuration desired without sacrifice of acoustic isolation, an objective which would have much more difficulty to achieve with a waffle slab, a steel frame structure, or a rib slab—any of which might easily have been selected during the early phases of a conventional sequential design process.

**Design**

With the flat slab thus predetermined, lighting design commenced by addressing the most limiting factor: the distribution of air conditioning and other services. With two levels of public spaces, ductwork could not be channeled entirely within the walls or run directly up from the basement, which might have been possible in a smaller and simpler building. Under these circumstances the most common approach is to use lowered ceilings in corridors to conceal the necessary services so that the major spaces can be kept free of ductwork.

However, because of the desire to use the connecting spaces as important galleries and public spaces, an alternate design was developed in which the perimeter of the major spaces is used for the distribution of services to those spaces themselves and to adjacent public areas (2). For this purpose a valance system (3) was developed to conceal ducts while supporting and baffling light fixtures. The dual purpose led to a universal rack for services and an unusually deep valance, with light sources fairly far out from the walls. The maximum display height on the walls is reduced somewhat with this system, but the design team felt that this was a worthwhile tradeoff in exchange for full-height circulation spaces.

The valance system was used wherever appropriate throughout the center, supplemented as required by other systems. During intermissions, the theater (5) is illuminated by wall lighting plus inconspicuous downlighting from the ceiling of the hall. During lectures with projection, the downlights alone are used. For the display of art and other material (4), wall lighting plus track-mounted adjustable downlighting was provided; art studios received a similar treatment. In music practice areas, wall lighting is quite sufficient for illumination of the back rows; supplementary downlighting was provided for front rows.

*Tree-type structures, based on two-way cantilevered platforms with integral perimeter service distribution channels, are discussed in Case Study Bi-f (Place Bonaventure) and in Section E, below.*
HYATT REGENCY HOUSTON HOTEL
Houston, Texas

(JV III), Koetter Tharp & Cowell, Caudill Rowlett Scott, Neuhaus & Taylor (joint venture architects); William Lam Associates, Inc. (lighting consultants); DuBoise Gallery (art consultant); Chenault & Brady (mechanical engineers); Walter P. Moore & Associates (structural engineers); W. S. Bellova Construction Corporation (general contractor); Elster's (interiors contractor). Schematic design started 1970. Construction completed 1972.

For the Hyatt Regency Houston Hotel, the design team attempted to attain some of the successful qualities of the O'Hare Regency lobby while working under the handicaps inherent in greatly different room proportions—narrow and high rather than wide and low. Fortunately, lighting coordination took place early enough so that modifications were still possible in the plan as well as in fenestration and other details.

The success of the O'Hare lobby came from the deep penetration of sunlight, which reflects from large areas low in the space throughout the day and creates a pleasant, outdoor environment. The intimate people-watching contact was equally important but less easily obtainable in a tall building such as the Houston Regency. It was observed that the Atlanta Regency lobby seemed comparatively "dead" because the small, clear oculus allows only small patches of sunlight to be seen. A luminous ceiling was to be avoided. The pendent fixtures used at O'Hare to help the growth of trees were to be avoided if possible.

Design

While desirable, a transparent roof over the entire space was not within budget. Consequently, clear skylights were placed along two edges of the space (5). Sunlight penetrates deeply into the space for much of the day. These bands of skylights were then con-

1 Early scheme.

Lobby Level Plan
1 main hotel entrance
2 Whistler's Walk (sidewalk cafe)
3 Park in the Lobby (sunken seating garden)
4 Coffee Shop
5 service kitchen
6 service bar
7 Keeping Room (restaurant)
8 auto entry
9 women
10 men
11 service elevators
12 access to tunnels
13 Back Room (music bar)
14 news and tobacco shop
15 front desk
16 administration
17 baggage
18 fire stair
19 elevators

3 Final scheme.
continued as windows down to the ground (3) to further increase the sunlight penetration low in the space and to add an element not present at Atlanta: some visual contact with the surrounding city. Concentration of planting in this area of high natural daylighting should make it relatively easy and inexpensive to maintain.

The decorative clear-lamp scheme of Chicago was expanded at Houston to define the elevator shafts (7) as well as the moving cars and to screen their shafts (the lines of bright sources making it more difficult to discern the details of the darker shafts behind). Lines of clear lamps above the elevator doors signal the arrival of cars (11). Doors to guestrooms were recessed, and it was natural to express their rhythm with strips of the same clear lamps. Handrail lighting could thus be restricted to the public levels, since the lamps over the guestroom doors provide ample corridor illumination. At the Houston Regency the handrail lighting was not considered a major architectural theme to be used consistently throughout the building, and a more neutral detail was developed (compared with O'Hare) based on the standard handrail designed for the Houston Regency.

It is relatively difficult to grow trees in most large interior spaces. While the trees in the Houston Regency lobby receive some daylight from the skylights, a steady additional 250 footcandles was estimated as desirable. Seven very-narrow-beam spotlights could have been used to provide the required illumination from an oculus in the ceiling. This

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Section
1 motor entry
2 Keeping Room (restaurant)
3 garages
4 exhibition hall
5 kitchen
6 offices
7 laundry
8 Imperial Ballroom
9 ballroom foyer
10 mechanical
11 Back Room (music bar)
12 meeting rooms
13 Window Box (gourmet restaurant)
14 elevators
15 Spindletop (revolving restaurant-lounge)

4 Tree lighting from a single oculus.
5 Tree lighting from a pendant chandelier. (A) Skylights. (B) Beam spread from tree chandelier as built. (C) Beam spread as designed.
scheme would have required an expensive fireproof room around the oculus. Therefore, an alternative was developed—a large chandelier 200 feet above the trees—which would be less expensive both to install and to operate (4, 5).

The clear-lamp theme is continued in the nightclub and terrace restaurant (8), while reflecting metallic sculpture provides the chandelier effect in the ballroom (10) and gourmet dining areas (9). Reflecting sculptured forms were spread out throughout the ballroom space and shaped so that any segment of the sculpture seems complete and natural when the space is subdivided. Original plans for lowering and raising chandeliers were dropped in favor of keeping the forms close to the ceiling where they would interfere as little as possible with any activities in the space.

In the design of any major hotel ballroom, a number of problems are almost always encountered. How to conceal tracks for partitions used to subdivide the space? How to provide flexible stage lighting? How to create a space which can be used as a single unit or as several separate units, yet present a finished appearance in any state? At O’Hare, the rectangular geometry of the ballroom suggested a ceiling of rectangular Plexiglas boxes which screen partition tracks, mechanical equipment, light track, and downlights. At Houston, a similar inexpensive ceiling was created out of short lengths of Sonotube sprayed with flock and hung below the ceiling hardware. The choice of circular forms grew out of the hexagonal room shape. Because the budget did not permit the design team to illuminate every tube, the downlights were designed so that they spill no light on the tubes themselves—a totally neutral solution which can be supplemented at will with sparkle from the glittering chandeliers and rich color from the walls.

The copper coffer/chandelier theme designed for the health club at O’Hare was reinterpreted for a new stand-up bar at Hous-
8 Whistler's Walk.

9 The Crystal Forest.
ton. In the Crystal Forest (9), the intent was to create a sense of glittering trees of metal and light. The ceiling was too low to create full-height artificial trees, so half trees were hung from circles of mirror which complete the illusion.

The Houston design team was able to maintain control of the guestrooms (12,13,14,15), which was not the case at O'Hare. Early commitments to lighting concepts made a new type of room foyer possible (12). The space was kept full height and its apparent width extended by the lighted transom and low closet doors. In the bathrooms (15), the quality environment was maintained by edging mirror tops with clear lamps. The usual unsightly access panels were neatly integrated into the bathtub niche.

The wall return enclosing the bed ends helps to give the bedside lighting a built-in look, even though the fixtures are traditionally “lamp-like” in form. Cost of the decorative ceramic lamps was kept down by detailing the fixtures so that the Mexican-made ceramic shades could be bought directly (separated from the electrical contract) and installed or replaced without an electrician.

The general design themes and qualities were extended to the automobile entrance, to the adjoining parking facilities, and also to an office building (Case Study F3), by the same developers and design team, connected to the hotel by a pedestrian walkway.

Critique

Late in the development stage, the lighting consultants lost control over the “tree-growing” chandelier. The substitute chandelier designed by the manufacturer failed to produce the very sharply defined narrow beam required to minimize glare directed toward the rest of the lobby.

12 Mock-up of the typical suite foyer.
13 Mock-up of the typical suite.

14 Mock-up of the typical suite with downlight only.

15 Mock-up of the typical bathroom.
SEQUENCES OF SPACES ORGANIZED ALONG FIXED CORRIDORS

As the design of any sequence of major spaces should relate each to the others, so a series of spaces along a fixed corridor should be interrelated in even more specific and definable ways. Such relationships, expected if the design is to seem natural, offer a challenge and an aid to the creation of a clear, ordered, forceful, and comprehensible design, rather than one which is homogeneous and characterless (the uniform, suspended ceiling with a regular pattern of light fixtures) or even disordered.

Assuming that the luminous environment of each space provides for its specific activity needs, what are the expectations which must be met to satisfy biological needs of orientation?

If one were to look out of several windows on the same wall, one would expect to see the same horizon, weather condition, time cues, etc. One would also expect the frame of reference, the window wall, to have some consistency in terms of structure, materials, etc., unless there was an apparent reason for variations. Because seeing is a mental rather than a merely photographic process, these expectations hold even if the windows are viewed sequentially rather than simultaneously.

Similarly, in walking down a corridor one expects similar consistencies in the corridor “view.” The ceiling, walls, etc., should be treated consistently and any variations should seem to be naturally derived from perceptibly different influences to which the design responds.

From a design viewpoint, the fixed corridor is a great help. Like the fixed window wall, it can be an anchor, giving a fixed condition to which other elements can be related. The fixed corridor position can be useful in the placement of skylights, lighting equipment, ductwork, mechanical rooms, load-bearing walls, columns, changes of ceiling height and materials, etc. Care must be taken, however, to assure that projected space subdivisions will not be unduly handicapped by the fixed corridor position.

Whether or not the opportunity is given strong expression, fixing of the corridor position almost always offers potential economy over more flexible designs. Building types in which fixed corridors are likely to be the selected tradeoffs include hospitals, dormitories, hotels, and some types of laboratories, schools, and office buildings.
The original design for this fine old building (dating from 1836) was based on a fixed-corridor scheme. Major architectural assets of the original design were the different types of vaulted brick ceilings which graced the various spaces. These positive assets as well as other important features were ignored when the other half of the building was remodeled to house the National Portrait Gallery (2).

The subsequent remodeling for the National Collection of Fine Arts might have been handled with similar insensitivity had not director David Scott engaged consulting architect Bayard Underwood. Despite the fact that remodeling plans had been underway for years, the new design team was able to halt the process, and redesigned most elements—particularly the lighting. There was to have been much unnecessary new construction, with air-conditioning grilles, fire-hose cabinets, and other elements placed in locations which would have interfered with the best display positions. These false starts were rectified wherever possible. Plans had called for the installation of very large, cumbersome fluorescent/incandescent valance fixtures, which might have been appropriate under other circumstances; however, when applied indiscriminately...

2 Obtrusive lighting forms in the National Portrait Gallery.

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across windows and in no consistent relationship to the several types of ceiling vaults, such valances were totally misused and out of place. To preserve and accentuate the old construction, new lighting was designed to complement rather than nullify the existing forms.

**Design**

Rooms with groin vaults and fixed walls (3) suggested the placement of a single pendent fixture (4,5) in the center of the space to illuminate the vault (when desired) and to house adjustable reflectorized lamps that could be directed anywhere on the four walls to accent the displayed works. The fixture forms evolved from the function: to provide louvering and a clean profile to reduce the dominance of the fixtures without excessive restriction of the aiming flexibility.

In the Lincoln Ballroom (in which President Lincoln held his Inaugural Ball), larger-scaled versions of the pendent “flower” fixtures were to have supplemented existing indirect fixtures located in the column caps (6). Their omission at the last moment was unfortunate and resulted in extensive use of local lighting mounted on display panels and overhead track (11). These add counterproductive visual noise when used in such a large open space.

Barrel-vaulted spaces (7; compare with 8) were illuminated from lighting track arranged parallel to the axis of the vault. Here the valance design could have been used with less conflict with the structural forms.

In corridors (9), small brick vaults run perpendicular to the main corridor axis. This suggested the use of discrete sources rather than the use of either continuous light sources or continuous power distribution track crossing the vaults. While a line of exposed adjustable fixtures aimed at both walls would have been satisfactory, the predictability of the fixture locations and the desire to keep the ceiling plane as unblemished as possible led to development of fixtures that could be aimed at both sides of the corridor, while presenting a clean profile when viewed down the corridor. These were related in concept and detailing to the pendent flower fixtures.

Galleries with new suspended ceilings were illuminated from recessed downlights (10).
Treatment of a similar space in the National Portrait Gallery.
Buildings with air conditioning and heavy service requirements frequently devote even more of their volume than necessary to mechanical services. Such waste is easily avoided in a typical hospital plan, with narrow zones of patient rooms at the perimeter separated by fixed corridors from interior work spaces. Since all spaces can be easily serviced from the corridors, the upper portion of the corridors themselves can be used as the main service distribution channel, and the surrounding spaces can be made correspondingly higher with only minimum enclosed ceiling depth.

Starting points of the design at Stamford were a desire to express the curving corridor shape and to take advantage of the
change of ceiling heights. Intermittent light slots were made to accentuate the curving walls and the openings which penetrate them (3). These slots also house incandescent nightlighting. Patients are not exposed to the usual glaring fluorescent lenses when looking into the corridors. The subdued corridor patterns made emphasis of the nurses' station simple. Patient rooms (5) are organized against the service wall which contains the intercom, oxygen, etc. Therefore, it was natural to organize the lighting around this headwall and the stipulated bed positions.

From this wall, it was simple to provide indirect illumination for a substantial part of the ceiling and wall surfaces, in order to overcome the sensation of gloom that results from dark room surfaces when contrasted with bright windows. This indirect illumination is also sufficient for most room activities. Additional direct lighting from 4-foot-long fluorescent sources in the same fixtures was supplied for reading. This direct/indirect combination makes most examinations possible without limiting posture or necessitating constant adjustment of the exam light (as would be the case with more concentrated incandescent sources). Indirect nightlighting, using 7-watt incandescent lamps, distributes a small amount of light throughout the room rather than at one spot on the floor. A night-light in this position can easily be used by a nurse to read a thermometer, etc., making it unnecessary to turn on other room lights which might disturb the patient.

The scheme established for the repetitive patient floors is continued to the extent possible on the main floor (6), which is subdivided irregularly for offices, etc. Supplementary local lighting (4) is provided as necessary.
Designed by the same team which was responsible for the Plymouth Schools (Case Study D9), the Sutton School takes on its distinctive character from the deep plaster-enclosed steel structure which spans between the main corridor and the perimeter walls of the building, creating a series of 20-foot-wide bays. This visually strong framing system offered the means for a consistent indirect lighting approach which could be applied throughout the school. Continuous, extruded aluminum cove fixtures were mounted on the bottom edges of the main beams which define each bay. Because of the considerable distance between the central corridor and the exterior wall, several lines of monitored clerestory windows were introduced. These define the main corridors (4) and the edges of class-
room spaces. Classrooms can be divided by folding partitions; the monitors were coordinated with both the movable partition lines and the permanent walls of the classrooms (6, 7). The corridor monitors admit sunlight, which helps to meet the biological information needs for sunlight, weather, and time orientation without interfering with other activities.

Because of the different nature of the biological and activity needs to which it must respond, the luminous environment of the windowless auditorium (8) is quite different from that of the typical classroom. Walls are illuminated from slots at the top, which has the effect of floating the suspended ceiling free from the walls. The glowing walls, which respond to expectations for bright surroundings during the day, provide a pleasant, cheerful environment for most activities. The slot lighting is supplemented by architecturally neutral recessed downlights in the ceiling, which can be used for note-taking during projection, when the room surfaces need to be dark. The downlight system can be dimmed.

In the gymnasium (9), on the other hand, a completely different system was called for due to the requirements for a cheerful, bright space free from glare when viewed from any position or angle. This was accomplished by indirect lighting, with continuous fixtures attached to the bottom chords of alternate roof trusses—a variation on the theme established in the classroom zone. Where it might be needed, supplementary track-mounted flexible downlighting was designed for special occasions. Unlike a college gymnasium, with its special spectator and TV lighting requirements, there was no need at the Sutton School gym for high-intensity downlights.
This design capitalized fully on a fixed-corridor scheme, which is given strong expression both in the facade and the open first-floor lobby (4).

**Design**

Lighting takes advantage of and reinforces the lines of the paired corridor edge beams and paired perimeter edge beams that were created to enclose service runs.

On typical floors, indirect cove fixtures along the edges of these concrete service channels illuminate the exposed concrete slabs in between. Since the large exposed duct would have blocked off some of the indirect light from below, the duct itself was used to shield additional indirect fluorescent strips, and its shape was changed from round to oval to improve its performance as a glare baffle (7). The indirect lighting could have been located on the other axis (perpendicular to the corridor), but this scheme was rejected since it would have created a hot spot on the bottom of the duct directly above each fixture.

The selection of fixture lengths was determined by the partitioning module. The natural gaps between fixtures in the cove fall on the module, so that partitions can be added or removed without requiring any modification to the lighting system (6).

Regardless of the level of general illumination, local lighting is
often desirable in laboratories, particularly those with overhanging cabinets. Local lighting is also an appropriate response for infrequently used counters by windows which are normally well lit during the daytime, rather than
trying to increase the level of general illumination so that these areas are always lit at night as well. Power and budget were allocated for this purpose. Individual room switching is also desirable because of the varying activity needs. The cost of individual switching in each room can be quickly offset by the great economy gained by keeping the artificial lighting off when daylight is sufficient or when rooms are unoccupied.

In operating rooms (9), the adjustable operating light is supplemented by the illuminated walls.

When fluorescent lighting was not feasible because the magnetic and other fields produced by both lamps and ballasts would interfere with sensitive instruments, the same scheme was executed with incandescent sources.

The high quality of the luminous environment achieved with this system is immediately obvious when comparison is made with basement rooms (8) and other spaces in which the general lighting scheme was compromised.

Critique

The corridors (5) would have been more spacious and interesting if treated asymmetrically (light slot on one side only) reflecting the asymmetric position of the elevator lobbies rather than the symmetry of the corridor-lab structure. An asymmetric arrangement of indirect corridor (10) and office lighting (11) was used, however, at ground level under the podium. On that level the structural coffers themselves were not used as light baffles for bare lamps except in a limited area to define an elevator lobby (12). Where the intent was not to create a focus, more neutral downlights were placed in the coffers.
When the plan organization, section, and materials in two hospitals are similar, one would expect to find similar lighting solutions; in this respect, the Griffin Hospital closely resembles the Stamford. However, one should not take these as universally applicable details. A glance at the Easton Hospital (Case Study E6) shows that where the nature of the building is radically different, entirely different lighting solutions are both possible and desirable.
In a science and classroom building, one expects the spaces to appear bright and shadowless rather than dramatic. Diffuse rather than strongly directional light is usually best, minimizing direct and reflected glare at desk tops. Design for comfort in viewing the chalkboard, teacher, and fellow students is at least as important as providing optimum conditions for note-taking and reading pencil handwriting—the task often taken as the simplistic basis for minimum footcandle criteria.

For accommodation of lighting and mechanical services, a small-cell waffle structure is no better than a flat slab. The structure provides no integral, easily accessible channels for services. It is only useful for baffling light if a lamp in each cell can be afforded or if a busy checkered pattern is acceptable. However, when downlighting from point sources is called for, small waffles can be a sympathetic background for mounting incandescent cans. While no better than small-scale waffles from the point of view of running ductwork, larger waffle structures allow more possibilities for lighting (compare with the Mount Royal Library, Case Study B4, and the lower levels of Quebec Government Center, Complex "G," Case Study H5).

Design

The waffle structure of the North Park College Science Building was treated as a flat slab. In corridors, dropped ceilings enclose ductwork, with the corridor and elevator recesses defined by edge lighting. This concentration of services allowed the classrooms the full height of exposed structure.
The corridor-to-window depth of these rooms was sufficiently narrow (20 feet) to make illumination from only two sides both feasible and practical (4). In recognition of the irregular room lengths, all indirect valance lighting was placed on corridor and window walls (3). Although the lamps were centered on each wall, valances were run from wall to wall in order to appear natural rather than stuck on.

The indirect lighting was made more effective by keeping the window height level with the door headers to allow maximum space above valances for light distribution (3). Panels required for acoustic purposes were placed level with the bottom of the perimeter cells to reduce trapping of the light by those cells (5).

Unlike the fixtures in buildings with a well-defined transverse module, such as Children’s Hospital, the lighting fixtures at North Park Science must be rearranged if room lengths are changed in the future. Such changes, however, were expected to be very infrequent, and the cost of rearranging the lighting was estimated to be an insignificant percentage of the total cost of moving a wall.

The adjacent first-floor auditorium (7) was expressed as a totally different structure, both within and without. The connecting lobby has a waffle structure, but was illuminated very differently from the classrooms (with decorative incandescent globes) to reflect the difference in use and to show its relation to the auditorium.

Exaggerated programmatic maintenance demands for the biology labs, requiring sealed fixtures to prevent the accumulation of dust, dictated a large compromise in the visual environment (8). In some laboratories indirect lighting was possible, and the resulting environment was far more cheerful and comfortable (9).
Blocked from erecting its own headquarters building by zoning restrictions, the AMAX Company negotiated a long-term lease on a conventional Emery Roth lofttype speculative office building under construction in downtown Greenwich, and hired the LCP team to create interior spaces appropriate for the headquarters of a multinational corporation.

**Design**

The consistent placement of private offices at the perimeter with supporting staff functions, conference rooms, and reception areas clustered in and around the core suggested that the conventional field of glaring lensed fluorescent fixtures in a flat acoustic tile ceiling could be replaced by an integrated ceiling and lighting design which would respond far better to the distribution of space uses. It was anticipated that the corridors would not be realigned during the lease period. The design recognized that the perimeter offices could be comfortably and effectively illuminated during the day with daylight from the windows balanced by indirect illumination from the corridor wall.

To increase the distribution and effectiveness of the indirect illumination, it was desirable that the ceiling should be as high as possible in this area within the constraints established by structure and mechanical runs. By keeping the major ductwork within the core zone, it became feasible to increase the ceiling height in the corridors as well as in the perimeter offices. The transition is made with a sloping plaster band which further defines the core zone (2). By glazing the upper portion of the corridor wall, both corridor and perimeter offices could be illuminated indirectly from a fluorescent strip located in a continuous shallow cove which caps doors, closets, and filing and counter recesses on the office side (3). Orientation in the interior zones is provided by the continuous clerestories, by windows at the ends of the major corridors, and by the consistent illumination from slots of all walls on the core side of interior work stations. Nondirectional low-brightness 2 x 2 foot fluorescent fixtures were used to provide supplementary lighting for the perimeter offices at night (4) and were coordinated with the interior work stations in the core zone (2). Incandescent lighting was provided for wall washing, and to highlight planting, works of art, and reception desks. The design team concluded that any resulting deficiencies in task lighting could be corrected through the use of local lighting under shelves or desk lamps.

**Criticism**

Several decisions which were made without our knowledge or approval somewhat undermined the effectiveness and economy of the original lighting scheme. The owner of the building doubled and in many instances quadrupled the number of recessed fluorescent fixtures called for in our layouts. Problems of glare were further aggravated when both dark furniture and dark carpet were installed. The team had originally called for light-colored carpet and furniture to improve the light distribution and brightness balance of interior spaces, and had capitulated to a request for dark carpet provided that the specified light furniture would be installed. This was not done. Bronze glass panels were installed between triple secretarial alcoves in the core zone (5), rather than solid partitions, which further reduced the reflectance of these spaces, worsened the brightness balance in them, and added unpleasant multiple reflections of the fluorescent fixtures, as well as making the spaces somewhat gloomy. The slot lighting at the rear of these alcoves was converted to under-shelf lighting throughout the project when shelving was called for in several areas, which reduced the effective contribution of the slot lighting to the general room illumination.

Despite these deleterious compromises, enough of the original concepts were implemented to create a distinctive environment, more comfortable and pleasurable than most.
permanently fixed, the series of spaces in this museum undergoes constant change. Therefore, a major design objective was to accommodate those expected changes with reasonable ease and flexibility.

**Design**

Although anticipating that the ceilings would be dark in color (to minimize competition with the exhibits), the design team nevertheless wanted to give a strong visual order to whatever structure was visible. A system of alternating mechanical service and lighting channels fed from the corridors (3) was designed to accommodate any service requirement (both above and below) with maximum convenience and without the appearance of "scarring" which occurs when a flat ceiling is interrupted by fixtures and by the inevitable random splashes of light accidently spilled from displays (6). The robustly expressed structural/mechanical/lighting system camouflages such irregularities and provides sufficient solid surfaces for anchoring partitions, etc. More "refined" types of structures, such as waffle slabs, would have had almost no flexible service capability, while continuous suspended louvers would have given much more flexibility than necessary.

Over the courtyard the ceiling/roof structure was somewhat modified. The service channels (5) were conceived as catwalks for suspension of displays and support of irregularly placed special lighting equipment. A regular pattern of house lighting was placed within the channels for ease of access for relamping and aiming.

In contrast to the exhibition spaces with their irregular accent and integral display lighting, the connecting corridors were illumi-
16 Conventional step light (A) with glass lens cast into concrete bollard.

17 Entry canopy.
nated to be visually simple organizing spines. Concealed, louvered slots were placed at the edge of a totally accessible ceiling of tectum planks (4,20). A similar approach was used in the stairs (11) and in the new main lobby (18,19) connecting the new wing to the original Museum.

In this lobby, clear edge skylights reduce the usual problems of joining to existing buildings with different materials, detailing, etc. (In this case, the old wall was resurfaced.) Note that supplementary lighting in the lobby is intentionally nonuniform, accenting the turnstiles and the landing to clarify circulation destinations (7).

In the auditorium, infill panels were placed between the service channels for acoustic control. Light sources were either concealed behind beams and panels or made architecturally neutral in appearance. The overall system was designed to permit a variety of effects by switching and dimming (8,9,12,13).

The book store was given a conceptually similar treatment—architecturally neutral sources, glowing wood, and highlighted displays (10).

Concepts of light sources concealed by structure were extended to the site; fixtures were integrated into bollards (14,16), benches, and the ramps of the adjacent parking garage. In contrast, decorative exposed lamps were used to create a positive focus at the entrance canopy (17) to aid orientation.

To minimize skyline clutter, the garage roof level is illuminated by one fixture of neutral shape and full cutoff, which eliminates spill light beyond the building. This fixture will be simple to move as the garage expands upward. Because service trucks would have some difficulty reaching the roof deck, the steel pole was provided with removable climbing rungs.

20 Emphasis on circulation (corridor edge slot illuminated).
The Plymouth Schools represent a building type in which all spaces are massed along fixed corridors in major clusters joined by lobbies. In this essentially linear scheme, corridor ceilings were lowered to provide channels which accommodate all major services.

**Design**

Since the distance between corridor wall and the exterior was not excessive, it was possible to emphasize the organizing function of the fixed corridors in the lighting design. All major lighting comes from these fixed elements (4). For the most part, lighting was kept away from the transverse walls, because they vary in their spacing. In special-purpose rooms, such as the art studio, the indirect lighting system was supplemented with incandescent fixtures mounted on tracks.

A large central open teaching area and the gym vary in execution but not in concept. The exterior and corridor walls of the central room (8) were defined by skylights. The gym (6) is indirectly illuminated from fixtures mounted on the bottom chords of the roof trusses. Shape and position of ducts were selected to relate to the lighting.

In the lower library level, where low ceiling height and furniture arrangement did not offer possibilities for indirect lighting, low-brightness 1 x 4 foot fluorescent downlights were used. In the two-story area, light from the large north-facing window was supplemented by illumination of the upper walls from slots and by incandescent downlighting.

The connecting lobbies (5) were treated as “weather enclosures” for the intervening spaces, which are crossed by bridges and ramps. The walls spanning between the major masses are totally glazed. Daylight is supplemented by illumination of the end walls of the masses from fixtures on tracks and concealed in the edges of the floating ramps. Floating of the ramps accentuates the perception of the lobbies as bridges between the major masses. The free-floating lobby roofs make this relationship even more clear. A similar concept was applied in the design for the lobby of the Boston Museum of Science (D8), and at the University of Wisconsin at Stevens Point (H4).
For introverted buildings such as museums, fixed corridors are likely to serve not only as the main channels for mechanical services and traffic but also as a replacement for windows as points of reference (orientation) and as visual rest centers (change of pace). In this second role, corridors are often supplemented by courtyards. In the west wing of the Boston Museum of Science, fixed corridors serving display spaces encircle an artificially illuminated multistory interior court, which contains large objects such as submarines and space vehicles. Controllable artificial lighting is usually best for the display of such diverse objects, since it can be used to create a variety of moods and effects suggestive of their natural settings.

Architects have traditionally felt that the display of paintings in a museum should not be much different than in the home or building for which they were originally created. "Rooms" should be provided to which the paintings will have a normal-scale relationship. However, the "natural habitats" of many objects in a science museum bear no relationship to "rooms" (consider an artificial wave or a locomotive), and such objects are probably best exhibited in settings quite divorced from conventional rooms.

Unlike hospitals or schools in which partitioning is likely to be
5 Integrated lighting and support catwalk above the central exhibit well.
Most older academic buildings were built with fixed corridors and with walls that were rarely if ever moved. When the Old Arts Building at McGill University was remodeled for better lighting, acoustics, and air conditioning, the design team attempted to retain as much of the original character as possible, for aesthetic as well as economic reasons.

The classrooms offered lighting opportunities usually unavailable in new structures: high ceilings which could be used to efficiently distribute indirect lighting. With all walls permanent, the natural solution was to apply valance lighting as low as possible. A continuous band just above the chalkboards might have appeared to bisect other walls where no chalkboard was present. At McGill, however, the valances could be coordinated with acoustic wall panels provided between the valance line and the ceiling to give needed acoustic absorption. Valance lighting from three sides was used to balance off the daylight distribution from the fourth wall.

When it was necessary to divide a classroom-sized space into smaller offices, the new “horizon line” created by the valances was maintained as an unlighted cap to the partition walls; the spatial and lighting character was maintained with clear glass transoms. Since the indirect lighting was made less efficient by the reduced area of reflecting “sky” available to the smaller rooms, the lighting there was supplemented by incandescent downlights. In the art department, a balcony was introduced, but the lighting organization was maintained (3) with some special detailing to accommodate the different room geometry.

With the corridors fixed, there was good reason for them to be finished and lighted quite differently from the classrooms. The existing pendant fixtures appeared somewhat dreary and were given sparkle by substituting clear lamps and glassware. In the form of a contemporary chandelier, sympathetic but different treatment was given the stairwells (along with new plaster ceilings and walls).

Similarly, in remodeling the auditorium, the character was maintained with lighting improvements. The windows were blocked off, and chandeliers refinished and supplemented by neutral downlighting. When used alone, the dimmed downlighting system provides an alternate luminous environment with unlighted walls and ceiling to allow note taking during lectures.

To achieve a space of better proportions for the display of paintings and to hide the busy original skylighting details, narrow corridors in the art department were reduced in height. Lighting track and fluorescent strips concealed behind the new large-scale wood louvers provide unlimited display possibilities very simply and economically.
SEQUENCES OF SPACES WITHOUT FIXED CORRIDORS: ARTICULATED SYSTEMS FITTED TO PREDETERMINED EXTERIOR FORMS

When the exterior forms of a project have been determined prior to the inception of lighting design, it is still possible to develop an articulated "system-of-systems" integrating structural, mechanical, and lighting elements which fits into the predetermined forms and provides required flexibility for moveable corridors and other subdivision, while achieving outstanding, successful, appropriate visual environments.

The case studies presented in this section illustrate three different design approaches: In the first two case studies, a predetermined structural system was maintained, while the proposed mechanical system was modified to accomplish lighting objectives. In the fourth, the MacMillan-Bloedel Building [E8], the initial structural system was modified to conform with new mechanical and lighting concepts. In other cases (the Cummins Building [E3], the University of Lethbridge [E7], and the Easton Hospital [E6]), entirely new structural systems were developed. In these buildings, both the interior environment and the exterior expression show clearly the influence of lighting as a formgiver.

While good results have been achieved in fitting integrated systems to predetermined exterior forms, the design possibilities of these systems are inevitably restricted by the constraints inherent in the foreordained designs. Better results have been achieved in projects where the starting point was the development of an integrated system-of-systems to meet the broadly outlined objectives at the stage of schematic planning. These latter cases, in which both exterior form and plan evolved through the application and refinement of a system-of-systems, are described in Case Studies Group G.
Lighting consultation for the American Republic Building began after the architects and engineers had developed a 4-foot-6-inch deep structure utilizing precast T beams spanning between the hollow walls of the building (which double as duct shafts). In the initial design, lighting louvers were to be placed flush with the underside of the beams to hide fluorescent lamps and the usual irregular array of stepped ductwork (5).

Design
In order to gain the spaciousness of the full structural depth, and so that spaces would receive illumination from perceptually meaningful surfaces, the louvers were eliminated and regularly spaced ducts of uniform cross section were suggested as shielding for super high-output Power Groove fluorescent lamps oriented with the grooves sideways (to distribute maximum light to the side of beams rather than to the slab above) (6). Excellent teamwork with the Syska and Hennessey engineering staff made possible the development of a detailed solution in 1 hour. Round, square, diamond, and triangular ducts were considered. The 14-inch-diameter round duct was selected as the cleanest, most economical shape to shield the lamps without creating a heavy silhouette that would compete unnecessarily with the structure. Alternate ducts supply and return air throughout the building. The need for acoustical absorption led to the selection of a perforated exterior casing (7)—a very effective sound trap when located within a coffer.

Within a few days, testing of a full-scale mock-up verified the calculations which had shown the feasibility of the air distribution details and the efficiency of the indirect lighting system. Some modification of the original structure was required. To break up the continuous lengths of duct and to give them support, cross-ribs were provided in the ceiling coffers. These served yet another purpose: most partitions oriented perpendicular to the main structure could be butted up against the undersides of the ribs to achieve good acoustic separation between adjacent spaces. Infrequent partitions not located on the rib module were handled by running the ducts through sealed glass transoms.

The new design proved to be economical, yielding substantial savings over the original louver-enclosed ductwork design. The environment created has been enthusiastically received by the users (8). While examination of a photograph of a single room might give the impression that the large-scale ducts overpower the space, one does not get that feeling in the actual building because of the consistency of the entire "sky" and the clear legibility of its parts as concrete structural elements and lightweight tubes.
Critique

The American Republic system is suitable for large blocks of single-use space which require no variation in mechanical services or lighting (i.e., for offices, not for a mixture of offices, classrooms, labs, etc.). Although comfortable, comprehensible, and pleasant, the spaces are not as good as those which can be generated with systems based on a larger module which permit the creation of visually simpler, more spacious, and restful environments (see, for instance, the MacMillan-Bloedel Building [E8] on its uncompromised floors, and the projects in Case Studies Group G).

It seems to be typical practice in contemporary office building design that executive and cafeteria levels are made vastly different from typical office floors. This is due to the fact that biological needs, calling for a pleasant, comfortable environment, are usually given full recognition on cafeteria and executive levels only, while a less satisfying environment designed only around criteria for desk lighting is seen as acceptable for the typical floors. When the initial concept is to design a system which will produce an excellent environment for all spaces, however, there is no need to design new systems for executive or cafeteria levels. Slight variations in finishes, furnishings, floor-to-floor height, intensity of illumination, and additional decorative lighting for sparkle are all that will be needed to adapt the basic system to all spaces.

Unlike most office ceiling systems, the American Republic lighting/ceiling system (9) was eminently suitable for use in other spaces such as the cafeteria (8), and even the executive floor was designed with the same system, with a greater ceiling height and accent lighting for artwork (10).

Related integrated building systems have subsequently been used by Skidmore Owings and Merrill in the Great Southern Life Insurance Company Building in Houston, Texas; the headquarters of the American Can Company in Greenwich, Connecticut (11,12); and by the author with architect James Goldstein at the Wayne TSPS Building for New Jersey Bell Telephone.
11 Headquarters of the American Can Company, Greenwich, Connecticut (Skidmore Owings & Merrill / Architects).

12 Typical interior of the American Can Company headquarters.
IBM BUILDING
Milwaukee, Wisconsin

IBM-Milwaukee was built using a precast load-bearing exterior wall with slip-formed concrete core. The differences between the integrated system-of-systems solution at IBM-Milwaukee and that of American Republic reflect the differences in plan (5). At IBM, the span between core and exterior walls is only 30 feet; consequently, much shallower precast beams could be used, and air supply could be handled from induction units at the perimeter and nozzles at the core.

Design

Lighting design began near the end of the working drawings. By that time, a mock-up had been built to test the air distribution and to demonstrate the pattern of pendent direct/indirect fluorescent fixtures (2). Though most of the building floors were expected to remain as open spaces occupied by IBM, rental floors had been designed with a band of suspended ceiling surrounding the core to enclose ductwork crossing the corridors.

Full indirect lighting was proposed instead of the glaring, busy, discontinuous pattern of pendent fixtures and their entrails of stems and outlet box covers. The superiority of the new concept was readily demonstrated to the clients, with the mock-up (3), and then refined. A V-shaped fixture profile was selected to avoid any confusion between lighting elements and the edges of the
SECTION THROUGH JOIST

SECTION THROUGH CORE WALL

6 Schematic section design study.

E2 IBM Building  213
structural beams. Modular lamp lengths were selected so that future partitioning would fall in the gaps between lamps.

Running the fixtures from wall to wall gave them a more integrated appearance, allowed them to be wired from the core, eliminated stems and cover plates (1/4-inch rod supports were used instead), and eliminated any need for suspended ceilings on tenant floors. Enlargement of the fixture cross section and separation of the wiring allowed use of the fixtures as air ducts to feed transition boxes and grilles at the partitions (7). Transparent gasketing was designed for acoustic seal between glass and fixture and to provide channels for running low-voltage switch wiring between glass joints; unfortunately, the gasketing was omitted in the actual construction in favor of field-applied silicone sealer.

On the ground floor, the core walls were illuminated from the edge of the suspended ceiling. The band of incandescent lamps was purposely left unshielded to act as a chandelier (9). In the corners, more neutral post-mounted chandeliers were combined with benches.
As in the factory building for the same owners, described earlier (Case Study B2), the structure of this office building was derived from its function as one component of an integrated structural/mechanical/lighting system. The plan (2) was originally developed on the basis of columnless spaces with a steel frame structure. At this early stage, the tentative lighting/ceiling design was to suspend 6-foot-square pyramidal precast plaster coffers with recessed fluorescent fixtures mounted at the top.

When, for cost and other reasons, the requirement that the space be column-free was dropped, a poured concrete solution became feasible. Having just positively evaluated the mock-up of IBM-Milwaukee, project architect Hans Neumann hoped to use similar indirect lighting at Cummins. Two limitations forced the design in a different direction.

First, the square plan shape with mechanical core at one corner meant a two-way network of service channels, hence, a symmetrical module. Second, the program requirement for a 6-foot partitioning module meant that the symmetrical modules would be quite small. Perceptually logical, continuous channels were created for the elements requiring continuity (air distribution), and the elements with static shapes (lighting) were placed in between. Chaotic, nervous spaces are created when this relationship is reversed (as at the Boston City Hall [5], or the Blue Cross-Blue Shield Building, Boston).

A 2' - 4' - 2' - 4' - 2' grid system was developed (3), which provided more than the programmed partitioning flexibility, but the resulting 4-foot-square cell limited the lighting hardware choices. Consideration of the biological needs for symmetry and for maximum comprehensibility of the structure suggested that lighting elements should be centered in each cell and baffled by it. Of the possibilities for indirect lighting sources, incandescent was too inefficient, mercury too expensive (in small sizes), and the economical 4-foot fluorescent lamp of the wrong shape. The choice was narrowed down to direct lighting from relatively uneconomical 2-foot fluorescent lamps in 2 x 2 foot fixtures, or direct/indirect lighting from the then-new 12-inch-square panel fluorescent lamp, which proved to be very efficient in the
manner used. An 87 percent efficiency from the front face of the lamp was attained using specially molded low-brightness louvers, and light generated from the rear face (usually trapped ineffectively in a recessed fixture) was utilized to illuminate the coffers indirectly.

A mock-up was built to demonstrate the effect and to corroborate the quantitative forecasts. Because of the time and expenditure which would have been necessary to build an exact facsimile, it was necessary to approximate the fixtures to yield the desired information. For measurement of illumination level at desk top, white louvers of equal efficiency were substituted in the mock-up (Fig. 108) for the parabolic wedges.

To give the clients the impression of how a single cell would appear, one fixture was fitted with an available parawedge louver with smaller baffles than called for, which while less efficient, demonstrated accurately the expected low surface brightness of the fixture (Fig. 107).

Illumination levels estimated from a mock-up of a single coffer were confirmed by the full room test, and subsequently in the completed building.

**Critique**

The environment produced appears very satisfactory for its purpose (6.7). However, I do have some second thoughts. Concrete surfaces were given a very smooth finish, and the semigloss paint applied to the entire ceiling disguises the difference between the lightweight metal infill panels and the concrete. Repainting the concrete in a matte white to contrast with the semigloss eggshell panels would help to differentiate the two elements.

Cost studies of using the then highly promoted new panel fluorescent lamp were predicated on
the normal price reductions anticipated with time and increased production. Instead, the lamp was practically discontinued and prices were raised before the building was even complete. Responsibility on the part of lamp manufacturers cannot always be depended on.

It is open to question whether a larger module—for instance, 3'-7'—3'-7'-3'—would not have been sufficiently flexible. The larger module would have been both more spacious and less expensive. Compare the spaces created with the Cummins module to those of MacMillan-Bloedel (E8), which are based on a larger module.
The ceiling, lighting, structural, and mechanical systems of this library were manipulated by the design team to create spaces quite similar to those in the other case study projects in this section, although the execution was in plaster rather than exposed concrete due to the relatively small scale of the project.

**Design**

By concentrating mechanical runs at the perimeter of the spaces, it became possible to create large, indirectly illuminated coffers with integral lighting coves on their long sides. Solid exterior walls were illuminated from slots. The book stacks were oriented perpendicular to the long axis of the coffers so that the books would "see" the brightest portion of the ceiling (3). At the ends of the building, the lowered ceiling band was widened beyond the depth required for mechanical runs so that the small rooms in these zones would have single rather than double-height ceilings. In these areas low-brightness 2 x 2 foot recessed fluorescent fixtures were provided for nighttime illumination, and switched separately so that they can be turned off when daylighting provides adequate task illumination (4). To make possible the highlighting of works of art and planting, lighting track was installed at appropriate locations throughout the building. Track lighting is also used to provide supplementary task illumination when the larger coffers are subdivided to form small offices (6). Local lighting is built into each carrel (8).

**Comments**

The Rochester Institute of Technology Library in Rochester, New York (for which we acted as consultants to Harry Weese and Associates) is very similar in concept and execution (Fig. 26).

Although the large coffers created in these projects were illuminated indirectly to provide excellent and well-balanced task and environmental illumination, this is not the only treatment possible for this sort of ceiling articulation. At the Cornell Commons, Cornell College, Mt. Vernon, Iowa (9), the same team used large-scale coffering to define spaces within the rather open plan of the Commons, but in this case the coffers were treated as room-scale chandeliers with continuous strings of decorative incandescent lights, since the use of the spaces called for a more sparkling treatment than would have been possible with full indirect lighting.
After seeing the design drawings and mock-up for Governors State University (Case Study G5), at the Houston office of CRS, architect Paul Kennon conceived of a similar luminous environment for the Santa Clara County Civic Building (1): large coffers indirectly illuminated from architecturally integrated coves. The finished interior spaces bear a clear resemblance to those at Governors State, though there are important differences stemming from differences in plan and from the unusual structural requirements at Santa Clara.

The governing consideration which dictated a steel frame rather than a concrete structure was that the center of civil defense in an area prone to earthquakes should have maximum resistance to earthquake damage. The recommendation of the structural engineer was to frame every floor with two independent layers—one above the other—of one-way longspan steel beams 28 feet on center, spanning between the exterior walls with intermediate columns. The beams in the upper layer always run perpendicular to those in the lower layer at each floor. The steel frame is fireproofed with a concrete cover which will crack during an earthquake, damping out shocks and putting the structure out of resonance.

Since none of the previously developed concrete-based integrated systems could be adapted directly to suit these stringent conditions, the design challenge became how to create the same spacious interior environments and unified, consistent appearance, using the unusual double-depth steel-and-concrete structure.

The cavities in the upper layer of beams were assigned to primary mechanical distribution (fed from the perimeter cores). To provide local mechanical distribution, drywall service channels were created between each pair of beams in the lower layer. Concentration of services into a system of discrete, regular, minimal channels left the remainder of the volume in the lower structural layer available for use as indirect lighting coffers. Both beams and service channels were edged with integral light coves. Air is distributed to the rooms via slots at the lower edge of the coves which border the service channels. An acoustic ceiling was hung at the top of these coffers, level with the top flanges of the lower steel beams.

Since a one-way coffering system like that of the IBM-Milwaukee Building (Case Study E2) would have been inconsistent with the symmetrical exterior designed for Santa Clara, cross baffles were introduced on 28-foot centers to break up the linearity of the coffers. Although the symmetrical exterior suggested the use of square coffers, a rectangular coffers was selected, after a model study of various coffers proportions. Even with square coffers, the disparity between the logical dimensions for structure and service channels running in one direction and the lightweight cross baffles running in the other would have destroyed any perception of a symmetric two-way system. The rectangular coffers reduce the directional characteristics of the ceiling, without confusing the delineation of structure, service bands, and cross baffles as distinct but related components of an integrated system.

Generally speaking, the complex relationships between all the systems of a building can best be explored and most easily communicated through detailed model studies such as those made during the design of the Civic Building. Similar studies should be a regular part of the design process for any kind of integrated structure.

The final design proposal was tested and refined in a full-scale mock-up. Fully furnished and accurate in detailing, finishes, and furnishing, this mock-up could be shown to clients, unlike the incomplete mock-up for Governors State University which was only used by the design staff for photometric measurements. Clients are
generally confused and alarmed, rather than reassured, when shown an incomplete mock-up. The presence of adjacent, unrelated rooms, incorrect or sloppy details, and inaccurate materials and finishes is hard to ignore, and those untrained in design and unfamiliar with the true intent of the designer find it hard to fill in the missing elements of the finished environment in their imagination. The Santa Clara mock-up was important both as a visible demonstration of the quality of environment which could be anticipated and as proof to the usual skeptics that the predicted levels of illumination could in fact be achieved, despite handbook data which suggested otherwise.

On the typical floor, the fluorescent cove lighting was to have been supplemented with incandescent fixtures recessed into the service channels. Although these fixtures would be required for task lighting in only a few furniture and partitioning arrangements, the supplementary incandescent units provide interest and orientation while highlighting objects low in the space.

For variety, and to respond to the different nature of activities in the ground-floor cafeteria and meeting rooms, the coffer system was maintained in these areas with decorative arrangements of clear lamps substituted for the indirect coves.

**Comment**

While this building is not as efficient (in terms of the ratio of habitable to total built volume) as any of the concrete tree or channel systems presented here, it does come close to the objective of maximum visible volume within the constraints imposed by this particular approach to earthquake-resistant construction. The standard approach—a hung ceiling below the lowest layer of structure—would have been a terrible waste of the potential for a truly spacious environment inherent in such an unusually deep structural system.

Because of an unfounded concern for measured uniformity of lighting, low-brightness fluorescent fixtures were substituted for the proposed supplementary incandescent fixtures without our knowledge. The change was unnecessary. A mock-up had demonstrated that the proposed task lighting would have been entirely adequate and that the drop in light levels under the unlit service bands would have been almost unnoticeable. The resulting environment is neither as pleasant nor as interesting as the original design, in which supplementary fixtures were to have been used only for specific purposes such as accent highlighting. The change was also a false economy, consuming more energy than a selective layout of incandescent fixtures as proposed. Although fluorescent lamps are inherently more efficient than incandescent lamps in terms of converting electrical energy into light, the overall energy consumption in a space may be higher if unnecessary fluorescent fixtures are used indiscriminately merely to make a regular pattern or to achieve some misconceived objective such as perfect uniformity of lighting, rather than using a smaller number of less efficient fixtures only where they are needed.
Unusual problems are often encountered in the design of an infill addition to a hospital, which would not be encountered in the design of a new hospital or a freestanding addition. For the Easton Hospital infill addition, the design team developed a special configuration of the "tree structure" to meet lighting and mechanical requirements within the constraints imposed by the preexisting plan.

Design

Each half of the six-cell directional concrete trees defines two single rooms and a bathroom. Since all services are easily accommodated in the continuous gaps between the edge beams of the trees (4, 5), no suspended ceiling is necessary within the trees, not even in the bathrooms. Room services are even more accessible than they would be with a complete suspended ceiling system.

Room lighting (3) and nightlights are indirect, reflected from the coffers formed by the beams of the tree structure, and supplementary reading light is provided from locally switched fluorescent strips concealed behind the edge beams (7, 8).

Similar trees, which vary in size because of the asymmetric layout of this building, house services and more powerful indirect lighting for labs and other areas. Gaps between the new tree structure and the existing buildings were defined by clear skylights (13).

1. These two-way cantilever structures are discussed in considerable detail in Case Studies Group G.
In order to achieve an articulated building system that would create optimal environments for the wide variety of functions of this new residential university, a close collaboration of the complete design team was initiated from the beginning of schematic design.

One decision, however, limited the possibilities of developing a simple, integrated module that could be multiplied into an entire academic complex (as at Governors State University [Case Study G5] or at Pierrefonds Comprehensive High School [E9]). The architecturally exciting decision to bridge the 500-foot-wide coulees (with broad layers devoted to academic, administrative, and social activities above and narrower layers of housing below) meant that further growth would have to take place in large increments (other bridges). The bridging, upward-expanding form limited the range of structural possibilities.

**Design**

With these limitations, a scheme similar to the Pierrefonds system was developed but proved to be too costly. However, a good alternative system with somewhat less service flexibility but even more visual spaciousness was developed and used throughout most of the building. For the academic/social office levels (6 and 7) the system consists of building-length bands of indirectly illuminated decking interrupted only by partitions and framed by natural-finish precast concrete girders that span between columns 36 feet on center (3). These girders contain integral coves for indirect lighting. Decking is white-painted precast concrete double-T's, the undersides of which form the lighting reflectors. The T's provide natural shielding for direct lighting of the cross walls (which run parallel to the T's). The 20-foot-wide indirectly illuminated band of double-T's generally occurs on both sides of a central band connecting vertical cores 130 feet apart. In the core zone (5) a suspended ceiling encloses major mechanical services and low-brightness recessed fluorescent or incandescent lighting.

On level 5, which has small offices (6) and seminar rooms all along the perimeter, a schematic reversal of the lighting system was indicated, and a narrower, dropped plaster plenum band edged with a wall-lighting slot was used in the corridors feeding perimeter offices and interior classrooms (7) in the core zone. On this level, core classrooms and perimeter offices are full height and indirectly illuminated. On the upper levels (6, 7, and 8), the building is widened with a sec-
ond narrower band of T's at the perimeter.

The nature of the structure is essentially one-way, with major girders running parallel to the long axis of the building. This limits flexibility and the size of service distribution channels in the other direction. These are concealed above drywall infill panels within the depth of the double-T's which serve as secondary structure. Spaces with maximum service requirements, such as labs, are restricted to the middle band, where services may be run freely in any direction above the suspended ceiling. In the perimeter bands, the visual impact of the lighting system and the exposed structure is sufficiently powerful that the few exposed pipes, ducts, etc., go quite unnoticed.

In the dormitory levels, desire for total flexibility of room arrangement and a minimal budget made complete built-in lighting impossible. Instead, some general lighting was provided from wall brackets, and each student was provided with a portable "Luxo"-type lamp that could be inserted into bushings built into every bed and desk (12). Concealed lighting was provided for kitchenette (8) and lounge areas, along with some adjustable floodlights to provide flexible accents as desired.

Site lighting design

At Lethbridge, pedestrian and auto traffic are separated, and the need to provide exterior lighting to ensure a sense of security from attack is minimal because of its location in a remote part of Alberta. This remoteness and the need to preserve the unspoiled, empty surrounding landscape from undesirable visual noise presented additional design challenges.

With separated pedestrian circulation, in a locale where none of the surrounding roads are illuminated, roadway lighting could be reduced to a minimum, serving primarily for guidance. From a distance, orientation to the University is provided by the building itself, conspicuous because of its size and well defined by floodlighting and by spill light from the interior (which also illuminates the immediate surroundings). The site entrance was marked with illuminated graphics, and the roadway was defined by low fixtures (11) mounted at a height that would not disrupt views of the building. Great care was taken to preserve the beautiful, fragile landscape. To this end the large parking areas were hidden behind berms so that they could not be seen from the building, and illuminated from adjustable floodlights mounted within monumental concrete shafts (10) whose shapes will be seen as environmental sculpture rather than visual noise during the day. The floodlighting is oriented away from the buildings so that from within the buildings only the illuminated ground and berms can be seen—no glaring fixtures are visible. The exhaust stack/lighting bridge on the plaza (13) and the integrated air-intake/floodlight housings which flank the building were given similar sculptural roles in the overall design concept.
9 Main kitchen (another indirect approach to kitchen lighting which relates the lighting to the equipment rather than the structure is shown in Fig. 24 on page 28.)
MacMillan-Bloedel presented an opportunity to test the advantages of larger modules. Having created a very classic exterior form—monolithic poured concrete punctured only by crisp square window openings glazed with uninterrupted sheets of glass—architect Erickson was anxious to have exposed concrete structure within.

From the inception of the project, two constraints had forced the design toward a homogenized suspended ceiling solution: cost and a programmatic requirement for a 5-foot partitioning module. These impediments were overcome by an integrated design approach and a more realistic look at the partitioning requirements.

Design

The original mechanical scheme was uneconomical because it was not “pure” enough; for instance, patches of suspended ceiling had been included to take care of mechanical distribution to the interior zones adjacent to the cores. Only slight modifications to the structure were necessary to increase flexibility, to eliminate such ad hoc elements, and to bring the mechanical cost into line.

Flanges of the structural beams were widened to 3 feet, so that the 10-foot-on-center spacing of the beams became effectively 3'-7"-3'-7"-3' for partitioning purposes. This made it possible to
create spaces from 7 to 13 or 17 to 23 feet wide with walls running parallel to the beams. Every beam was penetrated at two points, so that air supply and return could be handled from duct bands run through the holes, interconnecting the end service cores (6). This eliminated any need for a second mechanical room on each floor. The edge of the duct band was the logical place to locate indirect cove lighting supplementing light from the perimeter (5).

This combination was more economical than a suspended ceiling with its (necessarily) much larger number of lighting fixtures. Had the integrated solution been found earlier, additional economies could have been realized by reducing the floor-to-floor height by 6 to 12 inches; unfortunately, however, the preparation of new structural drawings would have delayed construction by a season and was therefore impractical.

Lighting distribution was predicted from a model of a single cell and confirmed with full-scale room mock-ups.

It is often difficult to sell a client sight unseen on an unconventional but superior system; full-scale mock-ups were used at MacMillan to demonstrate the superiority of the proposed indirect systems (11) over other, more conventional alternatives: suspended ceiling with fully recessed, direct fluorescent fixtures, and
large surface-mounted fluorescent fixtures which approximated a luminous ceiling. A single indirect fixture with a V profile was also proposed and mocked up as the least-cost acceptable alternative (10). The recommended double cove system was unanimously acclaimed as producing the best environment (11, 14, 15).

Unfortunately, despite the success of the mock-up, prior leasing commitments based on specified footcandle levels led to the selection of a compromise lighting solution on most floors (6, 8, 13). Even then, much better and less expensive lighting was achieved by the integration of structure and mechanical systems to yield biologically satisfying spaces (13). Another compromise required on the top floor (9, 12) because of interference with roof drains makes this building a good "laboratory" in which one may examine a variety of luminous environments under otherwise similar conditions.

In the lobby (14), the indirectly illuminated coffers were supplemented by recessed incandescent fixtures to increase the focus on ground-level objects in the high space. Exterior lighting was integrated into the pool edge (2) and benches. Floodlighting was supplemented by globes on the plaza to erase any shadows at the lower walls.

Critique

Unfortunately, final detailing of the executive floor ignored several key features of the tested and approved mock-up. Walls and furniture were dark-colored instead of light, reducing their reflectance. Both illumination levels and a sense of spaciousness were further sacrificed by the use of gray patterned glass (instead of clear) for the transoms.
9'-4'-9'-4'-9' rhythm. Partitions parallel with the structure can be located anywhere within the 4-foot bands (the undersides of the service channels). Cross partitions and corridors perpendicular to the channel beams can be placed anywhere without interrupting the lighting system; the fluorescent strip fixtures, which rest freely in the coves, are simply spread apart to accommodate partitions. With this integrated approach, spacious classrooms (10) and other large spaces with high ceilings were possible within a floor-to-floor dimension which with 5 x 5 foot modules and a suspended ceiling would have produced only 8 foot 6 inch flat ceilings.

The indirectly illuminated ceiling coffers cast plenty of light on vertical surfaces such as chalkboards. In addition, walls adjacent to any one of the open channels can be highlighted easily by mounting bare lamps behind the beams.

The channel-beam spacing was increased in the central cafeteria/library area (4,9), and the skylights spanning between the beams were supplemented by incandescent downlights to be used on overcast days and at night.

**Site**

Driveway and entrance were articulated by a hierarchy of clear globes. Parking lots are illuminated by adjustable floodlights housed in Corten steel shafts that appear like sculptures against the skyline (12).

**Critique**

Despite full-size drawings and a full-scale mock-up, the cove light fixtures were installed in the wrong position (with the lamps up), making the lamps somewhat visible from a distance and the illumination of the beams slightly spotty (8).
At $14$ (Canadian) per square foot, in 1968, this building was as economical as any of the Montreal "systems" school buildings, and if more of this type were built the precast system should be just as fast to erect.
CASE STUDIES
GROUP F

SEQUENCES OF SPACES
WITHOUT FIXED
CORRIDORS: FLAT-
CEILING SYSTEMS
FITTED TO PREDETER-
MINED EXTERIOR FORMS

Although articulated building systems such as the ones presented in the previous section offer the greatest potential in providing biologically satisfactory environments suitable to the activities which they house at lowest cost, there are many situations in which a homogenized, neutral solution\(^1\) may be appropriate—or unavoidable. Such circumstances might exist:

1. When scheduling requirements of a tight project timetable can only be met with a steel framing system and maximum utilization of factory-made components.
2. In labor-short locations, or areas without sophisticated concrete technology.
3. When unlimited rather than moderate partitioning and service flexibility is demanded, i.e., in speculative buildings.
4. When a building is designed from the outside in, so that the exterior forms and framing are established prior to design of the ceiling, lighting, mechanical, and partitioning systems. Such a process forecloses the possibilities of developing an integrated system-of-systems.
5. When a preference is expressed for "average" spaces, functionally usable for a wide range of activities but not particularly good for any—a "safe" choice of the developer or designers.

In short, homogenized buildings are usually a compromise, resulting from an inability to arrive at an articulated building system that can accommodate the various projected activity and spatial needs within the budget. When a homogenized building is called for, the primary objective is generally not to create positively expressed spaces, but, on the contrary, to create the most neutral spaces possible. To create spaces which are reasonably satisfactory for all activities, design objectives must be formulated completely and clearly. Achieving these objectives within correctly stated economic

\(^{1}\)By a "homogenized solution" I mean an approach which conceals all structure and mechanical appurtenances above a suspended ceiling, usually flat and unarticulated, and in which there is little or no evident intent to integrate structural and mechanical systems in such a way as (1) to maximize perceptible room volumes within a given floor-to-floor dimension, (2) to create natural service channels in the structure, and (3) to use the actual surfaces of the structure as sources of illumination for the spaces which they enclose, through the use of indirect lighting (sometimes supplemented by unobtrusive direct lighting).
constraints becomes the problem. Most homogenized buildings are clearly less than optimal, since many desirable design objectives have been compromised for economy—real or imagined.

Design objectives of homogenized solutions—assuming no cost constraints—usually include the following: The ceiling should be capable of distributing air and light in every module. The plan module should allow partitions to be aligned with windows, framing, columns, and other elements; should be nondirectional (so that rooms can run in either direction); and should provide easy access to mechanical, electrical, and plumbing services, without damage to ceiling material during this process or when partitions are moved. (Painting or replacing part of a homogeneous flat ceiling is likely to be conspicuous, while this is not usually the case with ceiling systems articulated in three dimensions because the variation in surface orientation to the light sources is perceived as explaining most changes in color or texture.) Light fixtures should be as inconspicuous as possible, should give off a minimum of direct glare, should cast only moderate shadows, and should allow variation in light output when desired for design or economic purposes. Good acoustic absorption is usually desirable, and good attenuation should occur at partitions. Excessive radiant heat and sound from lighting fixtures and other mechanical components must be avoided.

The most common design errors and compromises of these objectives are:

1. Use of directional fixtures (e.g., 1 × 4 foot) when the building and/or building module is nondirectional (square). Usually dictated by the economy of the 4-foot fluorescent lamp.

2. The generation of excessive direct glare as a by-product of a misconceived design goal: the provision of maximum footcandles rather than maximum comfort. Fixtures which produce maximum direct glare can be spaced relatively widely due to their high lateral distribution of light, and the temptation exists to trade an increase in glare for a reduction in the number of fixtures required to achieve a given horizontal distribution of illumination.

3. Improper alignment of the ceiling and lighting module with structural elements, windows, etc. Perceptible order in the visual environment facilitates comprehension and relaxes the user. The absence or misalignment of an overall organizing module often leads to visual chaos, which produces an opposite effect. Misalignment of the lighting module is frequently caused by a lack of coordination between standard dimensions of ceiling material and structure. More often, misalignment is the result of deriving the lighting module from the most “efficient” method of providing required footcandle levels, rather than from desirable visual relationships and partitioning studies. Obvious lack of coordination in the visual
environment is distracting and unpleasant, particularly when it involves strong elements of the visual field such as lighting fixtures and structural members.

4. The generation of excessive heat and/or shadows in work areas through the unjustified and excessive employment of directional incandescent systems.

5. Excessive spacing of fixtures, so that lighting must be rearranged whenever partitions are moved.

A number of opportunities exist for the design team to reduce costs, while simultaneously diminishing the negative effects of compromise solutions. The team should:

1. Minimize waste of space in the ceiling cavity with an articulated, integrated arrangement of ducts, lights, and structure.

2. Write the program for maximum comfort instead of maximum footcandles per dollar. This allows the use of less efficient but much more pleasant lamps, improves glare control, and permits lamp operation at reduced voltage (which greatly extends lamp life while reducing current consumption) for incandescent lamps.

3. Recognize the presence of daylight as a primary or supplementary light source, and realize that at night, lighting needs are reduced because one expects there to be less light at night than during the day. Separate switching of exterior modules, where artificial light is usually unnecessary during the day, and other variations of lighting design at the perimeter will permit the realization of considerable economies in operation and create a more relevant luminous environment. A room looks ridiculous when electric lighting is on (and cannot be turned off) in areas already fully illuminated by daylight.

4. Recognize probable corridor positions when possible. Less light is required in corridors than in work areas. Around building cores, reduction of lighting levels and the number of fixtures will give extra space for ductwork in the ceiling around the core where it is usually most needed, as well as saving money.

5. Use the largest possible module for the needs of each particular building to minimize both the number of light fixtures and the sense of spatial fragmentation.

6. Avoid excessive window areas, to reduce problems of heat and glare control and associated air-conditioning costs. Use building forms for louvering and sunshading (for instance, deep reveals with glazing at the inner rather than outer face of the wall).

7. Minimize fixture size to reduce cost and to minimize visual dominance.
8. Consider cost of moving fixtures (including administrative cost) during partitioning changes. This may offset the higher initial cost of smaller modules, which in turn could eliminate the need to move any fixtures during such changes.

There are also opportunities for long-term advances in product design. Striving for the ideal rather than the immediate compromise can create pressure on manufacturers to produce new, desirable products or to modify old ones on a competitive price basis. It was this sort of pressure which finally stimulated manufacturers to offer the multilevel fluorescent ballast as a standard catalog item.

We proposed the use of multilevel fluorescent ballasts for the 1100 Milam Building (Case Study F3) in order to save energy and reduce operating costs. Use of these multilevel ballasts would have made it possible to adjust illumination levels to match the spatial distribution of needs, despite a uniform layout of fixtures. While such ballasts were technically feasible at the time, ballast manufacturers were unwilling to undertake the necessary product development until I had proposed multilevel ballasts for a number of major projects and the concept had been incorporated into several important design guideline documents², largely at my suggestion.

Recognition of the hard facts of a long-term energy shortage will hopefully lead to an improvement in the boring homogenized environments typical in flat-ceiling office buildings. Increased energy-consciousness should expedite acceptance of nonuniform illumination schemes such as those made possible by the multilevel ballast.

Other energy-efficient tactics which have been applied to programs which might otherwise have been wastefully engineered into homogenized solutions include the following:

1. Recessed ceiling-mounted fluorescent luminaires can be used for local lighting, usually one per work station. These must then be relocated as part of the “furniture” with every change in the location of work stations. This scheme will not work unless the ceiling construction and power distribution system can accommodate such movement easily and without damage to the ceiling material. This strategy was used at the Eden Theological Seminary Library (Case Study B5). A variant on the approach was used at the AMAX Headquarters Building (Case Study D7) where the fixed location of work stations allowed the design of a layout of local (but stationary) recessed fluorescent fixtures coordinated with the layout of work stations. Although this type of local lighting may satisfy “task” needs at the desk, it is important to realize that the satisfaction of biological needs for visual information requires that walls and ceilings be adequately illuminated to meet expectations of the users. It was for this reason that we illuminated the walls at the Eden Library and the ceiling at AMAX in addition to

providing localized task lighting. (The proposed approach of using recessed fluorescent fixtures placed selectively in a layout coordinated with work stations should not be confused with the prevalent practice of using random, irregular layouts of 2 × 4 lensed fluorescent troffers to achieve numerical footcandle criteria stated as averages. The latter approach merely produces visual chaos and a sense of unpleasant irrelevance in the luminous environment.)

2. *Spaces can be entirely illuminated from portable lamps or from fixtures integrated into furniture units.* One of our earlier projects in which we used this approach is the Reed College Library (Fig. F1) in Portland, Oregon, for which we designed the lighting in 1963. At the Reed Library, direct/indirect fluorescent fixtures built into the carrels provide both local task lighting and general room illumination. (The traditional desk lamp which lights both desktop and ceiling above is another familiar example of this lighting strategy.) This approach can be very energy-efficient while satisfying both activity and biological needs for visual information. Building owners and managers have been reluctant to accept such schemes, however, because they are afraid to depart from the conventional high-footcandle, high-energy, high-glaze designs (which may be the only thing they have ever experienced). Perhaps clients will be more receptive to new design approaches now that the myth of "high footcandles everywhere" has been exposed for the propaganda which it is and life-cycle costing and energy conservation are beginning to receive more than lip service. It should be noted that furniture-mounted lighting is no panacea because not every room can be broken up effectively and attractively by this type of furniture. This limits the applicability of pure furniture-mounted lighting solutions, and suggests that their real potential can only be realized when they are used in conjunction with other lighting approaches. It is for this reason that we prefer the type of articulated building system represented by the projects in *Case Studies Groups E* and *G,* in which furniture-mounted and portable lighting can be used as appropriate for accent highlighting and for supplementary task lighting where the moderate level of general illumination provided from sources integrated into the building fabric is inadequate to satisfy the needs of users with special and unusually demanding tasks.
The square shape of this building in plan (2) as well as the need for directional freedom in the interior spaces dictated that ideally the fixture in each module should be nondirectional as well as low-brightness.

Design

At the time of design (1965), however, neither the lamps nor the fixture louvers for efficient, economical square low-brightness fixtures was available. Consequently, the design team compromised to 1 × 4 foot low-brightness louvers (with a cell one-half inch square) but even then were unable to get approval for the design. The final compromise (1 × 4 foot lensed fixtures) (3) was at least better than randomly placed 2 × 4 foot fixtures (with which equivalent light levels could have been produced at lower cost but with considerably more visual noise). Where the recommended low-glare design was used on the executive floor the superiority of the luminous environment is obvious (4). Fortunately, more appropriate lighting was possible in elevator lobbies (5, 6) and on the main floor.

Architecturally neutral downlight cans in the ceiling colters illuminate core wells and the lobby floor. The stairway, a major sculptural element during the day, doubles as a chandelier at night (7).
Architect Weese took good advantage of the fact that most of this building would be used as large open areas. Partitioning would be infrequent. Window height was kept low to decrease air-conditioning loads and sun-control problems (and cost) without sacrifice of the view (6). While low-brightness fixtures would have created a more pleasant environment, much of the discomfort and visual clutter usually associated with lensed fixtures was reduced by using $4 \times 4$ foot fixtures widely spaced (approximately 9 feet on center). This scheme leaves substantial areas of blank ceiling on which the eyes can rest (5). A range of small room sizes can be created below the gridless ceiling, although the fixture may not always be centered within the room.

On the main floor, a respite from ceiling fixture dominance was achieved by not "homogenizing" the Corten ceiling pan with a uniform pattern of light or luminaires. Rather, fixtures were arranged in the pans in such a way as to define vertical surfaces and edges and to create focus on displays, etc.

Within the core on the main level, the granite used in the walls of the lobby is continued as ceilings. To avoid having to punch holes through the granite ceiling plane for light fixtures, the ceiling was illuminated indirectly from fixtures concealed behind built-in benches in the waiting area (3).
The project schedule and program requirements for total partitioning flexibility in this speculative venture dictated a steel-frame suspended-ceiling building based on a 5 × 5 foot module.

Design

By 1970-71, quite efficient and economical 2-foot-square low-brightness fluorescent fixtures were available, but the design team had difficulty in getting approval for a scheme which called for one of these fixtures in the center of each module. At the time, speculative competition was using less expensive 2 × 4 foot fixtures placed randomly to provide an average illumination of 70 foot-candles; furthermore, though the available square low-brightness fixtures were by 1970 as efficient as lensed fixtures—and much more pleasant to look at—the U-shaped lamps required were still more expensive than conventional linear 4-foot fluorescent tubes. Use of a fixture in each module meant increased initial cost over a random scheme. It was recognized, however, that long-range economies could be realized if fixtures could be left untouched each time partitioning was rearranged to suit the needs of new tenants—approximately every 5 years.

Unfortunately, the tight project schedule made it impossible to offset the increased fixture cost through redesign of the air-handling system, which use of the square fixtures would have made possible. Regular spacing of the 2 × 2 foot fixtures (5 feet on center) would have created a grid of 3-foot-wide channels running in both directions at the level of the fixtures above the suspended ceiling. (Using 1 × 4 foot or 2 × 4 foot fixtures arranged end to end allows distribution in only one direction at the level of the fixtures themselves, parallel to the fixtures. Such a system requires greater structural depth for ducts which must run above the fixtures in the opposite direction.) If time had permitted redesign of ductwork to fit within the two-way channels created by the pattern of square fixtures, floor-to-floor height could have been reduced by as much as 14 inches per floor. This would have yielded considerable savings in terms of reduced exterior skin, foundation costs, structure, etc., which could have been applied to offset the increased cost of the square low-brightness fixtures.

Another proposed economy was operation of fixtures at reduced output in all but the smallest offices, which would have yielded substantial long-run savings in terms of reduced power cost, extended lamp life, and reduced air-conditioning load. The
additional initial cost of special "Hi-Lo" ballasts would have been amortized in months.

Elevator lobbies and other circulation spaces were handled consistently with incandescent downlights and wall washers to aid orientation. To expand the spaciousness of the elevator cabs, a mirror ceiling was proposed.

Much of the main-floor concept and detailing was coordinated with the design concepts of other units of the complex. These included the Hyatt Regency Hotel (Case Study C9) and a major parking garage, linked to each other and to the office building by second-level bridges which were illuminated in such a way as to emphasize their connecting function.

Critique

The design recommendation to use symmetrical low-brightness fixtures came too late in the design process to allow realization of potential savings in building height, etc., which would have helped to offset the higher initial cost of lighting fixtures. As a result, the scheme was compromised, and minimum cost 1 × 4 foot fixtures were used instead. Had lighting coordination been initiated on this scheme prior to the completion of structural drawings, the final design might have been quite different.
When integrated systems incorporating structural elements, services, and lighting must be fitted within the constraints of predetermined plans, further expansion of a project is usually possible only in quite large increments. Furthermore, the systems tend to be one-directional, which limits service distribution capabilities, especially service distribution perpendicular to the primary structural orientation. In contrast, modular, articulated integrated systems which incorporate two-way service channels allow much more freedom in planning and growth in any direction, vertical as well as horizontal. Increments of growth can be as small as a single module or as large as an entire university complex. Plans and expressive exterior forms derive naturally from the repetitive, cellular nature of the system itself. Repetition of the same module in large numbers generates substantial cost savings over more ad hoc approaches. If desired, plans can be irregular, and voids can be created at will in the form of courts or multistory open spaces by simply omitting certain modules.

While the nature of a flexible, modular integrated building system dictates the use of columns, the largest possible module should be used which can still accommodate the desired service distribution and partitioning requirements, to minimize visual fragmentation of spaces and to keep the number of columns and light fixtures to a minimum.

The integrated systems presented in this section drew on earlier developments in lighting and air-conditioning detailing from integrated systems worked out within the constraints of predetermined exterior forms, such as those of Place Bonaventure (Case Study C5), the Pierrefonds Comprehensive High School (Case Study E9), and others.

Even when no growth is expected, the superior service flexibility characteristic of buildings whose form is derived from the systems with which they are constructed—buildings designed from the inside out—makes this type of building particularly suitable when service requirements are heavy and unpredictable.
In 1966, 70 acres of land near MIT were cleared for a NASA Electronics Research Center designed by Edward Stone. When the very formal initial concept was changed, only the tower and an auditorium unit had been built. The Architects Collaborative was engaged to develop a more informal system of lower structures that could be constructed in a number of stages. Changes in national priorities, however, resulted in cancellation of the Cambridge center when only two TAC-designed units had been built. The center was subsequently taken over by the Department of Transportation.

Design

The design team began with an attempt to achieve the same degree of two-way design freedom as that inherent in the Place Bona-venture “tree” system (see Case Study G5). Design freedom was constrained, however, by the pre-determined location of the columns (dictated by the layout of caissons already in place for the earlier Stone design). Because it lacked bilateral symmetry and because the implied column spacing was inappropriate (too far in one direction and too close in the other), this foundation layout would have required an awkward and unbalanced tree structure. For this reason the design team abandoned the concept of a tree structure in favor of cantilevered platforms suspended from split columns (a “table” structure), with major service channels between the platforms and a smaller channel enclosed by paired beams at the center line of each platform. The vertical shafts created between the split columns offered a convenient place for mechanical risers.

Critique

The overly large tree dimensions (in one direction) created overly large spacing of service channels in one direction. That factor, aggravated by poor job supervision, resulted in a few unsightly exposed conduits and other service elements which might otherwise have been concealed. Despite its shortcomings, the system is visually powerful enough to camouflage these irregularities. The table module is unfortunately too large to be perceived as a generating unit (7). After partitioning, there were no spaces large enough to show a complete module, and as a result, its actual form is never apparent (5,6). Furthermore, the “growth” characteristics of the system were not expressed on the exterior, where infill panels were executed in poured concrete. In other projects (such as case studies G2 (The Bank of Canada) and G5 (Governors State University) more appropriate, detachable lightweight infill panels were used.
4 Reflected ceiling diagram.

7 Prior to partitioning.
8, 9 Typical section and indirect fixture detail.
BANK OF CANADA
Ottawa, Ontario

Marani, Rothmawte & Dick/Arthur Erickson Architects (joint venture architects); James C. Strusman (project architect); William Lam Associates, Inc. (lighting consultants); John R. Bain Associates Limited (acoustical consultants); Arde/Brais, Frigon (electrical and mechanical engineers); C. D. Carruthers & Wallace Consultants Limited (structural engineers); Ellis Don Limited (general contractor). Cost: $40,000,000. Square footage: 800,000. Schematic design started 1969. Construction completed 1976.

Following the precedent set by Erickson/Massey in their University of Lethbridge project, coordination of architecture and lighting, mechanical, and structural systems began at the stage of diagrammatic planning. The Bank of Canada project (1) was not limited by a predetermined planning diagram or building form, so that it was possible to develop a building system which would achieve all the goals of environment and services. In fact, the organic tree system which was developed allowed such flexibility in planning that it remained unchanged despite several substantial modifications in the plan (2,3). When, for instance, one of the initial clients withdrew from the project, leading to a drastic reduction in planned square footage, only 30 days were required to evolve a new schematic plan for the entire building. No modifications of the tree system and associated architectural details were required.

Design

The organic tree module was a development from the Place Bonaventure and NASA projects. The trees differ from the freestanding structures of Kahn (9) and Wright (7) in that the tree structures were created to frame two-way channels for mechanical services rather than to provide gaps for the introduction of daylight. In each tree, coffers (defined by the arrangement of branching beams
that was necessary to create the framing for typical room subdivisions) contain indirect lighting fixtures in integral coves along the lower edges of the structure. A study model (5,6) was built to evaluate the concept and to measure the light distribution of the indirect system.

Though most of the spaces were to be used as office landscape, the Bank required that the system should permit the creation of 10- or 15-foot-wide offices. Note the considerable variety of spaces made possible by this tree configuration (8,11).

A very important advantage of the tree approach is that mechanical rooms can be located anywhere, unlike post-and-beam systems in which major feeder ducts must usually either penetrate or pass below the beams. The usual problems encountered when large holes must be cut through structural members to accommodate mechanical runs can be avoided if a system permits the elimination of structure along lines of service distribution; tree structures are among the few generic types which permit such elimination. In a tree structure, mechanical rooms can be located wherever they may be required without affecting the layout or detailing of the exposed structure and surrounding spaces.

At the schematic stage of planning a tree structure, the interface between structure and air-
7 Johnson's Wax Headquarters, Racine, Wisconsin (Frank Lloyd Wright / Architect).

8 Preliminary partitioning study.
handling systems is so unconstrained that almost any type of air-conditioning system is feasible—multizone, dual duct, etc. The size of the service channels (12) can be tailored to fit the needs of almost any mechanical system. After tradeoffs in partitioning, flexibility, acoustic separation, cost of forming, etc., have been analyzed, coffers and service channels can be dimensioned to maximize the visible room volume. One system studies alternative is presented in Fig. 10. For the Bank of Canada project, a multiduct system was selected. Holes in the perimeter beams of the trees were carefully planned to accommodate all foreseeable future needs, so that almost all trees could be made with identical formwork. A detailed mechanical layout for a similar system is presented in the case study on Governors State University (Fig. G5–7).

Evolved from the nature of the system itself, the exterior skin

9 Olivetti Factory, Harrisburg, Pennsylvania (Louis Kahn / Architect).

10 Design development study for the tree structure.
Studies of typical office spaces.
of the building is obviously non-structural and visually reinforces the beholder’s awareness of the shape and dimensions of the basic tree module.

**Critique**

Unfortunately, the proposed indirect lighting scheme was changed to a direct/indirect system (13), except on the ground floor and in exterior coffers.

12 Service channels.

13 Typical structural tree.
Subsequent to creating an irregular tree structure for the Easton Hospital (Case Study E6), the same design team employed the same approach in a second hospital addition, one with fewer constraints in terms of the planning module. Problems of contact with the existing buildings were also simplified; with contact required on only two sides of the new structure, symmetrical trees could be used. A higher proportion of the program is assigned to open space at Charlotte Hungerford (1) compared with the Easton Hospital. This makes the building system more easily readable, maximizing orientation and comprehensibility for the users. Omission of the glazing mullions at transoms would have increased this effect.

The 20-foot-square trees bordered by 10-foot-wide service channels provide more than ample service distribution capability and adequate partitioning flexibility (2). The arrangement of indirect lighting fixtures within the tree structures differs from the configuration used at Governors State University, where the coves border the beams which form the branches of the structural tree. At Charlotte Hungerford the fixtures outline the perimeter of the trees (4), running along the edge beams which frame the service channels. Since the project was too small to amortize the costs of special formwork, which would have made it possible to cast the coves with the beams, extruded aluminum luminaires were used instead.
The inherent versatility of tree systems was further demonstrated by their application to the complex forms of this project (6). Architect Morgan’s competition-winning design had been based on slab construction with plans to apply mechanical and lighting systems in a configuration quite similar to that of a tree system.

Lighting consultation began just before the design development stage. Structural engineer William LeMessurier joined the team for a 2-day squatters session, as a result of which the tree system was adopted as an economically feasible and spatially more desirable approach. Relatively few adjustments of the original plan were necessary to eliminate irregular situations which would have required asymmetric trees. The system was maintained even at the parking level (although the
concrete was left unpainted and lower levels of lighting were used), since the service channels were as useful there in terms of providing an inherent visual order as they were in more finished spaces.

Tree spacing was 27 feet on center because of the special parking requirements for quick getaway of police cars—two cars per bay, parked diagonally. To accommodate furniture placement in the corners of the large number of partitioned rooms, X-shaped rather than round columns were considered most efficient (3). The rooms will be very spacious, as at Governors State, with the bottom of the beams 8 feet above the floor and a floor-to-floor height of 11 feet.

**Comment**

The Jacksonville (four-coffer) tree configuration and dimensions proved adequate to accommodate a wide range of room sizes. These trees were much less expensive to form than 12-cell trees such as those used for the Bank of Canada. For more conventional programs the 27-foot column spacing would prove somewhat tight for parking three cars per bay.

In terms of the detailing of indirect coves integrated with structural beams, it is instructive to compare the sections at Charlotte Hungerford Hospital, the Police Administration Building, and Governors State University (8). Casting the coves monolithically with the structural beams, as at Governors State, gives the simplest and most pleasing appearance. At Jacksonville, precast coves were fabricated separately and field-applied to the cast-in-place beams. The continuity of material gives a better appearance than an applied metal luminaire of the type used at Charlotte Hungerford, but the simplicity of the integral casting has still been lost.
GOVERNORS STATE UNIVERSITY
Park Forest, Will County, Illinois

G5

Caudill Rowlett Scott (architects for design development); Evans Associates (architects); Johnson Johnson and Roy (site planning and landscape architects); William Law Associates, Inc. (lighting consultants); C. P. Boner & Associates (acoustical consultants); McKee-Berger-Mansueti, Inc. (cost consultant); Davis MacConnell Ralston (educational programming consultant); Educational Testing Service (educational programming); Instructional Dynamics, Inc. (educational technology media planning consultant); DeHaan & Reed & Associates (interiors consultant); R. Morse (soils consultant); Brown Davis Mullen & Associates (mechanical engineers); M. Dean Worth (structural engineers). Cost: $19,500,000 (including partitions, lighting, finishes, and built-in equipment). Square footage: 420,000. Schematic design started 1970. Construction completed 1975. Lighting load: 3.3 watts per square foot.

This university complex was developed around a tree system similar to that of the Bank of Canada. The same tree module (2) is used throughout, except where larger, column-free spaces were required (such as the gym and swimming pool). In these spaces, one-way systems are used with a module of beams and voids related to the contiguous tree structures, so that service channels continue uninterrupted. Note the gridwork of service channels and their relationship to the structure and lighting diagrams (7, 8, 9).

Unlike the Bank of Canada, where small offices would clearly be required, the University could be designed with a 30 x 30 foot module readily divisible into two or four. In the early design phase it appeared that areas requiring finer divisions would represent only a small portion of the building, and that these could be treated as special cases and given a lowered ceiling if necessary. However, the final programmed landscaping for carrels, etc., made it possible to accommodate all the programmed spaces without resort to such ad hoc variations on the system. Introduction of the integrated system-of-systems approach came after an original design had been developed based on a suspended ceiling system.

Only a single morning "squatters session" was required
for the design team to review a number of possibilities and conclude that the tree system looked both workable and economical. Overnight the original plan (4) was modified around the tree system (5,6). Cost forecasts proved accurate and the building contract was well within the budget. A mock-up (13) was built to check light distribution measurements.

The lighting and mechanical systems are designed around the concept of adaptability rather than flexibility. The “trees” are perforated with sufficient holes to accommodate any foreseeable air-conditioning requirement; the natural channels between trees can enclose any foreseeable duct or plumbing requirement. Since ducts and pipes run in clearly defined, unlit channels, they can be left exposed (11) if economy or a need for frequent rearrangement dictate, yet remain inconspicuous because of the strong organization of lighted coffers and unlighted channels.

A number of provisions ensure total lighting adaptability. The fluorescent cove fixtures may at a moment’s notice be easily changed to high-output fluorescent lamps, pairs of high-output lamps, or pairs of super-high-output lamps, because the inexpensive cove fixtures are not firmly attached to the structure but
merely plug in and rest on the concrete coves. The plan was zoned according to use, and fixtures of appropriate output level were provided in each zone. Provision of an outlet point in the slab in each tree cell allows a single, adjustable fixture or a track system to be attached in lounges and other areas where accent lighting of trees, sculptures, walls, etc., or the creation of another type of environment is desired (i.e., with dimmed rows of decorative lamps). The lowered bands of ceiling between trees do not normally need any additional lighting. However, if they are isolated from the surrounding illuminated coffers (as in a corridor), recessed lights can easily be inserted in the infill ceiling panels. Similarly, important walls in the shadow of the lowered band can also be

6 Plan—final scheme.

7 Detail of HVAC layout in service channels.
highlighted with recessed wall washers.

**Comment**

This building was designed from the inside out. The exterior forms are derived almost entirely from the nature of the interior systems, which are clearly expressed and comprehensible. The underlying unity of the entire complex is immediately apparent.

Monolithic concrete beams and coves with undercut sections obviously cost more to form than simpler concrete shapes to which lighting fixtures are subsequently applied. However, when the scale of the project is large enough the additional investment in formwork can be offset by substantial savings in the electrical contract. Even on smaller jobs, I feel strongly that practical and aesthetic advantages of monolithically formed beams with integral coves are well worth the cost differential, unless the budget is so inflexible that no tradeoffs can be realized (less expensive carpeting, etc). Many who have seen such buildings as Governors State or Quebec Government Center Complex "C" (Case Study H5) would agree.
Just as the design options for a single room are reduced when it is part of a sequence of rooms or a flexible building system, so the design (both exterior and interior) of any single building should be influenced by the design of other buildings with which it is grouped, particularly when all are built at the same time to house similar or related activities.

Such principles have long been recognized in the relationship of building exteriors viewed from street and plaza. However, there seems to be less recognition among designers that these principles remain valid below plaza levels (within a structure); and that here, in fact, the orientation need is usually even more critical than above ground. Perhaps the failure is more from lack of understanding rather than lack of will. It is true that relationships above ground can be viewed simultaneously while relationships below grade are usually only perceivable in sequence. But designers must understand that the seeing process consists of gathering and processing information; of seeing facts rather than only pictures; of being able to see and relate similar elements, though separated by time. Continuity in a sequence (or its absence) is as immediately perceptible as consistency in a grouping which can be seen all at once. The more easily a designer can describe a design concept in words so that a listener can “see” the concept, the more likely it is that casual users of a building will be able to sense its application.
The approach to lighting design of the National Arts Center was decorative as well as functional. No preconceptions were imposed on its development. The lighting concept came from:

- Architectural forms and spaces of this project
- Perception principles
- Psychological and physiological needs of the users
- Coordination with structure, mechanical systems, and other details

The validity of this total design approach can be judged in a variety of applications in the Center because of the range of problems which had to be solved, because of the clarity of the architectural concepts, and, most of all, because of the attitude of the architects and engineers which allowed pursuit of the objectives with diligence to details, teamwork, and effective follow-through. The participating design and engineering staffs worked as a truly integrated team.

**Design**

From a distance, to a person approaching the Center on a sunny day, the overall impression is that of a series of unbroken building masses on connecting platforms
and terraces (2). Their hexagonal shapes of various sizes are quite obviously those of several theaters and supporting facilities of stage houses, stair towers, and lobbies.

At close range, when approaching the Center from the surrounding streets, a person's impression of "theater" is reinforced by the presence of billboard/chandeliers (14) which line Elgin Street and mark entrances to the building. Upon mounting the plaza, one gets the impression of public spaces below through the positive expression of skylights penetrating the plaza. Smaller hexagonal forms growing out of the plaza are interesting, but puzzling, and upon inspection turn out to be housings for
floodlights. To a person approaching the Center from a distance on an overcast day, without the crisp definition of form by sun and shadow the buildings tend to become more two-dimensional silhouettes. It was our intention to help maintain depth and liveliness by glowing forms and glitter at skylight openings, stair tower slots, and connecting ceiling planes of lobby areas, as well as with billboard/chandeliers.

From a distance, when one is approaching the Center at night, what is seen can be more totally manipulated, and we chose to compose selectively. Only the forms of the "egg" of the theater and the opera house-concert hall are floodlighted (1). As accessory facilities, the stagehouses were left dark, except for the shadow pattern cast by the floodlit Daude- lin sculpture at the rear wall of the opera stagehouse. In the darkness the kiosks sparkle brilliantly, as do the stair towers, with their glass sculptures and patterns of lamps reflected in clear skylights which were faceted and steeply sloping for this purpose. Trees were uplighted, to provide a lighted frame against the background of the city and to add enclosure to the plaza; but the trees were not lit from the street side, where they would be in silhouette against floodlit portions of the Center.

The exterior forms of stair towers and lobby areas were meant to become more mysterious and to remain secondary to the main halls. But the brilliantly lighted sculpture in the stair towers and the illuminated works of art in the lobbies should beckon, seen in silhouette through the architectural exterior screen. The sparkling reflections of decorative incandescent lamps in the skylights add further gaiety.

Because of the close coordination of design, it is difficult to say whether the lighting forms were created by the architecture, or whether the architectural forms were created by the lighting design. Both occurred. The clear articulation of the shape of the halls invited their being highlighted selectively. And the housing of the lighting equipment to achieve this purpose became the "raison d'être" for useful, sculptural-scale elements on the plaza (1,16).

The stair towers derived their shape and slotted corners from the lighting concept that the impression of "theater" and grandeur
could be heightened by having patrons circulate around a light-reflecting sculpture (5,18) illuminated as though by a shaft of sunlight from the top, and by presenting a view to the exterior of a glittery world, unlike that glimpsed in office building stair towers.

Another example, the need for a system of kiosk/sign-chandeliers, arose from the absence of a traditional theater marquee. The design team had to create a new form which would serve as a distinctive nighttime symbol for the theater while displaying advertising posters for current and coming attractions. We chose to develop the design around the hexagonal theater form and the basic interior lighting tool—the exposed, clear, incandescent lamp.

Inside the Center, lighting concepts and details were derived from the thematic architectural forms. The concept of lighting design was to emphasize the most dominant architectural characteristics. The lobby and hall of the opera house are one continuous space, separated only by a screen of unbroken columns, with boxes suspended between them. To emphasize this feature, bare lamp chandeliers are notched into both the hall and lobby sides of each column (4,7,11,12).

The design of the ceiling in the opera hall grew out of the need for an extensive catwalk system for stage lighting and screening for a wide range of randomly placed acoustic reflectors and absorbers. After attempting to leave voids for stage lighting, we decided instead to express the catwalks positively by patterns of light-reflecting white battens, flags, and lighting cylinders, of a scale large enough to distract the eye from the disorderly array of equipment above and arranged to follow the concentric catwalk curves (4). Study models were built to explore various alternatives (11).

Together the lighted columns and ceiling create a distinct room-size chandelier, unique to the architectural form of the National Arts Center Opera Hall. The effectiveness of this chandelier concept was tested with an illuminated model. By selective dimming and switching of these elements and by highlighting of the curtains, a wide variety of spatial and decorative effects can be achieved. At the beginning of intermission the lighting on the lobby side of the columns is turned on first to expand the space of the hall beyond the columns to the outer walls (12).

The exposed concrete interior walls of the Theater and its hexagonal shape suggested that the walls be highlighted with the same vocabulary of clear lamps used in the Opera House mounted this time behind perimeter beams. The form of the ceiling was again dictated by stage lighting requirements (3). The ceiling structure was created as a series of light-shielding, open-fronted, pyramidal boxes. Their junctions are articulated as part of the house lighting pattern. This room-sized chandelier is also unique to the National Arts Center Theater. A similar edge treatment was used in the experimental theater (10).

In the stair towers, instead of lighting design growing from the shape of the space, an appropriate space was designed to fit around the lighting concept, a spine of brilliantly illuminated, light-reflecting sculpture by William Martin (5,17). A ring of narrow-beam spots around the skylight spots are directed only onto the sculpture. The other surfaces of the stairwell receive light only from the sculpture, indirectly. Despite its extreme brilliancy, the sculpture causes no glare because it is what one wants to look at (maximum signal-to-noise ratio).
The idea of light-refracting sculpture used in the stairs was used in the salon in a somewhat different form. Here, reflecting elements are simple, graduated strings of glass beads, supported in a “frame” consisting of the edge beam of the skylight well (19, 21). This effect was also tested and positively demonstrated by a model (20). Later variations on this theme were important formgivers for such projects as the Hyatt Regency Hotels at O’Hare (Chicago) and Houston (Case Studies C7 and C9). Consistent with the design principle evident throughout, the skylight well was used, not only as the obvious space in which to place a chandelier, but as an integral part of the chandelier itself.

The lighting ceiling system of all lobby areas (6) connecting the studio, theater, and opera house was designed as a positive element, recognizing the importance and extensiveness of these surfaces, and as the most continuous and visible element when the spaces are filled with people. Rather than attempting a more neutral ceiling, with inevitable interruptions for access panels, air diffusers, etc., a richly sculptured, removable panel system was devised, using the decorative light fixture as the air supply, with the conical shape of the fixture providing a natural, neatly integrated air-deflecting element for the air diffuser (6). Some of these light fixtures were used to conceal loudspeakers; in these cells, the air diffuser was omitted.

Execution of the lighting concepts was coordinated with the detailing of other building elements, for example, in the lobby ceiling just described. In the opera house column lighting, the column cladding and air ducts, air diffusers, and lighting extrusions are combined. One of the inherent perceptual problems is to generate the appearance of a band of light from a series of individual lamps. This was accomplished by lining the gold anodized aluminum reflector with sheets of glass balls. Each ball produces point reflections of lights to any viewing position. (A spherical surface will always have a point of tangency to any viewing position.) In addition, each ball acts as a focusing lens and creates a brilliant spot on the gold backing. The combination creates a rich three-dimensional surface (7). Lamps are not evenly spaced through the vertical length, but spacing increases at the top of the column to produce the effect of “fading out.” The decorative light notch is terminated at the bottom by integral ashtrays.

The initial rectangular shape of the column was modified to accept the lighting notch gracefully; thus, the lighting became the “raison d’être” for essentially hexagonal columns, adding further to the architectural continuity of the National Arts Center.

Critique

Floodlighting of the sculpture at the back of the Hall stagehouse was not permanently installed until 1972, although the illuminated sculpture had been a key element in the exterior lighting concept. Temporary lighting was used by the lighting consultant at a “tuning up” session to determine the best arrangement for that particular piece of sculpture.

Also, in 1972, it was decided that the lobby side of the buildings should appear more prominent when viewed from adjacent streets through the intervening park. From this direction the mass of the lobby (initially conceived as fairly transparent) had interfered with the view of the hall itself; uplighting of the screen walls of the lobby restored the integrity of the exterior image.
At least one of the three small buildings in this project would probably have taken a different form if built separately in a different location. As a cluster, however, it was considered desirable that they be related in interior character as well as exterior forms, insofar as their various uses permitted. Development of a common vocabulary in the detailing and lighting was difficult but possible. The most important common denominator was the strong roof form hovering over its supporting brick walls.

**Design**

The starting point for the lighting design at the Eaglebrook School was the idea of supplementing the natural lighting by utilizing the white plaster ceilings floating above the perimeter walls to reflect light from fluorescent sources concealed at the top of the walls. Since the walls were interrupted by windows, it was necessary to create a horizontal band across the mullions at that level for continuous lighting and wiring (3). Whereas in some rooms a direct/indirect light distribution would have been best, in others the need to place bookshelves and laboratory cabinets up to that level dic-
tated the use of a closed-bottom channel, with light distribution upward only (4,5). This eliminated the potential problems of lamp reflections in the windows below. The channel was “floated” away from the mullions in order to allow a space for upward distribution of air from the brick cavity walls.

This basic light distribution was supplemented from other directions. In the double-loaded corridor building, which has similar height corridor walls and transom above, the indirect lighting was continued from the corridor walls of classrooms, etc. On the lower level, however, no convenient horizontal position was available, so the compromise was low-brightness incandescent downlights recessed in the ceiling (7).

Maintaining the scheme in the library building (9) was more difficult because of the presence of a balcony and the greater room size. At the perimeter, physically similar fixtures with two super-high-output lamps were used, with lenses to reduce their brightness when viewed from the balcony. Such reduction of the light spread was in opposition to the objective of illuminating the ceiling as uniformly as possible, but was an unavoidable compromise.

The central portion of the space (8) was illuminated from a fluorescent edge slot and by the central skylight (supplemented by incandescent downlights). The edge slot was originally to have been an edge skylight, which unfortunately had to be eliminated to meet budget problems. The central skylight was left totally transparent in order to get undiluted direct sunlight and sky view. The dynamic quality of the space with the introduction of a relatively small area of sunlight (maximum projected area of less than 64 square feet at mid-summer noon) was considered valuable enough in fulfillment of biological needs to offset the possibility that some students might be inconvenienced by the direct sun at times. The chamfered ceiling well provides some transition to the skylight brightness but, more important, brings the perceived size of the modest skylight up to a scale appropriate to the large central well space.

An initial scheme for translucent skylights covering the entire central area was quickly abandoned with the realization that the necessary construction would have appeared “busy”—the translucent glazing would seem glaring on bright days and gloomy on dark days, with no sky view or benefit of direct sunlight penetration. Air conditioning would also have been much more expensive and difficult.

Although some of the inherent drawbacks of large skylights would have been eliminated had low-transmission clear glazing been proposed rather than translucent glazing, the extensive pattern of cast shadows would still have been bothersome. (Such shadows would be more acceptable in a transitional environment such as a public circulation space where orientation needs usually outweigh task needs.)

Since the window band is continued around the corners in which a bathroom is located (10), the typical classroom artificial lighting is also continued. Had the window been stopped and the bathroom thereby consciously left “out of the system,” a lighting scheme more specifically tailored to the needs of a washroom would have been designed. However, as built, the best trade-off in cost as well as appearance was to continue the system. If this had been a “powder room,” the system would have been supplemented by local lighting at the mirror.
8 Library.

9 Section through library building.

10

11 Balcony in the library.

12 Below, right: typical study carrel with integrated local lighting.
When a building complex is unified by exterior forms and materials and by a common roof/ceiling structure, as is the Fathers of Confederation Center, the manner in which the different lighting needs are fulfilled should be consistent with the intent to unify the overall design.

Additional factors made the design problem at the Fathers of Confederation Center much more challenging than that at Eaglebrook. Because of the harsh climate and the shared supporting facilities, the principal circulation is below grade (7), which makes the achievement of positive orientation much more difficult. In addition, the Fathers of Confederation complex was intended to serve as a new focal point for the city of Charlottetown. At night, the success of the image would largely depend on the success of the lighting scheme (2). The concepts and design were described...
The architectural concept: Rather than sitting on top of a podium, the masses of library, museum, and theater rise out of the ground from a concourse level which, in the local climate, is the major circulation path much of the year.

The daylight design: By daylight the above ground organization of the masses is clear and powerful. What may not be apparent at first glance is the superb daylight design at concourse level. The narrow skylights surrounding each block allow daylight to define the continuity of those massive walls from concourse floor to skyline ... a relationship which can best be seen through the open courts (7), but can always be sensed throughout the underground passages, so that the underground and grade level orientation tends to be linked.

Supplementary daytime illumination fills out areas not sufficiently reached by daylight, without nullifying the dominance of the naturally lit areas. The obvious night-time design solution was simply to reverse the daylight effect (2,4).

The 6' x 6' waffle grid is dominant within each of the individual buildings. Even if it were not a visible common denominator on the exterior, consistent handling of the grid had to be the starting point for the lighting design ... despite the direct conflict between a uniform solution and the varying requirements of theater, museum, and library. The conflicting demands for unity and difference were resolved by using the same lighting fixture within each coffer, and controlling the appearance of the structure, spaces, and the lighting quality by utilizing variations in lamp sizes, and carefully developing switching and dimming patterns. The universal fixture, a pendent "can" centered in and aligned with the bottom of each cell, was designed to illuminate the cell without bisecting shadows, with separately controlled direct lighting which will appear as the same dark cone even though the lamps vary from 50 to 300 watts.

Most simple of the lighting problems occurred in the library (9) where the requirements are fixed and simply defined. Here diffused lighting is provided by maximum indirect illumination of every coffer, but, since the sand-blasted concrete is not the most efficient reflector, this indirect lighting is supplemented by a direct component from every cell. Fifty watt lamps are used to maintain the pattern in areas (such as at the overhanging soffit) where there is actually no necessity for the light. One may question the relatively low "efficiency" of illuminating the coffers, but the dark color and shadow-casting configuration are precisely the reasons for illuminating the structure, to relieve the daytime gloom of dark ceiling in contrast with bright window. Spaces not covered by the exposed ceiling grid are illuminated in a neutral manner, indirectly from book stacks or open-cove wall fixtures, by low-brightness recessed fixtures in suspended ceilings, and by local lighting under shelves and cabinets.

The museum (8) demanded a disciplined flexibility ... flexibility to create the proper focus for a wide variety of possible exhibits, but with a discipline consistent with the monumentality of the Fathers of Confederation complex. Casual arrangements of exposed adjustable lighting fixtures on tracks were thus avoided. Instead, flexibility was gained by:

1. Highlighting the most likely display planes by arrangements of reflector lamps in the ceiling coffer fixtures, i.e., 300 watt lamps at the perimeter and over the central well.

2. Circuiting so that each side of each concentric square could be switched and dimmed individually.

3. Adjusted edge lighting concealed from view along the side of the balcony enclosure in one of the galleries allows the upper walls to be lit either uniformly from above or with dramatic effect from below. The actual location and structure of the balcony—originally intended for the outside wall—was changed to make these effects possible.

4. Special recessed floor fittings to support and electrify posts for self-illuminating mid-floor display panels and cases.

5. For most exhibits, indirect lighting of the ceiling coffers would probably be dimmed to a very low level for maximum focus on the
exhibits. However, the level may be readily increased when a greater component of indirect lighting is helpful or for occasions, such as receptions, when the architectural space is to be emphasized.

The daylighting design (corner window) is a good compromise between providing contact with the outdoor environment and competing visually with exhibits.

In the theater (5,6), many different types of spaces are created with the lighting... again primarily by carefully planned switching and dimming patterns with the coffer fixtures. Basic architectural departures from the other buildings were the adjustable shape of the hall and the presence of acoustic clouds which were to be expressed in a positive sculptural manner.

To maximize the expression of the acoustic sculpture as a positive element (rather than a necessary evil) the panels were made translucent, so that when backlit they become the "chandelier" (5).

Some of the possible spaces to be created in the main hall:

1. Most dramatic: "chandelier" only, or plus illuminated back wall under balcony.
2. Neutral: downlights illuminating floor area of complete hall, but with walls and "chandelier" remaining unlighted.
3. Neutral: downlights illuminating floor area of contracted hall but with walls and "chandelier" unlighted.

4. Architectural emphasis: ceiling coffers illuminated plus downlighting of floor ("chandelier" expressed as silhouette). This might be the condition for a lecture-type program, or for daytime concerts when the hall lighting should relate to the daylight conditions outside, or at least provide a pleasant transition during intermissions.

Some change of pace is provided by patterns of bare clear lamps in the lower foyer and refreshment areas.

Some general considerations pertaining to all buildings:

1. Whenever the coffers are illuminated, every coffer in the space is lit. In this way the structure is always perceived as an uninterrupted plane (4,8,9).
2. Lighting of walls and floor is generally not uniform, but with selected emphasis for purposes of display, expression of structural rhythm, or defining nodes and axes in the circulation pattern (7,10).
3. All exterior lighting consists of light reflected from and spilling out of the buildings themselves. This was possible because of the limited size of the site (2).

**Critique**

There has been justifiable criticism of offices and other supporting facilities which are totally cut off from the exterior. In spaces at or above grade which are isolated from outside conditions, dissatisfaction is increased since the daylight is felt to be "so near, yet so far." Awareness of the available alternative is frustrating to the biological need for contact with exterior conditions. Windowless spaces deep in a basement, where daylight is obviously impossible, cause much less irritation to their occupants. However, this tradeoff was consciously decided in favor of maximum monumentality of the principal public elements. Some minimal windows or skylights would have been valuable but could not be accommodated within an already strained budget.
When main circulation is at grade, defining and distinguishing between the principal units of a complex are desirable but less necessary than when primary circulation is below grade.

Design

At the Fine Arts Building for Wisconsin State University at Stevens Point, edge skylights and coordinated lighting were used to increase the comprehensibility of the forms of theater and hall both from the exterior and within the lobby (3) during the day and at night. The ceiling infill was treated as a neutral enclosure for services and as a background for lighting track which allows the focusing of lighting as desired for exhibits and occasions (4).

In the hall and theater, the principal elements of the Fine Arts Building, balcony forms were treated as “chandeliers.” Used to screen ducts and allow flexibility
in placement of acoustic reflectors and absorption, the wood ceiling took its form and details from the arrangement of lighting. In the concert hall, stage and audience hall function as one room, and therefore the ceiling hovers over both in a continuous sweep; in the theater (8), on the other hand, stage and hall are separated and an implied proscenium is created by the interruption of the ceiling plane as it wraps around the lighting bridge (as was the intent at the Beloit Auditorium, A2).

The optimum locations for light fixtures suggested the module and joint detailing for the prefabricated wood ceiling sections. The design of the very simple and inexpensive custom-made sheet metal fixtures grew out of the proposed mounting detail. The detailing facilitated installation and makes it possible to relamp and aim these fixtures from the catwalk system above the ceiling (7).

Classrooms and studios and corridors occupy the lower level. Rather than treat this level as a basement full of randomly placed ductwork screened by the glare of industrial fluorescent fixtures, the design team attempted to create a restful background of illuminated "bays" supplemented by track-mounted, adjustable incandescent fixtures arranged as required for specific room activities.

Without being any less spartan, mechanical and lighting elements were integrated with the structure. Ducts and pipes were arranged and supported on pipe racks that also support fluorescent strips and wood valances. The pipe supports were meant to extend only as far as necessary (to clear the pipes and ducts) in each instance. Unfortunately, where this concept was not followed and unnecessarily long supports were used, the racks encroach somewhat upon the rooms, particularly the smallest ones.
Critique

An attempt to modify the structure itself to create integral service channels and lighting coves was handicapped by the lateness of the attempt to coordinate all aspects of design. As a result, on his next similar project (Beloit College, South Campus Complex, [Case Study C8]), architect Wenzler began with an integrated design team, so that structural, mechanical, and lighting designs would evolve simultaneously rather than in sequence.
Early attempts at the integration of structure with mechanical and lighting systems produced buildings such as Weese’s IBM-Milwaukee Building (Case Study E2) and Skidmore Owings and Merrill’s American Republic Building (Case Study E1). Though pioneering, these projects suffered from two defects. First, lighted coffers were based on a one-way module too small to be easily integrated into a perception of the created spaces as unified volumes, while the one-way orientation made subdivision of spaces difficult. Second, the integrated systems developed for lighting and air distribution made no provision for flexible distribution of other mechanical services such as plumbing, sprinklers, etc. These problems were subsequently addressed in projects such as the MacMillan-Bloedel Building (E8) and the NASA Center in Cambridge (G1).

Complex “G” of the Cité Parlementaire, Quebec City (2), is among the best and largest projects yet built which incorporates a successful solution to both problems.¹

Despite the fact that lighting design began late in the Quebec project (the garage level went out to bid simultaneously), it proved possible to redesign a neutral, homogenized suspended-ceiling concept into a well-articulated system integrating architectural, structural, mechanical, and lighting elements. The revised design was built for less than the estimated cost of the original design, without delaying construction.

While a unified design approach suggested the consistent

¹Others, which derive an even greater degree of flexibility from the tree-type structural approach, have been completed or are under construction in 1976; for instance, Governors State University (G5), the Bank of Canada, Ottawa (G2), and Jacksonville Police Administration (G4).
use of a single vocabulary of architectural materials throughout the project, the tower and the low buildings were sufficiently different in volumetric terms that it was by no means obvious that a single structural-mechanical solution could be developed to serve the needs of both. The design team was fortunate, however, in that the perimeter system developed for the tower (3) proved equally suited to the low buildings (8), with their longer spans and cantilevers. Functionally, the extension of one system throughout the project was entirely justified. In both buildings, the predominant activity was to be office work in office landscape arrangements, with enclosed offices the exception rather than the rule. It was assumed that most of these would occur at perimeter locations, to take advantage of the view.

**Design**

The architectural concept of service cores at the corners of the tower immediately suggested that the usual problems encountered in buildings with exposed structure—running service lines from central core to perimeter—would not be present. It seemed diagrammatically obvious that the most logical distribution of mechanical services would be inward and outward from service bands interconnecting the corner cores.

The problem then became how to enclose and finish the necessary channels. In a relatively simple low building, in which some waste of vertical space would be more tolerable, a network of plaster channels could have been created under the shallowest possible zone of structure. Instead, the design team was able to develop a deep structure which incorporated the necessary service channels while maintaining maximum visible height in between. A key to the solution was the decision to switch to a high-velocity dual-duct air distribution system for the tower (not for the low-rise

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4 Columns during construction showing the holes for the service channels.

5 PaTel detailed services distribution plan, typical tower level.

6 Detailed sections through a typical service channel.
structure), requiring only small holes penetrating the column branches which support the channel beams (4). In the service channels, the “shadows” created by the wide columns offered a natural place to locate the mixing boxes. The lowered service channels could thus be placed in the most logical position and still be of only minimum width.

Perimeter spaces are supplied directly from the main channel (5,7,8). If these spaces are subdivided, smaller channels spanning to the exterior wall are used for air supply. Economy and flexibility in initial construction and in adaptability of space use were maintained by providing a uniform pattern of holes for air supply and return, etc., throughout the structure. Partitions do not interfere with mechanical outlets since these are located in the sides of the beams (11), rather than in the infill surface on the underside (as in the earlier NASA project, Case Study G1). Initial skepticism concerning air distribution was dispelled by testing a full-scale mock-up.

Bronze-colored metal infill panels were consciously differentiated from the structure, lest the structure appear too massive.

Where the corridor under the service band is illuminated from adjacent areas, no additional lighting is necessary (12). However, when the corridor band is totally enclosed, recessed downlights are added (10). The perimeter service system designed for the tower was successfully adapted to the low buildings. Here the deep secondary channel form was even more advantageous structurally for the longer spans and cantilevers. The system was used successfully for areas of office landscape (12,15), lounges (14), and enclosed offices.

To minimize the size of the integral lighting coves, lighting
within the coffers consists of super-high-output lamps in minimum-size strip fixtures in each cove. The bulky ballasts were mounted within the adjacent channel beams and connected to the fixtures through the regular pattern of holes provided. Remote ballasts are acoustically advantageous, particularly in Canada where quiet super-high-output ballasts are not available.

To provide orientation to the major masses above grade in the levels below the podium, the perimeter corridors which edge these masses were treated with metal-slat ceilings and slot lighting which highlights the walls of the major masses (19). At the cafeteria level beneath the podium the infill areas between the major masses above grade are differentiated with a waffle ceiling (22). In the cafeteria area itself (17), where much less light was appropriate, standard fluorescent lamps were used in the indirect coves, though intended only for use on overcast, gloomy days. On sunny days and at night the column-mounted incandescent fixtures would be more appropriate for most occasions.

Edge-slot lighting is used in washrooms, serving areas for the cafeteria (18), lower corridors (19), stairs (21), and snack areas (20).
16 Large conference room.

17 Cafeteria.

18 Cafeteria serving area.

19 Slot-lit corridor.

20 Snack machine area.

21 Service stair.
A desire to create terraced forms on the plaza above resulted in an ideal structural form for lighting the auditorium below (24). Edge beams provide natural baffles for wall lighting, which was supplemented by neutral downlights in the coffers overhead and from the lighting/acoustic rig used for stage lighting from the house.

In the high entrance lobby of the tower (25), the usual indirect lighting was supplemented by incandescent downlights used to highlight objects at floor level.

On the exterior plazas, all lighting requirements for safety are satisfied by spill lighting from the building overhangs and interiors (26). Interior lights in perimeter bays are left on at night for circulation within and for protective lighting and image on the exterior (29). Major functions of exterior lighting therefore were to illuminate the buildings as focal points in the city, to provide interest, and to define circulation.

Since the daytime image is one of horizontal bands between vertical corner shafts, the corner shafts were highlighted from very-narrow-beam incandescent fixtures mounted in air wells at the corners (28). The horizontals are naturally defined in silhouette against the illuminated ceilings.

Conceptually, emphasis of the terrace horizontals was also desirable, but the means were not so obvious. Recessing lights into the public sidewalk would have created jurisdictional and maintenance problems, while uniform lighting of the great expanses of the other walls would have been extravagant.

Instead, the terracing was defined by selectively illuminating only portions of each wall—those portions which would be relevant to achieving the second objective of guiding circulation. First, lighting was provided from the underside of terraces overhanging truck entrances. In addition, large, cubic precast concrete chandelier/shelters were provided, varying from 8 to 16 feet in width (27,29). These provide shelter where it is needed by pedestrians waiting for a ride. Strings of protected clear lamps within each cube highlight wall and ground surfaces around entrances and provide sparkle (27). The upward light emanated from these shelters provides a subtle wash of light on the otherwise unlit building surfaces and trees. To those persons on the street and plaza or on the floors above, the illuminated cubes identify the points at which the terraces can be penetrated. Seen together or sequentially, they constitute “environmental sculpture.” Their presence at the edges of the podium defines its boundaries and frames the view, adding intimacy and a sense of scale frequently lacking in contemporary urban plazas.
26 Site lighting plan.
Comment

The considerable expanse of first-quality office environment at Complex "G" has proved an invaluable educational experience for both design professionals and building clients. It shows them what is possible—what can be achieved as a working environment. Field trips there have led to application of similar systems in the design of a number of major projects. Place Guy Favreau (33), a 4-million-square-foot federal government center in Montreal, is being designed with a variation of the Quebec system executed in precast concrete by project architect Gordon Edwards (consultant and principal designer for Complex "G"). Very different in exterior form but similar in its integrated structural/mechanical/lighting system is Arthur Erickson's British Columbia Government Center in Vancouver (30,31,32), which spreads out for three blocks, mostly under a park.

Although it may seem extravagant at first thought to demand field trips involving the entire design team and the clients, experience has proved that the resulting shared experience and common frame of reference for the whole team pays dividends in the final design, while expediting the entire process. A number of design teams have benefited in this way from field trips to Quebec "G," just as the team which designed Quebec "G" drew on experience gained during a field trip to the American Republic Building (Case Study E1).
Programming of lighting objectives for the underground stations of the Washington Subway System took place long before the conception of the tubular, vaulted station structures. The basic goal was to give a sense of spaciousness and airiness in order to reduce the natural tendency towards claustrophobia in underground spaces. To achieve this end, wall and ceiling surfaces needed to be well illuminated. The primary design requirement was to provide inconspicuous light sources which would attractively render the enclosing surfaces of the various stations. The integrated structural, mechanical acoustic, lighting, and graphics concept was developed in a morning design session in which representatives of all disciplines participated.

Design of underground stations
The initial architectural program called for related but individual stations, à la Montreal. When the program was revised toward a single design expression for all the underground stations in the system and a tubular design had been developed, the desire to illuminate the vaults from their bottom edges rapidly led to the concept of floating the platforms free from the vaults (Fig. 100, p. 89) to use perimeter railings to baffle the light sources (an alternative to using louvered gratings set flush with the floor).

Shielding the lamps by the geometry of platform floor, light sources, and vault instead of relying on hardware such as louvered gratings not only creates a more natural, distractionless space (1,2) with more economical lighting equipment and maintenance, but should also reduce vandalism (since the walls are out of reach).

Since the low-positioned light sources mounted in the platform edges could not be used in side-platform stations to illuminate the central portion of the vault overhead without glare to those on the platform, the edge lighting system was supplemented from fixtures concealed between the tracks and, when the tracks are covered by mezzanines, from fixtures concealed in the tops of the ticket kiosks and sign pylons (which are also used to distribute air).

Lighting pylons are also used to light the vaults of center-platform stations. This system proved adaptable to all of the many station configurations. These design concepts were then carried through the other spaces: escalators were "floated" in their tubes (13,14), and the pylons which have become symbols of the sys-
3 Presentation model.

4 Study model.

5 Study model.

6 Typical map pine study model for site lighting.

7 Typical underground station.

8
tem were used in the surface stations as spines for distinctive chandeliers. Initially conceived for lighting, the pylons will represent “Metro” at the street level (9)—a more classic form than typical subway signage elsewhere (10).

A number of models were built to verify the design and to demonstrate to clients the effect of illuminating the vault rather than aiming the light onto the floor of the stations (3,4,5). The models were dimmable so that a range of luminance levels could be shown and all concerned could be educated in the perception of brightness—that relatively large changes in luminance (approximately doubling or halving) are required to produce a perceptible change in brightness. It was shown that whether their surfaces were illuminated to an average brightness of 2 footlamberts, or 20, the stations would appear quite similar.

The existence of illuminated models probably contributed substantially to the generally high quality of the station renderings, which communicated more realistically than usual both the lighting and a sense of the finished station environment.

A full-scale mock-up in concrete was built to confirm choices of finishes, materials, and lighting (105, p. 93). However, the short length of the mock-up (only 6 per-
cent of the real length of a station) made any evaluation of the luminous environment somewhat unrealistic. Full-length mirrors on both end walls would have helped, but the cost was not deemed worthwhile since the models had already demonstrated the overall effect.

Exterior lighting

In addition to the conventional objectives of providing adequate illumination for safety, comfort, and visual guidance, two supplementary objectives had to be taken into account during the development of a concept for the exterior spaces of the Washington subway: first, the several exterior spaces of each individual station required unification, and second, the various stations as a group or system needed a clearly interrelated identity. Like the underground stations, the surface rapid transit stations were to follow a single design concept, with variations introduced only as required by special site conditions.

The lighting objectives and constraints were quite different from those of the underground stations, however. Underground, the most difficult objective to achieve is to dispel feelings of gloom which arise from the sensation of being underground and from the transition from exterior to interior brightness levels. In the surface stations, it was easy to accomplish this objective by good daylighting design. Since lighting for physical safety at night requires only minimal illumination levels, which can be provided in many ways, the more challenging design problem was to guide circulation and create an inviting, attractive image for the users of the system and the surrounding communities.

Design of surface stations

To achieve a consistent image for the entire system, the design of surface stations was tied as closely as possible to the already existing design for the underground stations. Platform guide lights and sign pylons were retained. The vaulted canopies,
16 Typical elevated station.

17 Study model of WMATA surface station.

Courtesy WMATA

Anthony Hathaway/WMATA
however, are not illuminated in the surface stations during the day since daylight from the open sides and from skylights is well balanced (19). At night, the skylights are transformed into a platform-long chandelier of clear lamps (17). Beyond the canopy, the theme of exposed clear lamps is continued in the form of the characteristic sign pylon/chandeliers. It is expected that these distinctive clusters of clear lamps on pylon will soon come to mean “rapid transit station” to the users of the system, offering an attractive sparkle to the adjacent neighborhoods and highways. The clear-lamp vocabulary was extended to the pedestrian facilities on grade: kiss-and-ride areas, bus shelters (18), etc. Major paths were marked with clear lamps, while minor paths were illuminated from more neutral, concealed sources.

Because of the tremendous variation in parking lot sizes and
PART 1 SUBJECTIVE EVALUATION

Please read each of the statements very carefully and rate your degree of agreement in relation to the area you are in now. In rating each statement, please bear in mind the purpose of the area and the activities that are to take place. If you strongly agree with the statement, circle 1; if you strongly disagree with the statement, circle 7; and if you neither agree nor disagree with the statement or you consider it to be irrelevant in the area you are in now, circle 4.

<table>
<thead>
<tr>
<th>Statement</th>
<th>STRONGLY AGREE</th>
<th>STRONGLY DISAGREE</th>
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<tbody>
<tr>
<td>I can see all that is necessary for safe unobstructed movement</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>I don’t feel that I am likely to be attacked or molested by someone here</td>
<td>1 2 3 4 5 6 7</td>
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</tr>
<tr>
<td>I would feel secure and safe from being attacked or molested to walk in this area unaccompanied</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>It is not possible for someone to be moving about in this area totally unobserved</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>The lighting here is adequate for me not to trip or fall over</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>I can recognize someone in this lighting before he is within 10 feet of me</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>I would feel secure and safe from being attacked or molested to walk in this area unaccompanied during the day</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>I feel secure here because it is not possible for an assailant to be hiding nearby</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>I consider this area to be brightly lit</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>I consider the lighting of this area to be highly satisfactory for the activities occurring here</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>I am able to read this evaluation sheet very clearly</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
</tbody>
</table>

PLEASE CHECK THAT YOU HAVE RATED EVERY STATEMENT!

23 Exterior lighting survey questionnaire.

layouts, it was unusually difficult to design a lighting scheme for the parking lots which could be applied consistently throughout the entire system. Because of the scale of the large lots and their sometimes untidy boundaries, conventional arrangements of poles dispersed evenly throughout the lots would have been potentially confusing to drivers. Instead, a visually simpler and substantially more economical design was developed based on illumination from the outer perimeters of the lots, with light being cast away from the surrounding houses and roadways wherever possible. This system proved feasible for all of the sizes and odd shapes of lots encountered (20,21,22). In each of the lots, the perimeter pattern of floodlighting poles was first designed,\(^2\) and then the number, size, and aiming angles of the light sources were engineered. The designs were checked for consistency using colored map tacks (6). Since the great variety of lot sizes and geometries called for a comparable variety of lamp types, beam spreads and clustering, and aiming angles, all floodlights were housed in uniform shadow boxes, sufficiently large to conceal the largest cluster of fixtures, in order to maintain a neat and uniform daytime appearance.

This approach to the parking lot lighting was made possible by the availability of quartz-lamp fixtures with very narrow vertical and very wide horizontal distribution characteristics, which can deliver “sheets” of light toward distant points. Illumination levels from parking lot fixtures decrease as one nears the station, allowing the distinctive station lighting to become the focus of the user’s attention.

Prior to its use in the design of the Washington subway system exterior lighting, this hierarchical approach had been applied and refined during the design of the Forest Park Community College in St. Louis, Missouri and the NASA Electronics Research Complex (Case Study G1). Variations were employed subsequently at Lethbridge University (Case Study E7) and Governors State University (Case Study G3).

When the illumination level criteria developed by the consultants for the Washington subway system were questioned by those in favor of much higher industry-promoted light levels, a large field experiment was conducted. Staff members of the Transit Authority, architectural and engineering consultants, and others were conducted on a tour of a number of parking lots, plazas, and a partial mock-up of the proposed design. A questionnaire (23) was distributed concerning the qualities of the illumination of the spaces which had been visited, and answers were matched up with the measured illumination levels. The observations clearly verified the validity of the initial criteria.