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ARCHITECTURAL LIGHTING

INSIDE: CREDENTIALING UPDATE • OLEDS • LEDS AND NEW MATERIALS • SKY REFLECTOR-NET AT FULTON CENTER • ONE-ON-ONE: STEPHEN SELKOWITZ
PLUS: LED SPECIAL SECTION

MAR/APR 2015

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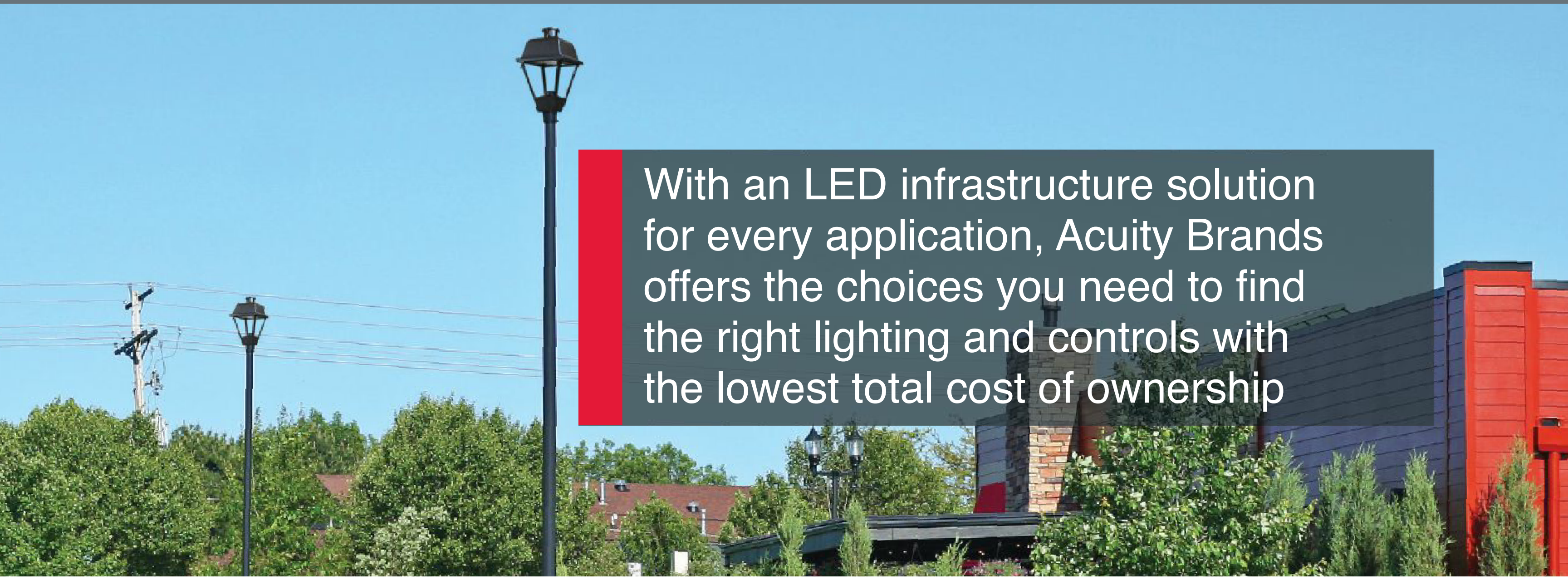

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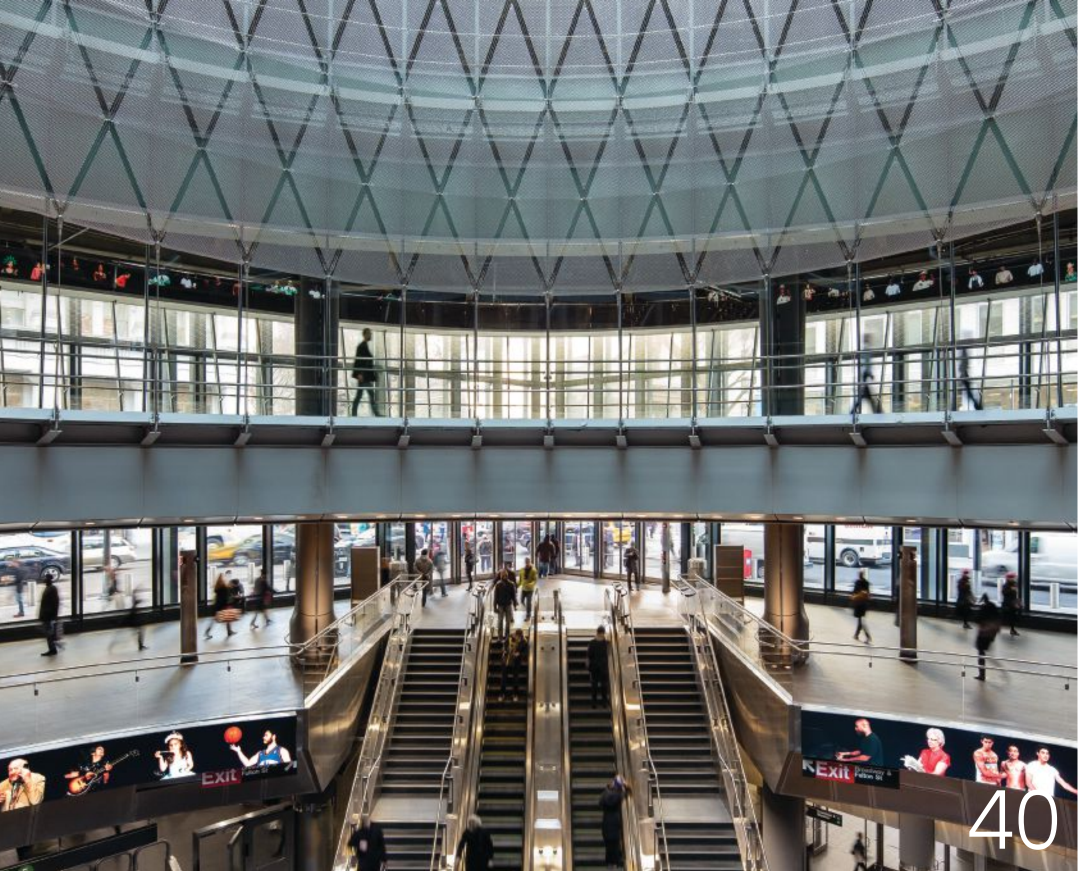

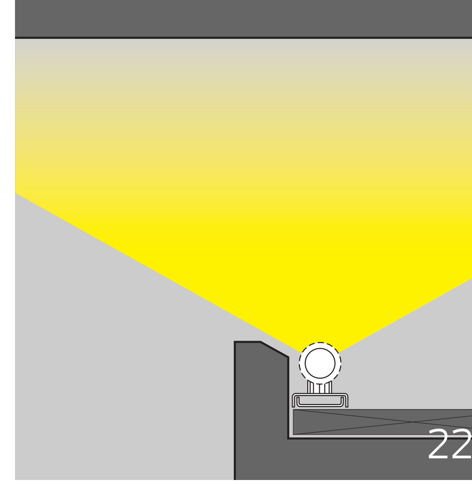

•CONTENTS

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On the Cover:
The Sky Reflector-Net at Fulton Center, in New York City. Photo by Connie Zhou/OTTO.

Left: James Ewing/OTTO

ADDITIONAL SERVICES: THE LIGHTING DESIGNER AS TECHNOLOGY EXPERT

"Does a lighting designer really need to know about the intricacies of binning, where an LED sits on the blackbody curve, or whether or not its tolerance lies within a two-step or a three-step MacAdam ellipse?"

Stephen Voss

As LEDs become the predominant light source in the industry's arsenal of product offerings, the rate at which the technology is advancing shows no signs of slowing. What that means for lighting designers and lighting manufacturers alike is a continued level of anxiety and frustration in keeping up with the latest technical information and LED component compatibility issues. This frustration was palpable at LEDucation, the solid-state lighting (SSL) product expo and seminar series held at the beginning of March in New York City.

The complexity of keeping up with SSL has never been greater. The challenge continues to be to what extent does the lighting designer need to be a technology expert? Does a lighting designer really need to know about the intricacies of binning, where an LED sits on the blackbody curve, or whether or not its tolerance lies within a two-step or a three-step MacAdam ellipse? More importantly, does this type of technical information and the questions that go with it move the focus of the designer–manufacturer dialogue away from where it should be—on lighting design solutions?

Over the past several years, as the industry has adopted these new sources and figured out how to update best practices to coordinate with the technical specifics of SSL, a number of checklists have emerged in an effort to aid designers in evaluating different product lines. This has been a helpful start, but as highlighted by one of the LEDucation seminar sessions ("Focusing on the Problems with the Execution of Integrating LEDs into the Built Environment"), those initial metrics—such as lumens per watt, and LM-79 and LM-80 compliance—are no longer sufficient. Rather, designers require a more specific set of metrics that get closer to key performance issues of concern such as color range and stability, and controllability and ease of dimming without inducing flicker. (As a quick aside, the industry also needs to come to consensus on the topic of flicker and establish a separate set of metrics for this condition.)

To their credit, lighting designers have arrived at this heightened point of technical awareness because they have spent the past decade educating themselves about SSL products and learning, often painfully in real project time, by trial and error what can go right and what can go wrong when specifying them.

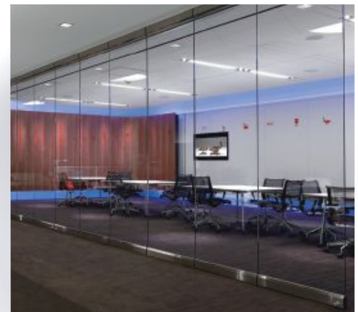
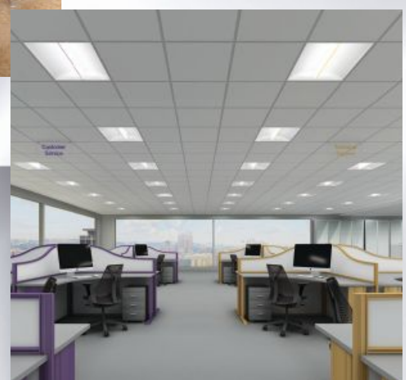
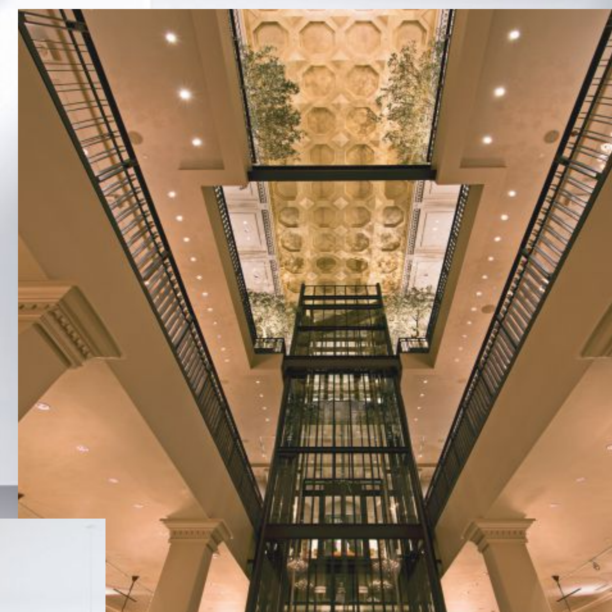
In the LEDucation seminar session mentioned—which included lighting designers Brooke Silber of Jan & Brooke Luminae, Paul Gregory of Focus Lighting, and Jim Benya of Benya Burnett Consultancy, as well as lighting manufacturer Gary Trott of Cree—the panelists highlighted the challenges that designers face on a daily basis in understanding how to both specify LED products and communicate to clients the risks involved with using an emerging technology. Benya suggested that field-measurable metrics such as candlepower, correlated color temperature, CRI, R9 values, flicker, and beam spread are some of the more useful criteria by which to test and gauge product performance.

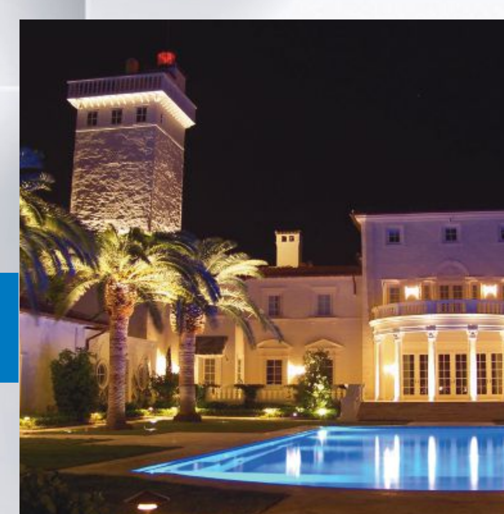
Beyond metrics, the designer's responsibility is also changing. At the same seminar, panelist Gregory noted that it's more important than ever for the designer to test what they are specifying, and that if the manufacturer cannot provide data and a sample then the designer is obligated to inform the owner or client that untested products are part of the specification.

This additional complexity in the designer–client relationship changes the nature of accountability and the contractual process. It opens room for debate about where responsibility lies when problems arise with a source or a fixture. Does it fall to the designer? The manufacturer? The component manufacture? The chip producer? At this time, we don't have a clear answer.

Reliable, validated, easily accessible products and product literature is a key to this discussion, as is a manufacturing community that stands behind its products. What's at risk is not just the adoption of a new technology, but the loss of the designer's time focusing on their main work: lighting design.

Elizabeth Donoff, Editor-in-Chief
edonoff@hanleywood.com

THE IALD ANNOUNCES ITS 2015 ELECTION RESULTS

Active participation among the membership resulted in a tie, and required a run-off vote to select the third director at large position.

text by Elizabeth Donoff

The International Association of Lighting Designers (IALD) recently announced the results of its 2015 elections for its board of directors and membership committee, as well as the Lighting Industry Resource Council's (LIRC) Steering Committee Members. Active participation among the membership resulted in a tie between Ronald Kurtz and Paul Beale and required a run-off to select the third director at large position. For more information about the IALD's organizational structure, visit its website at iald.org. •

THE NEWLY ELECTED 2015 IALD BOARD OF DIRECTORS

IALD PRESIDENT ELECT

Victor Palacio
Ideas En luz
Tlalnepantla De Baz, Mexico

IALD TREASURER

David Ghatan
CM Kling + Associates
Alexandria, Va.

IALD DIRECTORS AT LARGE (THREE POSITIONS)

Denise Fong
Candela
Lynnwood, Wash.

Kevan Shaw
KSLD
Edinburgh, Scotland

Ronald Kurtz
Randy Burkett Lighting Design
St. Louis

MEMBERS NO LONGER ON THE IALD BOARD OF DIRECTORS: Andreas Schulz, Licht Kunst Licht, Bonn and Berlin, Germany; **Paul Beale,** Electrolight, Melbourne and Sydney, Australia, and London; **Kevin Theobald,** GIA Equation, London

IALD MEMBERSHIP COMMITTEE

Claudio Ramos
Banks|Ramos Architectural Lighting Design
San Francisco

Colin Ball
BDP
London

Jill Cody
Dark|Light Design
Seattle
(Cody advanced to membership chair with Victor Palacio's new role of president elect.)

Reiko Chikada
Reiko Chikada Lighting Design
Tokyo
(Chikada was elected to serve out Jill Cody's term.)

LIRC STEERING COMMITTEE MEMBERS

Ron Steen (new co-chair)
Specialty Lighting Industries
Lindenhurst, Ill.

Lucas King
Licht Kunst Licht
Bonn and Berlin, Germany

Alexis Arnoldi
Cline Bettridge Bernstein Lighting Design
New York

Carrie Verkuil
Tivoli Lighting
Tustin, Calif.

IES PUBLISHES NEW DOCS FOR SSL

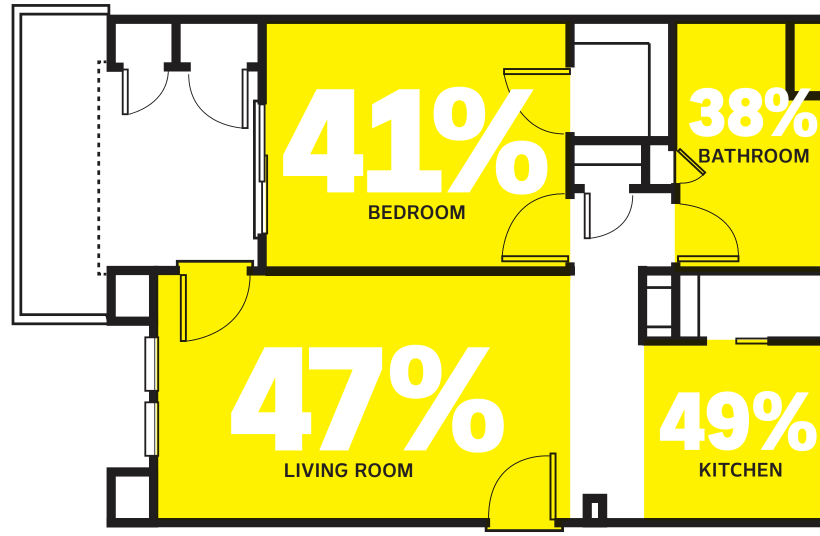
text by Elizabeth Donoff

The Illuminating Engineering Society (IES) has published three new reference documents regarding how various aspects of LEDs perform.

The first document is a technical memo: *TM-28-14: Projecting Long-Term Luminous Flux Maintenance of LED Lamps and Luminaires*. TM-28-14 is meant to serve as a guide and overview for "sampling, test intervals and duration, and a method for long term luminous flux maintenance projection for LED lamps and luminaires using data obtained when [a] product is tested according to *IES LM-84: Approved Method for Measuring Luminous Flux and Color Maintenance of LED Lamps, Light Engines, and Luminaires* and *LM-80: Approved Method: Measuring Lumen Maintenance of LED Light Sources*." According to Rita Harrold, IES director of technology, "This standard [*TM-28-14*] is meant to help both manufacturers and users, and standards developing bodies to avoid burdens related to excessive testing by balancing testing time effort and statistical rigor."

In addition to this guide, the IES has also published two new testing procedures for LEDs: *LM-84-14: IES Approved Method for Measuring Luminous Flux and Color Maintenance of LED Lamps, Light Engines, and Luminaires*, and *LM-85-14: Approved Method for Electrical & Photometric Measurements of High Power LEDs*. These documents help to establish the emerging body of standard and uniform laboratory testing procedures for solid-state light sources. *LM-84-14* addresses lumen decay and color shift, while *LM-85-14* addresses the optical performance of LEDs at higher power levels, which require higher operating temperatures.

All of the documents are available for purchase—in print or as PDF downloads—online from the IES store (ies.org/store). •



LED REPORT REVEALS CONSUMER PAIN POINTS

text by Hallie Busta

Consumers who use LED lamps in their home are satisfied with the light they provide, but understanding the technology remains a challenge, according to a December report commissioned by Osram Sylvania. "Discover LED Lighting" compiles the responses of more than 1,000 U.S. households polled online about their knowledge of LED lamp technology.

"[A]t times, lighting can be very confusing and a bit overwhelming for those outside our industry," Pamela Price, Osram Sylvania's retail marketing manager, said in an email. "As lighting leaders, our first task is to make the message relevant and easy to understand. [And] consumers appreciate guidance, but we need to resist the temptation to teach them everything we know about lighting."

To understand end users' grasp of LEDs, the company is conducting surveys that address consumer knowledge of the incandescent phase-out and its related issues. Price says the company wanted this latest report to dig deeper into the factors that are both helping and hampering the adoption of LEDs. Among the report's findings:

RESEARCH: More than three-fourths of those surveyed had not researched an LED lamp's color temperature prior to purchase; three in five had not researched its brightness. But more than one-third did research a product's energy use, lifetime, and cost-savings.

GENERAL KNOWLEDGE: More than two-thirds did not associate LEDs with standalone lamps. A majority of survey respondents (51 percent) associated the technology with holiday lights, followed by outdoor lighting (40 percent).

USE: Overall, LED lamps are not widely used in the home. Sites of regular activity—the living room (47 percent) and kitchen (49 percent)—saw more use. Fewer use LEDs in the bathroom (38 percent) and bedroom (41 percent).

SATISFACTION: Of those who do use LED lamps, nine out of 10 were "very satisfied" or "somewhat satisfied" with the technology's brightness and color. Slightly fewer—seven out of 10—were "very satisfied" or "somewhat satisfied" with the related products' price. •

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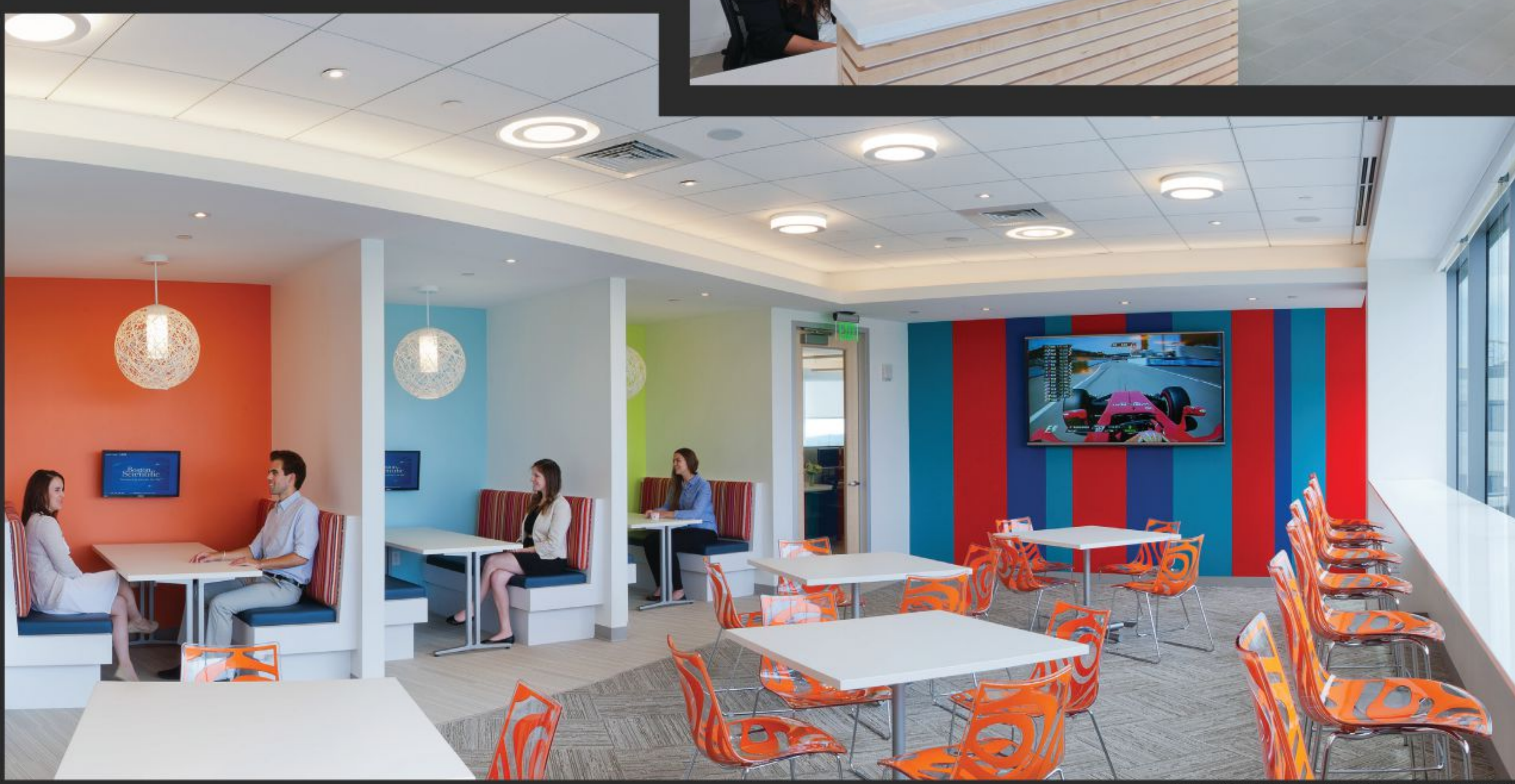


REPORT

CREDENTIALING UPDATE

Despite the program having completed its beta-testing stage, many lighting designers are still unaware of the initiative's developments.

text by Elizabeth Donoff

Why is the topic of credentialing one of the most debated issues in the lighting community? Because at its very core, credentialing alters processes and procedures that have been in place for more than 40 years. For many lighting designers, many of whom have been in practice for a very long time, this will be a difficult adjustment. In addition, credentialing potentially impacts how one pursues lighting education and it might even require a re-evaluation of how lighting degrees are offered at the various university-level programs around the world.

But credentialing is not a new issue. It has been part of the conversation about lighting design since the International Association of Lighting Designers (IALD) was formed in 1969. The ebbs and flows of contemporary design practice has seen the issue surface and then retreat a number of times over the past four decades, but the catalyst that most recently propelled the issue on its current trajectory centers around Texas House Bill 2649.

In May 2009, legislation was proposed in the state of Texas that, in essence, would have made it illegal for a lighting designer to practice their craft in the state if they were not licensed. A grassroots, 11th-hour mobilization of the lighting design community worked to make sure that the damaging language was omitted from the final version of the bill. But that experience was enough to make lighting designers seriously examine whether they need to create a credentialing system, and what the ramifications of this system might be, so that the community would not find itself revisiting similar situations in the future.

In 2010, the IALD started the process by establishing an international task force headed by committee chair David Becker, who at the time was director of lighting design at Sydney-based lighting firm Point of View, to examine the feasibility of such a certification program. The committee was made up of IALD members and participants from other lighting organizations and manufacturers, including the Professional Lighting Designers' Association (PLDA), the National Council on Qualifications for the Lighting Professions (NCQLP), and the Lighting Industry Resource Council (LIRC), which is the arm of the IALD that represents manufacturers. (One note: The PLDA is no longer a functioning professional organization; it disbanded in 2014.) While the IALD, as the principal professional organization representing lighting designers, has taken the lead on this initiative, the association has made it clear from the start that this program was not solely for its members, but for all professional lighting designers.

The credentialing task force's initial work involved gathering feedback from the various constituents and clarifying the definitions and differences of key terms that commonly are interchanged in such discussions. The most commonly mistakenly interchanged terms are the difference between licensure and credentialing, and the distinction is a very important one to make. A license allows someone to practice a profession in a particular state and is governed by health and safety issues. Credentialing, on the other hand, is a "method for maintaining quality standards of knowledge and performance, and in some cases, for stimulating continued self improvement. Credentialing confers occupational identity."

During this initial fact-finding phase, the IALD introduced a series of webinars to inform its members about the issues and gather feedback. It also distributed a survey to get the opinions of those involved, and received more than 600 responses to this initial questionnaire. Armed with all of this information, the organization decided to proceed with the development of a certification program over the next 12 to 18 months. Throughout this process, the credentialing task force enlisted the help of Judith Hale, a certification expert and psychometric consultant and principal of Hale Associates in Downers Grove, Ill.

One of the goals for pursuing the credentialing program has been to avoid legislative bodies establishing restrictions in the future, as Texas threatened to do. Another, equally as critical, purpose has been the validation of lighting design as a profession. As a field that functions in a consultancy capacity to architecture, lighting designers have often felt that they don't necessarily receive the same level of respect that they offer their architecture and engineering colleagues, whose professions do have a licensure system. A credential would serve the purpose of defining, not just for the lighting community but for the larger architecture and engineering community, the specific skills and qualifications that a lighting designer brings to the mix.

"The task force studying the viability of a global credential has observed that if the architectural lighting design community doesn't define the areas in which we practice and measure competency against a validated standard, there is the very real danger that others will force regulations on us or determine our destiny without our control," says Becker on the credentialing program info page on the IALD's website. (Becker is now the chair of the Certified Lighting Designer Commission.) "The alternative is that we make a proactive, unified effort as a global profession to define ourselves by determining the domains of practice and core competencies in which highly sophisticated lighting designers must excel in order to be eligible for certification."

In pursuing this certified lighting designer (CLD) program, a tremendous amount of work has taken place. Here's a breakdown:

2010–2011: JOB TASK ANALYSIS

The IALD credentialing task force commenced a fact-finding initiative examining best practices in the certification industry. They also started a task analysis to define what it is that a lighting designer does. This analysis looked

A credential would serve the purpose of defining, not just for the lighting community but for the larger architecture and engineering community, the specific skills and qualifications that a lighting designer brings to the mix.


45°
361°
5.00" 127mm
7.42" 188mm
2.50" 64mm
3.25" 83mm
1000 - 3000lm

CERTIFIED LIGHTING DESIGNER DOMAINS OF PRACTICE

1. GOALS AND OUTCOMES
Demonstrated skill at designing lighting solutions that satisfy project requirements and design intent so the solutions perform as expected.

2. COLLABORATION
Skill at interacting with other disciplines by serving as an integral member of the team so that lighting relates to its context and adds value to a project.

3. INGENUITY
A record of contributing ideas that demonstrate innovation, creativity, originality, or resourcefulness to foster the goals of the project.

4. SYNTHESIS
Demonstrated ability to integrate the technical and aesthetic elements of lighting with space and form.

5. SCIENCE
Showing how light interacts with people, materials, and building systems by applying the principles of light to meet relevant technical criteria.

6. STEWARDSHIP
Responding to known and potential social and environmental impact by designing solutions that avoid or minimize harm, discomfort, or waste.

7. HUMAN EXPERIENCE
Demonstrated ability to design lighting solutions that positively affect people.

Source: iald.org/about/IALDCertificationNews.asp

at international standards for a professional certification program and looked in depth at core competencies of the lighting professional to best ensure that the full scope of a lighting designer's work was taken into account.

2011: DOMAINS OF PRACTICE

From the task analysis emerged a list of core competencies (see "Certified Lighting Designer Domains of Practice" at left), organized into seven domains. Designers seeking certification would need to meet requirements in all seven.

2012: GLOBAL CERTIFICATION SURVEY

To test the validity and defensibility of all this preliminary work, the IALD conducted a global survey to evaluate whether or not the seven domains of practice accurately represent the scope of a lighting designer's work. Responding were 637 building-design industry professionals from more than 36 countries who confirmed that the seven domain were on target.

2013–2014: ALPHA AND BETA STUDIES

With the global certification survey complete, the credentialing task force initiated an alpha study. This limited-member test evaluated the CLD certification to examine whether the application process was clear and workable.

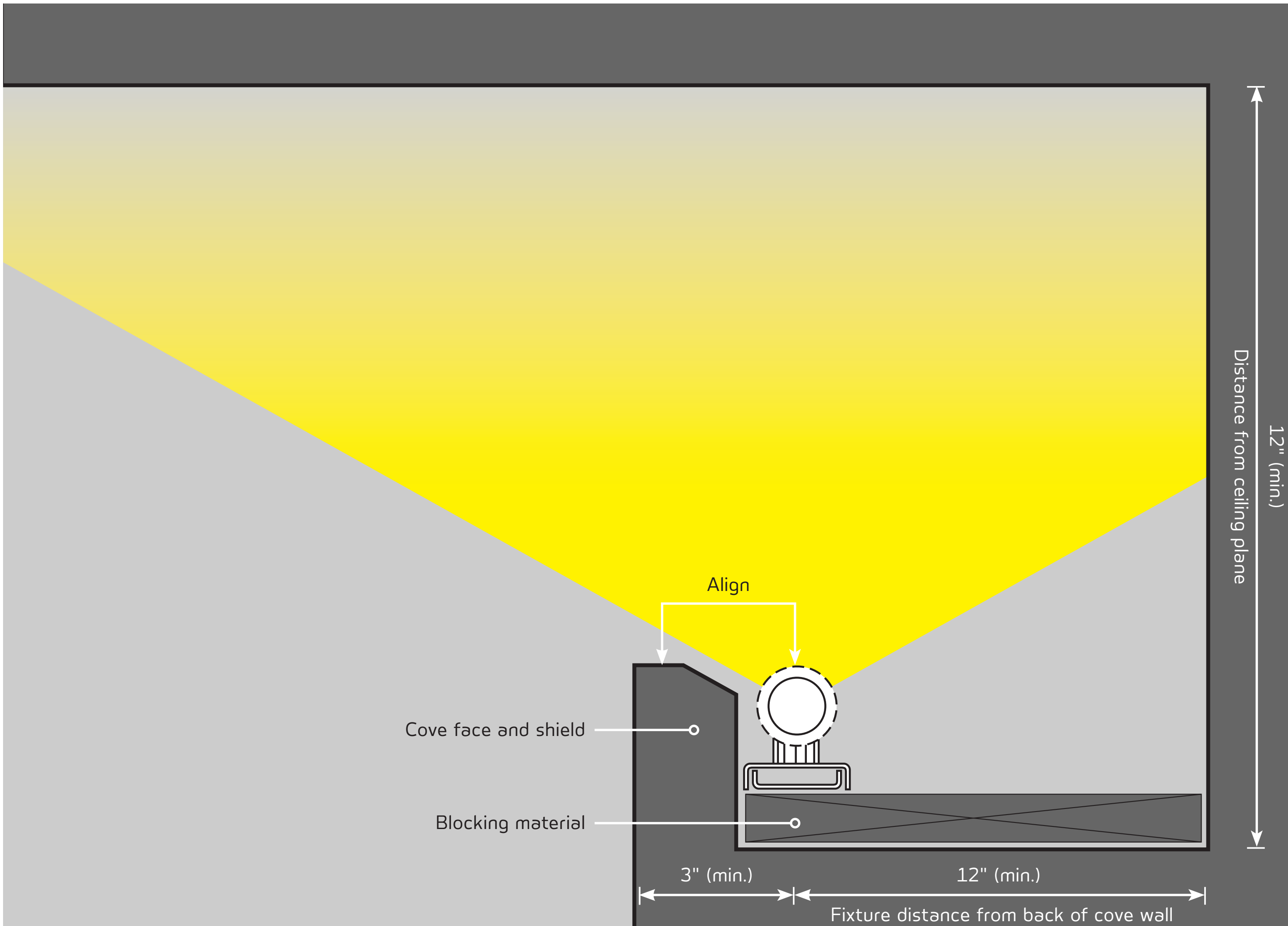
Participants provided feedback and the task force made further modification to the application process. A second-round beta test was started midway through 2013 and completed at the end of 2014. This test was opened up to a wider sampling of lighting design professionals to ensure geographic diversity, gender, length of time working, and size of practice.

The CLD Commission has adopted the work of the certification task force and the aim is to launch the program in early 2015. Learn more at the program's online portal — *cld.global*.

Professional members of approved lighting design associations will be able to participate — to date, this includes members of the IALD and the Asociación Profesional de Diseñadores de Iluminación, and an approval process is set up to review other design associations. The application fee is $625, but professional members of approved lighting design associations will receive a discounted price of $525. Recertification is required every five years.

Like any new program, the CLD is sure to go through growing pains after it is introduced. And while many in the lighting community might still be unaware of what's in store if they chose this certification route, they can be assured that a rigorous process has set it in motion for the program to succeed. •

Cove Lighting Detail with a Linear Fluorescent Source



IN FOCUS

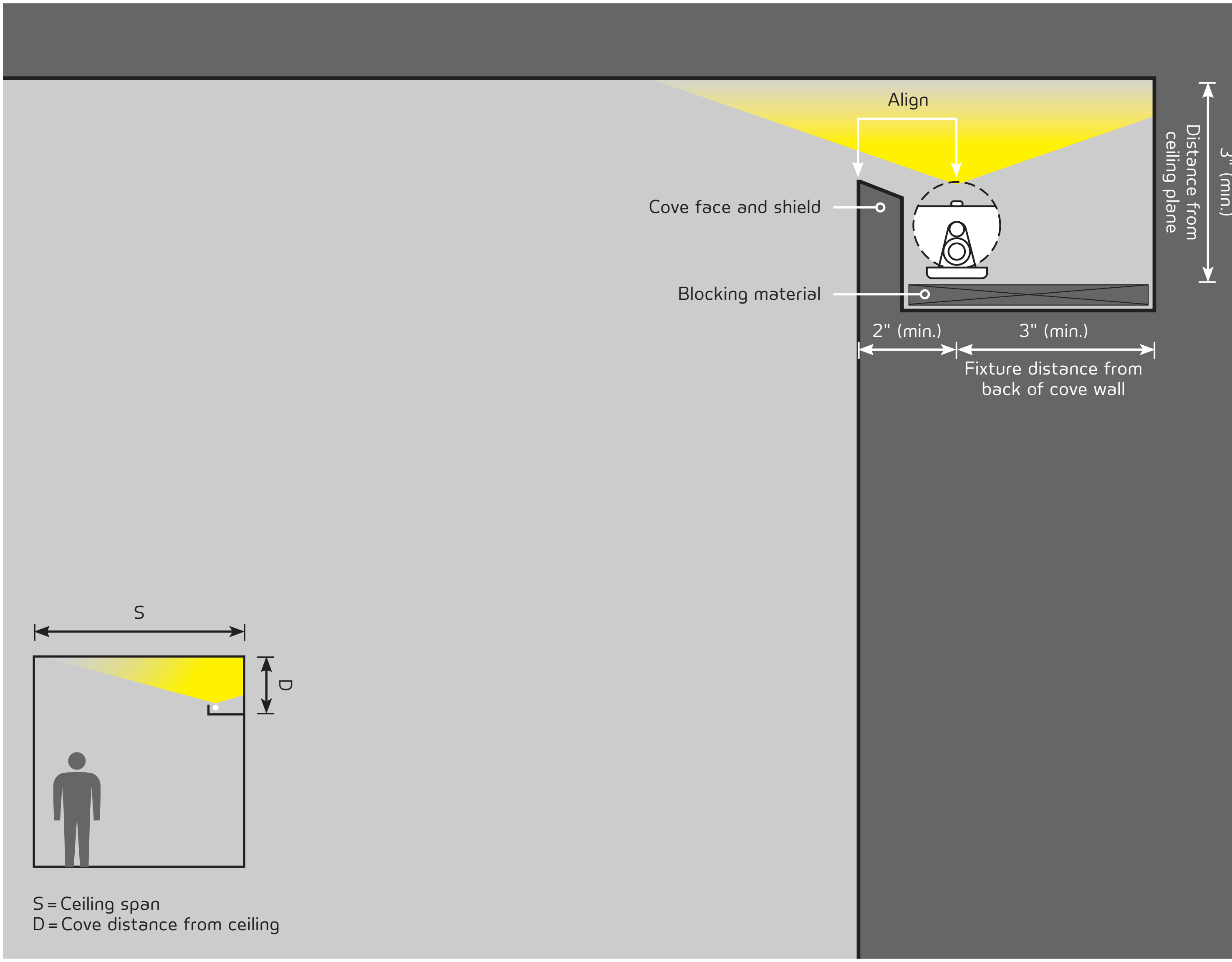
COVE LIGHTING

Breaking down the components of this core lighting detail.

text by Elizabeth Donoff

Cove lighting is one of the basic lighting techniques, a type of uplighting that directs light to the ceiling plane from a cove on one or more sides of a room to provide overall diffuse illumination. It is also referred to as ambient luminescence. Cove lighting is typically mounted to or incorporated into a wall, but it can also be located within a ceiling coffer.

Cove Lighting Detail with a Linear LED Array



SOME THINGS TO CONSIDER WHEN SETTING UP A COVE LIGHTING DETAIL:

1. Be aware of how you are positioning the fixtures. Any joints or gaps between fixtures will show up in the light pattern. Socket shadows (dark spots at the end of a lamp) can be eliminated by placing fixtures end-to-end, in a staggered or a slanted arrangement. Depending on source selection, make sure to use the appropriate spacing between fixtures as well as the positioning from the back wall of the cove.
2. The top of the lamp should be level with the cove fascia; if not, it will create shadow lines.
3. To prevent sharp cutoff lines, stop a cove short of the end wall.
4. Generally, ceiling surface should be a high-reflectance matte or satin finish surface. The inside surface of the cove should be flat white. This minimizes specular reflections.
5. As a cove nears end wall, maintain a minimum clearance of 12 inches at inside corners to prevent hot spots.
6. As the cove's distance from the ceiling plane increases, the uniformity of the ceiling brightness will also increase.

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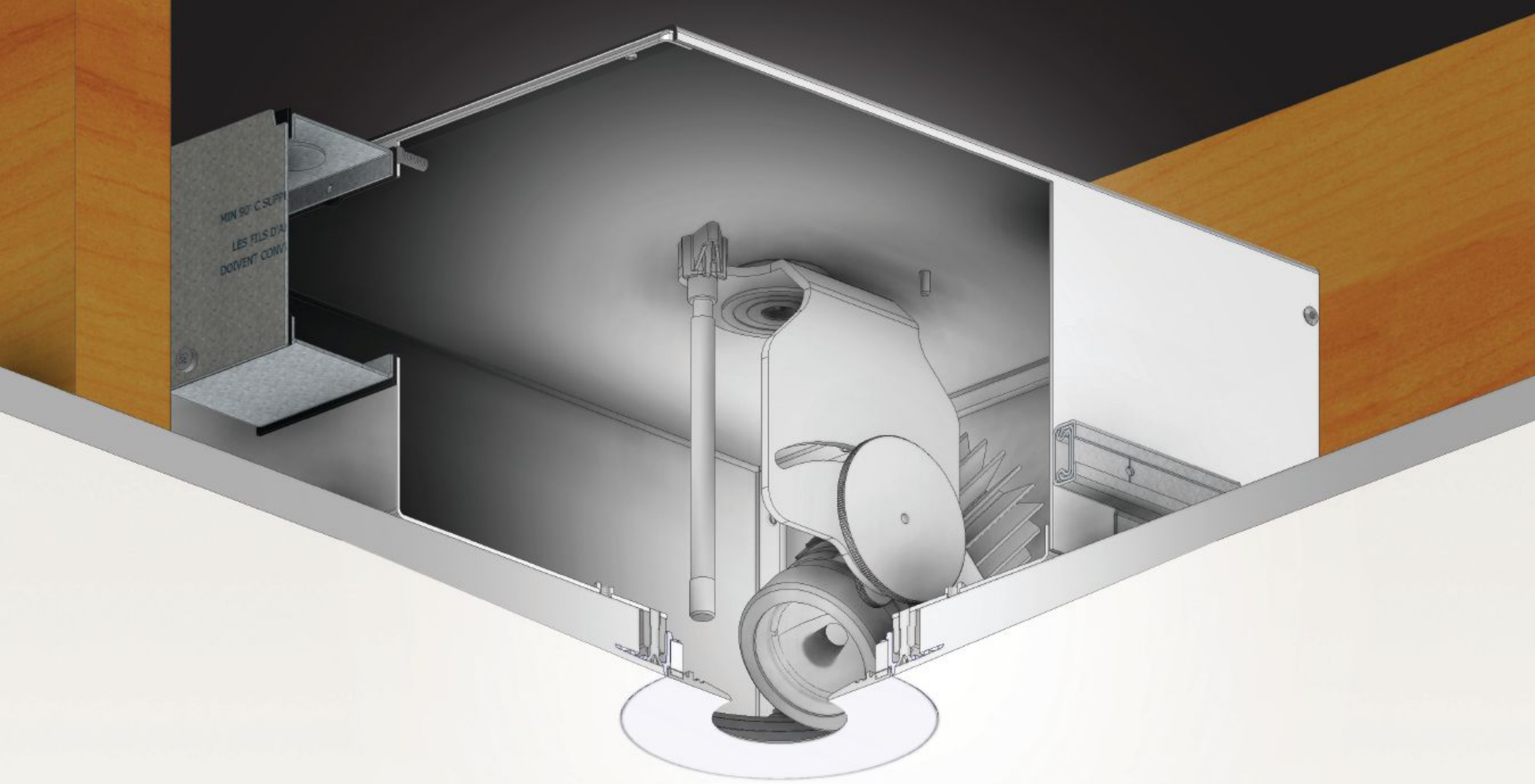
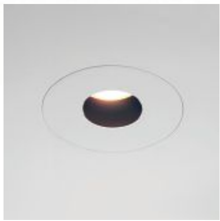
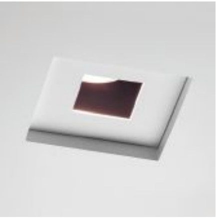






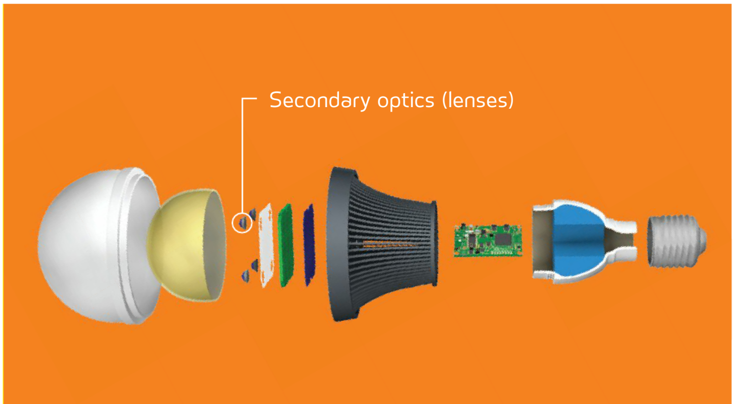
TECHNOLOGY

NEW MATERIALS IN SOLID-STATE LIGHTING

Moldable silicones and other nascent technologies are setting the stage for more freedom in design.

text by Timothy A. Schuler
illustration by Tang Yau Hoong

Lighting designers have long sought to conceal luminaires, illuminating spaces so that an inhabitant notices only the light, not its source. Today, the notion that a luminaire could nearly disappear is closer than ever, thanks to evolutions in material technologies. The trend in LED lighting is toward smaller, thinner, more integrated systems that provide optimized performance but are practically invisible. “Our vision is where the fixture *is* the LED, where you don’t have LED components but where



Dow Corning's moldable silicone offers a new option for secondary lamp optics.

Courtesy Dow Corning

the whole thing is made as one manufactured piece," says Julian Carey, a senior director of phosphor marketing at Intematix, which makes phosphor materials. Jim Anderson, the director of strategic marketing at Philips Color Kinetics, concurs. "Nobody wants to see the luminaire," he says. "It's been that way forever."

Innovation in the field of LED lighting is currently taking the form of a race to the finish without a clearly marked route. Companies are charting their own course, investing in some combination of new and legacy materials with an eye toward producing the most powerful, most efficient LEDs for the market.

One example of this experimentation is in the development and implementation of substrates, a crucial component of an LED's makeup. Today, companies use substrates made from various compounds, such as silicon, sapphire, polycarbonate, and gallium nitride, but no one material has emerged as the leader. And the same can be said for many of the materials in an LED fixture, from the optics to the light-emitting diodes themselves. "You keep looking for the next generation, and you're either going to add performance or take costs out," says Kevin Dunay, a market segment leader with Bayer MaterialScience.

Increased standardization would allow lighting companies greater flexibility in combining systems. On the other hand, Philips Color Kinetics' Anderson suggests, too much standardization could stall innovation. These conditions aside, research and development certainly isn't flagging. "LEDs are changing every day," says Hugo da Silva, the global industry director for LED lighting at Dow Corning, whose moldable silicone products have gained traction in the past year.

REMOTE PHOSPHOR

One of the biggest innovations in the past two years has been remote phosphor technology, which separates the phosphor from the diode. Phosphor is nothing new. The light-emitting substance is the basis of glow-in-the-dark toys, and it's been integral to solid-state lighting, typically in the form of a coating that is applied to blue LEDs to turn their light white. The key distinction with remote phosphor technology is that the phosphor material is integrated with the diffuser optic, increasing design freedom while decreasing manufacturing costs.

One company working in this realm is Intematix, which markets remote phosphor under the name ChromaLit. According to the company, remote phosphor can boost efficacy by as much as 30 percent because it effectively captures an LED's spill light, extracting more lumens per blue LED than traditional designs. "The key thing to remember about phosphor is that it produces light [in] 360 degrees when stimulated so you have to figure out a way to reuse that light," Intematix's Carey says. Particularly in linear lighting applications, "remote phosphor very efficiently recycles that light so you have maximum efficiency."

A major challenge for Intematix as they have pursued remote phosphor technologies has been achieving a consistency in color temperature. During initial investigations, researchers experienced subtle variations when their remote phosphor optic, typically made from a thermoplastic like polycarbonate, was combined with a customer's LED. "The human eye is very sensitive to color changes," Carey says. But with further development, these issues were resolved, and now remote phosphor offers a new way to control color, since hue and temperature now can be manipulated without altering the LED architecture.

"At Lightfair last year, there was a lot of interest from designers for very warm color temperatures for use in architectural lighting," Carey says. "For example, 2400K. That's not something that is easy to accomplish with a white LED. But with remote phosphor, you can just make that color. We dial in the formulation and you can have it."

Remote phosphor has been adopted for applications ranging from undercabinet to high-bay spaces, but cost continues to be a barrier for certain types of luminaires. And manufacturers like Intematix continue to search for even greater efficiencies. Currently, the holy grail in the search for new phosphor materials is narrow-band red phosphor, which would allow manufacturers better access to certain portions of the light spectrum. "This is subject to maintaining CRI, but you can get much more efficiency if you have narrow-band red phosphor, because you're not wasting light in the long portion of the red spectrum," Carey says. "That's one of the industry's priorities."

MOLDABLE SILICONE

While remote phosphor integrates the light source with the secondary optic, optics themselves are undergoing a material revolution. New LED configurations such as chip-on-board designs have resulted in achieving higher, more consistent temperatures than ever before, while the push to reduce costs has manufacturers on the hunt for materials that can be inexpensively produced.

One of the things that LED manufacturers do agree on is the superior thermal and optical performance of glass. At the same time, the demand for ever-thinner materials and for ever-smaller sources has made glass less desirable. As a material, glass is highly inflexible. (We won't even bring up how expensive it can be.) The alternatives, thus far, have been polycarbonate and PMMA (polymethyl methacrylate).

Polycarbonate is a type of thermoplastic polymer that enjoys a certain ubiquity in the modern world (the plastic case for Apple's iPhone 5c, for instance) and is equally versatile in the solid-state lighting industry. Makrolon, a polycarbonate manufactured by Bayer MaterialScience, can be injection molded into reflectors or secondary optics for LED lighting.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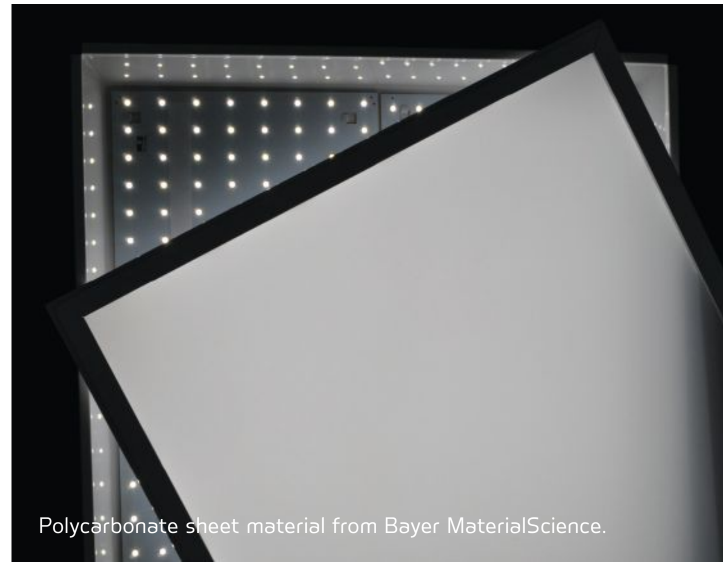
Bayer also makes Makrolon diffuser sheet products that have become popular in troffers. But polycarbonate does have its limitations, especially as LEDs get smaller. "You can only thin walls so much," says Bayer's Dunay.

Enter moldable silicone. In the hierarchy of materials, silicone is second only to glass, says Dow Corning's da Silva, who is an expert in lighting and electronics and an evangelist for his company's line of moldable silicone products. "Silicone combines the proven properties of plastics and the good properties of glass," he says.

From a performance perspective, moldable silicone withstands high temperatures, high levels of ultraviolet light exposure, and high lumen densities. But its stability with different wall thicknesses is perhaps its greatest advantage over polycarbonate, and this advantage allows for greater design flexibility, especially when it comes to details that require undercuts, micro optical features, and negative draft angles. "At the end of the day, designers [have more freedom] to design with silicone than they [do] with any other material," da Silva says.



Polycarbonate sheet material from Bayer MaterialScience.

Courtesy Bayer MaterialScience

Moldable silicone has gained a tremendous amount of momentum in the past year-and-a-half as manufacturers grasp the material's potential. "A lot of people believe that moldable silicone can completely take over the optic materials [industry]," da Silva says. "Being more realistic, I believe silicones can have a fair share of the market, maybe 20 to 30 percent. Today, it's not even close to that."

GALLIUM NITRIDE SUBSTRATES

At the micro level, the diode itself is evolving. Innovation at this scale has the farthest-reaching implications, since luminaires often contain dozens of LEDs. So if each diode produces more light at a lower cost, lighting companies see substantial benefits.

First-generation LEDs all used some combination of gallium nitride (GaN) and a substrate made of a different material. Those substrates were made from glass, silicon, silicon carbide, and sapphire. In recent years, however, several companies, including Soraa and Panasonic, have experimented with making the substrate out of GaN as well. Using the same material for both layers creates a much more reliable diode, even when running at incredibly high power densities.

This advantage was not unknown to most LED manufacturers, but the cost of GaN has been prohibitive. "The notion of using a GaN substrate like we do was considered crazy by most people because the substrates were on the order of 100 times more expensive than sapphire substrates," says Mike Krames, chief technology officer for Soraa. "Even when I was at Philips 10 years ago, we all knew that GaN substrates would be developed for lasers, but we couldn't convince ourselves you could ever develop an LED system on it."

Krames, however, was soon persuaded. "When talking to the founders after first joining Soraa," he says, "I realized that if we could develop an LED system that could operate at 10 times the power density, then you'd have a huge lever on cost because the substrate is only about one-tenth of the cost of the LED. The rest of it is all in the downstream fabrication. So if I can use 10 times less LED material, I can afford to pay about 10 times the price per square area of the substrate. And since I only need one-tenth of the area of the substrate, I can afford to pay about 100 times the price of sapphire."

GaN-on-GaN has also made possible full-spectrum LEDs that include violet emission. Until now, that's only been a pipe dream. "Violet-emitting LEDs do not tolerate the lower quality of GaN-on-foreign-substrate," Krames says. Blue LEDs create light that appears white but, unlike [the] incandescence of sunlight, is not full-spectrum because it lacks violet emission. By adding violet and harnessing the full spectrum, LEDs will be one step closer to imitating natural light.

Like several other LED companies, Soraa is vertically integrated. It oversees the manufacturing process from the fabrication of the LED to the assembly of the lamp. This helps drive down costs and is, in part, what allows the company to leverage its GaN-on-GaN technology. But Soraa's not alone. Other companies seem to be confident that the math for GaN-on-GaN pencils out. Panasonic has invested heavily in making LEDs on GaN substrates, and late last year the company unveiled an automotive headlight that uses the technology. Although automotive applications differ substantially from architectural lighting, the release of the GaN-on-GaN product could mean Panasonic is moving in that direction for all of its LED products.

THE RATE OF ADOPTION

LEDs have evolved so quickly that material innovation has struggled to keep up. But in many ways, today's technologies already have the power to transform the lighting industry. And now it is the industry itself, Dow Corning's da Silva says, that is lagging behind. LED lamps, for the most part, continue to be designed to mimic existing lamp form factors, and da Silva sees the romanticism of outdated technologies as a fatal flaw, noting that his company has run up against this misplaced nostalgia as it has marketed its moldable silicones. "It's been a journey the last four years to [create] new technologies that bring a lot of flexibility under the same technology umbrella," he says. "The challenge is how conservative the industry is."

Philips Color Kinetics' Anderson, however, argues that while the average consumer may be attached to the shape of the incandescent lamp,

the architectural lighting community is much more willing to try new technologies in order to get the effects it wants.

Anderson is part of the LED Systems Reliability Consortium, a committee of the Next Generation Lighting Industry Alliance (NGLIA). A white paper from NGLIA, in conjunction with the U.S. Department of Energy, first released in 2011 and updated this past September, and titled "LED Luminaire Lifetime: Recommendations For Testing And Reporting," proposed an accelerated verification process for new technologies in order to spur faster innovation. The proposal is modeled on what's used in the electronics industry. LED lighting, Anderson says, could be treated the same way, removing the inertia that comes with a validation process that requires 3,000 to 6,000 hours of testing.

This shift would be momentous—and symbolic. Early on, LEDs overpromised and underdelivered when it came to lighting performance. Manufacturers entering the lighting industry from the electronics world had little understanding of the unique and nuanced requirements of architectural lighting. But that is changing. "What people claim compared to the actual performance has significantly improved," Anderson says. "There's a better match there. The industry is maturing." •

RESOURCES

A list of reference sources that address LED materials.

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OLED UPDATE

text by Hallie Busta

Panel and fixture makers are developing luminaires that show off the potential for the still-niche technology.

On paper, organic light-emitting diodes (OLEDs) are a designer's dream. Thin, flat, cool, diffuse, and nearly glare-free, the modular light panels can be used to form fixtures or be embedded in walls, furniture, and even textiles. But an OLED-only future is unlikely—and that's not necessarily a bad thing. According to the U.S. Department of Energy (DOE), OLED panels currently cost an average of $500 per thousand lumens, or kilolumen (klm). To be commercially viable, that figure would need to decrease to $20 per klm by 2020, the DOE says. That's compared to LEDs, which according to DOE figures are expected to cost $2 per klm by 2015, having dropped from $18 per klm in 2010.

Recently, ARCHITECTURAL LIGHTING spoke with OLED experts to get their take on the leading drivers and impediments to this diffuse light source's adoption. Though cost and performance remain the leading barriers, the experts cited another hurdle that, in tackling, they think can help make OLEDs marketable: lack of exposure among designers. To turn that around, the lighting industry is developing new fixtures and furthering research and development that will help lighting designers and architects better understand where OLEDs fit in as a lighting option, and where they don't.

"We have to get people to understand that OLEDs are not a factor today but [they will be] tomorrow, so try to learn what you can do with OLEDs so that you are prepared when [they do come to] market," says Dietmar Thomas, Philips' manager of brand and integrated communications for OLED.

Here's a snapshot of where OLEDs stand in the market today.

BIG-BOX BARGAINS

In December, Acuity Brands announced that it would begin selling two OLED fixture families in the U.S. through the Home Depot's online store and in select locations starting in early 2015.

Aerelight

Aedan Pendant

The luminaires, says Jeannine Fisher Wang, director of business development and marketing for Acuity Brands' OLED Business Group, are meant to "explore the creative aspects of OLED" in residential spaces while giving consumers an easily installed "luminaire-in-a-box." Offered in a pendant and a sconce, the Aedan luminaire comes in 3000K and offers 68 lumens per panel. Chalina, which is available as a pendant, a sconce, or a ceiling-mounted fixture with five panels per module, comes in 3000K with a total output of 345 lumens. Both fixture lines are currently retailing online from $199 to $299.

TAKING ON TASKLIGHTS

Acuity Brands isn't alone in creating consumer-focused OLED fixtures, in part due to the lighting industry's recognized need to get the technology into end users' hands. But the forms that these initial fixtures are taking reflects OLED's current scale, says Michael Helander, president and CEO at Toronto startup OTI Lumionics, which develops OLEDs for lighting and displays and is piloting the manufacture of panels for small-scale, small-volume projects. Current OLED performance, coupled with the technology's cost, suits a smaller form factor, he says. Plus, decorative tasklights are ubiquitous. The company's Aerelight (shown on the previous page), which was born from the desire to test its OLED research and development with consumers, offers a thin form factor, 2900K, and consumes 7W.

CUSTOMIZATION

OLEDs are also being used for custom lighting solutions. Bruno Dussert-Vidalet, co-founder of French OLED maker Blackbody, argues that while the production and sale of consumer-grade fixtures are "a way to stimulate the market," the essence of the technology is in its ability to be customized. "OLED is a greenfield," he says. "It's not an evolution of technology. It's a new way to light your home and the space." The company's 5,382-square-foot showroom in New York City, which opened in the fall of 2013, shows the myriad ways in which OLEDs can be used to illuminate or accent a space. But for all its whimsy, even Blackbody offers replicable designs. Its Flying Ribbon, which was designed in February 2012 for use in a corporate client's conference room, features a pre-designed configuration that the company has since used as a blueprint when iterating the product for other spaces. "Your ribbon can be adapted [not only] to your space but also to your budget and your taste," he says. The fixture measures 12 feet long by 1.2 feet wide, and provides 2750K to 4000K with a CRI of 80.

Flying Ribbon

BETTER-PERFORMING PANELS

Panel makers are pushing for OLEDs to reach performance levels (and panel sizes) suitable for general illumination—according to the DOE, current OLED panels offer efficacies of 60 lumens per watt and CRIs greater than 90. Karsten Diekmann, senior manager of marketing, product and application engineering for Osram's OLED business, explains that the company's first generation of Orbeos OLED panels, introduced in 2009, had a light output of 25 lumens per watt with a brightness of 1,000 candelas/m^2. Today, Osram makes OLEDs, such as the Orbeos SDW-058+ panel (shown above), at 65 lumens per watt and 3,000 candelas/m^2.

Orbeos OLED Panel

There's still work to do, however. OLEDs need to be able to compete performance-wise with LEDs. "When OLEDs reach 100 lumen-per-watt values, they get really attractive for general lighting applications," Diekmann says. "Such values have been presented on the R&D level and need to be transferred into production."

This past fall, Seoul-based LG Chem announced that it had developed a 100-lumen-per-watt panel that will be commercially available in April, helping OLEDs enter the general illumination space, said Chang-Hoon Jeong, head of marketing for the company's OLED light division, in an email. In January, the company followed up on that news with the debut of a widely available 0.88-millimeter-thick, 320-millimeter-by-320-millimeter panel offering 60 lumens per watt with a CRI of 90-plus. The company also announced that it had developed a flexible OLED using a plastic substrate and, it claims, without diminishing either efficacy, luminance, or CRI. "Due to our experience in barrier and encapsulation techniques, it was possible to achieve the same [performance] level [as with a glass substrate], even with a plastic substrate," Jeong says.

NEW FACES

Today, OLEDs are primarily decorative—due to their small scale and limited uptake—but that could soon change. Philips' Thomas and others suggest a future for embedded OLEDs in applications including undercabinet lighting and retail displays. Later this year, Philips expects to launch its Brite FL300 L, which offers 300 lumens from a lit area measuring about 8.7 inches long by 1.8 inches wide. The product is a longer, more slender version of the company's 3000K, 4.7-inch-square Brite FL300 ww, which offers up to 50 lumens per watt. Acuity's Wang says that the Nomi family of OLED sconces from Acuity Brands/Winona Lighting, which was previewed at Lightfair 2014 and will come to market this spring, features a bendable glass substrate that helps achieve its contemporary form. And LG Chem says it plans to showcase an OLED track fixture in the coming months.

Nomi OLED Sconce

By designing luminaires that show off what OLEDs can do, manufacturers hope to awaken lighting designers, architects, and even consumers to the technology's potential. "One OLED panel doesn't really generate a lot of light," Wang says. "It's hard for people to visualize that you can, in fact, light a whole room using an OLED lighting system. It's kind of wrapping your mind around some different possibilities." •


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THE SKY IN THE SUBWAY

James Carpenter Design Associates, Grimshaw, and Arup design a giant daylight reflector that draws eyes to the sky

text by Gideo Fink Shapiro
images by James Ewing/OTTO

In George Tooker's famous 1950 painting *The Subway*, a woman navigates a claustrophobic, disorienting space filled with shadowy figures. The artwork perfectly represents "perceptions of compression, anxiety, [and] unease that accompany being underground," says Vincent Chang, a partner at Grimshaw's New York office. And until recently, this is exactly how it felt to trudge through a certain maze of dark underground passages that linked nine subway lines in Lower Manhattan just east of the World Trade Center site.

This site is Fulton Center, where a new transportation and retail hub opened this past November after more than a decade of work, and the new project reflects an altogether different vision of public transportation—a vision inspired, Chang says, by the soaring vault of Grand Central Terminal, which is pierced by oblique rays of sunlight. Among the many improvements to the Fulton complex, the most visible is the new "headhouse" building designed by Grimshaw with Arup, who oversaw work on the entire complex. For starters, there is a generous skylight, 53 feet in diameter and positioned 120 feet above street level, that allows daylight to reach all the way to the subway platforms underground.

But the space does more than just transmit natural light through an opening; it collects a larger view of the sky's changing conditions. This is thanks to Sky Reflector-Net, a 79-foot-tall tensile structure suspended inside the conical atrium. The combination sculpture–daylighting device was conceived by artist James Carpenter, who then collaborated with Grimshaw and Arup to fine-tune it and integrate it with the architecture and engineering. Composed of a steel cable net and 952 perforated, folded aluminum panels, it drives light deep into the cavernous space. At the same time, it draws the eye up to a luminous field of blue-gray tones. And for good measure, it conceals the hulking mechanical infrastructure. Carpenter likens the perceptual effect of the net to "folding the sky down into the station."

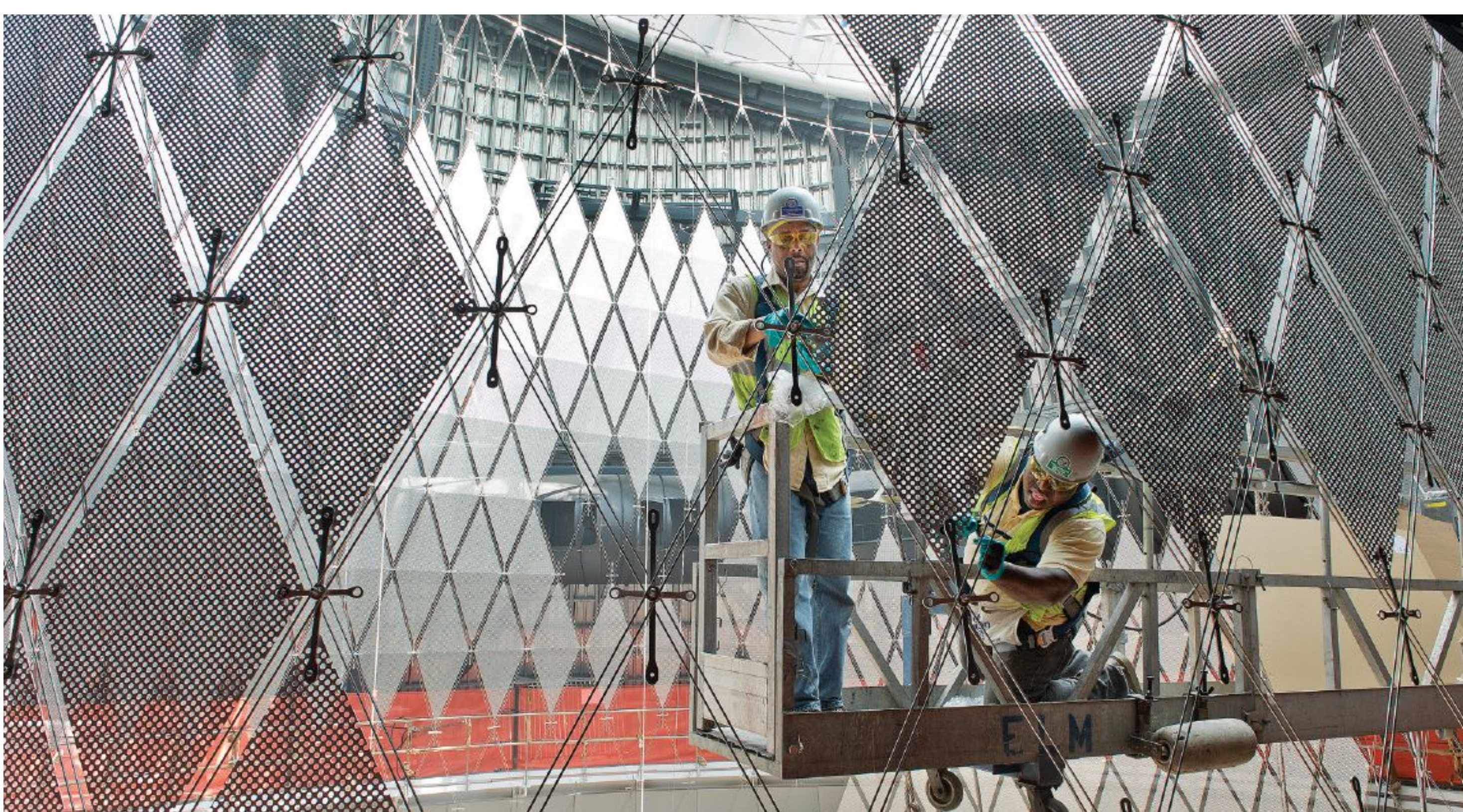
The artist has built his career on meticulously detailed installations that enrich the play of light and environmental phenomena in architecture. The work of his office, James Carpenter Design Associates (JCDA), frequently makes it difficult to separate art from architecture, engineering, and lighting. Sky Reflector-Net is no exception.

In 2004, JCDA won a competition sponsored by the Metropolitan Transit Authority's Arts and Design program to design a large-scale, light-harnessing installation for the future Fulton Center. At the time, the transit hub was supposed to have been topped with a glass dome. Historically, domes have been decorated with artistic representations of the sky and its associated mythology. Even the ceiling of Grand Central Terminal's Great Hall (while not a dome, it is an important precedent) is modeled with gold constellations and zodiac signs against a deep blue-green background, like a summer twilight sky. Carpenter thought of the Fulton Center commission as an opportunity to connect urban dwellers with the sky in a different way: not through pictorial representation, but through the play of daylight on a reflective surface, providing "a heightened experience of the sky and the mutable presence of light," he says.

Even when daylight is monochromatic—say, on a cloudy winter's day—Sky Reflector-Net creates a gradient of luminosity and tone. Each constituent panel is CNC-cut to a slightly different shape and size, and each has a different angle of exposure to the oculus and a different degree of opacity, which is a factor

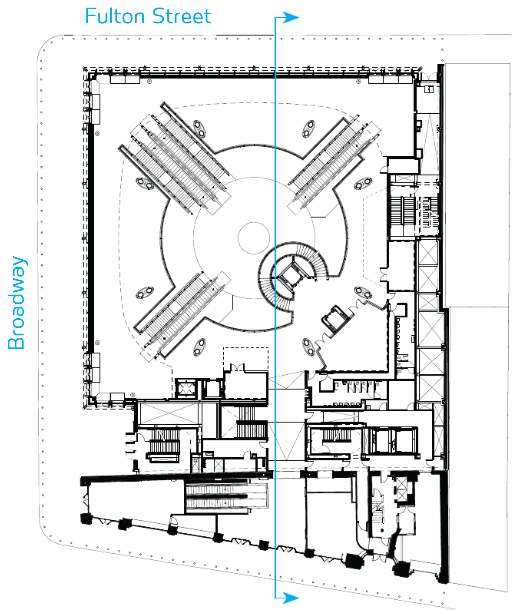
Sky Reflector-Net, a 79-foot-tall sculpture, harnesses natural light and brings it deep into the Fulton Center in Lower Manhattan (previous spread). A soaring sense of space and endless light fills the main atrium, lifting one's eye up to the sky (opposite).


Exit

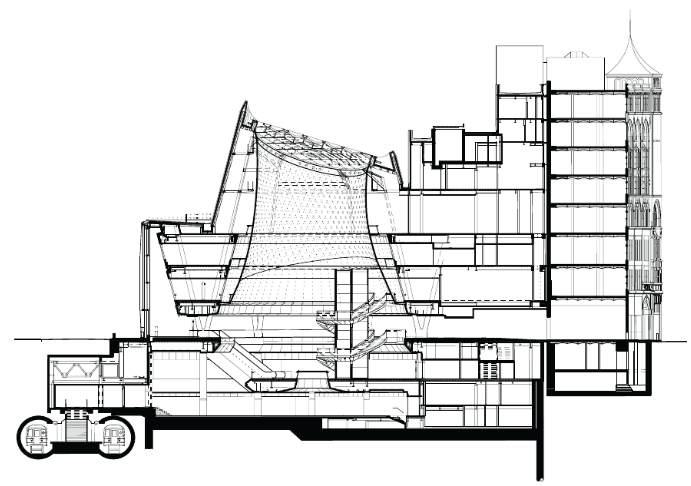


Bottom: Patrick Cashin

Street Level Plan



Longitudinal Section



The entrance to the Fulton Center sits at the corner of Broadway and Fulton Street in Lower Manhattan (opposite top). The new transportation hub serves up to 300,000 commuters a day who travel on nine different subway lines. The Sky Reflector-Net is composed of 952 perforated aluminum panels, each hung from a stainless steel cable net and uniquely shaped and positioned (opposite bottom).

of each panel's perforation. The panels nearest the bottom of the sculpture are the most perforated—48 percent open overall—and the size of the perforations grows smaller with each subsequent row of panels, so that the uppermost panels are only 20 percent open overall. The top of the sculpture thus appears brighter because its panels face the sky more directly so that it reflects more light, and it is nearest the skylight. Viewed from below, all that punched metal looks positively gauzy, holding the sky in a kind of embrace, more like a cloud than a building.

The perforations came about in response to a functional requirement. Sky Reflector-Net had to be designed so as not to obstruct the building's smoke evacuation system, says Arup associate and lighting designer Matt Franks, who worked on the project from its beginning in 2003. Air passes through the reflectors as through a screen or a vent. "It's not a hermetic shell, so it doesn't hamper operations," Franks says. Enormous air extract ducts—"almost large enough to stand up in," Chang adds—are hidden conveniently behind the net. It's a perfect example of technical performance overlaid with aesthetic intent.

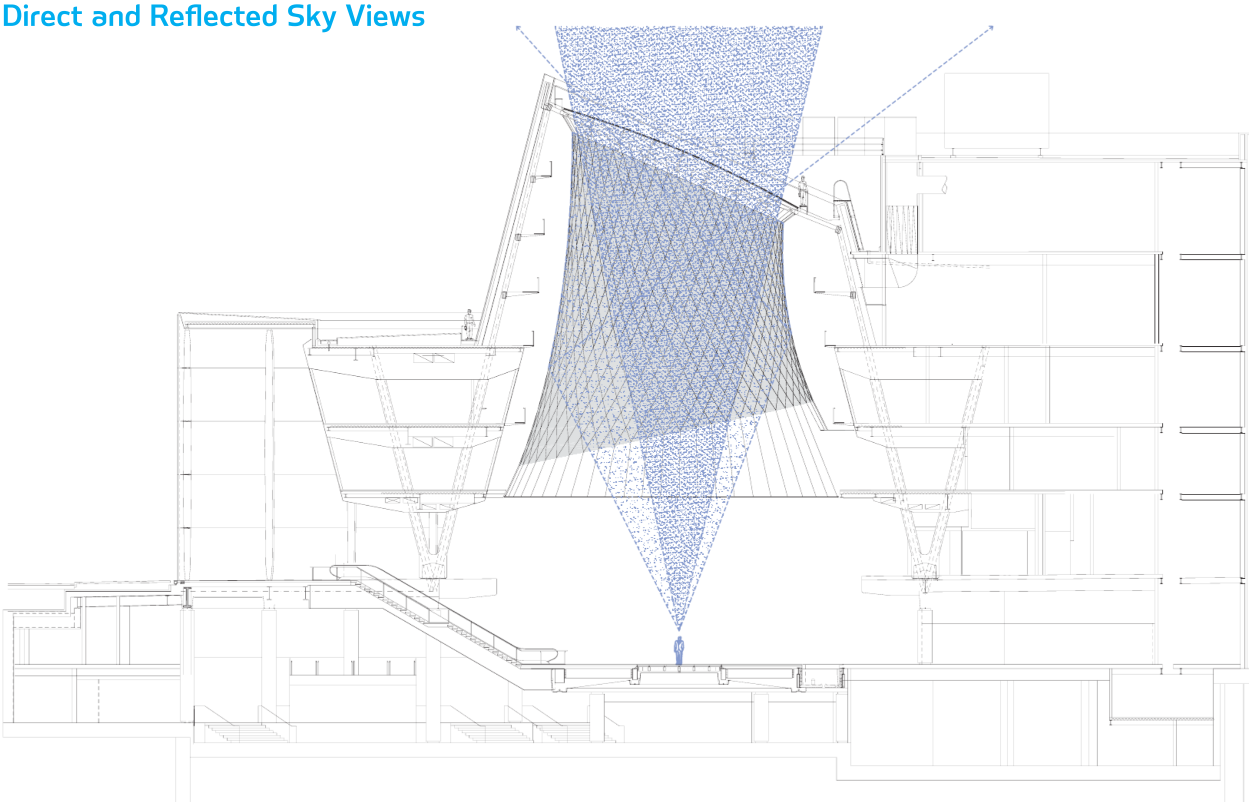
The view from behind the cable structure matters too, or at least it does to the retail tenants who will occupy the glass storefronts on the mezzanine that overlook the atrium. This, Chang points out, is another reason why Sky Reflector-Net is most porous and translucent toward the bottom, so that it screens—but does not block—the light and the view of the skylit atrium. The retail spaces also enjoy a glazed exposure to the exterior.

The optical performance of the suspended array stems in part from the panels' reflective finish. The aluminum panels have an anodized surface whose coating was originally developed for use as a material for reflectors in light fixtures. This material is approximately 95 percent light reflective and provides just the right balance of specular and diffuse reflection, says Star Davis, a lighting designer with the Arup team who worked on the project. It provides a soft reflection that spreads widely and evenly underground—and creates that ethereal field of brightness around the oculus.

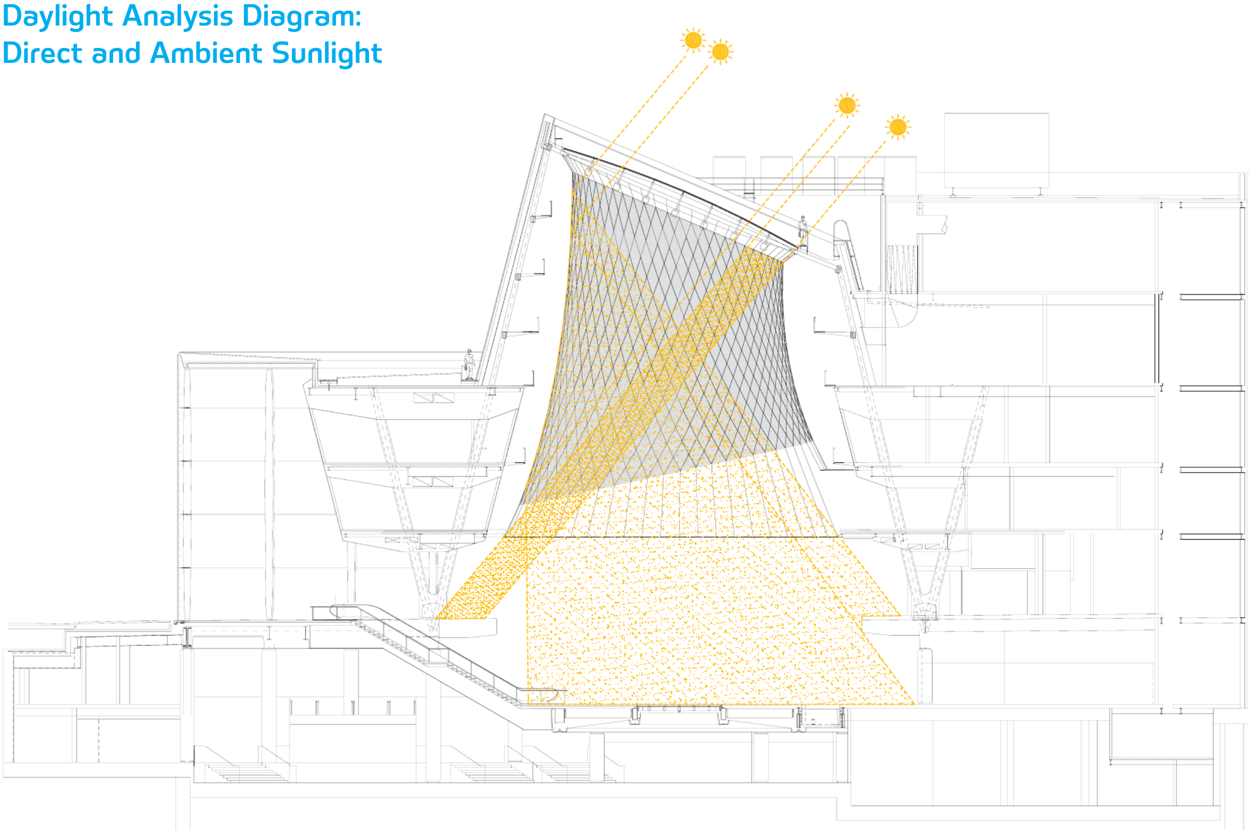
As for the double-curved, hourglass form of Sky Reflector-Net, the design evolved with the changing architectural design of the Fulton Center. Between 2006–08, due to rising project costs, the originally planned dome was reduced in size and then eliminated, so JCDA had to sideline their original design for a special glass skin composed of clear, diffuse glass and metal mirrors. Grimshaw and Arup designed a smaller, more economical atrium with a conical rotunda and glazed oculus skylight at the top. (Despite the change in scale, the atrium is still roughly as large as the rotunda at the Solomon R. Guggenheim Museum farther uptown, according to JCDA.) To maximize the solar exposure, the oculus is tilted 23 degrees to the south and positioned slightly off center to evade the shadows of adjacent buildings, a move that was based on earlier light simulation models.

None of the design team members regretted the loss of the dome, at least in retrospect. On the contrary, Carpenter said, the change turned out to be "a much better opportunity to harness light." Franks believes that it simplified the daylighting concept, replacing the omnidirectional light condition of the glass dome with a single, overhead light source. JCDA reconsidered their approach and began developing an optical liner, or sheath, to be inserted beneath the skylight. Working with engineers Schlaich Bergermann

Daylight Analysis Diagram: Direct and Reflected Sky Views



Daylight Analysis Diagram: Direct and Ambient Sunlight



Diagrams courtesy James Carpenter Design Associates

Escalators transport commuters from street level down to the main subway kiosks and turnstiles (left). Linear fluorescent lamps arranged in X patterns are incorporated into the metal ceiling panels of the pedestrian corridors to the subway platforms (right).

Right: Tod Seelie

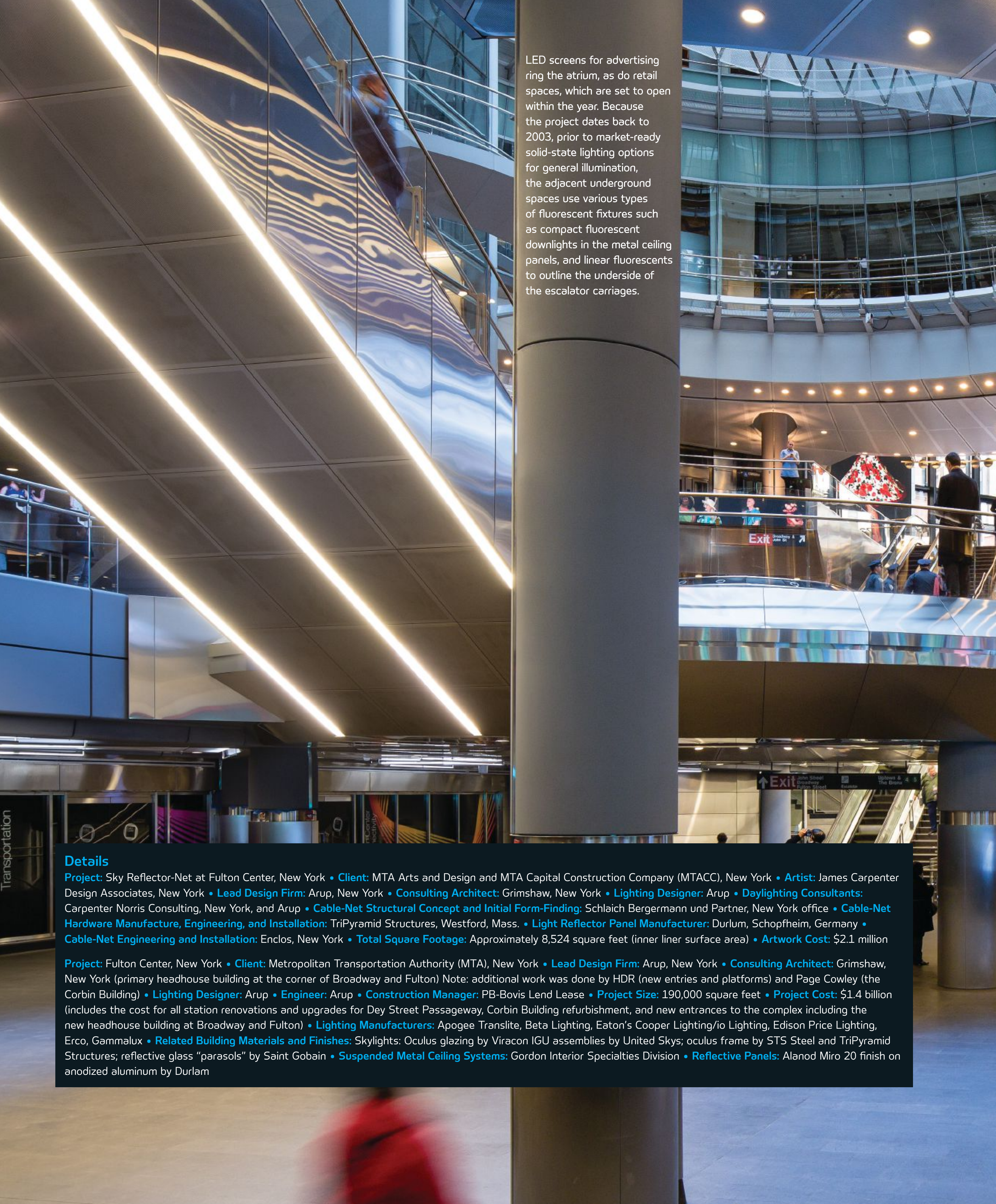
und Partner (SBP), they developed a parametric model of a two-way cable net.

This led to a series of structural form-finding exercises and ray tracings to determine optimum tensile and optical performance. "Light was the predominant thing, versus formmaking," says Richard Kress, senior designer on the project for JCDA. The hourglass-like form of the cable net makes the sky more visible than would be possible with a conventional dome. As Davidson Norris, an architect who specializes in daylighting solutions and collaborates with James Carpenter through an affiliated practice, Carpenter Norris Consulting, explains, "The curve opens up toward the oculus. And that opening-up gives you a better view of the sky." The view tends to be most dynamic at times of day when light comes in obliquely.

Mindful of the tensile loads of the 4,000-pound structure, SBP proposed attaching the net to the atrium structure only at the top and bottom—to the oculus compression ring and the second-level floor plate. Ultimately, with refinements by Arup, the design evolved into a stainless steel, paired-cable net supporting the 952 uniquely dimensioned panels, each one assigned to a specific place in the net's layout. Oversize slotted holes in the connector hardware allow for thermal- or pressure-induced movement of the net even after being tensioned. It took only two weeks to install the pre-assembled lattice, and four weeks to install the panels. To further reflect and refract daylight and create a dappled effect, Grimshaw designed an array of 88 glass fins that are suspended directly beneath the oculus. The architects used parametric modeling techniques to mount the panels at various angles, scattering points of sunlight to different parts of the transit center according to the time of day and year. Measuring 6 feet long by 9 inches tall, each panel is laminated for safety and clamped to the steel frame of the oculus. While not technically part of Sky Reflector-Net, this element revisits one of Carpenter's early ideas to have "target mirrors" embedded in the oculus dome to bounce specular reflections into the subterranean spaces.

At night, Sky Reflector-Net functions as a kind of reverse daylighting vehicle. Rather than bringing natural light into the space, it serves as a reflector for concealed electric downlights, Franks says. Metal halide lamps, grouped in fours and 400W each, are mounted around the oculus ring, mostly invisible from below. At night, these luminaires shine on the suspended net, which in turn disperses the light evenly. Compact fluorescent fixtures line the lower levels of the transit hub, and linear fluorescents in an X pattern light the underground mezzanines and passageways. Much of this lighting specification was done a decade ago, Franks says, before LEDs became readily available and suitable for general lighting. Perhaps inevitably, LED advertising screens wrap the atrium at street level, adding a significant source of brightness and a competing optical draw.

Still, Sky Reflector-Net offers a meditative moment of celestial reverie. The idea that commuters would end up resting their eyes in the sky, or in a reflection of the sky, seems almost utopian. The installation transforms commuters, however momentarily, into viewers. For this reason, architectural theorist and historian Sarah Whiting suggests in an essay from *Beyond Surface Appeal: Literalism, Sensibilities, and Constituencies in the Work of James Carpenter* that Carpenter's work produces what might be called a s*uspended public*—"a collection of individuals who share the experience of being suspended between memory and dream, suspended from everyday life … if only while they experience the project." Revealing the natural environment with augmented clarity, Sky Reflector-Net operates in a space between empirical experience and optical imagination. It succeeds in bringing together the usually separate worlds of the street, the subway, and the sky. •



LED screens for advertising ring the atrium, as do retail spaces, which are set to open within the year. Because the project dates back to 2003, prior to market-ready solid-state lighting options for general illumination, the adjacent underground spaces use various types of fluorescent fixtures such as compact fluorescent downlights in the metal ceiling panels, and linear fluorescents to outline the underside of the escalator carriages.

Details

Project: Sky Reflector-Net at Fulton Center, New York • **Client:** MTA Arts and Design and MTA Capital Construction Company (MTACC), New York • **Artist:** James Carpenter Design Associates, New York • **Lead Design Firm:** Arup, New York • **Consulting Architect:** Grimshaw, New York • **Lighting Designer:** Arup • **Daylighting Consultants:** Carpenter Norris Consulting, New York, and Arup • **Cable-Net Structural Concept and Initial Form-Finding:** Schlaich Bergermann und Partner, New York office • **Cable-Net Hardware Manufacture, Engineering, and Installation:** TriPyramid Structures, Westford, Mass. • **Light Reflector Panel Manufacturer:** Durlum, Schopfheim, Germany • **Cable-Net Engineering and Installation:** Enclos, New York • **Total Square Footage:** Approximately 8,524 square feet (inner liner surface area) • **Artwork Cost:** $2.1 million

Project: Fulton Center, New York • **Client:** Metropolitan Transportation Authority (MTA), New York • **Lead Design Firm:** Arup, New York • **Consulting Architect:** Grimshaw, New York (primary headhouse building at the corner of Broadway and Fulton) Note: additional work was done by HDR (new entries and platforms) and Page Cowley (the Corbin Building) • **Lighting Designer:** Arup • **Engineer:** Arup • **Construction Manager:** PB-Bovis Lend Lease • **Project Size:** 190,000 square feet • **Project Cost:** $1.4 billion (includes the cost for all station renovations and upgrades for Dey Street Passageway, Corbin Building refurbishment, and new entrances to the complex including the new headhouse building at Broadway and Fulton) • **Lighting Manufacturers:** Apogee Translite, Beta Lighting, Eaton's Cooper Lighting/io Lighting, Edison Price Lighting, Erco, Gammalux • **Related Building Materials and Finishes:** Skylights: Oculus glazing by Viracon IGU assemblies by United Skys; oculus frame by STS Steel and TriPyramid Structures; reflective glass "parasols" by Saint Gobain • **Suspended Metal Ceiling Systems:** Gordon Interior Specialties Division • **Reflective Panels:** Alanod Miro 20 finish on anodized aluminum by Durlam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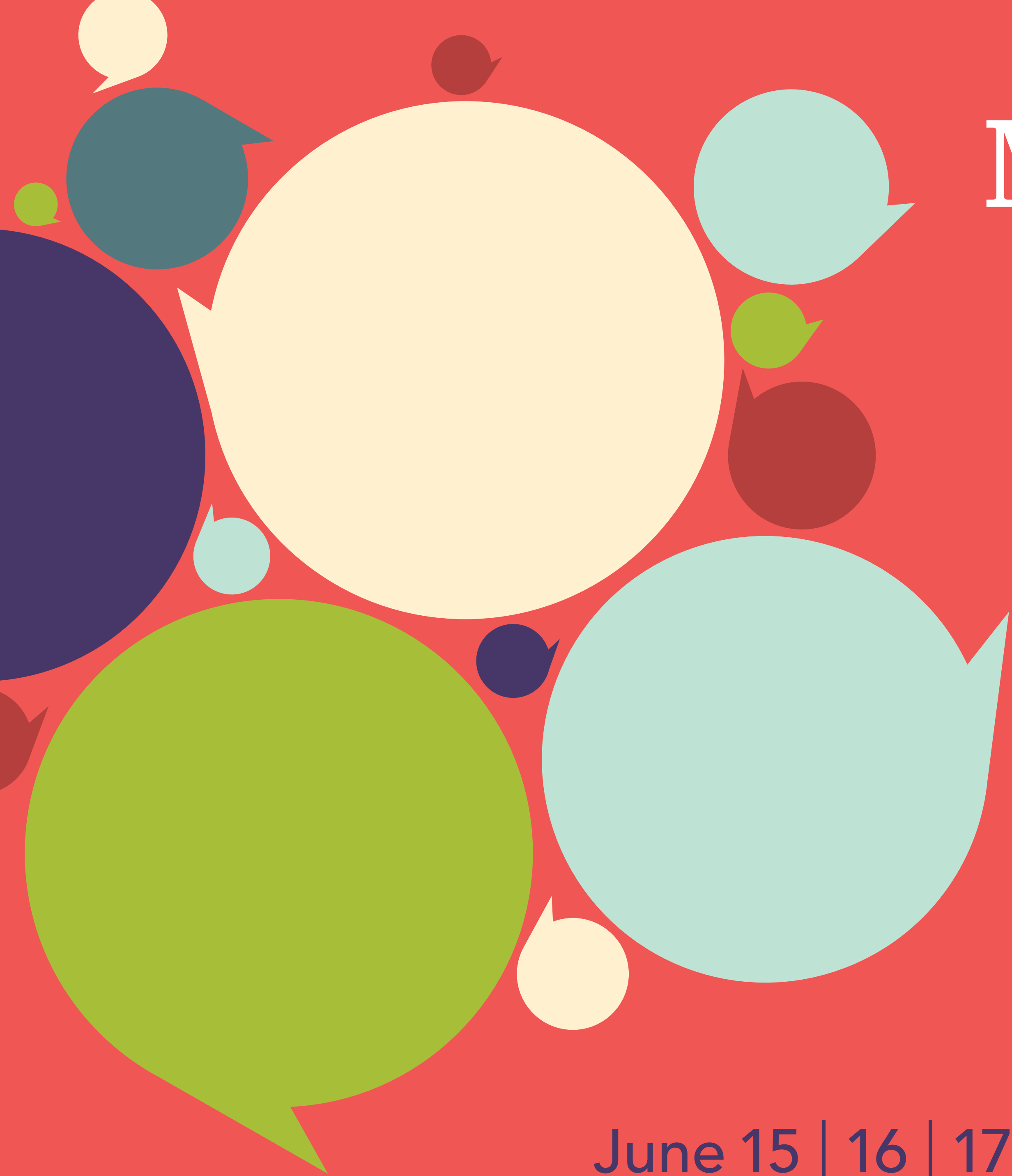

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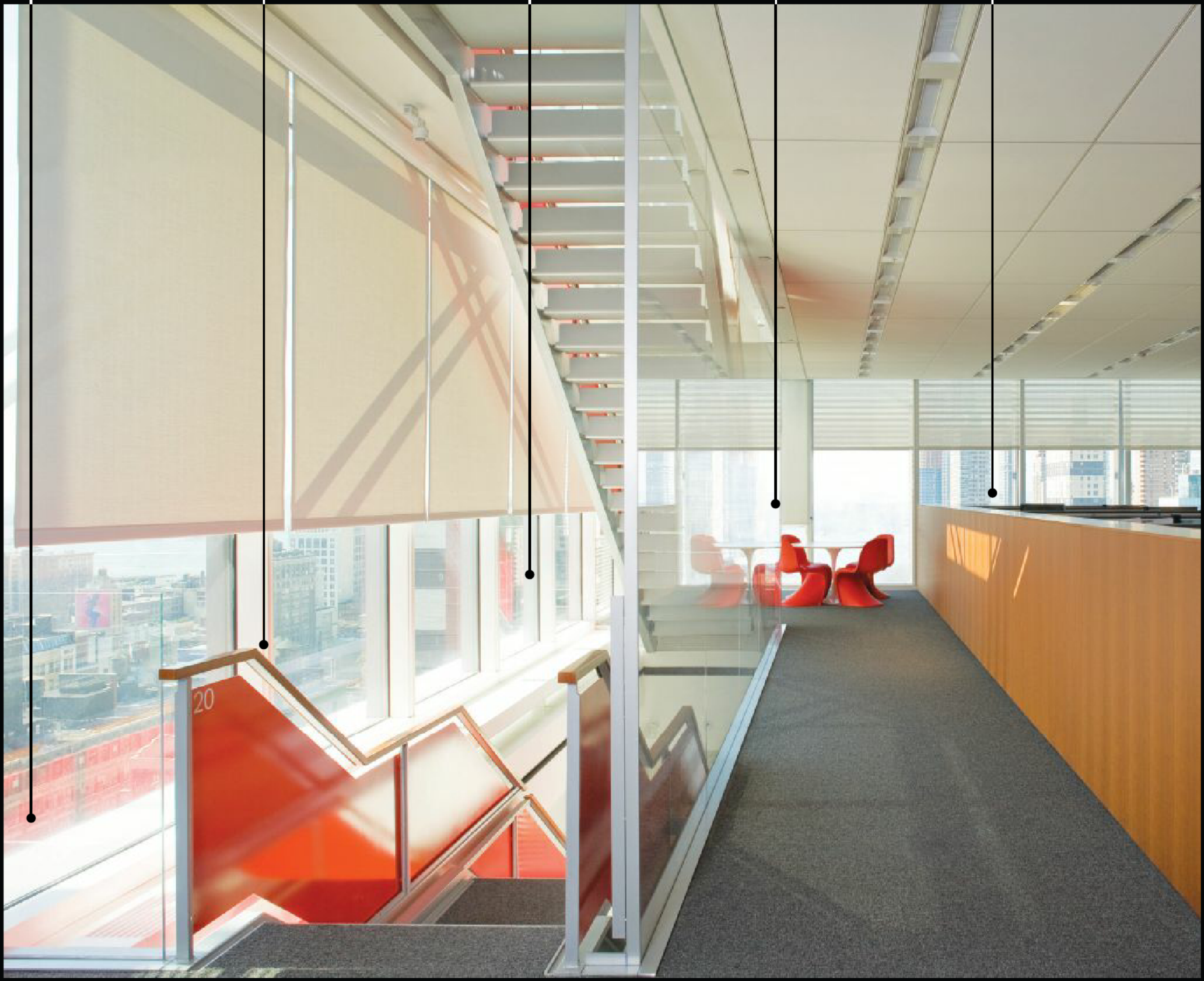

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Stephen Selkowitz

interview by Elizabeth Donoff
photo by Noah Kalina

"The divergence between the physical, measurable world and the perceptual world is really an opportunity to use technology to our advantage. It shouldn't be an excuse to say we can't create beautiful well-lit buildings that are also environmentally friendly."

Stephen Selkowitz has been at the forefront of building science, daylighting, and energy performance discussions for more than 35 years. He graduated with a degree in physics from Harvard and continued his graduate work at CalArts. While teaching at CalArts and SCI-Arc, he started his own consulting firm. Focusing on how to make structures more efficient—a hotbed issue, as it was the time of the energy crises—took him to Lawrence Berkeley National Laboratory (LBNL), in Berkeley, Calif., where a new group, led by building science specialist Art Rosenfeld and physicist Sam Berman, was starting to look at how science might address energy issues. With early funding for the group's research from the Energy Research and Development Administration (one of the precursor agencies to the U.S. Department of Energy) he focused on daylighting and façade performance. Selkowitz has led LBNL's Building Technologies Department for more than 20 years and continues as group leader for Windows and Building Envelope Materials and as a senior adviser for Building Science. His contributions cannot be underestimated, as they have helped shape the integration of energy-performance concepts into contemporary building design.

Can energy-related issues and design find common ground in lighting discussions?
In the energy world, we tend to talk about watts per square foot, kilowatt-hours, and footcandles. On the other side of the lighting world, we talk about beauty, appearance, and, of late, health, well-being, and performance. Closing that gap is where the interesting research is happening.

How has daylighting research evolved?
There has been a philosophical and pragmatic change rooted in a shift away from the original idea of minimum codes to the current, more nuanced sustainable designs.

Where does sustainability fit in the lighting conversation?
When you work in the lighting–energy world you are always bumping up against limits. It's important to look at a broader set of performance issues. Sustainable designs are not just about energy savings but include human factors, comfort, and productivity.

What's the greatest change you've witnessed in how we think about building systems?
We live in a world that's complex and dynamic. Building systems are both part of the problem and the opportunity. A key challenge is how to provide lighting and daylighting solutions for ever-changing building operating conditions. •


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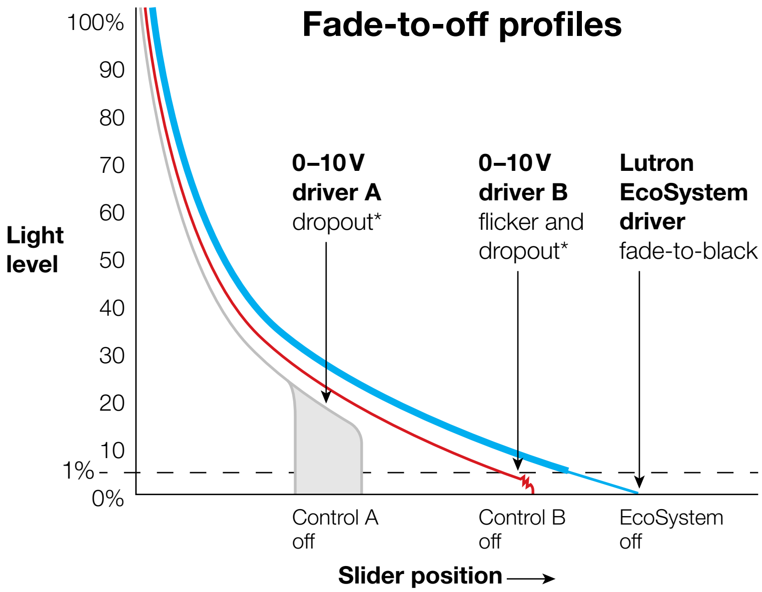

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