

Article: The IES Visionary Challenge: Beyond 2030: What Do You See?

Daylighting as a Design Driver for a Biophilic Approach to Lighting: Integrating Health and Net-Positive Energy

Mary Guzowski, Professor, School of Architecture, University of Minnesota

“Without positive benefits and associated attachment to buildings and places, people rarely exercise responsibility or stewardship to keep them in existence over the long run. Biophilic design is, thus, viewed as the largely missing link in prevailing approaches to sustainable design. Low-environmental-impact and biophilic design must, therefore, work in complementary relation to achieve true and lasting sustainability.”¹ - Stephen R. Kellert, et al., architect, author

ABSTRACT

A biophilic approach to daylighting, and its integration with electric lighting, provides a strategic method to promote the evolution from low-energy strategies toward net-positive goals that not only reduce fossil fuel consumption and greenhouse gas emissions, but also improve the health and well-being of humans, other species, and the planet. This whitepaper explores the opportunities of using daylighting as a design driver for a biophilic approach to lighting to integrate health and net-positive energy. Biologist and naturalist E.O. Wilson’s “Biophilia Hypothesis” suggests that there is an innate need for human connection with nature.² The lighting industry and allied design professions must redouble efforts to not only reduce energy consumption and greenhouse gas emissions, but to do so while simultaneously engaging sustainable approaches towards health and well-being. This paper considers how a biophilic approach to daylighting design and integration with electric lighting might fit within a larger sustainable and regenerative design trajectory for the lighting industry and allied design professions.

Keywords: Daylighting, Electric Lighting Design, Biophilic Design, Net-Positive Design

FRAMING THE CHALLENGE

In the coming decade, the greatest challenge for the lighting industry and allied design professions is to promote sustainable strategies that reduce energy consumption and thereby mitigate climate change, while also fostering health and well-being. A biophilic approach to daylighting, and its integration with electric lighting, provides a strategic method to promote the evolution from low-energy strategies toward net-positive goals that not only reduce fossil fuel consumption and greenhouse gas (GHG) emissions, but also improve the health and well-being of humans, other species, and the planet.

Over the past decade, lighting innovations (including advances in luminaire performance, solid-state and smart technologies, innovative controls and systems integration, connected lighting systems, and improved performance metrics and guidelines) have led to greater energy performance and comfort. It could be argued that the majority of energy savings through electric lighting efficiency have already been achieved under current codes and technologies for new construction – as James Benya asserts in his

article “The Law of Diminishing Returns Catches Up to Our Energy Codes. So What’s Next?”³ Benya proposes that the focus on energy codes should be directed at reducing energy use in existing buildings: “It’s time to say for new construction the job is done, and work together to make just as big a difference in the existing building stock as quickly as possible.”⁴ However, as the 2017 United Nations Environment Global Status Report estimates, the global building stock is expected to double by 2060 (Figure 1), and therefore it is critical to design for a future with the maximum amount of embodied energy and carbon savings designed into buildings through daylighting and passive architectural design. And as will be discussed below, from a purely economic perspective, the benefits of increased productivity that can be achieved through a biophilic approach to daylighting far exceed the cost savings of maximized energy efficiency.⁵

In addition to the energy savings achieved through daylighting and electric lighting advances, there are also important considerations for human health and well-being. Research regarding human responses to light has fostered innovations, such as development of circadian lighting criteria, tunable lamps and systems, expanded color metrics, and improved glare standards. While the lighting industry has focused on electric lighting, parallel innovations in daylighting design are found in advanced glazing technologies, integrated systems and wireless controls, renewable energy integration, circadian daylighting, and evolving daylight performance standards and metrics (Lighting Measurement 83, Spatial Daylight Autonomy, Annual Sunlight Exposure, among others). The benefits of daylighting have focused on energy savings; however significant health benefits of natural light are well documented.⁶ These and other lighting developments are reflected in evolving sustainable guidelines such as the *Living Building Challenge*, *Leadership in Energy and Environmental Design (LEED)*, and the *WELL Building Standard*.⁷

Yet despite the many lighting advances of the past decade, the correlation of energy and climate with health and well-being is still nascent. The lighting industry and allied design professions must redouble efforts to not only reduce energy consumption and greenhouse gas emissions, but to do so while simultaneously engaging sustainable approaches towards health and well-being. It is time to take a fresh look at the essential and expanded role of daylighting in the lighting industry and design professions.

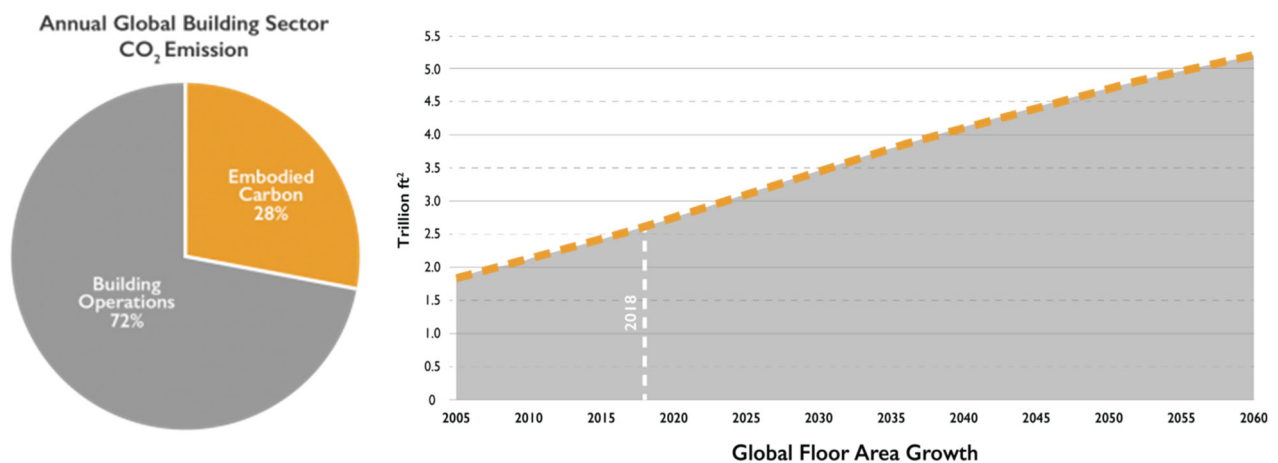


Figure 1: Annual Global Carbon Dioxide Emissions in the Building Sector and Projected Global Floor Area Growth (Credit: Architecture 2030, 2017 UN Environment Global Status Report, International Energy Outlook).

Concept of Biophilic Design

The concept of biophilia or “love of life” was introduced by psychologist Eric Fromm in his 1973 book *The Anatomy of Human Destructiveness*: “*Biophilia is the passionate love of life and of all that is alive; it is the wish to further growth, whether in a person, a plant, an idea, or a social group.*”⁸ Biologist and naturalist E.O. Wilson popularized the term in 1984 in his seminal text *Biophilia: The Human Bond with Other Species*.⁹ Wilson’s “Biophilia Hypothesis” suggests that there is an “innate emotional affiliation of human beings to other living organisms.”¹⁰ Over the past several decades, a body of scientific research has demonstrated the physiological and psychological benefits of contact with nature through such elemental factors as views, daylight, materials, gardens, and nature imagery.¹¹

In 2008, Stephen Kellert, Judith Heerwagen, and Martin Mador establish a foundational theory, science, and proposed architectural practice of biophilic design.¹² In doing so, they suggested that biophilia is a missing component of sustainability: “*Without positive benefits and associated attachment to buildings and places, people rarely exercise responsibility or stewardship to keep them in existence over the long run. Biophilic design is, thus, viewed as the largely missing link in prevailing approaches to sustainable design. Low-environmental-impact and biophilic design must, therefore, work in complementary relation to achieve true and lasting sustainability.*”¹³

In 2014, the consulting firm Terrapin Bright Green published a resource entitled “Terrapin’s 14 Patterns of Biophilic Design” by William Browning, Catherine Ryan, and Joseph Clancy.¹⁴ Building on the earlier work of Kellert et al., Terrapin’s patterns provide concise and designer-friendly conceptual frameworks, tangible goals, metrics, and strategies to implement biophilic design. The Terrapin patterns will be used in this paper to introduce biophilic daylighting strategies that work toward net-positive goals by reducing energy and GHG emissions, while promoting health benefits such as circadian entrainment, access to views, and physical connections to nature and natural forces.

Benefits of Biophilic Design

A growing body of research demonstrates the mental benefits of biophilic design, including improved cognitive functioning, mental agility, memory, and learning; the psychological benefits for concentration, lower tension, and reduced anxiety; and the physiological responses of muscle relaxation, lowered diastolic blood pressure, and reduced stress hormones, among others.¹⁵ Biophilic design also provides economic benefits, as shown in Terrapin Bright Green’s report *The Economics of Biophilia*: “*Biophilic design has often been regarded as a luxury for property owners who want the best possible workplace for their employees, or who want to showcase their efforts to be more environmentally responsible. In reality, improving community well-being through biophilia can impact productivity costs and the bottom line.... Today productivity costs are 112 times greater than energy costs in the workplace...incorporating nature into the built environment is not just a luxury, but a sound economic investment in health and productivity.*”¹⁶

Daylighting design health benefits and economic savings include enhanced productivity, improved satisfaction, and decreased absenteeism: “*Integrating quality daylighting schemes into an office space can save over \$2,000 per employee per year in office costs, whereas over \$93 million could be saved annually in healthcare costs as a result of providing patients with views to nature.... Whether it is hospitals that allow patients to heal more quickly, offices that boost productivity, schools that improve test scores, or retail outlets with higher sales.*”¹⁷ In *Human Spaces: The Global Impact of Biophilic Design in the Workplace* by

architect Bill Browning and Professor Sir Cary Cooper, et al., a study of 1600 employees in 16 countries around the world further confirm the essential role of daylighting to realize the benefits of biophilic design.¹⁸ The quality of daylighting and its connection to biophilic strategies for views, visual relief, and access to natural forces was a “crucial determinant” of well-being, productivity, and creativity.¹⁹

At the same time, a growing body of research on circadian lighting has further defined the visual and nonvisual circadian health benefits of daylight, with advances in electric lighting strategies supporting these benefits. The Lighting Research Center at Rensselaer Polytechnic Institute emphasizes the health benefits of exposure to natural light and the subsequent health risks of disruptions to human circadian rhythms:

“Circadian rhythms are biological rhythms that repeat approximately every 24 hours. Exposure to the natural sunrise and sunset synchronizes our circadian rhythms to exactly 24 hours. Circadian disruption...have been associated with increased risks for breast cancer, diabetes, obesity, heart disease, sleep disorders, and other ailments.... LRC researchers coined the term ‘circadian light’ as spectrally weighted retinal irradiance that stimulates the human circadian system. The definition of circadian light is based upon the potential for light to suppress melatonin synthesis at night.”²⁰

The electric lighting industry has applied this growing body of circadian research and science to many facets of lighting design and technologies, particularly tunable lighting to simulate the changing color and luminous intensity of daylight with electric light sources.” For example, a recent study by the U.S. Department of Energy found positive benefits of tunable LED lighting for nursing care residents with dementia to improve sleep and reduce agitated behaviors: *“Research suggests that lighting color and pattern of intensity that mimic natural daylight over the course of the day can improve circadian rhythm entrainment and health outcomes.... Results suggest that tuned lighting had a positive effect on residents’ sleep.”²¹*

Circadian Daylighting

While circadian lighting - a relatively new and evolving area of research - has been focused primarily on electric lighting, daylighting is also important for circadian well-being. In the article “Circadian Daylight in Practice” by Emilie Hagen and Henry Richardson from the environmental design firm Atelier Ten, they discuss a series of studies that successfully combined daylighting assessment tools (Radiance through DIVA for Rhino, Grasshopper, and Honeybee) to conduct daylight circadian simulations using the WELL Building Standards. As environmental consultants, they encourage designers to consider daylighting as the first approach to circadian lighting: *“Though designers are beginning to look to electric lighting to provide improved circadian function, the first step in designing to support circadian system function should be to ensure access to daylight through massing and façade optimization.... If daylight is not available or sufficient, electric lighting can be used to provide circadian stimulus, but requires additional energy and has a greater first cost.”²²* Hagen and Richardson also conclude that health criteria are not independent of other daylight and energy metrics: *“The proposed circadian daylight analysis methods easily integrate into the design process to assess circadian daylight potential, but do not holistically address the full range of daylighting concerns in a project. Circadian daylight simulation should be used early in the design process, but must be coupled with traditional daylight analysis to evaluate illuminance levels and glare potential throughout the year. Because the proposed simulation methods look at such a narrow issue, the impact of design decisions based on circadian daylight need to be assessed in relation to potential for increased energy consumption from conditioning energy, visual glare potential, and useable daylight.”²³* In *Biophilia and Healing Environments*, Catherine O. Ryan, biophilic design expert at Terrapin, raises a parallel question regarding

biophilic design metrics and what can and cannot be quantified and measured: *“So often industry insists upon the perfect quantitative metrics against which to measure design effectiveness, but perhaps we should instead be using rules, and the like, as contextually qualitative metrics. It is the quality of the space, as we have learned, and less so its size or quantity, to which we are viscerally responsive.”*²⁴

Daylighting to Integrate Health, Energy, and Climate

In considering energy as just one dimension of sustainability, the shift from low-energy to zero-energy, and now to net-positive energy, has also raised the aspirational bar for the lighting industries and allied design professions to consider not only economic and human benefits, but also broader ecological impacts. For example, in the 1990s, the concept of a “living building” emerged as a counterpoint to incremental improvements found in many green and sustainable rating systems. In 2006, the *Living Building Challenge (LBC) 1.0* standard introduced the aspirations for “net-zero” energy, water, and waste as well as focusing attention on issues such as beauty and equity.²⁵ In 2009, “biophilia” was first cited in the *LBC 2.0* standard. In 2014, the International Living Futures Institute (ILFI) introduced *LBC 3.0*, which included a shift from “net-zero” to “net-positive” energy, water, and waste. Building on Kellert’s biophilic strategies, the ILFI recently published the *Biophilic Design Guidebook* and Amanda Sturgeon’s *Creating Biophilic Buildings*.^{26, 27} The current *LBC 4.0* could be further developed and integrated to reveal the inter-relationships and trade-offs between these design issues and broader ecological impacts.

An emerging area of research on the integration of biophilic design, health, and climate metrics is discussed in the publication “Biophilic Design and Climate Change,” by Julia Africa, et al. which suggests that biophilia can serve as an “interstitial tissue” that connects varied ecological scales and issues: *“The best applications of biophilic design may be distinguished from other projects by their ability to synergistically integrate the building, site, and occupants through the creation of comprehensive ‘habitat.’ Habitat, in this context, encompasses the materials, structure and program of the building...a recognition that these features communicate habitability and community to human occupants through eons of evolutionary priming, and that this appeal is both desirable, comfortable, and health promoting.”*²⁸

Another recent article “The Slope of Circadian Enlightenment” by Colleen Hufford and Kelly Seeger also suggests that it is time to shift from the lighting industry focus on energy efficiency towards health and well-being.²⁹ They support an aggregated approach to energy performance standards for lighting: *“The lighting industry has achieved very highly efficient, consistently well-performing, safe lighting products at all market levels and in all segments, so the time has arrived to now focus on regulating the actual energy outcomes for buildings and considering the contribution of building systems in aggregate. We should move away from installed power and adopt whole-building energy use intensity (EUI) strategies that regulate all building energy from occupant amenity loads (e.g., lighting, HVAC) to process loads (e.g., office equipment, industrial machinery) to miscellaneous electric loads and plug loads.”*³⁰

Despite the complexity and challenges of integrating health, energy, climate strategies, standards, and metrics, it is only through such an integrated approach that these parallel advances and innovations in the lighting industry and allied design professions will foster ever-higher sustainable and regenerative design performance. Simultaneously considering health and climate-change metrics will expand a human-centered approach to lighting to also include ecocentric insights into lighting impacts on other species and the planet.

DAYLIGHT AS A BIOPHILIC DESIGN DRIVER

Positioning Daylighting and Biophilia within the Regenerative Design Trajectory

The definition of sustainable development in the 1987 Brundtland Commission report *Our Common Future* (“sustainable development meets the needs of the present without compromising the ability of future generations to meet their own need”) has evolved from “sustainability” towards “regenerative design”, as discussed in essays by John Tillman Lyle; Ray Cole et al.; Pamela Mang and Bill Reed, Julia Africa et al.^{31, 32, 33, 34} This evolution is well illustrated in Reed’s “regenerative design trajectory” (Figure 2).³⁵

This diagram reveals a spectrum of “degenerating” to “regenerating” design practices, and positions “biophilia” as nesting within a larger cluster of design strategies such as biomimetic and restorative strategies to “affiliate, mimic, and restore” nature.³⁶

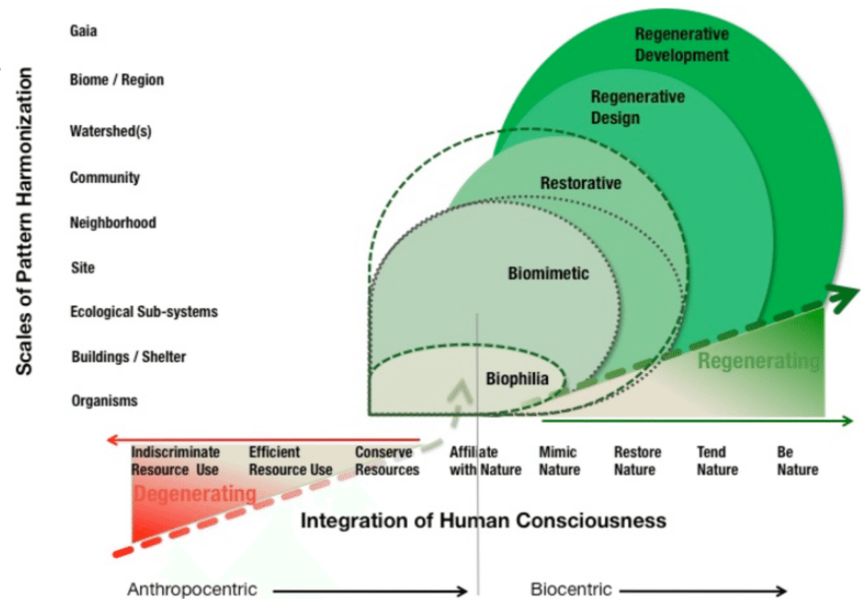


Figure 2: Regenerative Design Trajectory (Credit: Bill Reed, Regensis Group: “Regenerative Development and Design”).

Net-Positive Design and the Passive Potential of Daylighting

Building operations account for 28% of annual global carbon dioxide emissions.³⁷ Daylighting, electric lighting technologies, and improved energy standards and metrics have all contributed to an 18.9% reduction in emissions since 2005.³⁸ In the past two decades, we have seen the design professions strive to not only meet zero, but to move towards net-positive energy. This aspirational target continues to challenge designers toward ever-higher standards and more effective strategies. In 2002, architect Ed Mazria made an impassioned call to the design professions and allied industries to adopt the *Architecture 2030 Challenge*, a global initiative to achieve “carbon neutrality” by GHG emissions in “new buildings, developments, and major building renovations” by the year 2030.³⁹

The 2030 timeline has recently been extended by a decade to an initiative entitled *Zero by 2040*. The 2040 target includes strategic goals, strategies, and assessment tools for new and major renovations of existing buildings to support the goal of the Paris Agreement to limit the global temperature increase by 1.5 degree C over the next two decades.⁴⁰ The global *Zero by 2040* target couples architectural design with innovative technologies and systems by proposing the following “energy design hierarchy”: 1) apply low/no cost passive design strategies to achieve maximum energy efficiency, 2) integrate

energy efficient technology and systems, and 3) incorporate on-site and/or off-site renewable energy to meet the remaining energy demands (Figures 3 and 4).⁴¹

Unless there is an agreement that the “energy design hierarchy” is an effective strategy towards zero and net-positive energy, it may be easy to dismiss a biophilic approach to daylighting as beyond the scope of the lighting industry. Some may argue that daylighting is best suited for new construction and not impactful enough given current construction trends, that daylighting retrofits are too costly, or that there would be only minor benefits for climate and health. Yet, as Mazria argues, the “2040 hierarchy” (passive design strategies such as daylighting, natural ventilation, and solar heating) should be the first order of lighting design, and passive strategies can be applied to both new construction as well as existing building renovations.⁴²

Global CO₂ Emissions by Sector

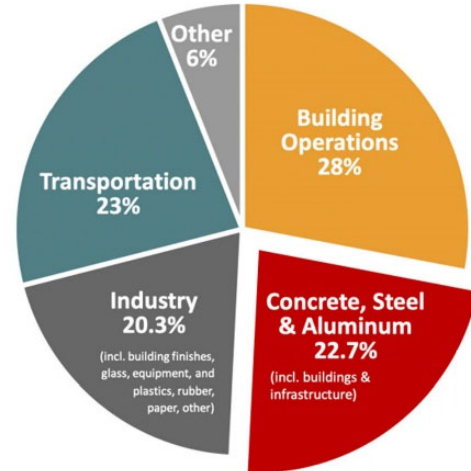


Figure 3: Global Carbon dioxide emissions (Credit: Architecture 2030; Source 2018 Global ABC Report, IEA).

Exploring Daylighting from a Biophilic Perspective

The potential of daylighting as a design driver for a biophilic approach to lighting that integrates health and net-positive energy is revealed through the lens of Terrapin’s 14 Patterns of Biophilic Design (Table 1). Many of Terrapin’s “patterns” draw direct biophilic connections between daylighting, passive design, and net-positive energy, including: site design; building form and orientation; section, room form, zoning, window size, window placement, spatial organization, finishes, detailing, and envelope design.

A direct biophilic relationship between daylight, health, and net-positive is found in at least five of Terrapin’s Patterns: #1) Visual Connection with Nature, #3) Non-rhythmic Sensory Stimuli, #4) Thermal and Airflow Variability, #6) Dynamic & Diffuse Light, and #7) Connection with Natural Systems. Each remaining pattern has at least an indirect relationship to support the health and energy benefits of daylighting through form, materials, or experiential qualities.

Net-Zero Energy Hierarchy (Zero by 2040)

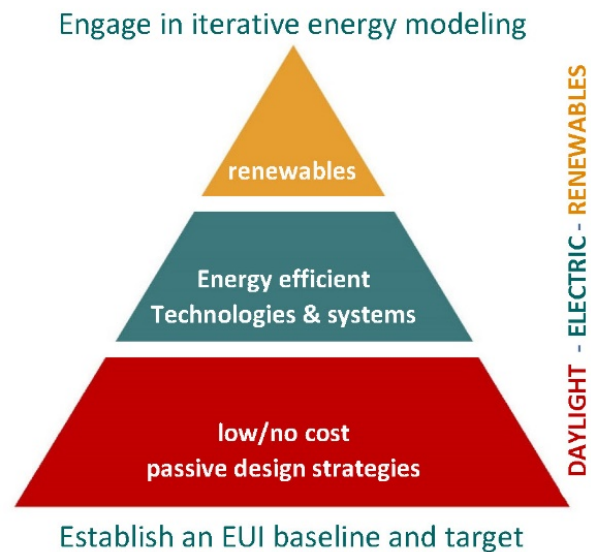


Figure 4: Net-Zero Energy Design Hierarchy (Credit: Author, based on “Zero by 2040”, Architecture 2030).

<p style="text-align: center;">DAYLIGHTING, NET-POSITIVE & HEALTH THROUGH THE LENS OF TERRAPIN’S 14 PATTERNS OF BIOPHILIC DESIGN</p>		
<p>Terrapin’s 14 Patterns of Biophilic Design</p>	<p>Daylighting Lens on Terrapin’s 14 Patterns</p>	<p>Net-Positive & Health Lens on Terrapin’s 14 Patterns</p>
<p><i>NATURE IN THE SPACE PATTERNS</i></p>	<p><i>Daylight Lens: Nature of the Space Patterns</i></p>	<p><i>Net-Positive & Health Assessments</i></p>
<p>1. Visual Connection with Nature</p>	<p>Daylight design to enhance visual access to nature and natural forces through siting, orientation, building form, section, envelope, room configuration, and window design</p>	<p>Quantitative assessment of the integration of daylighting with bioclimatic and passive strategies to reduce lighting, heating, cooling, and natural ventilation loads. Potential integration of health and energy performance metrics, for example:</p> <ul style="list-style-type: none"> - <i>Daylighting & electric lighting targets:</i> point-in-time and annual climate-based metrics (IESNA recommendations, Spatial Daylight Autonomy, Annual Sunlight Exposure, etc.); electric lighting integration. - <i>Energy and sustainability targets:</i> Energy Use Intensity (EUI): kBtu/SF; lbsCO₂; Architecture 2030 targets; electric lighting and systems integration. - <i>Circadian daylight & electric targets:</i> equivalent melanopic lux, circadian stimulus, etc.; electric lighting integration; nighttime strategies to eliminate circadian disruption (day vs night: blackout shades, night-time navigation). - <i>Visual comfort targets:</i> solar glare control, views, daylight management, color rendering, electric lighting integration.
<p>2. Non-Visual Connection with Nature</p>	<p>Daylight design to enhance sounds, smells, thermal experiences related to site, building form, envelope, and windows.</p>	
<p>3. Non-Rhythmic Sensory Stimuli</p>	<p>Daylight design to enhance sensory experiences: site, climate, time, and seasons through orientation, building form, section, envelope, room configuration, and window design.</p>	
<p>4. Thermal & Airflow Variability</p>	<p>Daylight integration with seasonal thermal comfort and strategies for passive solar heating and natural ventilation.</p>	
<p>5. Presence of Water</p>	<p>Integration of water elements with seasonal luminous, thermal, and acoustic experiences through site, envelope, and window design. Potential for qualitative daylight design integration through water reflection and refraction. Potential integration between luminous and thermal comfort.</p>	
<p>6. Dynamic & Diffuse Light</p>	<p>Bioclimatic, seasonal, and program appropriate daylight strategies and zoning for dynamic and diffuse light (daylight versus sunlight). Integration of passive and high performance systems to reduce energy loads.</p>	
<p>7. Connections with Natural Systems</p>	<p>Daylight design to respond to seasonal and temporal changes in daylight availability, solar radiation, sky conditions, and integration of luminous and thermal criteria for solar control, shading, envelope, and window operability.</p>	
<p><i>NATURAL ANALOGUES PATTERNS</i></p>	<p><i>Daylight Lens: Nature Analogues Patterns</i></p>	<p><i>Net-Positive & Health Assessment</i></p>
<p>8. Biomorphic Forms & Patterns</p>	<p>Daylight design for building form, section, room configuration, envelope, and windows design.</p>	<ul style="list-style-type: none"> - Quantitative and qualitative assessments of building form, materials, and spatial organization to optimize the integration of daylighting with net-positive design through siting, bioclimatic, passive strategies, and electric integration. - Integration of strategies and metric to improve health and reduce energy and GHG.
<p>9. Material Connection with Nature</p>	<p>Material choices to respond to climate, seasons, and program to optimize daylight effectiveness and light distribution in spaces.</p>	
<p>10. Complexity & Order</p>	<p>Integration of daylight with rich and varied sensory experiences.</p>	
<p><i>NATURE OF THE SPACE PATTERNS</i></p>	<p><i>Daylight Lens: Nature of the Space Patterns</i></p>	<p><i>Net-Positive & Health Assessment</i></p>
<p>11. Prospect</p>	<p>Integration of daylight strategies with desired spatial, experiential, and atmospheric qualities such as site connections, views, illuminance levels, contrast ratios, and luminous journey.</p>	<ul style="list-style-type: none"> - Qualitative assessment of climate and program appropriate luminous experiences. - Integration of daylight and electric lighting for experiential benefits and energy performance.
<p>12. Refuge</p>		
<p>13. Mystery</p>		
<p>14. Risk/Peril</p>		

Table 1: Daylight as a design driver for biophilic lighting using Terrapin’s 14 Patterns of Biophilic Design (Credits: Left column: Terrapin Bright Green: Terrapin’s 14 Patterns of Biophilic design. Center and right columns: Author).

CONCLUSION: DAYLIGHTING AS A DESIGN DRIVER FOR A BIOPHILIC APPROACH TO LIGHTING

Daylight is a dynamic environmental phenomenon and an ephemeral architectural material. It embodies the dimension of time as the movement of light and shadow reveal the changing diurnal and seasonal cycles. In a digital age that runs 24/7/365, daylight is an antidote to our increasing alienation from nature. The varied and changing material and atmospheric effects of daylight can awaken the senses and further enhance our understanding and relationship to the world in which we live. Daylight and the changing environmental forces of sun, wind, and weather help us to know “where we are” and “who we are” by rooting us in the ecological phenomena of a particular place, in that climate, and on that site. Continued collaboration between the lighting industry and allied design professions will play a critical role in achieving the next generation of daylighting and electric lighting integration. When coupled with biophilic and net-positive strategies for electric lighting, passive solar, and bioclimatic design, daylight can reduce energy consumption and provide ecological benefits while enhancing comfort, health, and well-being for humans, other species, and the planet.

ENDNOTES

-
- ¹ Stephan R. Kellert, Judith H. Heerwagan, and Martin L. Mador, *Biophilic Design*, New Jersey: John Wiley & Sons, Inc., 2008, 5.
 - ² Edward O. Wilson, *Biophilia: The Human Bond with Other Species*, Cambridge: Harvard University Press, 1984, 1.
 - ³ Architecture 2030, “Global Floor Area Growth,” *Why the Building Sector*, https://architecture2030.org/buildings_problem_why/.
 - ⁴ James Benya, “The Law of Diminishing Returns Catches up to our Energy Codes. So What’s Next?,” *Hot Topics*, Illuminating Engineering Society, 14 May 2018, <https://www.ies.org/lda/our-work-is-done-here/>.
 - ⁵ Terrapin Bright Green, *The Economics of Biophilia*, New York: Terrapin Bright Green, 2014, 3, 10-14.
 - ⁶ Nikos A. Salingaros, “Biophilia and Healing Environments,” New York: Terrapin Bright Green, <https://www.terrapinbrightgreen.com/wp-content/uploads/2015/10/Biophilia-Healing-Environments-Salingaros-p.pdf>.
 - ⁷ *International Living Building Challenge*, Seattle, WA: International Living Future Institute: <https://living-future.org/lbc/>; *Leadership in Energy and Environmental Design (LEED)*, Washington D.C.: U.S. Green Building Council: <https://build.usgbc.org>; *WELL Building Standard*, New York: International Well Building Institute: <https://www.wellcertified.com/certification/v2/>.
 - ⁸ Eric Fromm, *The Anatomy of Human Destructiveness*, New York: Holt Rinehart and Winston, 1973, 377.
 - ⁹ Edward O. Wilson, 1.
 - ¹⁰ Stephan R. Kellert and Edward O. Wilson, “Biophilia and the Conservation Ethic,” *Biophilia Hypothesis*, Washington DC: Island Press, 1993, 31.
 - ¹¹ Terrapin Bright Green, *Terrapin’s 14 Patterns of Biophilic Design*, New York: Terrapin Bright Green, 2014, <https://www.terrapinbrightgreen.com/report/14-patterns/>, 4.
 - ¹² Stephan R. Kellert, Judith H. Heerwagan, and Martin L. Mador, 2008.
 - ¹³ *Ibid.*, 5.
 - ¹⁴ The Terrapin Bright Green website includes a variety of publications on the topic of biophilia, including biophilic economics, healing principles, design case studies, among other related issues. See Terrapin Bright Green, “Publications”: <https://www.terrapinbrightgreen.com/publications/>.
 - ¹⁵ Terrapin Bright Green, *Terrapin’s 14 Patterns of Biophilic Design*, 2014, 11.
 - ¹⁶ Terrapin Bright Green, *The Economics of Biophilia*, 2014, 3.
 - ¹⁷ *Ibid.*, 3.

-
- 18 Bill Browning and Professor Sir Cary Cooper, *Human Spaces: The Global Impact of Biophilic Design in the Workplace*, 2015, Atlanta GA: Interface: https://greenplantsforgreenbuildings.org/wp-content/uploads/2015/08/Human-Spaces-Report-Biophilic-Global_Impact_Biophilic_Design.pdf.
- 19 Ibid., 34.
- 20 Lighting Research Center, "Circadian Light Defined," Troy NY: Rensselaer Polytechnic Institute, https://www.lrc.rpi.edu/resources/newsroom/pdf/2010/CircadianLight_8511.pdf, 1.
- 21 Pacific Northwest National Laboratory, "Measuring Light Exposure and its Effects on Sleep and Behavior in Care Center Residents," Washington DC: U.S. Department of Energy, November 2019, https://www.energy.gov/sites/prod/files/2020/01/f70/ssl-2019_acc-care-center_realistic-settings-report.pdf, iii.
- 22 Emilie Hagen and Henry Richardson, "Circadian Daylight in Practice: Determining a Simulation Method for the Design Process," *Façade Tectonics 2016 World Congress*, Newington, CT: Façade Tectonics Institute, <https://www.atelierten.com/articles/circadian-daylight-in-practice/>.
- 23 Ibid.
- 24 Nikos A. Salingaros, 7.
- 25 The *Living Building Challenge (LBC) 1.0* standard was introduced in 2006 by Jason McLennan, in collaboration with Bob Berkebile, Kath Williams, et al. In 2009, the newly formed International Living Building Institute (later renamed the International Living Futures Institute – ILFI) launched *LBC 2.0*, which included six "biophilic design elements" under the topic of "health." The biophilic design elements included six related topics: 1) environmental features, 2) natural shapes and forms, 3) natural patterns and processes, 4) light and space, 5) place-based relationships; and 6) evolved human-nature relationships). International Living Building Institute, *Living Building Challenge 2.0*, November 2009, <https://living-future.org/wp-content/uploads/2016/12/Living-Building-Challenge-2.0-Standard.pdf>, 27.
- 26 International Living Future Institute, *Biophilic Design Guidebook*, Seattle: International Living Future Institute, June 2018.
- 27 Amanda Sturgeon, *Creating Biophilic Buildings*, Seattle: Ecotone Publishing, 2017.
- 28 Julia Africa, Judith Heerwagen, Vivian Loftness, and Catherine Ryan Balagtas, "Biophilic Design and Climate Change: Performance Parameters for Health," *Frontiers: Perspective*, 19 March 2019, 1-2.
- 29 Colleen Hufford and Kelly Seeger, "The Slope of Circadian Enlightenment," *FIRES*, Illuminating Engineering Society, 18 March 2020, <https://www.ies.org/fires/the-slope-of-circadian-enlightenment/>.
- 30 Ibid.
- 31 Regenerative design theory and practice arose from organic agriculture and the work of Robert Rodale, and was later expanded through the practice of permaculture by Bill Mollison, David Holmgren, and others in the 1970s. In the 1990s, landscape architect John Tillman Lyle helped to translate regenerative theory into design strategies and practices for the built environment. Architects and researchers have further championed regenerative design in the past decade, including the work of Pamela Mang and Bill Reed; Ray Cole; Jason McLennan and Bob Berkebile with the *International Living Futures Institute*; among others. Pamela Mang and Ben Haggard, *Regenerative Development and Design*, New York: John Wiley & Sons, 2016, XVII-XXII. R. J. Cole, "Regenerative Design and Development: Current Theory and Practice," *Building Research & Information*, 2012, 1-6.
- 32 John Tillman Lyle, *Regenerative Design for Sustainable Development*, New York: John Wiley & Sons, Inc., 1994.
- 33 R.J. Cole and A.M. S. Kashkooli, "Clarifying Net Positive Energy," *CaGBC National Conference and Expo*, Vancouver BC, June 4-6, 2013.
- 34 Pamela Mang and Bill Reed, "The Nature of Positive," *Building Research & Information*, Volume 43, 2014 – Issue 1: Net-Zero and Net-Positive Design, <https://www.tandfonline.com/doi/full/10.1080/09613218.2014.911565>.
- 35 Pamela Mang and Bill Reed, "Regenerative Development and Design," *Encyclopedia Sustainability Science & Technology*, New York: Springer, 2019, 12-13.
- 36 Ibid.
- 37 Architecture 2030, "Why the Building Sector," https://architecture2030.org/buildings_problem_why/.
- 38 Ibid.
- 39 Architecture 2030, "About," <https://architecture2030.org/about/>.
- 40 Architecture 2030, "Accelerating to Zero by 2040!" <https://architecture2030.org/accelerating-to-zero-by-2040/>.
- 41 Ibid.
- 42 Ibid.