Integrating Biophilic, Net-Positive, and Resilient Design: A Framework for Architectural Education

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ABSTRACT: This paper explores how a biophilic framework can be overlaid on a net-positive-energy architectural design studio to expand students' definition of net-positive to include broader "positive benefits" - not only for human health, well-being, and resilience, but also for other species, ecological systems, and the planet itself. The paper considers some of the ecological challenges of today's design education; provides an overview of the biophilic frameworks considered in the studio; explores potential overlaps between a biophilic framework, net-positive energy, and resilient design; and provides example studio content and student work. Conclusions highlight key issues to support the integration of a biophilic framework in a net-positive design studio. While this studio focused on net-positive energy, the application of a biophilic framework is relevant for any regenerative design or "net-positive" topic such as net-positive water, net-positive waste, or net-positive materials. A biophilic framework can transcend the site and building design scales to inform design in the neighborhood, community, city, region, and beyond.

KEYWORDS: Biophilic Design, Net-Positive Energy, Net-Positive Design, Resilient Design

INTRODUCTION

In their essay "The Nature of Positive," Pamela Mang and Bill Reed reframe the traditional focus on energy to consider the ecological, community, and place-based potential and "added value" of "net-positive":

> How would ecological thinking shift the way building industry professionals think about adding value to ecological systems?... instead of starting with the building and what surplus it can generate, a designer would start by asking what ecological services have been disenabled in this place and what roles are missing that enabled those services in the past. Instead of asking how to deploy any excess in order to add value, a designer would ask what is the role of this particular project and the land it occupies in the larger systems of its place. How does its role enable other entities to play their roles? What are the patterns of relationships that need to be established or re-established between the building, its occupants and its community to enable their positive roles reciprocally? And then, what specific 'positives' can this project offer and/or catalyze (Mang and Reed, 2014, 9)?

This paper explores how a biophilic framework was overlaid on a seven-week net-positive-energy graduate architectural design studio to expand students' definition of net-positive to include broader "positive benefits" - for not only human health, well-being, and resilience, but also for other species, ecological systems, and the planet itself. As one of four parallel "Net-Positive Studios," the curriculum agenda for this cohort of instructors and students was to investigate net-positive design strategies, methods, tools, and metrics at the site and building scales that reduce operational energy and greenhouse gas (GHG) emissions. In addition to the required curriculum agenda, this studio introduced a biophilic framework to explore how net-positive energy strategies can be coupled with other "positive benefits" to support biodiversity, habitat, living systems, and climate change response.

The paper considers some of the ecological challenges of today's design education; provides an overview of the biophilic frameworks considered in the studio; explores potential overlaps between a biophilic framework, net-positive energy, and resilient design; and provides example studio content and student work. Conclusions highlight key issues to support the integration of a biophilic framework in a net-positive studio. While this graduate design studio focused on net-positive energy, the application of a biophilic framework is relevant for any regenerative design or "net-positive" topic such as net-positive water, net-positive waste, or net-positive materials. A biophilic framework can also transcend the site and building design scales, which were the focus of this studio, to inform design at the scales of the neighborhood, community, city, region, and beyond.

1.0 DESIGN CHALLENGES & BIOPHILIC DESIGN FRAMEWORKS

1.1 Design Education in the Age of the Anthropocene

As design educators and students, how might we remain hopeful and assured of the role and relevance of design in this time of global pandemics; ever increasing GHG emissions; unprecedented flooding, fires, and drought; loss of biodiversity, and all of the other of urgent ecological issues that require healthy, resilient, and adaptive design solutions for the benefit of all life? Over forty years ago, limnologist Eugene Stoermer coined the term "Anthropocene" to suggest that we have entered a new geological epoch that reflects our ever-growing impact on planetary systems. The concept of the "Anthropocene" gained popularity twenty years ago when Stoermer and Nobel Prize winning meteorologist and atmospheric chemist Paul Crutzen published their essay "The Anthropocene" in the *Global Change Newsletter* (Crutzen and Stoermer, 2000, 17). Ecosystems scientist Yadvinder Malhi suggests that this term challenges humans to reconsider our relationship to nature and current ecological dilemmas:

> The Anthropocene has become a scientific and cultural zeitgeist, a charismatic mega-category emerging from and encapsulating elements of the spirit of our age…. Much of the potency of the term results from its embracing and stimulating new thinking across so many intellectual disciplines and cultural spheres…in trying to define the Anthropocene we try to define the deeper meaning and context of the modern environmental challenge – and the relationship between the human and the natural (Malhi, 2017, 78-79).

Biophilic design frameworks aim toward the common goals of supporting the health and well-being of the environment and ecological systems; celebrating the unique qualities of place; and responding to the dynamic and changing forces and conditions of the Anthropocene. The *Resilient Design Institute* (RDI) emphasizes the versatility and potential overlaps of resilient design with other biocentric frameworks and concepts:

> Resilience is the capacity to adapt to changing conditions and to maintain or regain functionality and vitality in the face of stress or disturbance…. Resiliency is not any single solution, concept or perspective. Resiliency is a multifaceted lens which balances proactivity and reactivity to inform solutions to disruptions. Resilient Design is taking that lens and using it to rethink the built environment (RDI, 2021).

The studio's integration of biophilic and net-positive-energy design considered whether biophilic strategies can expand today's predominantly anthropocentric lens on architectural design to embrace a life-focused biocentric perspective? Can the life enhancing potential of a biophilic framework be further strengthened when integrated with select net-positive and resilient design strategies? This studio investigated why, how, and in what ways might biophilic, net-positive, and resilient design intersect to benefit all life.

1.2. Biophilic Design Foundations and Frameworks

The seven-week Biophilic Net-Positive Design Studio is one of four parallel "net-positive studios" in the second year of the three-year M.Arch Program at the School of Architecture at the University of Minnesota. This studio is followed by a seven-week Integrated Design Studio, in which the student cohort stays together and continues to work with a second instructor to focus on construction, systems integration, and detailing. The net-positive studio introduces the design strategies, methods, and tools to support net-positive energy performance goals and reductions in greenhouse gas emissions in building operations while meeting the highest standards for design excellence. Students are not required to achieve net-positive energy, but rather to define their individual project energy and GHG emissions goals and to consider design trade-offs to meet integrated design aspirations.

In the first phase of the Biophilic Net-Positive Studio, students explored definitions and the history of biophilic design. In reviewing different frameworks for biophilic design, they considered how it is an ancient way of designing, with many vernacular and bioregional and bioclimatic lessons from across time and cultures. They considered early definitions and the transformation of concepts in time, including the term "biophilia", which was introduced by psychologist Erich Fromm in the 1960s and popularized in the 1970s in his 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* (Fromm, 1973, 365). Biologist and naturalist E.O. Wilson popularized the more common anthropocentric concept by proposing the "Biophilia Hypothesis," which suggests there is an *"innate emotional affiliation of human beings to other living organisms* (Wilson, 1984, 1)." Although the concept of "biophilia" was translated into a design framework in the 1980's, only recently has biophilic design begun to gain real popularity with the publication of design frameworks by Kellert, Heerwagen, and Mador, (Kellert, et al., 2008); Kellert and Calabrese (2015) and Terrapin Bright Green (Terrapin, 2014). Students also explored other resources such as the *Living Building Challenge, Fitwel System*, and *WELL Building Standard* (LBC, 2021; Fitwell, 2021; WELL, 2021).

Students compared the similarities and distinctions in biophilic frameworks, including the first set of design strategies, entitled *Biophilic Design Elements & Attributes,* which was developed in 2008, includes six "elements" and seventy related "attributes" (Kellert et al., 2008, 15). In 2009, biophilia was first cited as a design topic under "health", in the International Living Futures Institute (ILFI) *Living Building Challenge (LBC) 2.0* standard, which continues today under the "beauty + biophilia imperative 19" in *LBC 4.0*. In 2014, Terrapin published the *14 Patterns of Biophilic Design*, explaining that the framework of patterns arose from collaborations with many biophilic design experts:

> The patterns have been developed through extensive interdisciplinary research and are supported by empirical evidence and the work of Christopher Alexander, Judith Heerwagen, Rachel and Stephen Kaplan, Stephen Kellert, Roger Ulrich, and many others…. These 14 patterns have a wide range of applications for both interior and exterior environments, and are meant to be flexible and adaptive, allowing for project-appropriate implementation (Terrapin, 2014, 4).

Terrapin added a fifteenth pattern entitled "Awe" in 2020 (Brown and Ryan, 2020, 5). In 2015, Kellert and Calabrese published a simplified framework entitled *Biophilic Experiences & Attributes* that include only three "categories" with twenty-four attributes (Kellert and Calabrese, 2015, 10). ILFI has recently developed supplemental resources to support Kellert et al. (2008), including Amanda Sturgeon's book *Creating Biophilic Buildings* (Sturgeon, 2017) and the *Biophilic Design Guidebook* (ILFI, 2018).

In reviewing these resources during the first phase of the studio, it became clear that biophilic design is not only about human health and well-being but rather, as framed by Fromm, it is consistent with broader ecological agendas found in net-positive, resilient, and regenerative design frameworks. The first phase of the studio also touched on the body of scientific research that has developed over the past several decades that demonstrates the physiological and psychological benefits of human contact with nature, such as gardens, views, daylight, materials, and nature imagery (Browning and Ryan, 2020), along with the benefits for non-human species and the ecological well-being of the planet. These foundational studies established biophilic design within a larger historic and ecological context and its potential role in integrating with the nature and natural forces of place and passive and climate-based design strategies.

2.0 COMPARING & TRANSLATING BIOPHILIC DESIGN FRAMEWORKS

2.1 Comparing Biophilic and Bio-Inspired Design Frameworks

In the next phase of the studio, students compared three biophilic frameworks to discern different emphases, strengths, and limitations. Kellert et al.'s 2008 *Biophilic Design Elements & Attributes* provides a robust list of potential strategies to integrate biophilic issues across design topics and scales. The seventy "attributes" include a smorgasbord of design strategies. While potentially overwhelming, it is important to note that even the identified "seventy attributes" only begin to illustrate the many ways in which the six "elements" could be interpreted and should not be viewed as exhaustive. In contrast, Terrapin's 2014 *14 (15) Patterns* provides a curated list of biophilic topics that are left to the designer to interpret. The *15 Patterns* capture, in a concise manner, the essential issues found in Kellert et al.'s two frameworks and provide a simplicity that supports ease of design application. Kellert and Calabrese's 2015 *Experience & Attributes* is framed from an anthropocentric perspective that emphasizes the direct and indirect human experiences of nature, space, and place; however, the underlying design intention is for the benefit of human and non-human species and natural systems. Given its clarity and flexibility in design interpretation, Terrapin's *15 Patterns* was selected as the primary biophilic design framework for the studio (Table 1). As students moved into the design phase, Terrapin's *15 Patterns* were integrated with the "Energy Hierarchy" as a net-positive design framework, with a sequence of integrated biophilic net-positive design exercises developed to consider mutual design benefits (discussed in Section 3.1-3.4).

2014/2020: Terrapin Bright Green **14/15 Patterns of Biophilic Design**		
Nature in space	**Nature Analogues**	**Nature of Space**
1. Visual connection with Nature **2. Non-Visual Connection with Nature** **3. Non-Rhythmic Sensory Stimuli** **4. Thermal and Air Flow Variability** **5. Presence of Water** **6. Dynamic and Diffuse Light** **7. Connection with Natural Systems**	**8. Biomorphic Forms and Patterns** **9. Material Connection to Nature** **10. Complexity and Order***	**11. Prospect** **12. Refuge** **13. Mystery** **14. Risk/Peril** **15. Awe** ***NOTE:** Pattern 15 Awe was added in 2020.*

Table 1: Terrapin's 15 Patterns of Biophilic Design. Source: (Terrapin Bright Green, 2020)

2.2. Biophilic Design & A Biocentric Built Environment

Select readings and resources enabled students to explore potential overlaps with other ecological design frameworks. In their 2008 seminal text *Biophilic Design*, Kellert, Heerwagen and Mador clarify an ambitious bio-inspired design intention:

> Unfortunately, the prevailing approach to design of the modern urban built environment has encouraged the massive transformation and degradation of natural systems and increasing human separation form the natural world…. The new paradigm is called here 'restorative environmental design,' an approach that aims at both a low-environmental-impact strategy…and a positive environmental impact or biophilic design approach that fosters beneficial contact between people and nature…. Biophilic design is, thus, viewed as the largely missing link in prevailing approaches to sustainable design (Kellert et al., 2008, 5).

Biophilic design could be viewed as an overarching biocentric perspective that embraces principles from a variety of frameworks, such as resilient, regenerative, restorative, biomimetic, and net-positive design (Figure 1).

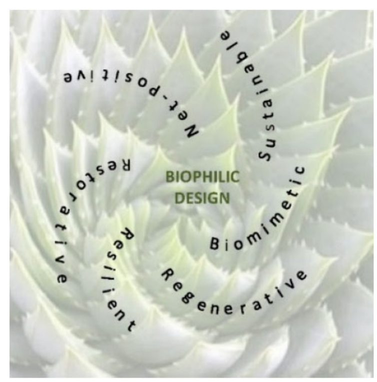

Figure 1: Biophilic design as an organizing strategy to overlay with other ecological design frameworks. Source: (Author, 2021)

Students considered how biophilic design might also connect with other "bio-inspired" design perspectives. A biophilic framework might overlap with a combination of bio-inspired design lenses, including biomimetic, bioclimatic, bioregional, and biomorphic, among others (Figure 2). For example, The *Resilient Design Strategies at the Building-Site Scales* (RDI, 2021) can overlay many of the *15 Patterns* of Biophilic Design (Table 2), particularly in the "Nature in Space" category, which are directly related to resilient design strategies to reduce dependency on fossil fuels while increasing passive survivability, on-site renewable energy, access to local water and waste resources, and local material sources.

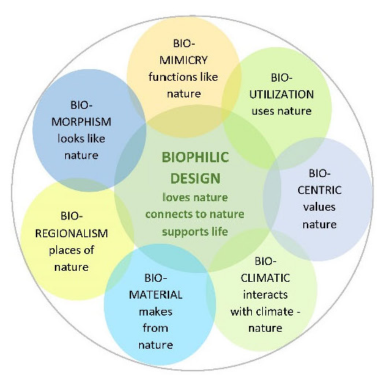

Figure 2: Biophilic design as a framework for other bio-related design principles. Source: (Author, 2021)

While not the focus of this studio, some students explored net-positive water, waste, or materials, including resilient design approaches to harvest and process water and waste on site, among other biophilic, net-positive, and resilient material intersections. The resonance between biophilic and biomimetic design can also be found in the Biomimicry Institute's (BI) *10 Patterns of Nature* (Table 2) (BI, 2021). Overlaps can be fostered in the "Nature in Space" and "Nature Analogue" patterns through passive strategies, habitat and biodiversity, and on-site water, waste, and regional materials. The "Nature of Space" patterns are indirectly related to resilient and biomimetic design by experiencing time, weather, seasons, and atmospheric conditions of place.

RESILIENT DESIGN **Resilient Design Institute** **Strategies for Resilient Design**	**BIOPHILIC DESIGN** **Terrapin** **15 Patterns**		
BUILDING & SITE SCALES **See Resilient Design Institute** https://www.resilientdesign.org/resilient-design-strategies/	**Nature in Space**	**Nature Analogues**	**Nature of Space**
1. Design for severe storms, flooding, wildfire, and other climate impacts	X	X	
2. Locate critical systems to withstand flooding and extreme weather	X		
3. Model design solutions based on future climatic conditions	X	X	
4. Passive survivability: reliance on passive heating and cooling	X		
5. Durable buildings: rainscreens, windows, finishes	X	X	X
6. Beautiful buildings to love and maintain	X	X	X
7. Reduce dependance on complex controls; manual overrides	X	X	
8. Onsite renewables	X		
9. Water conservation	X		X
10. Redundant water supplies	X		
11. Options for human waste disposal: non-operating municipal system	X		
12. Locally available products and skills	X	X	
13. Products and materials that will not offgas or leach hazardous substances		X	
14. Rely on vernacular design practices	X	X	X
15. Provide redundant electric systems; back-up power	X		
16. On-premises non-perishable food supply		X	

BIOMIMETIC DESIGN **Biomimicry Institute:** **10 Patterns of Nature**	**BIOPHILIC DESIGN** **Terrapin:** **15 Patterns**		
BUILDING & SITE SCALES **See Biomimicry Institute:** http://biomimcry.org	**Nature in Space**	**Nature Analogues**	**Nature of Space**
1. Nature uses only the energy it needs and relies on freely available energy	X		
2. Nature recycles all materials	X	X	
3. Nature is resilient to disturbances	X	X	
4. Nature tends to optimize rather than maximize	X	X	X
5. Nature provides mutual benefits	X	X	X
6. Nature runs on information	X	X	X
7. Nature uses chemistry and materials that are safe for living beings	X	X	
8. Nature builds using abundant resources, incorporating rare resources only sparingly	X	X	
9. Nature is locally attuned and responsive	X	X	X
10. Nature uses shape to determine functionality	X	X	X

Table 2: Example of potential overlaps with Terrapin's 15 Patterns of Biophilic Design, Resilient Design Strategies, and Biomimicry Patterns of Nature. Source: (Author, Resilient Design Institute, Biophilic Design Institute, and Terrapin, 2021)

2.3. Integrating Biophilic, Net-Positive & Resilient Design

After establishing some fluency in the principles of biophilic and other bio-inspired design frameworks, a series of iterative exercises were introduced to investigate the potential qualitative and quantitative benefits of a biophilic approach to net-positive design. The program brief for the studio was an 8,000-10,000 square foot student health facility located on campus, with the health-related program and activities for the site and building defined by individual students. All were asked to consider how select biophilic patterns might inform health and well-being at the site, building, envelope, and room scales, while addressing current ecological challenges and dynamic forces of climate change.

The studio explored potential design overlaps and integration of Terrapin's three categories for the *15 Patterns* and how they might be translated and integrated with net-positive energy and resilient solutions for ecological and health benefits. To avoid a checklist approach to the biophilic design framework, students were asked to select three to five relevant and impactful patterns to inform design, with at least one pattern from each of the three categories of the *15 Patterns*: 1. Nature in Space, 2. Nature Analogues, and 3. Nature of Space. The following discussions illustrate potential biophilic net-positive energy design issues, exercise topics and methods, assessment tools, and related examples of student work. The three categories are discussed in sequence; however, students were asked to "scale-jump" and move back and forth in an integrated way between the three categories and related topics during the 7-week studio.

The Biophilic Net-Positive Studio has a site and passive design focus with a charge for students to develop a schematic design proposal that would further consider construction, systems, and details in the following seven-week Integrated Design Studio. The organization of the biophilic net-positive assignments is illustrated in Figure 3.

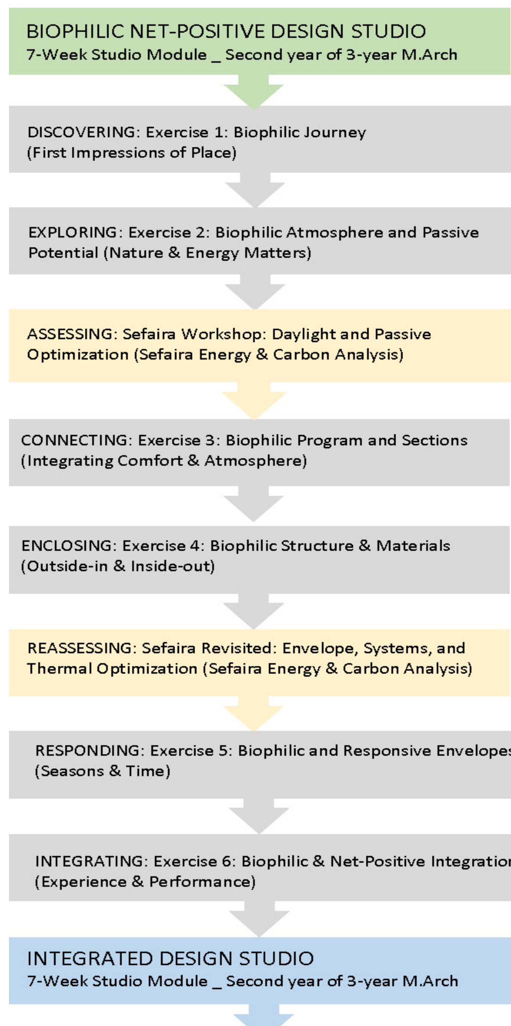

Figure 3: Right: Sequence of Biophilic Net-Positive Exercises: 7-weeks Module A; followed by Integrated Design Studio: 7-weeks Module B. Source: (Author)

3.0 NATURE IN SPACE, NATURE ANALOGUE & NATURE OF SPACE PATTERNS

3.1 Nature in Space Patterns and the Energy Hierarchy

Terrapin's "Nature in Space Patterns" explore relationships to place, time, seasons, weather, environmental forces, and natural systems (Table 3). The seven corresponding patterns include visual and nonvisual connections with nature, light, and dynamic forces such as water, air, thermal variability, and natural systems. Based on program approaches and design intentions, students explored select patterns that could provide biophilic, net-positive, and resiliency opportunities.

Students were asked to balance qualitative experiences of site and place with quantitative assessment of thermal and luminous comfort, energy consumption, and GHG emissions. Architecture 2030's "energy hierarchy" and energy targets were used as the net-positive framework for the integration of passive design, high performance systems, and renewable energy (Figure 4) (Architecture 2030, 2019).

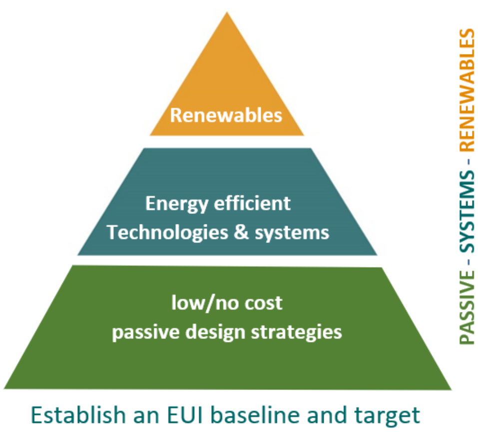

Figure 4: Energy Hierarchy as a Net-Positive-Energy Framework. Source: (Architecture 2030, 2019)

TERRAPIN'S 15 PATTERNS: Integrating Biophilic, Net-Positive & Resilient Design	
NATURE IN SPACE	**Net-Positive Energy Design: Example Issues, Methods & Assessments**
1. Visual connection with Nature **2. Non-Visual Connection with Nature** **3. Non-Rhythmic Sensory Stimuli** **4. Thermal and Air Flow Variability** **5. Presence of Water** **6. Dynamic and Diffuse Light** **7. Connection with Natural Systems**	**Design Issues:** • Building siting, massing, plan, and section to optimize passive strategies for daylighting, natural ventilation, heating and cooling and resiliency • Site and landscape restorative design, biodiversity, habitat • Ecological systems integration • Building envelope: seasonal bioclimatic response **Design Exercises & Methods** • Site, building, room, and systems seasonal programming for daylighting, passive systems, envelope response • Site and living systems analyses • Existing & proposed habitat and biodiversity inventories • Seasonal sketches and renderings • Sefaira iterative parametric building siting, form, section, and envelope studies • Velux Daylight Visualizer iterative daylight studies for massing, section and select rooms • Physical study models: siting, massing, section concepts • Ecological and building systems integration **Assessment** • Quantitative assessment of the integration of bioclimatic and passive strategies to reduce lighting, heating, cooling, and natural ventilation loads. Integration of health and energy performance metrics. Resiliency strategies. • *Energy and sustainability targets*: Energy Use Intensity (EUI): kBtu/SF; lbsCO2; Architecture 2030 targets; technologies and renewable energy systems integration. • *Daylighting & electric lighting targets*: point-in-time and annual climate-based metrics (IESNA recommendations, Spatial Daylight Autonomy, Annual Sunlight Exposure, etc.); electric lighting integration. • *Circadian daylight & electric targets*: equivalent melanopic lux, circadian stimulus; electric lighting integration; nighttime strategies to eliminate circadian disruption (blackout shades, night-time navigation). • *Visual comfort targets*: glare control, views, daylight management, color rendering, electric lighting integration. • *Thermal comfort targets*: ASHRAE, adapted thermal comfort, seasonal response to site, building, envelope. • *Water & waste targets*: water harvesting, graywater, and potable targets and metrics (optional: student choice) • *Biodiversity & habitat*: Sustainable SITE & Resilient Design Institute metrics ***NOTE:*** *Net-Positive Water, Waste, or Materials or other Resilient Design issues optional for studio due to 7-week timeline.*

Table 3: Nature in Space Patterns and potential overlay with net-positive and resilient design. Source: (Author, Terrapin 15 Patterns, 2021)

As a net-positive design framework, the "energy hierarchy," locates passive design as the foundational strategy of a three-fold approach: 1) reduce energy demand and promoting energy conservation (including site design, architectural form, and bioclimatic and passive design), 2) use energy efficient and high-performance systems, and 3) integrate renewable energy systems. Biocentric approaches to site and landscape design were encouraged to integrate ecological systems, urban habitat, biodiversity, flora and fauna, seasonal and migratory species, and restorative and resilient design. Students considered how biophilic and experiential considerations might overlay regenerative and resilient design strategies for daylighting, natural ventilation, passive heating and cooling, as well as restorative strategies for the landscape and site habitat. A biophilic lens encouraged students to balance quantitative metrics and assessments of building siting, form, section, and envelope to optimize energy performance and GHG emissions while considering qualitative human-nature connections, experience of time and seasons, and enhanced biodiversity and habitat. The same design strategies employed to reduce energy and GHG emissions could also support their biophilic agendas.

Sefaira energy software, Climate Studio, Climate Consultant, and Velux Daylight Visualizer were used to evaluate quantitative performance goals, with students determining the trade-offs they were willing to make to integrate qualitative and quantitative biophilic and net-positive goals and performance metrics. Supporting resources to bridge the net-positive energy analysis with broader biophilic and ecological scales included select landscape design resources such as the RDI's *16 Resilient Design Strategies* (RDI, 2021), the *SITES v2 Rating System* (SSI, 2015), and the *Living Building Challenge v.4* (ILFI, 2019). Table 3 (above) illustrates the potential intersection between quantitative issues and metrics and qualitative experiential site issues to foster "positive" human and ecological benefits. Example student work is found in Figure 5 below.

Figure 5: Example "Nature in Space" site and building studies. Source: (Connor McManus, Drew Tangren, Yalun Chen)

3.2. Nature Analogue Patterns and the Energy Hierarchy

Terrapin's "Nature Analogue Patterns" consider literal, metaphoric, and symbolic connections with nature through material selection, biomorphic and organic forms, complexity and order, and related finishes and details. Students developed seasonal programming, renderings, collages, and physical models to explore material qualities and to consider the experiential and ecological impacts of structure and materials. The envelope was explored through the lens of "fivefold function," to address the multiple roles the building envelope could play to foster seasonal connections between inside and outside, contact with flora and fauna; harvesting onsite energy; celebrating the atmosphere of place, among other related issues. The facades, roof, and exterior spaces were explored as opportunities to create habitat and biodiversity. Qualitative assessments were evaluated based on the programming goals, desired atmosphere and experiential aspirations, and seasonal response.

Biophilic intersections with net-positive and resilient design were considered through iterative exploration of building and envelope form and details, structure, materials, and systems integration to simultaneously reduce energy consumption, GHG emissions, and waste while fostering durability and the reduction of ecological impacts on natural systems, habitat, and biodiversity. The selection of materials for the building envelope, interior finishes, and details where quantitatively assessed using Sefaira to determine the impact of materials specifications and properties on luminous and thermal comfort as well as annual energy performance related to heating, natural ventilation, and cooling. Table 4 includes potential issues, design exercises, and assessment methods. Examples of student work are found in Figure 6 below.

NATURE ANALOGUE PATTERNS	Net-Positive Energy Design: Example Issues, Methods & Assessments
8. Biomorphic Forms and Patterns **9. Material Connection to Nature** **10. Complexity and Order**	**Design Issues** • Form, materials, sections, envelope and details for daylight, natural ventilation, and passive design to enhance literal, metaphoric, or symbolic nature connections. • Material qualities and thermal and luminous properties (massing, color, textures, and reflectivity) to support nature connections, atmospheric goals, and optimize passive design for heating, lighting, and cooling. • Structure, construction methods, materials selection for design, health, durability, ecological impact, and resiliency. **Design Exercises & Methods** • Structure, materials, and envelope seasonal programming • Seasonal design of select building envelope conditions • Iterative structure and materials massing studies • Iterative form, section, and envelope studies • Material inventories: experiential and eco-impacts • Video, time-lapse photography of study models to consider atmospheric qualities of structure, materials, envelope • Integration of biophilic, net-positive, and resiliency goals. **Assessment** • Quantitative assessment of envelope optimization with Sefaira, Climate Studio, and Daylight Visualizer for thermal comfort, passive strategies, and systems integration. • Quantitative of materials to address health and wellbeing energy, GHG, waste, durability, lifecycle, and related issues. • Qualitative assessment of seasonal experience and atmosphere of structure, materials, and finishes using video, time-lapse photography, study models, and/or rendering; revisit seasonal programming. ***NOTE:** Net-Positive Water, Waste, or Materials or other Resilient Design issues optional for studio due to 7-week timeline. .*

Table 4: Nature Analogue Patterns and potential overlay with net-positive and resilient design. Source: (Author, Terrapin 15 Patterns, 2021)

Figure 6: Example "Nature Analogue" Structure, materials, and form studies. Source: (Shay Koohi, Yutong Yang, Yifan Liu)

3.4. Nature of Space Patterns and the Energy Hierarchy

Terrapin's "Nature of Space Patterns" emphasize the human experience of time, weather, quality of space, form, materials, and details to realize the seasonal experiential and atmospheric program goals. The five patterns explore the desired character and quality of space, including prospect and refuge, mystery, risk and peril, and awe. Students developed an atmospheric program for one "important space" to refine and integrate biophilic and net-positive strategies across the three categories of "nature of space," "nature in space" and "nature analogue" patterns. They revisited the relationships between the desired atmospheric character of space and earlier design decisions regarding siting, massing, section, envelope, room form, materials, structure and the dynamic and changing qualities in time and seasons.

Atmospheric programming and exercises focused on seasonal qualities of space, form, materials, and light using time-lapse video, digital renderings, collage, photography, and large-scale physical room modeling. Iterative quantitative analyses using Velux Daylight Visualizer, V-Ray, Lumion, and/or Sefaira enabled students to consider qualitative and atmospheric trade-offs related to earlier energy and GHG analyses. See Table 5 and Figure 7.

NATURE OF SPACE PATTERNS	Net-Positive Energy Design: Example Issues, Methods & Assessments
11. Prospect **12. Refuge** **13. Mystery** **14. Risk/Peril** **15. Awe**	**Design Issues:** • Seasonal site and building experiences; interactions with flora and fauna; atmosphere • Integration of daylight, natural ventilation, and passive strategies with desired spatial, experiential, and atmospheric qualities such as site connections, views, illuminance levels, contrast ratios, and luminous journey. • Envelope: seasonal response; occupant interaction; habitat integration. • Finishes, furnishings, systems integration. • Designing spaces that are valued and loved through time to foster health and well-being, resilience, and sustainability. **Design Exercises & Methods** • Atmospheric programming; Seasonal space use, ambiance, and inside-out relationships. • Iterative envelope, room, detail studies. • Time-lapse rendering, models, and detail studies, • Seasonal and diurnal video walk-throughs. **Assessment** • Qualitative assessment of luminous, thermal, and experiential qualities of structure, materials, form. • Quantitative considerations on related net-positive performance on a seasonal basis. Revisit Sefaira, Velux, Climate Studio analyses. ***NOTE:*** *Net-Positive Water, Waste, Materials, or other Resilient issues optional for studio due to 7-week timeline.*

Table 5: Nature of Space Patterns and potential overlay with net-positive and resilient design. Source: (Author, Terrapin 15 Patterns, 2021)

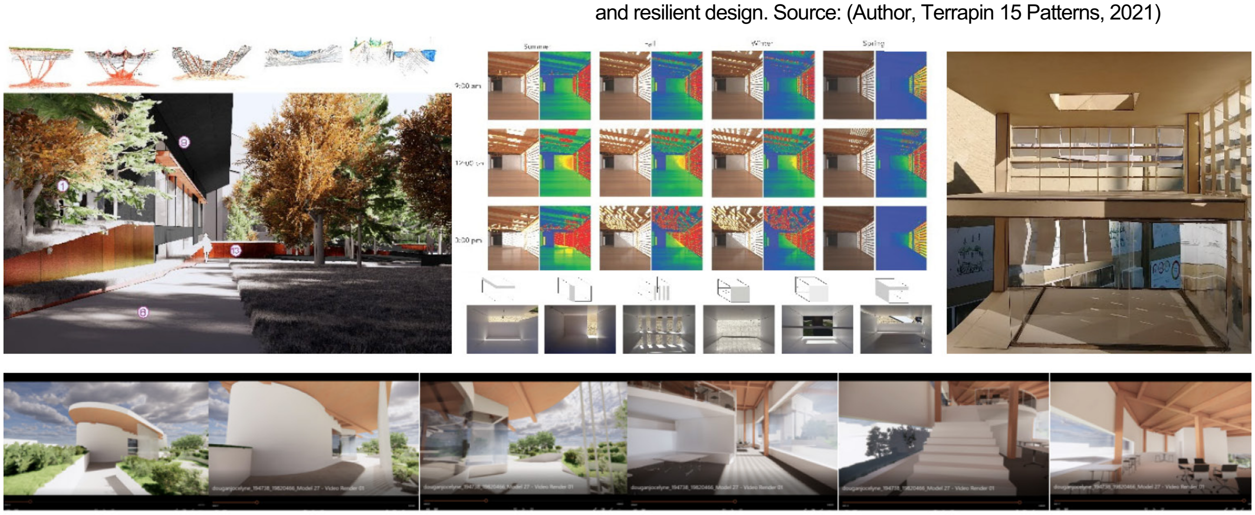

Figure 7: Example "Nature of Space" studies; site, building, and room atmosphere studies. Source: (Whitney Donohue, Jocelyn Dougan, Josh Himes, Emma Rutkowski)

CONCLUSIONS

The Biophilic Net-Positive Design Studio has been taught in the M.Arch Program at the University of Minnesota for three years. Several lessons have emerged that are useful in considering the integration of Terrapin's *15 Patterns of Biophilic Design* in a "net-positive" studio (energy, materials, waste, and/or water):

1. *Biophilic Framework Overlays for Site and Passive Design*: The *15 Patterns* easily overlay resilient and regenerative design approaches to net-positive energy design. Passive design strategies at the site, building, envelope, room, and systems scales strongly integrate with qualitative and quantitative issues related to the "Nature in Space" patterns that define essential relationships to place, time, and the dynamic forces of weather, sun, wind, light, and climate change. These strategies can be strategically integrated with biophilic benefits for comfort, health, and well-being, while fostering biodiversity and habitat protection/restoration at the site scale.
2. *Define Integrated Biophilic, Net-Positive, and Resilient Design Programming*: Explore and revisit the site, building, envelope, and room programming to determine how the biophilic design strategies can integrate and reinforce other design issues and priorities across seasons and scales.
3. *Select Several Biophilic Patterns as Design Priorities*: Consider which biophilic patterns are most impactful and provide the greatest human and ecological benefits.
4. *Explore Qualitative & Quantitative Design Dimensions of the Three Categories of Patterns*: 1) Nature in Space, 2. Nature Analogues, and 3) Nature of Space. Work back and forth across scales to integrate qualitative experiential goals with quantitative assessment and performance metrics. Consider design and ecological priorities and trade-offs. Repeatedly revisit and update the program and performance goals and critique opportunities and trade-offs for integration.
5. *Next Steps: Translate other Net-Positive Topics:* Explore how a biophilic framework might intersect with not only net-positive energy, but also waste, water, and materials, and/or other "positive benefits".
6. *Take Biophilic Breaks*: Integrate hands-on contact with nature and other species by taking breaks outside to explore the bioregion, site, weather, flora and fauna, and the personal impressions, experiences, and "positive benefits" of nature.
7. *Next Steps*: The upcoming studio will develop a pre- and post-studio survey to better determine the effectiveness of the studio assignments as well as more explicit qualitative and quantitative performance goals for project evaluations.

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