Biophilic Net-Positive Architecture: Integrating Nature, Health, Wellbeing and Passive Design

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ABSTRACT: The energy, carbon, and environmental benefits of net-positive design have received much attention, but less so the health, wellbeing, and experiential promises. Architects Pamela Mang and Bill Reed suggest that the definition of "net-positive" should be expanded to "*buildings that 'add value' to ecological systems and generate more than they need to fulfil their own needs' moves net-positive beyond simply a technical challenge . . . [by including] benefits to the systemic capability to generate, sustain and evolve the life of a particular place* (Mang and Reed, 2014, 1)". Could a biophilic approach to net-positive architecture provide an expanded understanding of health and wellbeing for humans, other species and the planet? Architect Stephen Kellert identified biophilic design as the "largely missing link" in sustainable design: "*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….Low-environmental-impact and biophilic design must, therefore, work in complementary relation to achieve true and lasting sustainability* (Kellert et al., 2008, 5)". This paper discusses a seven-week graduate architecture studio that explored the potential "added value" of a biophilic approach to net-positive architecture, using the Architecture 2030 *Energy Design Hierarchy* and *Terrapin's 14 Patterns of Biophilic Design* to address the design, programmatic, performance, and experiential dimensions of biophilic net-positive architecture (Architecture 2030, 2020; Terrapin 2014). Integrated biophilic net-positive architectural goals, strategies, performance metrics, and tools will be discussed to support human and ecological health and wellbeing.

KEYWORDS: Net-Positive Architecture, Biophilic Design, Passive Design, Health Design

INTRODUCTION

Could aesthetics, beauty, atmosphere, health, and wellbeing be as important to net-positive design as are reductions in energy and environmental impacts? From a regenerative design perspective, architects Pamela Mang and Bill Reed suggest that the definition of "net-positive" should be expanded beyond energy performance to include broader considerations: "*…buildings that 'add value' to ecological systems and generate more than they need to fulfil their own needs' moves net-positive beyond simply a technical challenge…[by including] benefits to the systemic capability to generate, sustain and evolve the life of a particular place* (Mang and Reed, 2014, 1)". To "sustain and evolve" life and the places we live requires not only attention to the environmental impacts of design as measured in carbon and energy reductions, but also to respect and care for nature and other species. This includes awareness of and appreciation for the unique qualities, culture, and biological diversity of place. Architect Stephen Kellert identified biophilic design as the "largely missing link" in sustainable design: "*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….Low-environmental-impact and biophilic design must, therefore, work in complementary relation to achieve true and lasting sustainability* (Kellert et al., 2008, 5)". This paper discusses a seven-week graduate architecture studio that investigated the potential "added value" of a biophilic approach to net-positive design by integrating the Architecture 2030 *Energy Design Hierarchy* and *Terrapin's 14 Patterns of Biophilic Design* (Architecture 2030, 2020; Terrapin 2014) with an emphasis on passive design strategies to optimize energy and carbon reductions while also fostering connections to nature, sense-experiences, time and seasons, and nature-based health benefits. The discussion includes the biophilic net-positive framework, strategies, metrics, tools, outcomes, and lessons to simultaneously support human, environmental, and ecological health and wellbeing.

1.0 BIOPHILIC NET-POSITIVE STUDIO OVERVIEW

1.1. Design brief and clients

The required seven-week Net-Positive Design Studio is offered in the spring of the second year of the three-year M.Arch Program at the University of Minnesota. A cohort of instructors teach parallel studios with a program requirement to introduce students to the architectural opportunities and trade-offs of net-positive design, with a focus on building operational energy and carbon reduction strategies, metrics, and assessment methods. After seven weeks, a new instructor joins the student cohort for the Comprehensive Design Studio to further develop the building technologies, structure, construction details, and mechanical and renewable systems. The project brief involved design of a 10,000 square foot Center for Health and Wellbeing. Drs. Mary Jo Kreitzer and Pamela Cherry of the Bakken Center for Spirituality and Healing (CSH) acted as clients. They helped to frame the program (which was a similar project slated for future development at the university), served as guest critics, and acted as resource experts on health and wellbeing. A hypothetical project site was chosen in a business district on the north boundary of campus. The site afforded excellent solar and wind access and opportunities to enhance biodiversity and connections to the Mississippi River and proposed urban habitat within an old railway corridor.

1.2. Framing the problem

To launch the studio, Dr. Kreitzer introduced the goals of the CSH and their "Wellbeing Model," which includes six dimensions: 1) health, 2) relationships, 3) security, 4) purpose, 5) community, and 6) environment (Figure 1). As Dr. Kreitzer explained, ecological and human health must be simultaneously considered: "Wellbeing is … about finding balance in body, mind, and spirit. These take into account our interconnectedness and interdependence with … the personal and global environment we live in (CSH, 2020)." During the seven-week studio, students investigated the following topics, which are addressed in the discussion below: 1) Resources for a biophilic approach to net-positive design, 2) Integrating *Terrapin's 14 Patterns of Biophilic Design* and the *Energy Design Hierarchy*, and 3) Design processes for a biophilic approach to net-positive design.

Figure 1: Wellbeing Model, Center for Spirituality and Healing. Source: (CSH, 2020)

2.0 RESOURCES FOR A BIOPHILIC APPROACH TO NET POSITIVE

2.1. Biophilic and net-positive design resources

Working with seminal texts and related design standards, groups of students started by exploring how biophilia fits within a larger sustainable and regenerative design trajectory. Reviewing the history and evolution of biophilic and net-positive design helped to discern underlying design goals, strategies, methods, and potential intersections. The concept of biophilia or "love of life" was introduced nearly fifty years ago by psychologist Eric Fromm, 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)". Biologist and naturalist E.O. Wilson popularized the term in his seminal text *Biophilia: The Human Bond with Other Species*, with his "Biophilia Hypothesis" suggesting that there is an "*innate emotional affiliation of human beings to other living organisms* (Wilson, 1984, 1)". Two decades later, architect Steven Kellert and colleagues translated these concepts into design theory, principles, and strategies, including six biophilic topics and seventy-two design elements (Kellert, Heerwagen, Mador, 2008). Building on the work of Kellert et al., the firm Terrapin Bright Green formulated *Terrapin's 14 Patterns of Biophilic Design* (Terrapin, 2014). *Terrapin's 14 Patterns* were selected as a biophilic design framework for the studio, as the patterns provide concise and designer-friendly goals and strategies (Table 1).

Design standards for biophilic, health, and net-positive design were reviewed to understand the design approaches and metrics, including the Living Building Challenge (LBC), Fitwel System, and WELL Building Standards. Students explored the parallel histories of the biophilic and sustainable design movements of the 1990s, which gained momentum with development of LEED, BREEAM, and other international guides. In 2006 that the International Living Futures Institute (ILFI) introduced the Living Building Challenge 1.0 (LBC 1.0) with the aspirations for "net-zero" energy, water, and waste as well as a focus on issues such as beauty and equity (LBC, 2006). In 2009, biophilia was first cited in the LBC 2.0 standard under the topic of health (LBC 2.0, 2009). In 2014, the LBC 3.0 shifted goals from "net-zero" to "net-positive" for energy, water, and waste (LBC, 2014). In support of Kellert's biophilic strategies, the ILFI recently published the *Biophilic Design Guidebook*, a supplemental resource for the LBC, as well as Amanda Sturgeon's book *Creating Biophilic Buildings* (ILFI, 2018, Sturgeon, 2017).

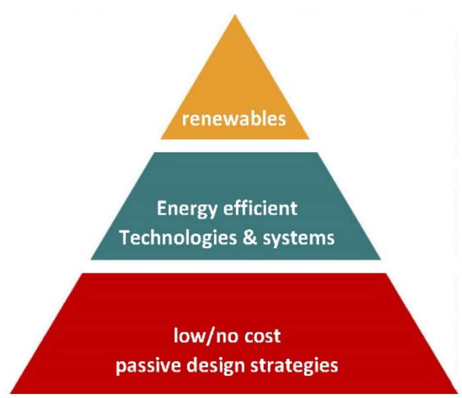
2.2. Affinity between biophilic and net-positive design

While perhaps overlooked, there is an affinity between biophilic and net-positive design, both of which respond to nature and environmental forces to achieve respective design goals. As traditionally defined, the primary goal of net-zero and net-positive architecture is energy reduction, as clarified by the U.S. Department of

Energy in the publication *A Common Definition for Zero-Energy Buildings*: "An energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy" (DOE, 2015). Yet, as Mang and Reed suggest, "net-positive" can be defined to bring "added value," which could include biophilic benefits among other issues. Kellert suggests that the first goal of biophilic design is to enhance contact with nature to foster health, fitness, and wellbeing (Kellert, 2015). When biophilic and net-positive goals are coupled, "added values" are revealed that foster human and ecological health and wellbeing, as well as place-based sensory and atmospheric experiences of nature and natural forces.

The challenge of integrating two seemingly parallel design goals was to identify a net-positive framework that could be integrated with *Terrapin's 14 Patterns*. 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" for greenhouse gas (GHG) emissions in "new buildings, developments, and major building renovations" by the year 2030 (Architecture 2030, 2020). 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. The *2030* timeline has recently been extended by a decade with an international design initiative entitled *Zero by 2040*. The *2040* target supports the goal of the Paris Agreement to limit the global temperature increase by *1.5 degree C* over the next two decades (Architecture 2030, 2020). The global *Zero by 2040* target couples architectural design with innovative technologies and systems by employing the *Energy Design Hierarchy, w*hich includes three levels of design: 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 (Figure 2). Students found that the first level of the *Energy Design Hierarchy*, which focuses on passive design strategies (daylighting, natural ventilation, and passive heating and cooling) was easily coupled with biophilic design patterns in response to the unique conditions of place, site, fauna and flora, sense experiences, and atmospheric qualities of seasons and time. The second and third levels of the *Energy Design Hierarchy* (technologies and renewable systems) were more challenging due to an indirect relationship to biophilic design; however, levels two and three were explored by focusing on how mechanical and renewable energy systems help to reveal and reframe human-nature relationships within the framework of energy consumption, environmental impact, and seasonal environmental forces. *Terrapin's 14 Patterns* and the *Energy Design Hierarchy* provided a framework to integrate goals, strategies, and metrics for biophilic net-positive design (Table 1 and Figure 2).

TERRAPIN'S 14 (15)* PATTERNS OF BIOPHILIC DESIGN		
Nature in Space Patterns	**Nature Analogue Patterns**	**Nature of Space Patterns**
1. Visual Connection with Nature	8. Biomorphic Forms & Patterns	11. Prospect
2. Non-Visual Connection with Nature	9. Material Connection with Nature	12. Refuge
3. Non-Rhythmic Sensory Stimuli	10. Complexity & Order	13. Mystery
4. Thermal & Airflow Variability		14. Risk/Peril
5. Presence of Water		15. Awe*
6. Dynamic & Diffuse Light		
7. Connections with Natural Systems		
**Terrapin added a fifteenth pattern in 2020: "#15: Awe", which is not discussed*		



Energy Design Hierarchy

Table 1: Terrapin's 14 Patterns of Biophilic Design. Source: (Terrapin, 2014)
Figure 2: Net-Zero Energy Design Hierarchy. Source: (Author, based on "Zero by 2040", Architecture 2030, 2020)

3.0 AN INTEGRATED BIOPHILIC NET-POSITIVE DESIGN FRAMEWORK

3.1. Passive integration of the Energy Design Hierarchy and Terrapin's 14 Patterns

The three levels of the *Energy Design Hierarchy* provided both direct and indirect means of connecting net-positive design and *Terrapin's 14 Patterns* to inform the site design, building form and massing, envelope, solar control and shading, materials and structure, and room details. The following table reveals example design intersections and qualitative and quantitative considerations and metrics between the first level of passive design strategies in the *Energy Design Hierarchy* and *Terrapin's 14 Patterns* (Table 2).

Passive design strategies through the lens of Terrapin's 14 Patterns of Biophilic Design		
Terrapin's 14 Patterns	**Passive Design and Terrapin's 14 Patterns**	**Qualitative and Quantitative Performance Metrics**
NATURE IN SPACE	***Passive Design: Nature in Space Considerations***	***Net-Positive Considerations***
1. Visual Connection with Nature	Daylight, natural ventilation, and passive design to enhance visual access to nature and natural forces through siting, orientation, building form, section, envelope, room configuration, and window design	Quantitative assessment of the integration of bioclimatic and passive strategies to reduce lighting, heating, cooling, and natural ventilation loads. Potential integration of health and energy performance metrics: - *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.
2. Non-Visual Connection with Nature	Daylight, natural ventilation, and passive design to enhance sounds, smells, thermal experiences related to site, building form, and envelope.	
3. Non-Rhythmic Sensory Stimuli	Daylight, natural ventilation, and passive design to enhance ephemeral and dynamic sensory connections and experiences of nature.	
4. Thermal & Airflow Variability	Daylight, natural ventilation, and passive integration with seasonal luminous and thermal experiences and comfort.	
5. Presence of Water	Integration of water elements with seasonal luminous, thermal, and acoustic experiences for site, envelope, and window design. Phase change of water, sounds, reflections, and refractions integrated with luminous and thermal comfort.	
6. Dynamic & Diffuse Light	Seasonal program appropriate daylight strategies and zoning for dynamic and diffuse light (daylight versus sunlight). Daylight and high-performance systems to respond to light and sky conditions.	
7. Connections with Natural Systems	Passive design strategies to respond to seasonal and temporal changes in daylight availability, solar radiation, sky conditions and to enhance connections to atmospheric, biological, hydrologic, geological, and human-environmental systems.	
NATURAL ANALOGUE	***Passive Design: Nature Analogue Considerations***	***Net-Positive Considerations***
8. Biomorphic Forms & Patterns	Biomorphic building form, materials, sections, envelope and details for daylight, natural ventilation, and passive design to enhance literal, metaphoric, or symbolic nature analogues.	- Quantitative and qualitative assessments of building form, materials, and spatial organization to optimize the integration of net-positive design through siting, bioclimatic, passive strategies, and electric integration. - Quantitative considerations on how passive strategies improve health and wellbeing and relate to net-positive to reduce energy and GHG.
9. Material Connection with Nature	Material thermal and luminous properties (mass, color, textures, and reflectivity) to support atmospheric goals and optimize passive design.	
10. Complexity & Order	Integration of daylight, natural ventilation, and passive heating and cooling to create seasonally rich and varied sensory experiences.	
NATURE OF SPACE	***Passive Design: Nature of Space Considerations***	***Net-Positive Considerations***
11. Prospect	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.	- Qualitative assessment of luminous, thermal, and experiential qualities - Quantitative considerations on related quantitative implications for net-positive performance on a seasonal basis.
12. Refuge		
13. Mystery		
14. Risk/Peril		

Table 2: Passive design through the lens of Terrapin's 14 Patterns of Biophilic Design. Source: (Terrapin, 2014; author, 2020)

3.2 Design exercises

After exploring the potential intersections between the *Energy Design Hierarchy* and *Terrapin's 14 Patterns*, students worked with six exercises that considered the integration and trade-offs between poetic, pragmatic, and performance-based design issues and goals. Students selected biophilic patterns from the three categories based on their individual approaches to programming the site and building. The six exercises were organized into three phases and grouped into two exercises in each phase to corresponded with the three categories of the *Terrapin's 14 Patterns* and three levels of the *Energy Design Hierarchy* (Figure 3).

3.3. Phase One: Nature in Space Patterns and the Energy Design Hierarchy

The first and second exercises explored the intersections between "low/no cost passive design strategies" in the *Energy Design Hierarchy* and *Terrapin's #1-7: Nature in Space Patterns.* The first seven patterns directly intersect with passive design strategies, given the focus on qualitative site and bioclimatic conditions, flora and fauna, seasonal experiences, views, and connections to the sun, wind, water, precipitation, and changing seasonal sense-experiences. The net-positive energy approach to passive design strategies were considered from a bioclimatic and experiential perspective, while also considering thermal and luminous comfort, energy and GHG performance through the site, building massing, and early concepts for seasonal and dynamic envelope strategies. The CHS Wellbeing Model was revisited to consider health and wellbeing.

3.3.1 Discovering: Exercise 1: Biophilic journey (nature of place)

The students began with iterative site visits to document and define a proposed "Biophilic Journey" (Figure 4). Exercise 1 used time-lapse video, photographs, diagrams, and collage to illustrate the relationships between biophilic phenomena of nature and place while considering potential bioclimatic and passive response to seasonal conditions for sun, wind, precipitation, flora and fauna. They considered "existing conditions" and "potential design responses" to support the intersection of biophilic, net-positive and wellbeing goals. Students considered the seasonal and diurnal "biophilic journey" to explore how the site and building spatial organization, massing, and strategies might reduce energy while enhancing human experience, habitat and connections with nature. Climate Consultant was used to analyze bioclimatic forces, the psychometric chart, solar tools, design strategies, and case study links to the 2030 Palette (Climate Consultant, 2020; 2030 Palette, 2020).

4.2.2 Exploring: Exercise 2: Biophilic atmosphere and passive potential (nature and energy)

Iterative "atmosphere boxes" were used to study the experience and phenomena of nature early in the process (Figure 4). In Exercise 2, students scale-jumped from the site to the interior of the main assembly room. While the first two exercises focused on Patterns #1-7, the atmosphere boxes allowed students to also consider other patterns related to materials, structure, and the quality of space. Working from the inside-out, they developed iterative physical study models using a simple ¼" = 1'-0" box to explore the biophilic atmosphere (such as connection with nature, site, time, and weather) while weighing net-positive issues for daylight, natural ventilation, and passive solar design. Altering only one or two variables per study, students developed multiple "atmosphere boxes" and photographed the incremental alterations to compare the changing qualities of light and material effects for select seasons. The atmosphere studies were useful in elevating the experiential dimension of biophilia in relation to passive strategies for net-positive.

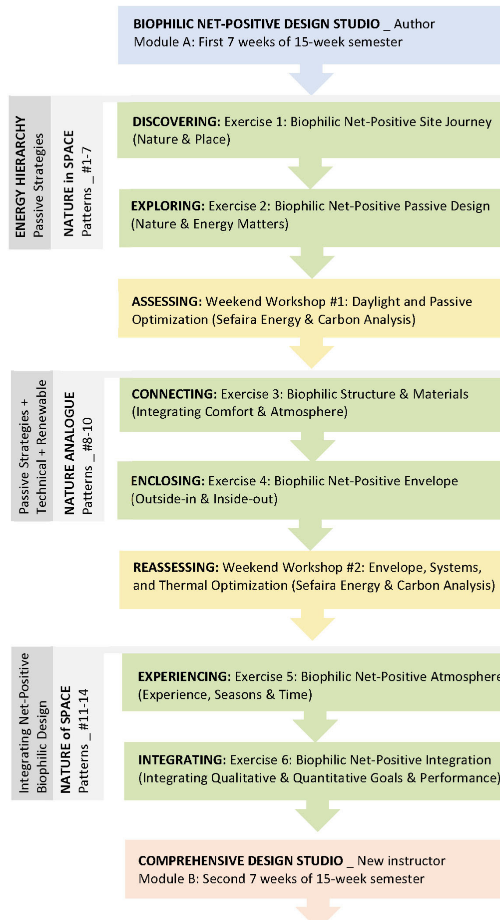


Figure 3 Biophilic net-positive exercise framework. Source: (Author, 2020)

4.2.3 Assessing: Weekend workshop #1: daylight, thermal, and passive optimization

At the end of the second week, Chris Wingate (an architect at MSR) and Pat Smith (a Research Fellow at the Center for Sustainable Buildings) conducted the first Sefaira energy-modelling workshop (Figure 4). Parametric analysis methods were used to evaluate daylighting and passive design strategies and energy and carbon performance. Students selected one proposal (or a hybrid from the early scenarios) as a "base case" and iteratively altered one or two design variables to compare performance relative to the base case, including: building massing and number of stories; orientation; glazing area, orientation and percentage; presence or absence of shading; and presence or absence of natural ventilation. Summaries of the parametric studies included site-building massing diagrams and performance data, including: 1) Annual Energy Use per Gross Internal Area: kBtu/square foot (vs Architecture 2030 targets); 2) Annual CO_2 Production: lbs CO_2; 3) Spatial Daylight Autonomy (sDA) and 4) Annual Sun Exposure (ASE). While students were not required to attain a "net-positive energy target," they were asked to investigate "how low they could go" by only reducing energy through site and architectural design strategies. The second workshop introduced additional reductions through envelope variables, building systems, and renewable energy. Students compared the advantages and disadvantages of bioclimatic and passive design scenarios in relation to their net-positive, biophilic, and health goals. One project scenario was selected to move forward in phase two exercises.

Figure 4: Example site, massing, atmosphere, and Sefaira workshop #1 studies. (Source: Shay Koohi, Yalun Chen, Drew Tangren, Yifan Liu.)

4.3. Phase Two: Nature Analogue Patterns and the Energy Design Hierarchy

The third and fourth exercises explored the intersections between all three levels of the *Energy Design Hierarchy* (including passive, efficient technologies, and renewable systems) and *Terrapin's #8-10: Nature Analogue Patterns.* These studies added additional biophilic patterns to consider materials, structure, and details to support biophilic atmospheric and experiential goals while refining the passive strategies and systems integration for net-positive design. The Wellbeing Model was revisited to further consider health.

4.3.1 Connecting: Exercise 3: Biophilic programming (comfort and atmosphere)

In Exercise 3, students personalized and further developed the program brief based on emerging design concepts. A "biophilic program" was developed for each space and activity using narrative text, precedents, and nature images to refine seasonal experiential, atmosphere, material, and structural design goals. After refining the program, students scale-jumped back to iterative site-building massing and section physical models using one or two of *Terrapin's 14 Patterns* from the second category (Nature Analogues) to explore structure and material scenarios in relation to thermal, luminous, and atmospheric goals and connections to site and nature.

4.3.2 Enclosing: Exercise 4: Biophilic structure & materials (outside-in & inside-out)

A refined site-building massing scenario was selected and a seasonal envelope program was developed to consider the biophilic and net-positive design concepts and goals for each façade orientation including the roof. Students considered early envelope goals, concepts, structure, and materials from the interior quality of spaces and the exterior façade attributes (Figure 5). Iterative scenarios were developed using annotated exploded axonometric diagrams and precedent studies. Each façade was considered in terms of the effect of orientation, activities, and the site relationships from the outside-in and the inside-out. Students developed renderings, collage or time-lapse digital videos to compare biophilic strategies with the seasonal qualities of daylight, passive solar, and shading for net-positive, while weighting the biophilic and experiential connections to site, time, and nature.

4.3.3 Reassessing: Weekend workshop #2: envelope, systems, and thermal optimization

In the second Sefaira workshop, students selected one proposal (or a hybrid of strategies) to use as a "base case design" and multiple scenarios were developed by altering design variables that included massing, size and location of glazing, shading, envelope thermal parameters, glazing parameters, and HVAC and renewable energy systems. A summary of comparative graphics and performance data was developed to assess each design scenario, including: 1) Annual Energy Use per Gross Building Area: kBtu/ square foot, 2) Annual CO2 Production from energy use (lbs CO2); 3) Spatial Daylight Autonomy (sDA) and Annual Sun Exposure (ASE); 4) Total energy breakout from Sefaira; 5) HVAC system type selected; 6) Amount of photovoltaic panels (in square feet) needed to meet the 2019 performance targets for Architecture 2030 Challenge (70% carbon reduction below the regional average for building type); and Amount of photovoltaic panels to achieve net-positive design. Based on net-positive, biophilic, and wellbeing goals, students selected one proposal to develop in the remaining three weeks of the studio (Figure 5).

Figure 5: Example material and structure studies. (Source: Yalun Chen, Zixing He, Mitch Lampe, Emma Rutkowski, Brandon Thompson, Yuyi Lin.)

4.4. Phase Three: Nature of Space Patterns and the Energy Design Hierarchy

The last two exercises focused on schematic design resolution of the poetic and experiential dimensions of biophilic design and the passive and systems integration of net-positive design at the site and building scales. Previous biophilic patterns were reconsidered in the context of the third category of patterns (Nature of Space) to further develop the experiential and atmospheric qualities while maintaining net-positive goals for the three levels of the Energy Design Hierarchy and final consideration of the Wellbeing Model.

4.4.1 Experiencing: Exercise 5: biophilic envelopes (seasons & time)

Using an in-class charette, the site-building massing and envelope scenarios were revisited to integrate the second Sefaira energy analysis workshop. Annotated seasonal site-building section drawings further developed net-positive and biophilic strategies for summer versus winter. Following the charette, students selected “one important room” to develop ½” = 1’-0” physical envelope detail models of select wall conditions. Envelope detail drawings and renderings further illustrated seasonal responses to daylight, natural ventilation, passive solar and connections to site, views, habitat, natural systems and select biophilic patterns (Figure 6).

4.4.2: Integrating: Exercise 6: Biophilic net-positive synthesis (experience & performance)

In the last two weeks, students illustrated the integration of biophilic patterns and net-positive design strategies at the site, building, room, and envelope scales (Figure 6). One select room was studied using a ½” = 1’-0” detailed physical model to study the quality of space and envelope. The group defined the required drawings and models for the final review, including concept diagrams, seasonal rendered site-building sections and/or axonometric drawings, structure and envelope exploded axonometric or detail drawings, Sefaira performance assessments, and a client summary. Physical models included the final room model, envelope detail studies, and all process models. The final biophilic net-positive schematic design proposal was taken into the following seven-week Comprehensive Design Studio to develop the structure, materials, and systems.

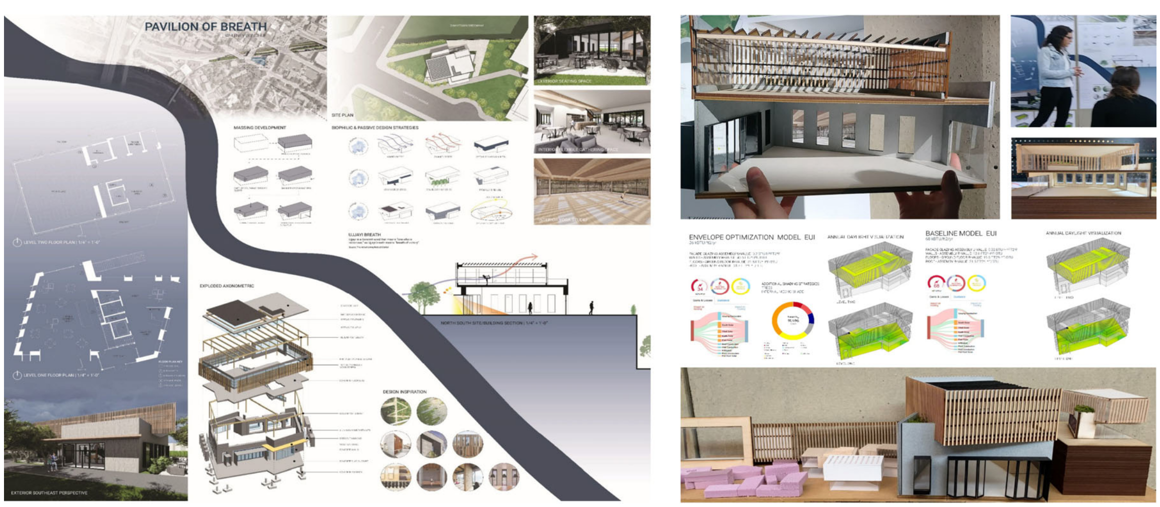


Figure 6: Example final project. (Source: Whitney Donohue.)

CONCLUSION

The Biophilic Net-Positive Studio outcomes include the following conclusions and lessons:

1. *Explore biophilic design as a "missing link" in sustainable – regenerative design*: Elevating the experiential dimensions of nature, place, and health and wellbeing for people, other species, and the planet expanded the design explorations beyond the traditional – and essential - net-positive design focus on energy and GHG. Combining the biophilic lens with net-positive revealed that nature-based design patterns and strategies can also celebrate the beauty of place, time and seasonal phenomena, sense-based experiences, and the interconnections with all life.
2. *Take a fresh look at passive design to integrate biophilic and net-positive design:* The studio explorations revealed the relative ease with which passive and bioclimatic design can be integrated with passive strategies for net-positive design. The three levels of the *Energy Design Hierarchy* and *Terrapin's 14 Patterns* provided an accessible framework to explore the direct connections between passive design and the "Nature in Space Patterns" and material, structure and atmospheric and experiential connections with the "Nature Analogue" and "Nature in Space Patterns".
3. *Work with qualitative and quantitative assessment tools to integrate biophilic net-positive design*: Assessment tools and performance metrics for net-positive design are well-developed compared to those for biophilic design. Despite the nascent state of biophilic performance tools and standards, there is clear evidence of the health benefits of nature connections in architectural design (Africa, 2019, Terrapin 2020). Traditional qualitative design tools of physical modeling, rendering, photography, video, and collage are essential and of great value in assessing the intersections between net-positive and biophilic design strategies from experiential and atmospheric perspectives on health and wellbeing.
4. *Integrate poetic, practical, and performance design goals and concepts early in the process*: Introducing qualitative studies early in the design phase integrated biophilic experiential and atmospheric strategies with practical performance goals for net-positive design. Scale-jumping between site, room, building, and envelope balanced poetic, pragmatic, and performance-based goals and criteria.
5. *Next Steps*: Building on the lessons of the studio, additional attention will be given to the emerging biophilic and health metrics from the LBC, Fitwel System, and Well Building Standard.

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