Empowering Architectural Performance through Biophilic Shading and Hands-On Teaching

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Abstract

This paper presents a collaborative educational initiative between academic institutions aimed at empowering architecture students through experiential learning and design-build collaboration within an active systems curriculum. Centered on biophilic shading devices, the project explores how integrating biophilic principles into climate-responsive systems enhances building performance, occupant well-being, and sustainability. By engaging students in designing and fabricating solar control solutions, this initiative demonstrates the synergy between biophilic ornamentation and functional systems in creating efficient, health-promoting architectural outcomes.

Through hands-on coursework, students gain a comprehensive understanding of how shading devices influence thermal comfort, carbon reduction, energy efficiency, and daylighting. Leveraging advancements in digital design and fabrication, students explore the transformative potential of ornament—redefined as a functional, biophilic element—to foster deeper connections between architecture, the environment, and human experience. Case studies and prototype testing, including performance analyses and cooling load calculations, highlight how biophilia-inspired shading systems reduce energy consumption while enriching user engagement and repositioning ornament as a vital component of adaptive, climate-responsive design.

Aligned with the conference theme "Empowering through Architectural Performance," this paper underscores the transformative potential of architectural education in addressing pressing societal and environmental challenges. By cultivating creativity, ecological sensitivity, and technical expertise, the project equips future architects with tools to design sustainable, resilient, and inclusive buildings. This approach highlights architecture's role in solving real-world problems and advancing equity and environmental consciousness in the built environment.

Introduction

The escalating impacts of climate change demand architects develop innovative solutions emphasizing sustainability, energy efficiency, and environmental responsiveness. According to the Intergovernmental Panel on Climate Change[1], the built environment significantly contributes to global energy consumption and carbon emissions, positioning architects as critical agents in the fight against climate change. This reality underscores the necessity for architectural education to equip students with theoretical knowledge and practical skills to address these challenges effectively.

Contemporary research in sustainable architecture highlights the importance of early integration of environmental considerations into the design process, focusing on strategies such as passive design, green building technologies, and biophilic principles.[2] Despite these pressing challenges, traditional architectural curricula often operate in isolation, with significant hands-on learning deferred until students enter professional practice. In the face of climate change and evolving educational needs, there is an urgent requirement for pedagogical innovation to enhance the performance of architectural outcomes.

Experiential learning, or "learning by doing," has emerged as a powerful approach to bridge the gap between theoretical understanding and practical application.[3] Small-scale projects incorporating layered learning opportunities provide students with essential skills in problem solving, collaboration, and technical proficiency. Moreover, projects that promote cross-institutional collaboration expose students to diverse perspectives and broaden their ability to address global architectural challenges. Collaborative learning between institutions with varying cultural and demographic contexts offers unique opportunities for innovation in design education. Research indicates that such collaborations enhance design outcomes, foster community, and encourage creative solutions by incorporating regional and cultural influences.[4] These collaborative efforts enrich architectural education by challenging students to engage with complex design problems while fostering communication, teamwork, and a shared sense of responsibility.

This paper examines the integration of experiential learning and cross-institutional collaboration within architectural education. Specifically, it explores a case study in which students from two distinct institutions designed, developed, and constructed a functional biophilic shading device. The project emphasizes how hands-on, collaborative approaches can effectively bridge the gap between theory and practice, equipping future architects with the skills to address the multifaceted challenges of climate-responsive design.

Literature Review

Architectural Ornament and ornamental sun-shading devices include integrating art, deliberately making patterns, and shaping surfaces on buildings to communicate values and reduce cooling loads. Systems of architectural ornament are returning to the theory and practice of architecture. Revolutions in digital design and fabrication make incorporating ornaments into new buildings easier. Theorists in the field of biophilia use neuroscience to determine what is truly necessary to help and heal human beings, and ornament is now seen as a tool for incorporating biophilic patterns and strategies into our buildings.[5] The integration of sun-shading into the design of new buildings and retrofits presents the opportunity to introduce biophilic patterns into our built environment while simultaneously controlling and modifying daylight and lowering our dependence on energy for cooling.[6]

The new ornament also can connect us to our physical environment and each other. In this context of both nature and culture, it is worthwhile to ask who determines what these new systems of ornament will be. Is the work of future architects to continue the advancement of ornaments? Courses on ornament and biophilia are offered in a few architecture schools, however, young architects are entering the field with very little understanding of architectural ornament's theoretical and practical applications.

In 1913, the Viennese architect and theorist Adolph Loos famously compared ornament to crime.[7] This single piece of writing perennially emerges in most ornament and Modern Architecture discussions. While Loos is not personally credited with banishing ornaments from buildings, his work is seen as seminal. His attitude almost explains the anxiety many modern architects feel about mentioning the word “ornament.” After a century of architectural and historical developments, recent theorists have pointed out an inherent racism and colonialism in Loos’s stance.[8] The old arguments against ornament are losing their power.

In truth, ornament did not entirely disappear from the work of some architects we would identify as Modernists. In the mid-20th century, Frank Lloyd Wright still incorporated pierced screens and patterned blocks into his Usonian Houses. Edward Durell Stone used decorative sun-shading screens as major compositional elements in huge public buildings as well as his own townhouse (1956) in New York. The Post-Modernist period of architecture saw the revival of decoration and pattern as a method of humor and lightening the subject, and this evolved into a period of serious ornamental revival with the work of Kent Bloomer—probably the leading theorist and practitioner of ornament of our day—most famously breaking into the discussion with the facades of Thomas Beebe’s Harold Washington Library, which was built in 1989, and more recently with the sun-shading ceiling of the atrium in the Slover Memorial Library in Richmond, Virginia.

In the present day, we can observe many more occurrences of ornament in projects we would describe as modern. We see examples of this resurgence in the buildings of Avant Garde practitioners such as the John Lewis Department Store (2008) by Farshid Moussavi, and the Eberswalde Library (1998) and the 40 Bond Street Apartment Building (2007) by Jacques Herzog and Pierre de Mueron. Ornament is also returning to the work of civic- and community-focused architects, such as the aforementioned Thomas Beebe as well as Nicole Hollant-Denis in her design for the Virginia Key Beach Museum (2018). It is becoming more commonplace to see deliberate patternmaking in the exterior screens, railings, and surfaces of new buildings. Frano Violich, who lectured at Norwich University in 2017, showed an apartment building designed and built in Boston with pierced screens for balcony railings. When asked if these railing patterns could be described as “ornament,” Violich, a serious modernist, replied, “Yes, they probably are.”

One reason for this recurrence of complex patterns in the making of building components is the revolution in fabrication technology.[9] Digital design and Computer Numerically Controlled (CNC) fabrication machines allow designers much more formal freedom and variation in the making of building parts. For example, the railings in the lobby of the Visual Arts Building at the University of Iowa by the architect Steven Holl were fabricated using numerically controlled steel-cutting equipment. Whereas in the past these patterns may have been gridded or rectangular, in this project they are complex and not entirely predicative. This is much more biophilia than machine age.

According to Steven Kellert, “Biophilic design is the deliberate attempt to translate an understanding of the inherent human affinity to affiliate with natural systems and processes—known as Biophilia[10,11]—into the design of the built environment.” Lance Hosey, in his book *The Shape of Green* (2012), expanding on the work of Kellert, Heerwagen, and Mador,[12] proposes that architecture can create biophilic environments through three strategies. According to Hosey, “Heerwagen … distinguishes between three kinds of biophilia—literal (actual natural material, such as plants and gardens), facsimile (photographic reproduction and realistic representation), and evocative (nonrepresentational images that emulate nature's order)." Hosey goes on to illustrate in his book that many architects are moving in the direction of literal biophilic strategies by incorporating living plants into the design of spaces. He also points out that the revival of ornament is based on replicating images of plants and living things (this is clear in the work of Kent Bloomer), identified as Facsimile Biophilia, which is also seeing a resurgence. The truly groundbreaking work that Hosey emphasizes is the third category. Evocative Biophilia, which is based on abstract natural patterns, can be seen, as Hosey indicates to " … Embody the qualities and organizing principles of nature … without slavishly copying natural forms."

The practice of incorporating systems of ornament into the built environment is a growing trend. The topic has been the subject of many exhibitions, including a recent Lisbon Architecture Triennale, which included an exhibition titled "What is Ornament." According to Bharani Sri Gujuluva, between 2005 and 2015, thirty-eight exhibitions were held that focused on architectural ornament worldwide.[13] Regular academic conferences that focus on the making or teaching of ornaments do not happen frequently, however, there is an occasional symposium or conference track.

There is a growing body of recent literature on the subject. Many of the practitioners of ornament, such as Farshid Moussavi, Kent Bloomer, and Neutelings Reidijk Architects, have all published books on the subject. Moussavi's book, *The Function of Ornament* (with Michael Kubo) is the most complete survey of what we could call modern ornament. This book creates a taxonomy of ornament divided into categories of Form, Structure, Screen and Surface, and it provides beautifully drawn illustrations of examples from 1964 to 1999.[14] Kent Bloomer's book, *The Nature of Ornament, Rhythm, and Metamorphosis in Architecture*, published in 2000, establishes both an argument and a historical precedent for the design and implementation of ornament.[15] Bloomer has published many articles to make his case, and in 2019, Yale University, where Bloomer taught, hosted a symposium titled "Natures of Ornament," dedicated to Bloomer's theories, work, and legacy. The result of this symposium was the 2020 publication of *Kent Bloomer: Nature as Ornament*.[16] This collection of essays concludes with an essay by Bloomer, "On Teaching Ornament Today."

The connection between architectural ornament and biophilia is clearly identified in the work of Stephen Kellert, Judith Heerwagen, and Martin Mador. In their book *Biophilic Design*, they state:

> Some biophilic architects consider that neurological nourishment comes strictly from living biological forms. In their view, ornamented forms and surfaces are derived of natural forms and thus provide only a secondhand (i.e. vicarious) experience. We, on the other hand, believe that the underlying geometrical complexity of living structures is what nourishes humans. This geometry could be equally expressed in biological organisms as in artifacts and buildings . . . Today it is finally possible to build an intensely connective building and justify it scientifically, by extending the geometrical logic of the natural world into the built world.[17]

In his writings, Lance Hosey takes the theories of Kellert, Heerwagen, and Mador, as well as those of Richard Taylor, and presents an argument for using Evocative Biophilia as a means for developing a new way of designing ornament. Hosey's views and those of other practitioners, including Phillip Esocoff, were presented publicly at a symposium organized by the Washington DC AIA, titled "Provocations: Towards a New

Architectural Ornament" in May 2021.[18] Hosey states explicitly that one of the most functional and logical integrations of biophilic ornament into our buildings is through the design of sun-shading and daylight modulating facades.

While this is still an emerging theory of design, it is rare to find any courses offered in architecture schools that connect these theories of biophilic design with a course specifically focused on designing and making ornament.

Collaborative Approach and Project Overview

This project exemplified a collaborative effort between two professors from different institutions. Throughout the academic year, they worked together to establish the assignment's objectives, learning outcomes, and grading criteria. The assignment was a key component of a three-credit core curriculum at both institutions. Aligning the academic calendars required extensive negotiation, particularly regarding the assignment's start and end dates.

The primary focus of the assignment was to design and construct a functional sun-shading device to reduce solar gain on the south-facing windows of the Mackey Building in Washington, D.C. The project sought to address solar heat gain challenges, thereby contributing to reduced energy consumption and CO_2 emissions in alignment with sustainable design principles. The design required integrating biophilic elements, ornamentation, and symmetry to produce a shading system that was not only functional but also visually appealing. The shading device comprised 8" x 8" pierced screen modules housed within a frame. Each student designed patterns incorporating biophilic principles, such as natural forms, fractals, and symmetry, while achieving optimal shading performance. Fabrication was carried out using a laser cutter and chipboard at a 1" = 1" scale, with each student responsible for producing and assembling four modules into a cohesive four-panel frame.

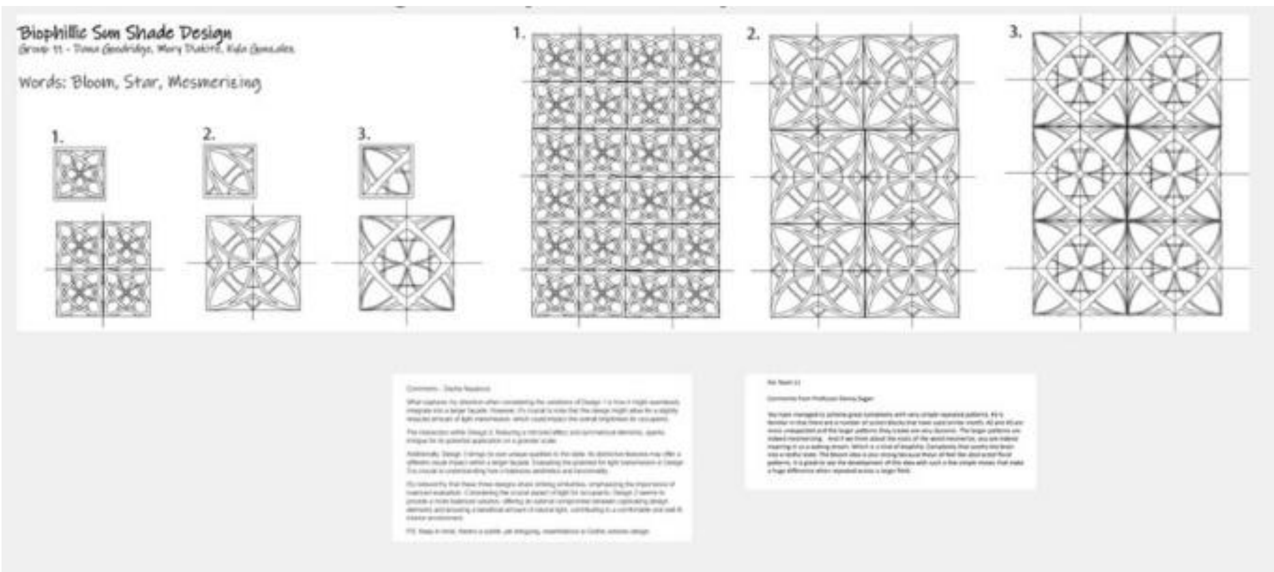
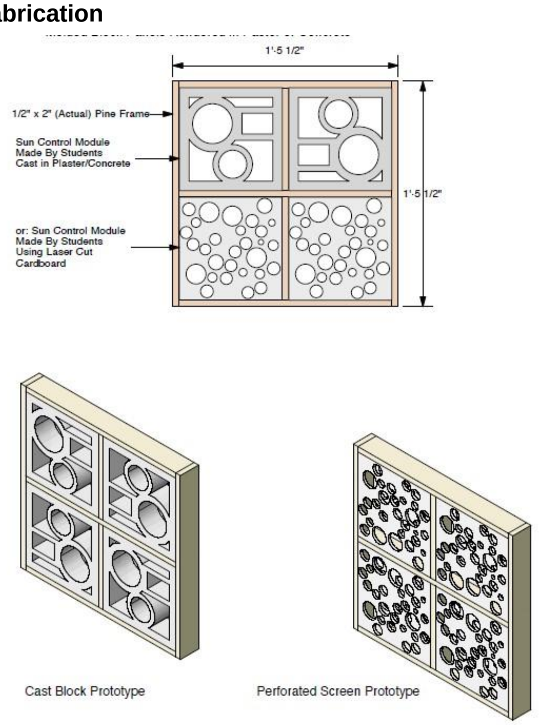


Fig. 1. Concept board design development

Coursework

A three-week module was inserted into two courses at both institutions to support the project. Professors from both schools delivered lectures on biophilic design, symmetric patterns, fractal geometry, and integrated sun-shading strategies for architecture. These lectures were offered in person and online, ensuring participation and engagement from students at both institutions. Teamwork was encouraged throughout the design process. Students from both institutions worked collaboratively on concept boards (see Fig. 1) to aid in discussions and were encouraged to provide feedback to one another. This collaborative environment was further enriched by the diversity of the students, who came from multidisciplinary backgrounds, including architecture, engineering, and construction management. Before moving to the fabrication stage, students received feedback on their designs from both professors, allowing them to refine their concepts.

Fabrication



The fabrication and design phase spanned three weeks, during which students gained hands-on experience with various materials and techniques. In the shop, students worked with plasters to create vacuum-formed molds and cast plaster units. Using templates provided by the professors, students assembled four units into a screen prototype. In parallel, students laser-cut the chipboard to fabricate one module, which was subsequently assembled into the frame (see Fig. 2). This project emphasized precision, collaboration, and practical application of design and fabrication techniques, providing valuable experience in translating conceptual designs into physical prototypes.

Fig. 1. Fabrication module

Energy Performance

We gave our students the problem of looking at the nine windows on the south wall of The Octagon Museum in Washington DC. These nine windows alone allow more than 26,000,000 extra BTU of heat energy over the course of a summer into the building. If the air-conditioning system is working hard to remove heat energy from the Octagon, then the sun shining in the windows makes the job harder.

The students were asked to calculate how much energy was coming in the windows. They were asked then to figure out how much carbon dioxide this would produce. In one summer, the south-facing windows allows in extra heat energy so that the cooling system needs to consume extra electricity and therefore generates an extra 2.4 tons of carbon dioxide. The students were then asked to calculate how much reduction in this extra air conditioning their shading devices would accomplish. In some cases, their designs would reduce the carbon dioxide pollution caused by the nine windows by almost 90%.

The total excess BTU for all nine windows combined is 26,000,000 btu per summer.

Convert this to Tons of Chilling.

26,000,000 BTU x 1 Ton Chilling / 12,000 BTU = 2167 Tons of Chilling needed to remove the heat energy coming in both windows.

Removing 1 ton of chilling takes approximately 1.1 KW of electrical energy input.

2167 Tons of Chilling x 1.1 KW/Ton of Chilling = 2383 KW for removing the extra heat that enters through the nine windows.

Each KWH in Washington, DC, that is received from the electrical grid produces approximately 2# of CO_2.

So, for these nine windows alone, running the air conditioning to remove the excess heat energy would create 4766# of CO_2 per summer (see Fig. 3).

Fig. 3. Reduction in CO2 production

The Funghi Design removes 90% of the unwanted heat energy (see Fig. 4).

Fig. 4. Funghi Design

Amount of CO2 With No Shading		Percentage of Shading		CO2 Produced	% Reduction in CO2 Production
2.4 Tons of CO2 Per Year	x	0.90	=	0.24 Tons	90.00

Peer Evaluation

The project's final phase involved a comprehensive presentation where students showcased their work to professors and their peers. The presentations included simulated elevations, written design descriptions, and detailed calculations of the carbon reduction achieved by their designs. Students also visualized the facade implementation of their sun-shading screens, demonstrating their designs' shading performance and environmental value (see Fig. 5).

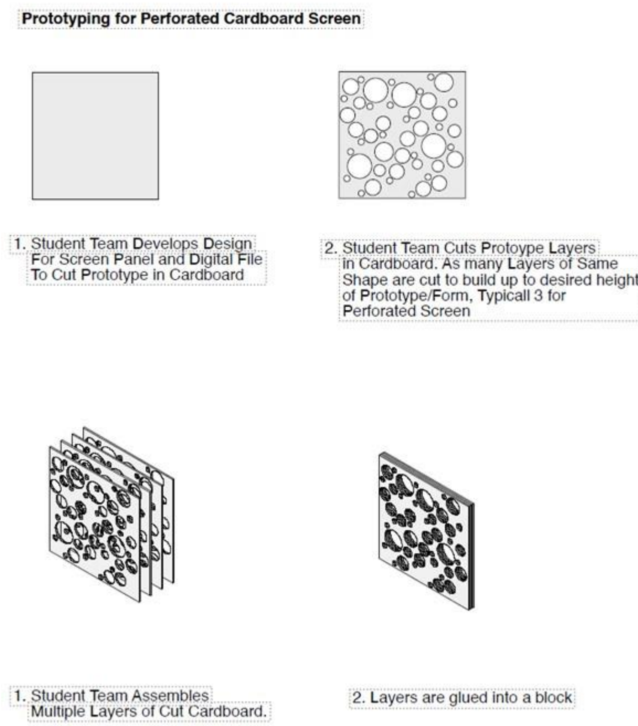


Fig. 5. Prototyping for cardboard screen

Peer grading was implemented to foster accountability and collaboration. Additionally, surveys were conducted to evaluate the lessons students learned throughout the project. These evaluations highlighted the importance of iterative design, interdisciplinary teamwork, and the real-world application of architectural concepts.

Student Reflections

The student reflections revealed various challenges and insights during the project, offering a deeper understanding of the learning process and practical difficulties. One recurring theme was the complexity of calculations involved in the project. For many students, this was their first time addressing solar gain metrics, making it particularly challenging to integrate accurate data while maintaining an engaging and functional design. A significant hurdle was balancing aesthetic considerations with performance calculations, such as ensuring the perforations allowed sufficient light while reducing solar heat. Due to the technical nature of these problems, several students also found it difficult to calculate the shading device's effect on solar heat and carbon reduction.

The design process posed another layer of difficulty. Conceptualizing a biophilic design that adhered to principles of ornamentation and symmetry while ensuring functionality proved to be a time-intensive and iterative task. Students struggled to create abstract yet coherent patterns and translate these ideas into functional shading devices. The need to visualize how the design would perform and appear in real-world conditions further complicated the process. Software use, such as AutoCAD and Rhino, also emerged as a challenge for some, particularly in ensuring the designs were continuous and fabrication ready.

Fabrication and materials were also frequently cited as challenging aspects. Students highlighted the difficulty of working with laser cutters, noting alignment issues and occasional material wastage due to errors or machine malfunctions. Building the frame and assembling chipboard modules required precision and problem-solving to ensure all components fit together correctly.

Constraints on time and materials, particularly for students managing tight schedules or limited resources, added pressure to the fabrication process. Teamwork and collaboration brought challenges as well. Scheduling conflicts, differing skill levels, and limited access to workshop facilities for construction management students sometimes made it difficult to distribute tasks evenly. Some students also faced challenges staying on the same page with their team members, particularly in aligning their design approaches and division of labor.

Logistical barriers, such as accessing the woodshop, managing time effectively, and coordinating shop schedules, further compounded these issues. Construction management students faced restrictions on accessing specific resources, which occasionally led to frustrations with participation.

Despite these challenges, students acknowledged the project's valuable learning opportunities. Understanding and applying biophilic principles was a rewarding experience for many after they grasped its concepts and saw how seamlessly it could influence design. The project's iterative nature also taught them resilience and the importance of refining their ideas through feedback and hands-on experimentation.

In summary, while the project posed significant challenges in calculations, design, fabrication, and collaboration, it ultimately gave students critical insights into the complexities of architectural design and environmental responsiveness. These reflections highlight the importance of integrating real-world constraints and interdisciplinary teamwork into educational projects, preparing students for professional challenges in the field (see Fig. 6).

Fig. 6. Example of finished work

Conclusion

This hands-on, interdisciplinary project allowed students to explore the intersections of biophilic design, environmental sustainability, and architectural fabrication. By combining conceptual thinking with

practical application, the assignment emphasized the iterative nature of design and the role of architecture in addressing pressing climate challenges. The collaboration between institutions and integrating lectures, fabrication processes, and presentations enriched the learning experience, equipping students with the skills and knowledge necessary to tackle real-world architectural problems. One of the students' feedback items: "The new information that was part of this unit that will be helpful in my future design practice is the solar gain calculations. Even though the calculations themself won't be a part of my daily practice, the knowledge of how light impacts my structures is very important. The calculations reflect that importance." The performance of the building and its importance is evident in this student reflection. By incorporating the design and prototyping of a sun shading module as part of the required active systems class in architecture programs, we have the opportunity for students to learn and understand biophilic principles through a hands-on project. In this teaching unit, we also have students learning the history and theory of ornament and an introduction to fractal geometry. The students' work shows that their understanding of the material and their natural creative inclinations produces biophilic sunshades of great variety and sophistication. Their worksheets also show that their designs will reduce the cooling load on their case study buildings; they add complexity while reducing carbon.

Notes

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