Biomimicry in Architecture

By

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Abstract

Biomimicry is an emerging field in architecture and design that seeks to create innovative solutions through the abstraction and transfer of insight from biological models. This thesis project uses one the most prominent techniques in this field, process based biomimicry, to design a primary education building in Ottawa with a biomimetic adaptive façade module and interior interactive components. Using plants as biological role models to inspire the design, the project shows how biomimicry can be used to create multipurpose solutions specific to the Canadian climate. Additionally, the project demonstrates that biomimicry may be used not only to enhance technical parameters of building performance, but also to enrich the occupants' experience by targeting the qualitative aspects of design.
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PART 1
Introduction & Background
1.1. Biomimicry Definition & Brief History

There are multiple terms that circulate in the field of architecture and design that relate to the natural sciences. In order to study biomimicry it is first necessary to differentiate it from other terms that relate to biology (Figure 1a). Bioutilization is the direct use of natural life or objects inside buildings for beneficial purposes. A common example of this is the use of green roofs and facades. Biomorphism is the use of forms found in nature with an aesthetic or symbolic aim. Biomimicry, on the other hand, is only the transfer of the functional principles found in nature to analogous functions in a building (Pawlyn).

Although the idea of biomimicry has undoubtedly existed for thousands of years, it is not possible to track exactly at which point humans started to look at nature for solutions. However, there are several well-known examples throughout history (Figure 2). An early frequently quoted instance of biomimicry in design is Leonardo da Vinci’s study of the flight of birds in the study of flying machines around the time of the 1480s. An example from architecture from the same time period is the dome of the Florence Cathedral designed by Filippo Brunelleschi with reliance on the study of the forms of eggshells (Jamei, 1; Pawlyn).

In the early 1900s, many structures constructed during the Art Nouveau period imitated nature. The publications of biologist Ernst Haeckel which illustrated biological lifeforms were a key influence that inspired artists and architects at the time. The entrance gate to the 1900 World Exhibition in Paris by René Binet is an example of such a structure, inspired by a radiolarian skeleton (Pohl, 29). However, it was only during the mid-20th century that the reliance on the transfer of the key ideas found in nature and not only their forms became a more widespread practice. Biomimicry became a common tool in engineering to aid in the design of aircrafts, vehicles and ships by deriving mathematical modeling rules from biological studies (Niebaum and Heike, 3). This time period also saw several inventions on a smaller scale, with less computational input, such as Velcro, a product designed from the study of burs by George de Mestral in the 1940s.
Figure 1: Definitions + subcategories. 

a) Definitions of the most common directions in architecture that utilize biology. 

b) The subcategories of biomimicry.
Figure 2: Biomimicry historic timeline. Brief highlights of important projects influencing biomimetic development. Projects from architecture, engineering and product design are shown.
The term biomimicry formally appeared only in 1982. It is interesting to note that fewer than 100 papers per year were written on biomimicry in the 1990s, but this number increased to several thousand per year during the 2000s -2010s. Part of this is related to the popularization of the term by scientist and author Janine Benyus in her 1997 book "Biomimicry: Innovation Inspired by Nature". The technological progress in computational design and fabrication is also a significant driver for the surge in interest in biomimicry and availability of its study at the academic level (Jamei, 2; Pawlyn).

A lot of significant biomimetic work in architecture currently occurs in academic research group. A notable example is the work of the Institute of Computational Design (ICD) in collaboration with the Institute of Building Structures and Structural Design (ITKE) at the University of Stuttgart. Led by designer Achim Menges and Dr. Jan Knipppers, the institute builds multiple research pavilions and prototypes based on the results of detailed observations of material arrangements of living things. One such example is the 2013-2014 pavilion made from robotically woven fibers based on a detailed understanding of the morphology of beetle shells (University of Stuttgart).

Other research groups work at the intersection of biomimicry and bioutilization. The work of Neri Oxman, founder of the Mediated Matter laboratory at MIT Media Lab is an example of this type of research. Working with five main materials (glass, polymers, pigments, cellular solids, and fibers) the group has been successful at 3D printing several biopolymers and finding new methods of material production. A notable examples of their work is "Aguahojía", a mini tower fabricated from chitosan paste, apple skins and fallen leaves. Not only bio-based but also acting like a biological life form, the structure slightly varies its colour and material properties depending on temperature and environmental conditions and is able to decompose fully when exposed to water (Oxman).

1.2. Biomimicry Standards & Subcategories

With the immense interest and progress in biomimicry throughout the years, different research groups and different practicing architects have taken diverse approaches
to the study and application of the biomimetic process in their work. However, several standards and common directions have emerged. In general, all biomimetic projects rely on one or more biological role models from which key principles are abstracted to generate the design. The definitions given by the Association of German Engineers (called VDI) regarding biomimicry are quoted by multiple sources. The VDI 6220 guideline states that biological models may be biological processes, materials, structures, functions, organisms, and principles of success as well as the process of evolution itself (Pohl, 34).

Regardless of the nature of the biological model that is chosen, the need to narrow down on the most useful principles and abstract the information is emphasized as the key to generate a successful design project. VDI states that a project is considered biomimetic when it fulfills three criteria: 1. Biological precedent 2. Abstraction from biological precedent 3. Transfer and application (VDI-Desellschaft Technologies of Life Sciences,13).

In practice biomimicry is introduced into architectural projects through either the top down or bottom up method. The top down method starts with the design problem, identifies how equivalent problems have been solved in biology and then translates that into a solution. Bottom up goes in reverse order by starting with the biological phenomena first, then identifying its key principles, and only then deciding what design solutions can be generated from these findings. Since the design process is rarely linear, combinations of both methods are often used (Pawlyn).

In general, in architecture and design there are currently two prominent sub-categories or streams of biomimicry – structural biomimicry and process biomimicry (Figure 1b).

Structural biomimicry explores how organisms achieve strong but material efficient morphologies with low stress concentrations such as the way bones and trees grow (Pohl, 6; Mattheck, 26). This is often done through digital simulation methods and usually applied to small scale structural subparts and interior components. However, with specialized equipment structural biomimicry may also be achieved by direct study of biological
organism through microscopy and may be applied to large scale structures such as the research pavilions produced by ITKE described in section 1.1.

Process biomimicry focuses on simulating the way organism interact with changes to their external environment to regulate internal homeostasis or just maximize their survival (Pohl, 6). One of the most popular directions in architecture from this sub category is the development of responsive shading devices.

It is important to note that some study of structural principles may also be necessary in processes biomimicry and vice versa; therefore these categories are not absolutely separate. The academic work described in section 1.1 above demonstrates that the line between these different streams are often blurred.

1.3. Process Biomimicry – Shading Devices

The focus of this research is on process biomimicry and the development of a biomimetic shading device.

Although there are many adaptive shading facades constructed globally, only a subset of these are designed with a reliance on a biological model. In order to understand their main characteristics, several biomimetic shading devices, either built project or academic studies, were analyzed (Figure 3a).

Most biomimetic shading devices rely on plants as precedents. Due to their fixed location, plants have developed a variety of adaptation strategies that allow them to respond to their environment at all times. These characteristics can thus be a source of inspiration for façade design that essentially seeks to introduce the same principles to buildings (López et al., 696).

Shading devices may be either kinetic or static. Kinetic biomimetic shading devices reference movements found in plants, the major categories of which are either those that respond to stimulus directionally (tropic), or non-directional (nastic) (López et al., 697).
Kinetic devices generally take on the form of movable vertical louvers or grid-like modules, each having different advantages for different sun angles. The mechanical strategies to generate movement may either rely on a series of hinges, known as rigid body mechanisms, or material properties with less mechanical parts known as compliant mechanisms (Korner et al., 2).

Although there are countless static shading devices, most are created without referencing a biological precedents. However, an example from literature by Hosseini et al. created complex layered structures based on the success of dense plant matter at blocking and filtering daylight (67).

With all shading devices, visual comfort for the building’s occupants is maintained by allowing adequate daylight to penetrate into the interior space. With more perforations in the shading material, more light may enter into the space. However, greater perforated area also compromises the functionality of the shading device. A careful balance must be maintained to enhance the building’s technical performance through reduction in cooling load while still allowing enough light into the building so as to not increase artificial lighting demand.

1.4. Evaluating Biomimetic Projects

Biomimicry is primarily aimed at improving the quantitative areas of building performance, and there are distinct parameters that are used to evaluate the success of projects within each stream of biomimicry.

In terms of shading devices, their ability to reduce cooling loads can be evaluated by modeling energy use with or without the shading device. Their secondary aim, maintaining occupant visual comfort, is measured through parameters such as daylight glare probability (DGP) and useful daylight illuminance (UDI) (Parsaei et al. 30) (Figure 3b).

It is also necessary to clarify the way in which the level of biomimicry itself is evaluated. Projects that satisfy all three of the VDI criteria by undergoing the process of abstraction and transfer of knowledge from a biological model are considered as
biomimetic. To some extent it is possible to evaluate the degree of inspiration, technical application, and the significance of biomimetics for the development of a project (Pohl, 34). However, aspects such as inspiration are always slightly subjective as they are best understood by the designer or design team.
Figure 3: Biomimetic shading devices. a) Their classifications and b) methods of evaluation are shown.
PART 2
Design
Research
2.1. Design Intent and Program selection

The goal of this thesis project was established as the intent to focus on process biomimicry and design a shading device as well as other interior components in a proposal for a new building in Ottawa. As with most biomimetic projects, the design was aimed at improving technical performance within a building.

Although shading devices are typically associated with cooling dominated climates, there is motivation for their use in heating dominated climates as well. They can address excessive solar gain in the summer, and in some highly glazed buildings reduce the need for cooling in the winter. The control of visual comfort can be beneficial in any climate.

When looking at the precedents described in 1.3 above, all the shading devices appear to be quite playful, although the ability of building occupants to directly interact with these devices is not something that was taken into consideration in any of the projects. This observation inspired the idea of creating a shading device that was both technically functional in terms of its environmental benefits, but also qualitatively functional, enriching the experience for the occupants.

The typology chosen for this project was an educational building, specifically the design of a daycare. The programs of such buildings inherently emphasize play and interaction, therefore putting a significant emphasis on the qualitative experience in a space. The general design proposal at the start of the project outlined the idea that the shading module would change in different areas of the building, being strictly functional in some areas and more play oriented in other areas. The more playful and less functional portion of the shading modules could also be placed on the inside, while the rest of the adaptive façade remains on the exterior of the building. Although the resulting module changed from the time of these initial speculations, a sketch of the initial design thinking is shown in Figure 4.
2.2. Methodology

The project started with the development of several ideas for the biomimetic shading module and interior components independently of a building design. One biomimetic component was developed using the top down strategy of abstraction from nature, while the other was developed with the bottom up strategy. Additionally, a site analysis for the environmental conditions influencing the site was conducted. The schematic design for the daycare building was influenced by the placement of the shading device in the best way to interact with the environmental conditions and overall site constraints. Following this, in reverse, the constraints of building and site also influenced the biomimetic components, allowing them to undergo development and modification to work with the established layout. The primary tools used throughout the project are shown in Figure 5.

2.3. Challenge of the Canadian Climate

Feedback received at the first colloquium presentation pointed towards the need to further research the potential of introducing thermal properties to the adaptive façade to address the heating load in the Canadian climate.

There is very limited information regarding any adaptive facades, biomimetic or otherwise, intended for thermal insulation, although there is some research at the academic level. Several papers from Laval University made suggestions regarding the use of adaptive facades in northern Canada. One method was the potential to combine shading devices with a multi-skin façade system. This system could first of all be used to reduce heating loads by trapping solar radiation in the cavity space, and if placed inside the cavity, the shading device could be protected from weather damage (Parsae, et al.,23). Another method was the possibility of reducing heat loss when a building is not occupied by covering openings with movable insulation panels (Du Montier et al., 442).

Although a double skin façade may be advantageous for energy performance in the winter, it may result in a kinetic façade module that is less effective at shading, especially if placed between layers in the double skin façade instead of the exterior of
Figure 4: Conceptual project proposal sketch. Shading modules could change with the change in program and could flip to the inside of the façade in areas that are less functional.

Figure 5: Methodology. Key tools used throughout the design process as well as the sequence of steps to develop the project are shown.
the building. Additionally, there would also be less reliance on new insight gained from biomimicry to solve the design problems since non-biomimetic passive design would be used to address energy performance in the winter. Although options that are more biomimetic may be possible in combination with a double skin façade, the decision was made to start experimenting with a biomimetic façade module that could address both winter and summer energy performance goals without other passive technologies.

The design goal was thus identified as an interest in combining two properties – shading and insulation – in one façade module. Based on the research proposed in the work of Du Montier et al., the design would utilize a solid insulation panel to buffer energy losses when the building would not be in use and a translucent layer for shading and light control during daytime hours. The translucent layer could be a material like PTFE, a highly weather resistant but semi-translucent fabric which still allows for light and view outside thereby maintaining visual comfort.

2.4. Biological Model Selection and Analysis - *Physalis alkekengi*

According to the top down method described in section 1.2., biomimicry would be used as a tool to find solutions in nature that could combine two materials or two properties in one structure. Various methods of folding to transition between the thermal and shading layer were hypothesized as the most likely method of design for such a façade. Similar to other kinetic shading devices, it was decided to use a biological model from the plant kingdom.

The ITKE institute in Germany is one of the leading research groups regarding biomimicry inspired by plants with several successful prototypes being created in recent years (namely the Flectofin and Flectofold modules). Some of their publications focus on plant movements that are a result of externally applied loads, known as non-autonomous nastic movements (Figure 6). These movements can be diverse and either cause an immediate deformation or be redirected to also trigger some secondary transformation processes (Schleicher, 57; Poppinga et al. 405). This subcategory of movements was seen as the
Figure 6: Subdivisions of nastic plant movements. Non-autonomous nastic movements were explored in this project, specifically reversible elastic deformations. Figure modified from Poppinga et al.
best method of experimentation for this research as it exists to some extent in all plants and can be immediately observed and repeated multiple times without the need for microscopy or advanced tools.

Since the key step in the biomimetic process is abstraction from the biological model, it was also necessary to decide on how this process would be done. Different research groups have different methods, but in general abstraction is based on finding the key essence or main idea that the particular biological model presents (Badarnah and Kadri, 121). The method used in this project was to organize the definitions of a biomimetic model, as defined in section 1.2, from the more general terms to the specific and to use this strategy to uncover the principles available for design (Figure 7).

Several non-autonomous deformations were observed in plants that were locally available. One of the observed plants, the Chinese Lantern \( (Physalis alkekengi) \), was found to have a highly articulated structure that combined two types of material zones with several deformations possible between them. Figure 8 lays out the observations that could be made regarding the plant from general to specific in order to uncover the key principles that could be carried forward to a façade design.

The initial observation that can be made about the plant concerns the unique evolutionary adaptation itself. This genus has a unique adaptation where the plant’s calyx (the protective outer covering around the flower), continues to grow after pollination in a phenomenon known as the inflated calyx syndrome (ICS). The shape transforms from a small white flower in the summer to a progressively enlarging lantern shape subsequently after pollination. The structure provides an advantage to the plant as it protects an interior seed throughout the winter, allows it to be dispersed by wind and float for a considerable amount of time (Li, 3). On a more specific level, the reason for its resilience may be found in the material organization of the inflated calyx.

Several observations can be made from direct manipulation of the plant (Figure 9). The inflated calyx structure has five stiff and narrow protrusions (named full ribs here),
“Biomimetics combines the disciplines of biology and technology with the goal of solving technical problems through the abstraction, transfer, and application of knowledge gained from biological models. Biological models in the sense of this definition are biological processes, materials, structures, functions, organisms, and principles of success as well as the process of evolution itself.”

- VDI Guideline 6220

Figure 7: Conceptual strategy used to abstract movements from observed plants.
Figure 8: Abstraction from first biomimetic role model. Observation of the Chinese Lantern plant from the general to the specific.
between which there are flexible zones each reinforced by another set of ribs that does not
extend all the way (named half ribs here). It is possible to observe two non-autonomous
movements: first that the full ribs can move laterally without much secondary deforma-
tion in the rest of the structure, and secondly that each half rib can be compressed but
rapidly reverts to its original shape. When the half rib is compressed it also causes a net
slight inward movement in the full ribs on either side of it.

The half rib may be able to quickly recover back to its original shape due to its
elastic material properties and the fact that it may be slightly pre-bent in the opposite
direction. The reason for the secondary motion in the full ribs when the half rib is load-
ed may be simply due to the direct connection of the two structures through the flexible
zone. This motion may also be amplified through a connection called curved line folding
(Schleicher, 57).

2.5. Module Experiments - *Physalis alkekengi*

Just as the key principles available for biomimicry can be organized from the
general to the specific, it is possible to organize design strategies inspired by these findings
from the general to the specific as well.

Starting with the general idea of folding using an outer stiff layer and an inner flex-
ible layer, the insulation panels can slide horizontally to reveal the shading layer (Figure
10a). More specifically, based on the lateral motion of the full ribs in the plant, the insu-
lated panels can fold out to reveal the shading layer in several ways (Figure 10b). Based on
the deformation of the half ribs that move from a convex to concave shape and can trigger
a net movement in the full ribs, elastic components can be introduced to the shading layer
to allow it to have similar characteristics (Figure 10c).

2.6. Model Selection and Analysis - Pilea Cadiere

Another plant in which non-autonomous nastic movements were observed was
the Pilea Cadiere (Figure 11). Similar to the method used for the previous biological role
model, the key principles available for biomimetic abstraction were also organized from
Figure 9: Chinese Lantern non-autonomous movements. Process of compression and folding are shown.
Figure 10: Initial conceptual design strategies for the development of a multipurpose façade module. a) Based on folding in general b) based on lateral motion of the full rib c) based on flexible deformation of the half rib.
general to specific. In general, the plant can be seen to have an articulated structure where its leaves have two distinct material zones. Its leaves each contain four rows of slightly raised silver patches. This appearance is what gives rise to the plant’s several common names, which are the “aluminium plant” and “watermelon pilea”. These patches are more flexible and may be inverted repeatedly when pressure is applied (Figure 12). This deformation can stay in place for several seconds before slowly returning to its original shape.

Scientific studies done on this plant and others with the same structure call these patches “air blisters”. Looking into the specifics behind their development, microscopic study shows that the tissue is unique because it contains a separation between the leaf’s epidermis layer and sub-epidermal layer (usually around 30 microns in a mature leaf). It is speculated that this development may deter pathogens (as the sub-epidermal layer stores phenolic compounds) or act as temporary shading devices when natural shading is temporarily lost (potentially due to their umbrella-like shape) (Vaughn, 468).

2.7. Module Experiments - *Pilea Cadiere*

This plant was not used to develop shading modules, but rather inspired the development of interior components for interaction. Abstracting the idea of a surface with locally deformable zones inspired several ideas for flexible seating. In the first option (Figure 13a), a screen may be placed over a window which could support the weight of a seated person. Provided the screen was securely placed over the window, it could be opened allowing for fresh air circulation, shading, and occupants’ comfort at the same time. In the second option (Figure 13b), a textile wall with stiff material and local pockets of flexible material could be stretched across a large space with the flexible pockets again acting as seating for occupants. In this option the seating pockets can vary, either clustering together or being further apart, creating different opportunities for interaction for children in the daycare.
Figure 11: Abstraction from second biomimetic role model. Observation of the Aluminum plant from the general to the specific.
Figure 12: Aluminum plant non-autonomous movement. Process of inversion of one of the plant’s leaves is shown.
Figure 13: Initial conceptual design strategies for the development of interior seating components. a) An option stretched over a window and b) and option in the form of a wall are both inspired by the flexibility of the Aluminum plant.
PART 3
Design Proposal
&
Documentation
3.1 Program Description

The daycare follows the rules and ratios established by the government of Ontario with three primary age groups: infants, toddlers, and preschoolers. The infant and toddler groups have one designated classroom respectively. Since the preschool group has the widest age range, it is split into two groups to allow children to be closer in age.

3.2 Site Context and History

The daycare is set to be located at 690 Reverie Private, currently an empty lot on Stittsville Main Street. Known as Old Stittsville, the area is historically significant. It was previously a key connection and transportation point due to a main train station in the area. Many buildings surrounding the site date back to this time period (Figure 14).

This site was chosen as the surrounding community is undergoing development with many new residential projects recently built or in the planning process. The increased development creates a demand for a new daycare center for new families moving to the area (Figure 15).

Additionally, the site's history allows for an interesting interaction between traditional building typology and the unconventional forms created using biomimicry.

3.3 Site Analysis

Sun exposure is primarily concentrated around the street edges of the site, with the front of the site (that which is aligned with Main St.) facing south-west and the right hand side of the site (aligned with Reverie Private) facing south-east (Figure 16). As a result, solar radiation is highest at the corner of Main St and Reverie Private (Figure 17).

These site constraints directed the placement of the shading panels, which in turn influenced adjacent spaces near them to maximize interaction and visibility from the street. This also influenced the structural decisions and culminated in the final building proposal.
Figure 14: Current site photos and old Stitsville historic site photos.

Figure 15: Context plan. Site and new developments are shown.
Figure 16: Sun path around the site in plan and perspective view.
Figure 17: Solar radiation dome around the site in plan and perspective view.
3.4 Plans

Site

The site may be accessed by either going around Reverie Private on the right side of the site or more directly through a new route branching off of Main Street on the left side of the site, which connects back to Reverie Private. The parking for the daycare is shared with the adjacent building near the site, which is the Royal Canadian Legion.

The first entrance which is closest to Main Street is intended to be the primary public entrance while the secondary entrance is more private. However, either entrance may be used to access the private or public programs.

Ground Floor

The public entrance opens into a lobby with a secretary desk, several public amenities and seating for parents (Figure 18). Following the lobby, a ramp leads into a slightly lowered indoor playground space containing multiple activities for different age groups. This space runs along a curtain wall and turns the corner of the building where it can be exited with another series of ramps. A long outdoor yard which is designated for preschool children runs along the outside of the curtain wall. The curtain wall has the biomimetic shading device installed on the exterior with the lowest panels being modified to allow for children to interact with it. A winding path moves along the curtain wall through raised topography.

Adjacent to the play space runs a wide public corridor which can also be used as a play space for different activities. However, its primary purpose is to be used to access the two classrooms on the ground floor which are the infant and toddler classrooms. The outdoor play space designated for the younger children is a smaller yard which may be accessed directly from their classrooms.

The back of the building contains a concentrated private block with the director’s office, staff break room and a laundry room.
Second Floor

The upper floor contains the two preschool classrooms as well as a library space (Figure 19). It may be accessed with either of two staircases or elevator from the ground floor. The library is intended to contain the flexible seating components described in section 2.7.

Basement Floor

The building contains a partial basement which may be entered through a stairwell located beside the front window (Figure 20). This allows some light from the curtain wall to penetrate into the basement space as well. Part of the basement is reserved for MEP equipment and storage, while the public portion contains a kitchen and seating for children and parents as well as a stage to present plays and performances that children may be involved in. The intent for this space as well as the play space on the floor above is to be used for community events after hours or when the daycare is not occupied.

3.5. Sections

The lowered play pit on the main floor changes shape throughout the length of the building creating a range of different spaces for different activities. At the front of the building the space is widest, towards the back there is a covered cave-like area designated to have a small rock-climbing wall. On the exterior, this space is used as a deck for the outdoor yard and is the highest point of the outdoor path. This relationship between interior and exterior of the building can be seen in cross-section (Figure 21). Finally, the building narrows towards the back of the site where there is an overhang at the point of entry to the outdoor yard.

The structural system that was chosen for the building is also evident in cross-section. The building uses timber framing with a slightly curved glue laminated frame to support the roof. The shape of the roof allows for the use of clerestory lighting along the length of the building between the changes in pitch of the timber frames.
Figure 19: Second floor plan

Legend
10 Preschool Room 1
11 Preschool Room 2
12 Library
Figure 20: Basement floor plan
Figure 21: Building cross-sections
3.6. Module Development

The final shading module was modified from one of the initial ideas proposed in section 2.5. The resulting design has the two layers as described previously: an outer insulated shutters and inner textile shading layer. The curtain wall façade extends from northeast to west of the building and is primarily covered by 2-3 panels vertically; the highest panels are always strictly functional while the lowest panel is smaller and modified for interaction. The insulated shutter is identical on all modules consisting of two sections that can fold in half in opposite directions. The functional shading layer moves in a similar manner, having two sections that also fold away from each other.

The modified shading layer is inspired by origami and also by the form of the folds of the Chinese Lantern plant. There are several colour and shape variations throughout the façade for variety of interaction and discovery. All variations of this type of shading layer consist of a single panel with multiple inflection points that fold to one side. Although all panels may be adjusted manually, the lowest panel is the one primarily intended for manual interaction.

As a result of these different layers, the module can undergo different configurations, from fully closed during the night to buffer thermal losses, open but having the shading layer drawn over the glass during the summer, and finally to fully open during the winter to allow for thermal gain during times of strong sun (Figure 22).

The proposed construction and mechanism is modified from the details of Bai-er-GmbH, a shutter company specializing in largescale architectural projects (Figure 23). Both layers, shading and thermal, have independent top and bottom rails attached to a sill or (with extra structural support) connecting at a midpoint of the façade. Hinge points in each layer that run along the façade have a motor to guide them along their rail, while hinge points that fold away from the façade are stabilized with an aluminium band. All square panels are stabilized with a continuous aluminium frame around the perimeter of the component. The origami panel would also require a frame to stretch out the PTFE
fabric and add stability. The frame used for such a component would most likely sit within several layers of PTFE as a safety measure for children playing with the component.

The proposed construction mechanism for the flexible wall seating component would consist of independent thick fabric (most likely cotton or polyester) pod sacks suspended from the truss system above surrounded by more translucent fabric to create the appearance of a wall (Figure 24). The surrounding fabric would be sewn to the seating pods for continuity and also have several points of attachment to the ceiling structure and floor. However, these points of attachment would not be load bearing.
Figure 22: Shading module configurations. Configurations going from fully closed to fully open at different points on the sun path during the year.
Figure 23: Shading module potential technical resolution. Each stage of the module’s opening sequence is shown in plan, section and elevation.
Figure 24: Flexible seating potential technical resolution
PART 4
Conclusions
&
Future Directions
This project focused on developing two biomimetic components from two plant models. The shading device created based on the properties of the Chinese Lantern was a more technically functional component, while the flexible seating created based on inspiration from the organization of the Aluminium plant was a more experimental interior component. Further development of this work could introduce two more devices from the same two plants, but reverse the type of device created. The Chinese Lantern could be used to create an experimental interior component, while the Aluminium plant could be used to generate an exterior shading component. Structural biomimicry could also be introduced to generate experimental play structures based on loading from a biological model. Some initial sketches of these ideas are shown in Figure 25.

By focusing on simple movements found in commonly available plants this project demonstrates that biomimicry can be achieved without specialized equipment or a multidisciplinary design team (Figure 27a). The main goal of biomimicry is the idea of inspiration from nature which leads to novel solutions. The result could have a lot of technical complexity, but is not in itself the goal of biomimicry. The idea that biomimicry requires a high degree of scientific analysis and technical complexity is a misconception that is probably held by many students and professional in the architecture and design fields. If the key ideas of biomimicry were better communicated and understood, biomimetic projects could be significantly more widespread in academia and in practice.

Another conclusion of this work is that inspiration from nature generally ends up being holistic. Although the project started with an interest in the functions that could be abstracted from the plants, the end result had those functions but in addition also acquired some level of visual resemblance to the plants. The ongoing development of the project resulted in the incorporation of a lot of naturalistic elements such as the winding outdoor path through topography, large windows for natural daylight, etc. So in fact the project shows that biomimicry, biomorphism and bioutilization are very much connected (Figure 27b).
Figure 25: Conceptual sketches for future project development. The folds of the Chinese Lantern may be used as inspiration to generate a way to divide the space in the nap rooms of the daycare. Experimental structures could be generated with structural biomimicry.

Figure 26: Future methodology. Key tools to be used in future development of the work are shown. Environmental analysis would be done with ladybug + honeybee plugins for grasshopper.
It is also interesting to note that although this project started with a focus on biomimicry, the importance of detail in design became an prominent conclusion and focus of the work. The building typology originated from the study and development of a component instead of the design of a component for a predetermined typology. The interest in creating a shading device led to the focus on play, which in turn led to the selection of a daycare as the building type. The placement of the device around the sun path influenced the rest of the building layout, and there was a back and forth development of the device influencing the building and the building influencing the device (Figure 27c).

This relationship between detail and overall design development relates to the work of Marco Franscari and his critical publication "The Tell-the-Tale-Detail". Similar to the conclusion gained from this project, he describes that design must not always proceed from the general to the specific (Emmons, 173). In his article Franscari describes the importance of detail as an initiator and method of completion of a building, primarily focusing on the work and thought process of Carlo Scarpa. He makes an analogy that architecture is a system in which there is a “total architecture”, the plot, and detailed architecture, the tale. He states that a plot with appropriate detail becomes a fully developed and successful tale (Frascari, 26).

This project demonstrates how detail can act as a design generator. However, the work still remains at the conceptual level of design and has a lot of potential for further development in terms of its technical resolution and refinement. Future research could potentially focus on demonstrating the environmental benefits of the chosen shading device by showing its ability to improve technical performance factors such as a reduction in solar radiation in the summer while still maintaining desired lighting levels. Figure 26 shows that future methodology of the work would again allow for a back and forth development between experimentation and module development. With continued interaction between the details of the project and the overall building, the work could become an example of what Marco Franscari calls an overall harmonious and complete tale.
Figure 27: Project conclusions. a) The shading module initial sketch was used to generate the initial design scheme followed by adjustment to the module and final developed building b) Non-autonomous nastic plant movements were a simple method of experimentation in the project. c) Although concentration on biomimicry in terms of transferring the plants’ properties was the main goal, biomorphism and bio-utilization were also involved.
Bibliography


Image sources

Figure 1
https://tonkinliu.co.uk/fresh-flower
https://www.britannica.com/plant/sensitive-plant

Figure 2
https://longnow.org/ideas/02021/11/10/nature-x-humanity/
https://www.itke.uni-stuttgart.de/research/icd-itke-research-pavilions/icd-itke-research-pavilion-2013-14/
https://www.istockphoto.com/photos/velcro

Figure 3
https://www.archdaily.com/208700/in-progress-one-ocean-soma