Beneficial Invasive: A Rhizomatic Approach to Utilizing Local Bamboo for COVID Responsive Educational Spaces

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BENEFICIAL INVASIVE:
A RHIZOMATIC APPROACH TO UTILIZING LOCAL BAMBOO
FOR COVID RESPONSIVE EDUCATIONAL SPACES

A Thesis Presented
by
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Approved as to style and content by:

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ABSTRACT

BENEFICIAL INVASIVE:
A RHIZOMATIC APPROACH TO UTILIZING LOCAL BAMBOO
FOR COVID RESPONSIVE EDUCATIONAL SPACES

MAY 2022

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The United States has an abundant stock of naturalized wild growing bamboo species that are generally considered invasive. This project explores the use of locally harvested, so called “invasive” bamboo as a potential building material incorporated into a modular, kit-of-parts style construction system. These structures are uniquely suited to address the need for expanded spaces and extensions that bridge between the strictly indoor vs. outdoor distinction of existing buildings, as revealed by the Covid-19 pandemic. The rhizomatic mechanism of spread that is characteristic of bamboo species is used as the framework to propose a tectonic system that is decentralized, adaptable, and deployable. Drawing on a series of formal explorations, this system is further developed through a case study proof of concept design for Morningside Elementary School in Atlanta, GA, by supplementing, expanding, and adapting the existing facilities for eating, gathering, recreation, and learning to address the requirements of a Covid-19 safe school environment and to propose an ongoing outdoor learning program.
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CHAPTER 1
INTRODUCTION

The United States has many wild-growing naturalized bamboo species, mostly introduced from China or South America within the last 150 years.¹ While the material has remained underutilized in the United States, many countries where bamboo occurs naturally have long traditions of building lasting bamboo structures. The species occurring most frequently in the U.S. are not the largest preferred “timber” bamboos. However, these small to medium cross-section species offer unique material properties that lend themselves to different design applications: the high strength to weight ratio combined with the smaller cross-section of wild-growing U.S. bamboos makes them particularly suitable for lightweight, semi-outdoor structures of the kind that are especially desirable to create spaces that allow for safe but protected gathering in the time of Covid-19, which has, among other things, revealed the limitations of our existing buildings. Using the rhizomatic growth pattern of bamboo as a conceptual point of departure to imagine an architecture that forms an interconnected relationship between designer, inhabitants, and the natural environment, this project explores ways that bamboo could be used to create modular, deployable, kit-of-parts style structures to fill the need for expanded spaces that bridge between traditional indoor and outdoor. Designing structures out of the bamboo that grows locally in the U.S offers an opportunity for a form of design and inhabitation that is in symbiosis with

¹ Berger, “Raising Canes.”
nature and our changing environment and transforms the status of an underutilized building material.
CHAPTER 2
BACKGROUND

Bamboo in the U.S.

Many escaped bamboo species now grow wild in the United States, extending as far north as Connecticut (Figure 1). Most bamboo species now growing in the U.S. were introduced from China or South America during the 19th century. Bamboo occurs naturally on most continents. The U.S. has three species of native bamboo (genus *Arundinaria*), also called “cane,” that originated in the Southeast and which were utilized extensively for a variety of uses by native peoples of the area. Cane is a relatively small sized clumping type of bamboo, growing to a maximum of 20ft. tall and 3in. in diameter. The Department of Agriculture began importing various bamboo species, mostly of the genus *Phyllostachys*, from China at the end of the 19th century.

Figure 1: Bamboo species growing wild in the US (photographs by author)

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2 Wu Renwu et al., “A Survey on the History of the Introduction of Bamboo from China to the United States (1898-2010) and the Application of Bamboo in Urban Greening.”
and beginning of the 20th century in a campaign to promote bamboo for agricultural and manufacturing uses. Many more species have since also been imported by both private and public importers for landscaping and decorative use. Bamboo has never been fully embraced as an agricultural crop in the U.S., and most all bamboo material used for building or manufacturing currently is imported from South America or Asia. In recent years there has again been a push by some in the southern U.S. to promote bamboo growing as an agroforestry business. Bamboo species’ rapid spread and abundant success in ecosystems around the U.S. has led to a number of species being labeled as invasive. Cultural concepts around “invasive” vs. “native” plant species shape the way bamboo as a non-native plant is received and has limited its adoption as a crop in United States.

A Sustainable Material

Bamboo is a uniquely sustainable building material due to its rapid growth and ability to be harvested without killing the plant. A ‘tall statured’ member of the grass family, it puts on new shoots (culms) annually, each reaching maturity within 3-7 years, after which new culms can be harvested every year. The rapid growth and opportunity for annual harvesting makes bamboo ideal for sequestering carbon at a much more efficient rate than other vegetation. Bamboo is also very successful in growing on land previously degraded by farming or formerly built sites and can be

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3 McClure, Bamboos of the Genus Phyllostachys under Cultivation in the United States. [Electronic Resource].
4 Gray, “North America Should Be Growing Huge Swaths of Bamboo.”
5 Rebelo and Buckingham, “Bamboo.”
6 Rebelo and Buckingham.
used to restore nutrients to the soil, filter and process contaminants, improve water retention, stabilize soil, and control erosion.7

**Bamboo as a Carbon Sink**

Managed bamboo forests are one of the fastest ways to sequester large amounts of carbon and as such are being explored as a way to combat climate change. As cited by Roshan Sharma, Himlal Baral, and Jaya Wahono in their paper on bamboo as a bioenergy crop: “[A] Moso bamboo (*Phyllostachys edulis*) ecosystem can store up to 106.36 t ha−1 (34.3 t ha−1 in the above ground green vegetation and 72.2 t ha−1 on the forest floor and soil up to 60 cm in depth).”8 Some consider planting large expanses of bamboo to replace forests lost to ecosystem degradation or forest fire as an extreme but pragmatic way to deal with the looming threat of global warming.9 Though a slow growing hardwood forest will outperform bamboo in carbon sequestration over a century, most managed forests in the U.S. will never reach this age, and the fast growing quality of bamboo becomes a much more desirable trait in the urgent timeline required to prevent climate catastrophe.10 It is for these reasons, and in the interest of promoting new opportunities for rural farmers, that there is renewed interest in developing a bamboo growing industry for the U.S.

7 Sharma, Baral, and Wahono, “Bamboo as an Alternative Bioenergy Crop and Powerful Ally for Land Restoration in Indonesia.”
8 Sharma, Baral, and Wahono.
9 Gray, “North America Should Be Growing Huge Swaths of Bamboo.”
10 ibid
Agroforestry Bamboo in the US

A few companies, such as Only Moso and Resource Fiber, have begun trying to promote bamboo growing in the U.S. as an alternative revenue stream for farmers, particularly in the rural South.\(^{11}\)\(^{12}\) By offering incentives, training, assistance in containing running bamboo, and guaranteed purchase of mature culms, they hope to grow a bamboo agroforestry industry for rural communities. In addition to promoting bamboo growing to farmers, these companies are developing bamboo manufacturing facilities for various bamboo products including biochar, paper pulp, fiber, railroad ties, and laminated and composite building materials. Daphne Lewis of Bamboo Farming USA has been studying and developing farming methods and best practices for farming various species of bamboo in the U.S. as a sustainable carbon sink and in order to promote the opportunity for a U.S. bamboo industry.\(^{13}\) These projects have run up against concern about the potential for bamboo escaping plantations into the surrounding ecosystems and becoming invasive, and hesitation from farmers unsure of whether to embrace an unknown new crop and take a chance on a undeveloped industry.\(^{14}\)

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\(^{11}\) "OnlyMoso."
\(^{12}\) "Resource Fiber | Natural Fiber."
\(^{13}\) "Bamboo Farming USA."
\(^{14}\) Gray, "North America Should Be Growing Huge Swaths of Bamboo."
Bamboo as a Building Material

Building with Culms

Many countries in Asia and South America have long traditions of building with timber bamboo poles in their natural round culm form. The most desirable species for building depends on the climate, with members of the Guadua genus being primarily used in South America (where it originates), members of the Phyllostachys genus endemic to China being the primary type used for building in China and Japan, Dendrocalamus species in Bali and Indonesia, and Bambusa species in India. Large species of other genera are used regionally for building as well.\textsuperscript{15} The species most used now as the gold standard for large structures include Guadua angustifolia (max. height 30m, dia. 12cm) grown primarily in Colombia and exported around the world, Phyllostachys pubescens (or Phyllostachys edulis, aka. Moso Bamboo, max. height 21m, dia. 17cm) primarily grown in China, and the species that is being promoted for growing in the U.S.\textsuperscript{16} Because of their popularity for building, these are the species that have been studied most for their structural properties.

Preparation of Culms

Bamboo culms (the above ground portion of the plant) reach maturity usually at 3-7 years, depending on the species. At this point the tissue of the stalk becomes woody: the vertical running vascular bundles dry out and become

\textsuperscript{15} Minke et al., Building with Bamboo.
\textsuperscript{16} Minke et al.
hardened and the bamboo culm is ready to be harvested.\textsuperscript{17} This process is called lignification. To prepare harvested bamboo culms for building they at minimum need to be dried for at least four months to reduce the moisture content of the pole to the ideal 12\%.\textsuperscript{18} Dried, untreated bamboo can last up to 10-15 years in good conditions, however, further treatment is usually desired to prevent the development of mold, fungus or attack by insects. Preservation treatments include lime surface wash, treatment with borate solutions through immersion, injection, or pressure.\textsuperscript{19} Fire-retardant treatment uses the same process as that for other wood materials.

**Construction Joints**

The round profile of bamboo culms necessitates different joint connection technologies from other building materials. A variety of traditional methods have been developed using different combinations of bamboo pins and natural cord or rope lashing.\textsuperscript{20} Newer joint construction technologies utilize steel bolts, plates, and endcaps for connections (Figure 2). Filling the internode cavities with concrete allows for reinforcement at connections, and steel hose clamps cinched around the ends of the culms prevents splitting.\textsuperscript{21}

\textsuperscript{17} Minke et al.  
\textsuperscript{18} Xu et al., “Mechanical Properties of Structural Bamboo Following Immersion in Water.”  
\textsuperscript{19} Minke et al., Building with Bamboo.  
\textsuperscript{20} Disén and Clouston, “Building With Bamboo.”  
\textsuperscript{21} Minke et al., Building with Bamboo.
Laminated Bamboo Material

Laminated bamboo material, sometimes called “plybamboo” is already in common use in the U.S. for furniture, flooring, wall paneling, and other goods, due to its predictable form and dimension. At this point this material is all imported from other countries. The structural and dimensional predictability of laminated bamboo products makes it more easily accepted as a building material for the U.S. Unfortunately, life cycle assessment of the manufacture of “plybamboo” building material shows that it requires significant energy use and produces environmental contaminants affecting ecosystems and human health, placing it above concrete and traditional plywood in its impact, while staying
below PVC, steel, or aluminum.\textsuperscript{22} Plybamboo’s environmental impacts are partially offset by the carbon sequestration properties provided by the bamboo material itself. The life cycle assessment of laminated plybamboo points toward a need to develop ways to use bamboo as a material in its natural form and utilize its unique characteristics: its round cross-section, segmented length, natural taper, high strength, and flexibility.

**Structural Qualities of Bamboo**

Bamboo culms have a hollow tube structure, with periodic nodes which resist buckling and perpendicular wind loads on the growing plant\textsuperscript{23} (Figure 3).

\textit{Figure 3: Physical characteristics of the bamboo plant}

\textsuperscript{22} Chang et al., “Environmental Benefit of Utilizing Bamboo Material Based on Life Cycle Assessment.”

\textsuperscript{23} Minke et al., Building with Bamboo.
Strong longitudinal cellulose fibers of the culm wall make up its primary structure. The culm as a whole tapers gradually along its length towards the top of the shoot. The diameter of the culm as well as the wall thickness are greatest at the bottom, however, a higher percentage of starch in the upper portion of the plant balance out the narrower diameter and makes for relatively uniform strength and mechanical properties along its length.

Bamboo is known for being flexible and having a very high strength to weight ratio. Its longitudinal fibers make it particularly strong in tension and compression along its long axis with strengths approaching that of steel. The nodes along its length function as diaphragms that brace against buckling and make bamboo strong in bending while still being light and flexible. This flexible but strong quality is what makes bamboo a particularly desirable material for resisting earthquakes. Bamboo has relatively low strength in resisting shear and tension forces perpendicular to its long axis and it is prone to splitting. This has led to the development of different methods of reinforcing connections to prevent splitting or buckling at joints. Many different unique joint designs have also been thoroughly tested for their mechanical properties.

The most mechanical testing for building has been carried out on the South American Guadua angustifolia species. Other large timber bamboos have

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24 Xu et al., “Mechanical Properties of Structural Bamboo Following Immersion in Water.”
26 Minke et al., Building with Bamboo.
27 Disén and Clouston, “Building With Bamboo.”
28 Disén and Clouston.
been researched as well. Because each species has unique characteristics of strength, dimension, and growth characteristics, unique testing on each timber bamboo species must be carried out in order to establish its mechanical properties.

Building with Bamboo in the US

While other countries, particularly in Asia and South America, have developed codes for regulating building with bamboo, the International Code Council has not incorporated bamboo into its codes. Bamboo as a structural material is currently not accepted by code in the U.S., which has prevented the design and construction of bamboo structures. Efforts have been made to change this, however. In 2004 the International Network of Bamboo and Rattans (INBAR) developed two International Standard Organization (ISO) standards: ISO 22156 – ‘Bamboo structural design’ and ISO 22157 – ‘Determination of physical and mechanical properties’ in an effort to get bamboo approved for use in building.  

Additionally, a company called Bamboo Living based in Hawaii that specializes in prefabricated bamboo houses has gotten approval through a Special Evaluation Service Report of the ICC to build its bamboo designs in the U.S.  

The Report specifically approves the use of *Bambusa stenostachya* poles grown in Vietnam for use as structural elements and lays out the standards and

29 Disén and Clouston.  
30 “Bamboo Living.”
requirements for their use. As such, this is currently the only use of structural bamboo in the U.S. accepted by code.

Working with the Existing Bamboos of the US

While a number of people are already working on the acceptance of bamboo as a building material for the U.S. through the traditional economic and regulatory pathways, this project aims to explore a different opportunity presented by the bamboos that are already growing wild or semi-wild here in the U.S. Introduced in parks and people’s back yards, many species have become naturalized and offer an underutilized opportunity as a building material. Species of many sizes and genera can be found growing frequently throughout the U.S. The relative ease of harvesting and processing makes bamboo an ideal locally foraged material that could be deployed in lightweight semi-outdoor structures in a decentralized manner.

It is from this viewpoint that this project approaches the opportunity presented by introduced bamboo species growing wild in the U.S. As climate change increasingly ravages historic ecosystem species, bamboo will continue to thrive in many areas of the U.S. The already abundant resource of introduced bamboos offers a potential source of renewable building material. Given the existence of these localized bamboo species, what are the ways that this material could be utilized in our built environments? Could lightweight bamboo structures be used to expand classrooms outside the traditional school
envelope? An envelope that has proven to be all too restrictive in light of the Covid-19 pandemic.
CHAPTER 3
LITERATURE REVIEW

Bamboo and Invasiveness

The term “invasive” used to define bamboo species has shaped the way the plant is viewed in the U.S. and limited how it is grown or utilized. A number of states list bamboo species as invasive in their ecosystems, and some areas even have legislation limiting the planting of specific bamboo species identified as invasive.³¹ The most widespread bamboo species categorized as invasive in the U.S. is Phyllostachys Aurea, a tall, thin species commonly known as ‘Golden’ or ‘Fishpole’ bamboo, which is seen often along roads or in other disturbed soil areas throughout the U.S. and was first introduced from China to Alabama in 1882.³²

Invasive Species as a Novel Ecosystem

The prevalence of wild occurring introduced bamboos growing in the U.S. has transformed existing ecosystems. Ecologists call ecosystems such as these, which have rapidly transformed due to introduced species, extinction, or changed abiotic conditions from human pollution or other activities “novel ecosystems.”³³ Novel ecosystems are documented developing at a rapidly increasing rate as

³¹ Prohibited and Regulated Invasive Species.
³² Wu Renwu et al., “A Survey on the History of the Introduction of Bamboo from China to the United States (1898-2010) and the Application of Bamboo in Urban Greening.”
³³ Hobbs, Higgs, and Harris, “Novel Ecosystems.”
human impact and intervention in ecosystems expands, along with human introduction of species into new areas, and environmental alterations due to climate change.\textsuperscript{34}

The rapid development of these novel ecosystems and the degree of transformation that has occurred means that restoration to previous forms of ecosystems is infeasible or even impossible. Some ecologists now argue that restoration efforts should be evaluated based on their likely success and the current merits of the novel ecosystem, not just based solely on the assumption that the historical ecosystem is best.\textsuperscript{35} This has also called in to question the traditional notions of “invasive” or “alien” species as no longer useful categorizations.\textsuperscript{36} These are culturally derived ideas that do not reflect the role of the species within an ecosystem or their larger impact. A simple designation of historical ecosystems as “better” than novel ecosystems does not take into account the actual contributions of “invasive” species within the current ecosystem and to human economies. It also disregards the reality that many other changes to the ecosystem environment may have made it uninhabitable to previous species and in turn more suitable to well-adapted introduced species, and ignores the fact that change is a fundamental characteristic of ecosystems.\textsuperscript{37,38}

\textsuperscript{34} Hobbs, Higgs, and Harris.
\textsuperscript{35} Hobbs, Higgs, and Harris.
\textsuperscript{36} Davis et al., “Don’t Judge Species on Their Origins.”
\textsuperscript{37} Hobbs, Higgs, and Harris, “Novel Ecosystems.”
\textsuperscript{38} Davis et al., “Don’t Judge Species on Their Origins.”
The Myth of Untouched Nature

William Cronon further explores this idea of cultural conceptualization of nature and how it shapes the ways “wildness” is valued. He traces the origin of the desire for untouched ecosystems, or pure wilderness without human intervention, to the Romantic period of landscape design and painting in the 1700s. These values were then utilized by early environmentalists in the U.S. during the 1800s to create a false myth of an untouched American wilderness that supposedly existed before European settlers, which they argued needed protection, giving birth to the national park system.\(^{39}\) The reality was that the ecosystems of the U.S. had already been shaped and altered by native peoples and by farming by European settlers over the last century as well. Cronon argues that these ideas about wilderness and untouched nature still influence contemporary environmentalism and affect attitudes and policies around ecological restoration and ecosystem management that are no longer practical or useful in light of our rapidly changing environment.\(^{40}\) The status of bamboo in the U.S. is affected by the idea of the primacy of untouched ecosystems and for this reason the primary concern from an environmental standpoint has been its eradication rather than appreciation for its positive carbon impacts or material use.

\(^{39}\) Cronon, “The Trouble with Wilderness; or, Getting Back To The Wrong Nature.”
\(^{40}\) Cronon.
Novel Ecosystems as an Opportunity

Peter Del Tredici documents how introduced plant species occurring in novel ecosystems, such as bamboo, reflect a natural adaptation that has allowed them to thrive in ecosystems undergoing transformation due to human settlement, climate change, or a combination of both. He argues that “environmental stability is an illusion” and that “an unpredictable future belongs to the best adapted.” He argues for the study of these species to understand their values within the ecosystem and how species will adapt to increasing changes in the environment due to climate change. He identifies the border of human settlement as a productive space of ecological adaptation that could produce the ecosystem resiliency required for a warming planet. This thesis takes on this challenge by evaluating and proposing possible architectural uses for the bamboos of the U.S.

Rhizome Growth Patterns

Bamboo is one such plant that has proven particularly well adapted to human and climate change affected ecosystems. As a member of the larger grass family Poaceae or Gramineae, it is characterized, among other things, by its rhizomatic growth pattern. Rhizomatic plants send out underground offshoots

41 Del Tredici, “The Flora of the Future.”
42 Del Tredici Peter, “Spontaneous Urban Vegetation.”
that send up new above ground shoots along their path creating wide spreading networks. Any portion of the rhizome network, when severed from the whole, will continue to flourish independently and send out new self-propagating rhizomes. This spreading pattern that creates abundant lateral offshoot clones that can function as individual plants and exponentially reproduce themselves, is the mechanism of bamboo's success in challenging environments and its invasiveness within ecosystems.

Literature addressing the invasive characteristics of bamboo subdivides species into two different categories based on spreading pattern: either running or clumping (Figure 4). Both types are rhizomatic. Running bamboos send out an underground rhizome “runner,” an underground stem, from which new culms (aerial shoots) emerge along its length, allowing for faster lateral spreading that enables quick propagation and spread, sometimes crowding out other species in

**Figure 4:** Running vs. clumping rhizomatic growth
an ecosystem.\textsuperscript{43} The clumping types develop rhizomes which branch off of each other directly, each one sending up its own culm, causing a densely matted radial pattern that is slower spreading and sometimes self-limiting at a maximum footprint. The bamboo species that are considered invasive in the U.S. are exclusively running varieties.

\textbf{The Rhizome}

Deleuze and Guattari, in the introduction to their 1988 work \textit{A Thousand Plateaus}, draw on the metaphor of the rhizome to describe the organization of their book and to propose a new system of thought that is in opposition to the traditional “arborescent” or tree structure that permeates Western tradition, with its focus on duality, binaries, and hierarchies. Deleuze and Guattari associate this form of thought with the typical tree root system consisting of a main tap root from which all others branch off of in a hierarchical system of sub-roots:

> Arborescent systems are hierarchical systems with centers of significance and subjectification, central automata like organized memories. In the corresponding models, an element only receives information from a higher unit, and only receives a subjective affection along preestablished paths.\textsuperscript{44}

They emphasize the limitations of this form of knowledge creation. Brent Adkins elaborates on how the tree-form is self-limiting and anti creative: “…insisting that everything conform to a pre-existing idea reproduces that pre-existing idea ad infinitum. These arborescent principles see only trees and reproduce only

\textsuperscript{43} Buziquia et al., “Impacts of Bamboo Spreading.”
\textsuperscript{44} Deleuze and Guattari, “Introduction: Rhizome.” 16
trees…” In contrast to the “arboreal” tradition, Deleuze and Guattari offer the pattern of the rhizome described as “acentered systems, finite networks of automata in which communication runs from any neighbor to any other,” as an open and expanding form instead of the self-limiting hierarchy of the tree (Figure 5). To clarify they create a list of characteristics as principles that describe the system of the rhizome:

1. Principles of connection and heterogeneity: any point of a rhizome can be connected to anything other, and must be...

2. Principle of multiplicity: it is only when the multiple is effectively treated as a substantive, “multiplicity,” that it ceases to have any relation to the One as subject or object, natural or spiritual reality, image and world….

3. Principle of asignifying rupture: against the oversignifying breaks separating structure or cutting across a single structure. A rhizome may be broken, shattered at a given spot, but it will start up again on one of its old lines, or on new lines.

Figure 5: Rhizome patterns

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45 Adkins, Deleuze and Guattari’s A Thousand Plateaus, 11.
46 Deleuze and Guattari, “Introduction: Rhizome.” 17
5 and 6. Principle of cartography and decalcomania: a rhizome is not amenable to any structural or generative model. It is a stranger to any idea of genetic axis or deep structure.\(^{47}\)

They see the inherent characteristics of the rhizome as a structure that resists any overarching organization. Its multiple nodes, which function neither as individuals nor as one larger whole, work against the traditional subject/object duality and allow it to be split anywhere but continue to grow and send out new offshoots. Deleuze and Guattari extrapolate this rhizomic nature far beyond the root structures of plants, likening it to the form and function of the brain, the relationship between the wasp and orchid that have coevolved together to be indistinguishable to each other, and the genetic intermingling between humans and other species. They emphasize the impact of the rhizomatic relationship between humans and the DNA manipulations of viruses: “we evolve and die more from our polymorphous and rhizomatic flus than from hereditary diseases, or diseases that have their own line of descent.”\(^{48}\) The rhizome space is generative and transformative, forming a pattern that is non-hierarchical and extensive: “The rhizome is any network of things brought into contact with one another, functioning as an assemblage machine for new affects, new concepts, new bodies, new thoughts….\(^{49}\) The rhizomatic form of thinking is freed of the constraints of rules and traditions: “[Deleuze and Guattari] offer the reader an open system of thought.”\(^{50}\)

\(^{47}\) Deleuze and Guattari. 7-12
\(^{48}\) Deleuze and Guattari, 11.
\(^{49}\) Parr, The Deleuze Dictionary, 232.
\(^{50}\) Parr, 232
The Rhizome for Architecture

The idea of the rhizome as described by Deleuze and Guattari offers a lot to architectural thinking on a number of different levels: how the component parts of a project work together to form an interdependent whole, on the level of materials and joints, spatial organization of the program, and the relationship of the project to the larger urban space, landscape, and ecosystem. Outside of the formal and tectonic it suggests a new way of thinking about the relationship between the architect, the inhabitant, and the many other actors that are a part of the rhizome of an architectural project.

Anna Querrien draws out these rhizomatic connections in conversation with the architects Doina Petrescu and Constantin Petcou of atelier d’architecture autogérée (studio of self-managed architecture). The mandate of their practice is overtly rhizomatic: “The aim was to create a network of self-managed projects and to appropriate and transform temporary, available and underused spaces.”

They elaborate on this speaking specifically on their project R-Urban, a community garden and gathering space for the neighborhood of Colombes near Paris, where they dig into what makes an architecture project successfully rhizomatic. The project is conceptualized as open and participatory and intended to be appropriated, transformed, and repropagated by its inhabitants: “In our projects we preserve the possibility for space to evolve with its users; our

51 Querrien, Petcou, and Petrescu, “Making a Rhizome, or Architecture after Deleuze and Guattari,” 262.
projects involve forms of minimal intervention, remaining in this way open, indeterminate, adaptable and transformable in time by new users.”

Over the course of the project a network is formed out of the participation of the local community and gradually the responsibility for maintaining and creating the space passes from the architects to the users. “Through our work we participate in the identification of social-spatial entities in formation, which transform continually into new networks. We are, if you like, the ‘gardeners of the rhizome,’ but we pass on this role, little by little, to other users who wish to become stakeholders.”

The architect sets the project in motion, but ultimately does not control its outcome: “The aaa team has a role to play here as catalyst. Particularly with respect to our approach, which is to transmit the role of catalyst to others.”

The rhizomatic project develops a life of its own through the communal effort “Making a rhizome, as an alternative approach to architecture, is a way of constructing the infrastructure of a common territory, the infrastructure of commons.”

Anna Querrien, Doina Petrescu, and Constantin Petcou do acknowledge the contradiction of receiving state funding that brings requirements and expectations for a rhizomatic community-based project that is supposed to be outside of this form of top-down control. They argue that to counteract the regulating power structure of government funding, “Things need to be co-

52 Querrien, Petcou, and Petrescu, 268.
53 Ibid., 266.
54 Ibid., 270.
55 Ibid., 266.
produced without explanation or request for approval,\textsuperscript{56} and that the radical form of extended participatory practice that they themselves partake in with locals on the site is essential to creating the living network of the project. Through this the process becomes “no longer about trying to impose order over space, or about creating a hierarchy within living spaces, but about retrofitting in a way that dismantles hierarchies.”\textsuperscript{57} Success for them is when a project has grown so far as to have spawned independently created imitation projects that expand the network further becoming self-replicating in the nature of a successful rhizome, as they have witnessed with their ECOBox 200m\textsuperscript{2} micro urban garden project. This project also aims to become a self-propogating network, and as such this rhizomatic framework would be its measure of success.

**Biomimetics**

Using the forms or systems of the natural world—such as the rhizome—to inform design and technology is the particular focus of the study of biomimetics or biomimicry. The term was first coined in 1997 by Janine Benyus in her book *Biomimicry: Innovation Inspired by Nature*. She outlined the three principles of biomimicry as:

1. *Nature as model*. Biomimicry is a new science that studies nature’s models and then imitates or takes inspiration from these designs and processes to solve human problems.

2. *Nature as measure*. Biomimicry uses an ecological standard to judge the “rightness” of our innovations.

\textsuperscript{56} Querrien, Petcou, and Petrescu, 266.

\textsuperscript{57} Ibid., 270.
3. *Nature as mentor.* Biomimicry is a new way of viewing and valuing nature. She lays out a manifesto of a new methodology of technology development that utilizes the forms, systems, and strategies of the natural world and is thereby ecologically based rather than extractive. She proposes studying the mechanisms of biological systems to inform new technologies and pulls together examples of this form of innovating already occurring. Benyus suggests that nature could serve as a productive model on both the level of individual product or material, such as photosynthesis of plants as a model for photovoltaics, or the microscopic study of grappling hooks on seeds as the inspiration for Velcro, but also on an ecosystem level understanding how multiple systems work in concert to thrive efficiently as a whole. While the ideas are inspiring, the models she presents are relatively literal in their translation of form or function from nature and her focus is particularly on the technological. By focusing intensely on the relationship between humans and nature, a human vs. nature dichotomy is reinforced, and the entangled codependencies already in existence between humans and nature are disregarded or possibly considered only “extractive,” in opposition to the idea of the rhizome structures of humans being in the world as imagined by Deleuze and Guattari and reinforcing the romanticized “pure nature” myth as argued against by William Cronon and Peter del Tredici. However, when approached in light of these other contexts, biomimetics offers an interesting

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58 Benyus, Biomimicry.
opportunity as an approach to an architectural project based on a specific natural material.

**Biomimicry In Architecture**

A number of people have written about the application of the concept of biomimicry to architectural design. Biomimetic design is seen as an opportunity to discover novel solutions to design problems, particularly more ecological and efficient solutions: “Biological organisms can be seen as embodying technologies that are equivalent to those invented by humans, and in many cases they have solved the same problems with a far greater economy of means.” In this way biomimicry has become a particular focus of sustainable design technologies in architecture.

Michael Pawlyn in his book *Biomimicry in Architecture* clarifies biomimicry as distinctive from other forms of bio-affiliated design practices in architecture. He defines “bio-utilization” as the “direct use of nature for beneficial purposes” using trees or shrubs for shading or wind break for example, “Biophilia” as first defined by E.O. Wilson as the “instinctive bond between human being and other living organisms,” and “Biomorphism” as a mimicking or translation of natural *forms* specifically to inspire architectural form. In contrast he defines biomimicry as a deeper study of the larger patterns and systems of nature where, “the intentions is…to transcend the mimicking of natural forms and attempt to understand the

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59 Pawlyn, Biomimicry In Architecture, 1.
60 Pawlyn, 2.
principles that lie behind those forms and systems.”

Then these principles can be used to find solutions to architectural problems. Julian Vincent delves further into the mechanics of how biomimetic knowledge is translated from nature into a design application in “Biomimetic Patterns in Architectural Design.” He says the key is abstraction: “The more abstract the derivation, the more one relies on the recognition of pattern in the data rather than the shapes of physical objects….

Abstraction thus simplifies technology transfer by emphasizing the main principles to be used, and so makes the technology more powerful and pervasive….” This abstraction allows for the translation of principles from nature to other applications and Vincent classifies this as happening at three different levels: the first level as a direct copying in form or function to a different scale or material, the second level recognizes patterns or systems and applies them in different contexts, and the third as answering the question “What did I want to improve and what was stopping me making that improvement?”

This third level offers a way of imagining solutions outside of the usual frameworks or traditionally excepted limitations or methodologies and seems to ask for the rhizomatic form of thinking that Deleuze and Guattari propose that allows any idea to connect organically to another and form an offshoot. Vincent suggests the method to do this is to focus not on how something (technologically) will be

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61 Pawlyn, 2.
62 Vincent, “Biometric Patterns in Architectural Design.”
63 Ibid., 76.
64 Ibid., 81.
achieved, but instead on the ideal result in terms of function and then analyze all possible resources in relation to this desired outcome.65

While the methodologies that Pawlyn and Vincent are outlining certainly have a lot to offer, the application that seems to be imagined by them is still technologically focused and is primarily being imagined solving problems of sustainability or structure. Their thinking does not seem to incorporate human use and social interaction into the systems or bio-inspired buildings they imagine, that would in reality be connecting into a larger human context.

**Bamboo Architecture as a Symbiosis with Nature**

Y.M. Solanilla and D.V. Mamchenkov explore the idea of incorporating humans into the larger ecosystem exchange with a form of biomimetic design in their paper “The Organic Technique: The Formation of a New Type of Human–Technique–Nature Relationship as Exemplified in Bamboo Construction.” They specifically characterize building with bamboo as an opportunity for a new technological relationship between humans and nature that they term “the organic technique,” similar to what others term biomimetics, arguing that we should be “designing technical devices based on the possibilities of nature and the logic of technological progress… Construction of bamboo buildings can become the prototype for a new type of relationship between humans and technology.”66 They identify the sustainable and resilient qualities of bamboo

65 Vincent, 81.
66 Benyus, Biomimicry.
material as being particularly suited to the pressing environmental concerns of the future. As a unique natural material, bamboo resists the trend toward regularization that characterizes building material technology, and thereby building designs, and instead requires new adaptive ways of building in collaboration with each species and each culm’s individual characteristics.

Solanilla and Mamchenkov continue:

In the new architecture of bamboo constructions, we are witnessing the emergence of an innovative approach to the relationship between humans, nature and technology. Here, humans cease to take away natural resources in order to then impose them on nature in a revised form. Instead, humans adapt to the possibilities of nature, based on the characteristics of the material, to design buildings and merge them with the surrounding landscape.\(^67\)

Their proposal highlights the relationship between human design and a natural building material as an opportunity for a transformed practice that is symbiotic with nature through new technologies, and in this way does not just pull inspiration from nature to apply elsewhere but learns from and designs with nature.

**Symbiosis: Biodigital & Organic Technique**

Dennis Dollens further incorporates the idea of merging technology, specifically digital design, into the idea of biomimetic architecture. He creates digital forms out of generative patterns and systems taken from nature to create what he calls “biodigital” designs. Writing about his work he describes a new type

\(^67\) Solanilla Medina and Mamchenkov.
of digitally created architecture that is both a translation and an extension of nature:

Information from plant and animal morphology, algorithms and biochemistry mediated through the designer’s vision and mediated again through software and digital fabrication is creating a species of biomimetic ideas that index nature while propelling design and architecture into the living, organic world.68

This is a much more interconnected and rhizomatic form of biomimetic design than imagined by Janine Benyus, Michael Pawlyn, or Julian Vincent. Dennis Dollens specifically writes about the differentiation of human created spaces from “nature” as a false separation that inhibits the design process, that “in our stereotyped view of nature, which excludes places like concrete jungles and reclaimed coastlines, we make the mistake of further alienating ourselves from nature.”69 This resonates also with the work of Peter Del Tredici studying the resilient and adaptive qualities of urban plant species, and William Cronon writing about the false notion of untouched wilderness versus human landscape. Dollens takes his proposal a step further, imagining hybrid buildings of bio-prosthetics, “an appropriation and colonization of nature different from anything that has come before, placing emphasis on hybridized buildings with biomechanical and biological systems” that he suggests would be the built equivalent of Donna Haraway’s cyborg.70 This proposition is exciting because it expands the scope of the biomimetic project not just to incorporate the human social ecosystem, but

69 Ibid., 417.
70 Ibid., 419
also the digital space that is intermeshed with our human and biological environment.
CHAPTER 4

PRECEDENTS

In the process of converting theoretical research into architectural application, analysis of projects that address similar ideas—whether in materiality, technology, program, relationship to users, or to environmental context—becomes particularly important. This thesis considers four precedents that relate to particular aspects of this project and subsequently inform the design of the bamboo construction system and case study application.

**Buckminster Fuller**

Buckminster Fuller’s fervent search to find the minimum structure to volume enclosure resonates with sustainable design principles of material efficiency and resulted in structures that lend themselves to the introduction of bamboo material. For this reason, many bamboo structures are clearly identifiable as falling within the Fuller tradition (for example see the ETH Zurich Digital Bamboo Pavilion discussed below). Fuller’s work is particularly applicable to this project for the connection he made between lightweight architecture, deployability, and disaster relief, as well as his exploration of the separation of enclosure and program.
The Dymaxion Deployment Unit

An early iteration of Fuller’s Dymaxion House project called the Dymaxion Deployment Unit (or DDU) was designed in 1940 as deployable emergency housing for people displaced by the bombing of British cities during WWII. The round steel structures reminiscent of grain silos produced in collaboration with Butler Manufacturing Company, were designed to be additive, with multiple combining through portal doors into a single larger unit. They became popular with the US army and were used as deployable military structures throughout the war, though they never achieved the universal civilian application that Fuller had imagined.

With his Dymaxion Deployment Unit Fuller made the connection between mass-production, the military idea of deployability, and disaster relief, particularly for housing. This type of design has become more and more relevant as climate change has contributed to increasing displacement and with the current need for adapted spaces in response to the global Covid-19 pandemic. The Dymaxian Deployment Unit is relevant to this project as an early conceptualization of emergency response architecture. While Fuller was envisioning his design as fully prefabricated units shipped as a whole to the site, the ability to conglomerate a string of individual units into one larger building allows for a modular design that adapts to many different applications. Over time the concept was proposed as a solution to a number of different scenarios, starting with its design as war-

71 Gorman, Buckminster Fuller: Designing for Mobility, 65
72 Fuller, Hays, and Miller, Buckminster Fuller, 217
time emergency civilian housing, to military deployment buildings, to its later version as post-war low income prefabricated housing through the Wichita House concept, revealing Fuller’s interest in designing a basic unit that could be applied across a variety of situations.

The Standard of Living Package

Another proposal, Buckminster Fuller’s “Standard of Living Package,” imagined a new form of the pre-manufactured house that was shipped in parts for on-site assembly. This concept, developed with students of the University of Chicago in 1948, was designed to include all of the required amenities of a 3 bedroom house fit into a trailer that could be shipped to the site with the shipping box folding out to be the floor and an enclosing geodesic dome system built over top (Figure 6). While many architects of the WWII industrial era where exploring prefabricated housing, the Standard of Living Package is interesting for its separation of program and enclosure and its proposal of a radically different way of living.

In Fuller’s home, the enclosing envelope structure is separated from the interior

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73 Gorman, *Buckminster Fuller: Designing for Mobility*, 106
living spaces, breaking down the building into its basic architectural elements and thereby highlighting their unique functions: the exterior envelope is what creates the ‘bubble’ separating the inside living space from the outside environment. It also creates a universal system in which the living spaces can be modified to suit the individual requirements of the users. The prefabrication aspect is imagined as a combination of mass-produced parts, furniture, and appliances, with simple on-site assembly.

Underlying the designs of both the Dymaxion Deployment Unit and the Standard of Living Package is a concept of accessible modularity and mobility. Developed in response to the housing crises of WWII and the immediate post-war era, Fuller conceived of portable, disaster relief forms of housing for displaced families. The idea of easy, low skill on site assembly from a prefabricated system is pertinent to this project. The separation of enclosure from interior elements allows for a concept that can adapt to varying degrees of investment and permanence, whether it is a temporary covering structure to enable social distancing of students at a school entrance, an informal outdoor gathering space to supplement indoor curriculum, or a fully outfitted outdoor classroom intended to replace indoor learning.

**Digital Bamboo Pavilion by Students of ETH Zurich**

A contemporary precedent, the Digital Bamboo pavilion (2020), designed and built by students of the Digital Building Technologies department of ETH Zurich is interesting for its use of cutting-edge technology to address the
challenges of working with bamboo material. The 9m x 9m x 5m tall project includes 379 3D printed fixed joint connections pre-designed to join 900 individual pieces of bamboo\(^7\) (Figure 7). The joints consist of a central hub that fixes the angles of the bamboo members and separate standardized connection pieces that snap closed connecting the bamboo to the joint. Consisting of three space-truss columns supporting three wing-like projections, the pavilion is designed to be as materially efficient as possible, weighing only 200kg in total.\(^5\)

The shade material was also digitally fabricated “through add-on 3D printing of a recyclable UV resistant thermoplastic on a lightweight lycra textile.”\(^6\) This project represents a particularly technologically innovative form of the “Organic Technique” as imagined by Y.M. Solanilla and D.V. Mamchenkov, in which digital fabrication is used to respond to the natural irregularity of bamboo and to celebrate its inherent lightness and strength. The lightness of the structure and

\(^{7}\) “Digital Bamboo.”
\(^{5}\) Ibid.
\(^{6}\) Ibid.
the prefabricated parts also mean that it can be easily and quickly assembled and dis-assembled with minimal skill required, making it an easily deployable design. While the parts may be applicable to other designs, the Digital Bamboo pavilion has been intricately predesigned with each 3D printed part addressing a specific application within the structure, rather than being an open, modular and adaptable system that could create a range of shapes and structures. The nature of the joint system also requires particularly straight pieces of bamboo at specific diameters and does not incorporate tolerance for material irregularities.

The Digital Bamboo pavilion is informative for this project for its innovative use of 3D printing technology in combination with bamboo as a way to use the material to its best ability. The design of parts to have a clarity of function that allows for both assembly and dis-assembly without requiring specialized skill is inspirational in the idea that the parts themselves can serve as instructions for their use. Splitting the joints into two parts: the unique hubs that set the angles of a specific joint, and universal connector pieces to join the bamboo to the hub is a clever example of modularity at the level of the most basic elements of the system.

MoMA PS1: Canopy by nArchitects

An example of a bamboo structure project in the United States, Canopy (2004), was designed by nArchitects as an 11,000sf seasonal bamboo installation for the MoMA PS1 courtyard summer music series.\textsuperscript{77} An undulating

\textsuperscript{77} “Canopy MoMA/P.S.1 NARCHITECTS.”
mesh made of thin green bamboo poles shipped from Georgia create an interactive environment incorporating a wading pool, fog cloud, and ‘sand hump.’ As described by nArchitects, “The project relied on a singular tectonic system to bind together provisions for overhead shade, structure and varying atmospheres, resulting in a ‘deep landscape’ that affects the entire depth of the courtyard.” This project is interesting as a precedent particularly for its use of invasive species of bamboo grown in the US to build the structure. nArchitects used 1,400 pieces of Phyllostachys Aurea bamboo, the species most commonly labeled as invasive in the US, from Dudley, Georgia. This project can be seen as a test case for US sourced bamboo being used to construct outdoor structures. It is also inspirational for its approach to landscape and its interaction with the existing site and structures. The woven grid-shell of bamboo engages with the existing buildings and flows over the courtyard walls creating a series of outdoor rooms. The project also incorporates a sense of playfulness and movement with its 3-dimensional waves and subtle screening, as well as with water, fog, sand, and greenery elements dotted throughout.

**The Living Room by Students of Mississippi State University**

The Living Room (2020) is an educational project precedent. It is a proposal by students of Mississippi State University for a school garden and outdoor education system that is modular and adaptable to different locations.

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78 “MoMA PS1: Canopy.”
79 Ibid.
80 Ibid.
Initially envisioned to address the need for fresh local food for students in a food desert, the project expanded into a curriculum that incorporated outdoor learning covering many other subjects including time, color, math, biology, and seasons.\textsuperscript{81} The design consists of central round garden beds divided into individual student workstations.\textsuperscript{82} Arching steel poles radiate out from the center and create an enclosure defined on its far edge by a curved bench (Figure 8). The radial pattern of the basic classroom unit allows it to be chopped up into 90° segments and combined in repeated units for a variety of different site layouts and numbers of students making for an adaptable modular design that can be applied to different sites, scales, and contexts. The different arrangements of units can also be used to direct and regulate the flow of students through the site.\textsuperscript{83} The project team

\textit{Figure 8: The Living Room - basic unit and different arrangements of segments}

\textsuperscript{81} Mississippi State University, “The LivingRoom: A Freeware Learning Garden Focused on Health, Food, and Nutrition Education.”
\textsuperscript{82} Ibid.
\textsuperscript{83} Ibid.
used a case study format to explore in detail a specific application of their system and as a proof-of-concept for the design.

The Living Room project connects students to the natural environment and creates a pedagogy of outdoor learning, but limits its environmental engagement to its program, not its materiality or structure. In its adaptability and deployability it imagines a rhizomatic form of project that could be co-opted and reconfigured by users in the manner described by Constantin Petcou and Doina Petrescu. It can be used to create endless iterations of site plans but as of yet it has been imagined as freestanding—its engagement limited to the existing open areas around a school, not interacting directly with existing buildings or structures. It is also a great precedent for this project in that it illustrates the case study as a method for testing out a predesigned modular system. Through the process of applying the system to a concrete site and program through a proof-of-concept project, the practical details of the design can be worked out, the efficacy of the proposed system is established, and the range of modular possibilities can be demonstrated.
CHAPTER 5
DESIGN PROJECT

This thesis project comprises two parts: (1) the design of a system for building lightweight, transformable structures out of the wild growing bamboos of the US that incorporates the principles of modularity, deployability, and simplicity of construction as well as accommodates the natural irregularity of bamboo material; and (2) a case study application of that system to transform an existing school in response to the safety guidelines of Covid-19 for schools and to propose an ongoing outdoor education program.

The System

The specific US context informed the parameters for designing the system for building with the naturalized bamboos of the US. The species that have naturalized into US ecosystems are primarily mid-sized species that commonly range in diameter from .75-4 inches. The size of available bamboo material determines the scale of structures that can be produced, while the system of joints must have both the tolerance to accommodate a range of diameters and the flexibility to incorporate the natural irregularity of bamboo poles that may not grow perfectly straight, may have kinks at the nodes, and that taper over their length (Figure 9). In order to be a successfully rhizomatic system that can be built, modified, and appropriated by users, the joint based construction must be easy to use and functionally legible.
Figure 9: Principle of system flexibility & tolerance

Physical Modeling For Form

Initial investigations into developing the building system began with an exploration of working with bamboo as a material through a series of physical models. The scale of the material lends itself to rhythm and repetition, while its flexibility offers the opportunity for curved forms. The round profile suggests rounded or radial forms. Splitting the bamboo poles along their length creates semi-rectangular profiles that simplify the joints or can be woven together. Bunches of smaller bamboo poles can be grouped together to create larger columns (Figure 10).
A series of prompts was used to explore the range of forms of building with bamboo (Figure 11):

1. Two-way grid shell
2. One-way grid shell
3. Fountain columns (center – out)
4. Outward – in (with a counterweight)
5. Traditional bamboo scaffolding
6. Umbrella construction
7. Spine + ribs
8. Fabric wings in tension
Certain challenges emerged from this investigation: bending the bamboo caused some pieces to break at weak points in the individual piece of material. Woven or irregular grid shell forms were more challenging to build and control the form of and bound joints have a tendency to slip. The scale of the material means that for structures that use the spacing of the bamboo to create the space enclosure the quantity of joint connections increases quickly. These different models for
building with bamboo were evaluated for the ease of construction and opportunity for modularity and adaptability. The concept of umbrella construction was selected for further development due to the combination of simplicity and flexibility (Figure 12). This system is characterized by repeated frames made by joining lengths of bamboo at given angles to create braced arch forms. The individual pieces of bamboo can slide through the joints to shorten or extend, and the frames can rotate in plan creating a system of bamboo construction that is open ended and flexible, while still adhering to certain rules and characteristics to produce a distinctive language of forms. The systems allows for both standalone constructions or attachment to an existing structure. By limiting the material to

Figure 12: Further exploration of umbrella construction form
straight lengths of bamboo the system relies on the design of the joints to produce its forms and assures that the simplicity of construction is built into the design.

**Design of Joints**

The key to bamboo construction is the joints, since the round hollow profile of the material presents unique challenges when compared to traditional lumber. The US does not have a tradition of bamboo craft, so the design of the system must be simple and intuitive, relying on the design of the parts instead of requiring skilled carving and fitting of joints. As such, the characteristics of the system are defined by the design of the joints. The basic strategy is a steel tube joint incorporating a cinch which allows for a range of diameters to be tightly secured. An optional screw drilled through the joint pins the bamboo in place to resist slippage at joints that may be under increased tension. The primary connection that defines the system is the variable angle joint that incorporates a set of holes drilled so that the joint can be rotated and bolted in a set series of different angles (15°, 30°, 60°, 90°) (Figure 13). The curved partial tube form holds the bamboo pole in line with the angle of the joint while the cinch secures it in place without requiring a specific diameter of bamboo. By loosening the cinch, the bamboo pole can slide through the joint to allow for easy adjustments during construction and a range of different extension lengths to create a variety of forms, accommodate material irregularities, and attach to existing infrastructure.
or buildings. Allowing the ends of the bamboo poles to float free relieves the

required exactitude of an end-to-end connection, further enhancing the system's flexibility and tolerance for variability in the material. Being predesigned and prefabricated ensures the simplicity of construction for anyone to use with limited required skill or pre-existing experience or knowledge. A 3D printed version of this joint provided proof of concept for this system (Figure 14).

*Figure 13: Variable angle joint*
A catalogue of other joints and attachments round out the rest of the bamboo building system. A set of different bases are designed for a single pole, a plate that connects a set of poles arrayed in series, and a multi-pole base for a centralized group (Figure 15). The bases are designed to be attached to existing slabs or heavy furniture to ballast the constructions, while a wall attachment joint is designed to attach to the surfaces of existing buildings or
structures (Figure 16). All of these joints utilize the basic metal tube + cinch with optional pin design. A central hub joint allows a group of poles to be joined in a radiating formation (Figure 17). Rotating cinches on pins attached to the central hub allow the bamboo poles to radiate out at any required angle. A cross bracing connection uses a simple plate with a ring of holes combined with two cinches to attach short lengths of bamboo anywhere along a pole to brace the lightweight structures of the system (Figure 18).

A plate with a cinch is used to connect fabric panels with a ring to the underside of a bamboo structure, or solid panels with a nut and threaded rod system which allows for fine-tuned adjustment in order to connect a rigid panel to a potentially irregular structure (Figure 19). Inverting the enclosure of the structures, with the fabric or solid panels attached to the underside allows
for the free-floating ends of the bamboo poles that enable joint tolerance. A flexible connection that enables fabric or solid panels to be attached anywhere along the bamboo frames allows for different degrees of enclosure for different types of spaces, while different transparencies of material produce different degrees of shading and privacy. Regularizing the fabric or solid panel shapes and sizes can become a driver of the overall form of the structure.

This basic set of prefabricated joints allows for the creation of a broad range of forms. These joints define the spatial characteristics of the system, while remaining open ended and allowing the user to build a variety of different forms that respond to the requirements of specific projects or existing sites. The simple set of building materials required—the set of joints and attachment hardware combined with a stock of locally available bamboo—makes the system easily and quickly deployable. It allows the structures to grow up anywhere, modifying and expanding existing buildings and landscapes in keeping with the principles of a rhizomatic system (Figure 20). Though the connections are designed to accommodate a range of bamboo diameters, fabricating additional joints at different scales would further expand the range of usable bamboo material.
Construction System Analysis

The design of the joints and the nature of the building system give it certain inherent formal characteristics. A series of digital models, diagrams, and the development of a set of simple basic structures reveal the potential of the system.

Form Exploration

A series of digital models demonstrated the range of forms produced by the system (Figure 21). The basic unit of the braced half arch shape created by the angle brackets generates forms that either radiate inward or outward when arranged in a circle, or gable forms from a linear arrangement. These forms are
combined and transformed to create more irregular shapes through different lengths of bamboo poles, a variety of joint angles, arranging the frames along non-linear paths, or intersecting different combinations of forms. The models

*Figure 21: Form exploration models*

were used to find the most basic structural forms and test the extremes of complex and irregular conglomerations. Through this exploration the formal characteristics of the system started to emerge along with the rhythm produced by the thin scale of the material and the repetition of frames. The characteristics of the inherent forms produced by the system were further described in a set of diagrams as: radial, rectilinear, or transforming in arrangement and defined by whether the structure was freestanding, engaged with an existing building, or
interior in nature (Figure 22). The scale of the structure was recognized as being related to the diameter of the bamboo, and a rule of thumb guide to structure sizing based on the size of bamboo material was developed (Figure 23).
Basic Typologies

From this investigation into the formal characteristics of the system a set of simple basic typologies were developed as small-scale standalone structures to model a set of different spaces and enclosure types and analyze the programmatic implications of the different basic forms. Diagrams describe the different types of space enclosure strategies including stretched fabric, fabric panel, solid panel, or heat reflective (Figure 24). Similarly, the structures can incorporate a variety of different types of furniture—whether reappropriated existing indoor or outdoor components, using informal blankets, stumps or straw bales, or buying or building new—depending on the budget of the project.

Figure 24: Seating and enclosure strategies
Linear Gable Form

A set of linear gable form structures accommodate one or two tables for a small to medium sized group gathering to eat or work (Figure 25). Incorporating fabric panels creates a shade structure with some weather protection of repeated draped forms. A solid panel version demonstrates that with careful adjustment to the heights of the frames the structure can be designed to successfully shed water in order to make a more protected space. When connected in series, these linear gable forms can brace each other and produce cantilever forms. Extending the bamboo poles of the angled roof plane creates an overhang for additional spaces with different qualities.

Figure 25: Linear gable forms
Outward Facing Hub

When the basic bamboo frame units are arranged in a central circular column, a radial tree form is produced that creates an outward facing structure (Figure 26). The tree hub form is distinctive and eye catching, making it particularly suited to serve as a gathering point, a defining focal point in a landscape, or simply a location for individuals or pairs to sit. Multiple tree hubs gathered together start to create a canopy and define a larger gathering area. When triangular cloth panels are incorporated the structure provides shade and can be used to gather water in a barrel incorporated into its central column.

Figure 26: Outward facing hub

Inward Facing Circle

The inward facing circle form defines a round room that is particularly suited to discussion or other engaged interaction (Figure 27). Partial circle forms create spaces that are more directional while still being intimate. Similar to the other basic forms, these structures can be covered and enclosed using triangular
fabric or solid panels for shade and weather protection. Different scales of circular structure define the size of the group that the space accommodates.

Figure 27: Inward facing circle

The formal explorations, development of basic structure typologies, and the proposal of a set of enclosure and furniture strategies, defines the range of basic structures that can be built with the system and starts to define the types of programs that they can accommodate. These structures are by nature semi-enclosed, making them function somewhere between indoor and outdoor space. They are lightweight and easily constructed. The intuitive system of joints makes them deployable, adaptable, and transformable without required skilled workmanship. They can even be deconstructed and reused as necessary. The simple, flexible system empowers users to create and adapt their own space. Depending on the sizes of available bamboo material, a range of different types and scales of structures can be built to create spaces for different programmatic requirements and numbers of people.
The Case Study

The case study serves to experiment and test the previously described bamboo system in a real setting. Specifically, the case study explores how the bamboo system could be used to adapt an existing school building in response to the COVID-19 pandemic and address the limitations of traditional building envelopes. Constructing semi-enclosed spaces makes for more porous buildings that can open up and expand into the adjacent outside space and provide opportunities for beneficial outdoor learning and increased connection to the natural environment.

Site

The case study site, Morningside Elementary School, is an existing school campus in the Morningside neighborhood of Atlanta, GA (Figure 28).
acre site is well suited to this study because there is ample open space surrounding the school building. The surrounding low density, single-family residential neighborhood and a nearby park make for a relatively green area that is the appropriate context for a more open and porous school and a robust outdoor learning program. The existing brick school buildings, originally built in 1929, include three wings with courtyards and other outdoor spaces between them. The school is currently undergoing renovations and is under construction as of spring 2022.\textsuperscript{84} The school is a total of 98,000sf on three levels and accommodates 966 students in 46 classrooms, which averages to about 21 students per a classroom.\textsuperscript{85}

**Site Layout and Existing Program**

The main entrance to the school is centered on the east façade of the middle wing at the interior of the site, accessed by a one-way drive that enters under a bridge connecting the middle wing to the east wing which houses the gym, music, and a few classrooms (). The middle wing is the largest of the three. In addition to being the main entry point of the school, it also houses the kitchen and cafeteria in the south portion of the ground floor, administration in the central portion adjacent to the entry, and a media center at its north section. The upper level has classrooms, while the lower level has parking in the south two-thirds of

\begin{footnotesize}
\textsuperscript{84} “About Us.”
\textsuperscript{85} Atlanta Public Schools, “Architect Pre-Proposal Briefing.”
\end{footnotesize}
the building and art classrooms and a lab in the north portion. The west wing of the school houses two levels of classrooms, as does the piece of the building connecting the west wing to the middle wing along the north end of the property with admin offices and storage spaces at the south most end of the west wing. The existing outdoor spaces include parking along the main entry drive, with playing fields and a basketball court in the open area south of the east wing. A central courtyard with garden beds, a paved patio outside the cafeteria, and paths connecting the different wings occupies the space between the middle and west wings of the school. To the south of the west wing is an existing playground, some grassy areas and a few trees. To the west of the west wing is a series of slabs for outdoor seating areas connected by a path running along the west side
of the property, with surrounding grassy areas and plantings, and a line of trees at the border of the property.

Project Program

The program for the interventions and additions to the existing school was developed by analyzing the existing spaces and informed by research into the design of Covid-19 responsive spaces and spaces for outdoor education programs.

Adapting Schools in Response to the Covid-19 Pandemic

The American Institute of Architects document “Reopening America: Strategies for Safer Schools” describes the adaptations required to make an existing school building safer for Covid-19 pandemic learning. These strategies focus on spreading students out in the classroom, opening spaces up to increased fresh air, introducing more sanitizing stations for hand washing, and reducing congestion in high traffic areas such as the main entrance, hallways, and restrooms. Diagrams show the increased space required for student social distancing within classrooms and other gathering areas of the school compared

86 “Reopening America: Strategies for Safer Schools.”
with traditional school space planning (Figure 30). The AIA document informed

**Figure 30: Space planning and social distancing**

the areas of focus and the high-level issues presented by existing school spaces in light of the Covid-19 pandemic, as well as the rules of thumb for space planning with social distancing. However, interventions proposed by the AIA are limited to adapting schools within the existing building envelope or by altering or staggering the schedules of the students to reduce congestion. These guidelines do not address the potential for expanding the learning environment into available outdoor spaces.

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87 “Reopening America: Strategies for Safer Schools.”
Adapting An Existing School For Outdoor Education

Green Schoolyards America works to increase the greenspace of schools and promotes outdoor education and learning spaces.88 In response to the Covid-19 pandemic the organization founded an initiative to help schools adapt their existing campuses for outdoor learning. They put together a website that catalogues resources, strategies, and ways to address potential issues when moving classes and other school functions outside.89 Green Schoolyards was instructive for this project in understanding the value of outdoor education and learning environments for improving children’s focus and behavior, providing unique wholistic learning opportunities, creating a sense of ecological connection, and fostering social growth.90 The Covid-19 adaptation initiative in particular was helpful in understanding the essential requirements of outdoor learning spaces and in outlining potential challenges to be addressed.

Different Types of Education Spaces For Different Types of Learning

The final area of program research that informed the design of this project was into current trends and philosophies in school design based on new research in primary school pedagogy. Documents produced by the architecture firm SMMA described this research and how it informs the design of education spaces.91 Particularly applicable to this project was the emphasis on project-

88 “Vision.”
89 “Covid-19 Outdoor Learning.”
90 “Vision.”
91 “Elementary School Learning Environments.”
based learning, in which smaller groups of students would work together on a specific project or problem for a more actively engaged form of learning. Project-based learning necessitates spaces for small groups of students to meet together in a democratic set up, in contrast with a traditional lecture room layout.92 Another concept that is reflected in the program and design of the case study was the inclusion of secluded spaces for students to remove themselves from the rest of the class for individual time apart. These separated spaces are important for students working through behavioral challenges or needing sensory accommodations and allow them to remain a part of the larger class while having a nearby space to break off to as necessary.93 Another newer idea in school design is the concept of cluster plans or learning neighborhoods, in which a group of classrooms shares resources and teachers can collaborate, at times combining classes for group instruction.94 Finally, the importance of students learning through play and engagement with their environment was a key idea in understanding the role the bamboo structure system could play in a school

92 Ibid.
93 “Glossary of Terms For School Planning & Design.”
94 “Elementary School Learning Environments.”
setting. The different types of learning spaces and their formal implications were explored in a diagram (Figure 31).

![Diagram of different learning contexts]

**Figure 31:** Spatial organization of different learning contexts

Ultimately through this research, the primary areas of program intervention became: (1) Creating an expanded and better-defined main entry to the school in order to provide space for students to be dropped off or wait for pick up and to organize the flow of people into and out of the building; and (2) creating a variety of classroom spaces that accommodate the range of different types of learning whether a full class gathering in one place, smaller groups of 4-6 students working on a group project, or a single student breaking off from the group alone or with an aide to take time apart.
The alterations and additions would also serve to create connection to the environment, provide increased space for physical distancing, better ventilation, and opportunities for engaged learning and play.

**Design Intervention**

The case study design proposes a full-scale intervention to an existing school by utilizing the bamboo structure system to open Morningside Elementary to the surrounding outside environment and create a gradation of spaces that bridge between traditional indoor and outdoor to support a variety of different types of learning (Figure 32 & Figure 33).

**Entry**

At the main entry to the school portions of the façade are removed to create a passthrough from the main drop off point through to the inner courtyard space between the middle and west wings of the school (Figure 34). A canopy structure above better defines the main school entrance, while also serving to humanize the imposing brick façade. Seating areas along the front of the building and flowing into the newly created passthrough space provide places for students to line up for organized entry into the building or sit and wait for pick up at the end of the day.
Figure 32: Site plan

Figure 33: Long section through school
Figure 34: Entry intervention. From top: elevation, enlarged plan, rendered view
Existing Classroom Expansion

The existing classrooms in the west wing of the school sprout bamboo shade structures that grow off the building (Figure 35). New glass doors replace existing windows to allow the classrooms to extend out into the adjacent outdoor space, both expanding and blurring the boundaries of the classroom. These spaces extend the existing classrooms and provide outdoor space for learning, while also opening up the existing classroom to the outdoors. The continuous outdoor space along the row of classrooms allows for collaboration between students and teachers in a learning neighborhood. At the interior of the classroom, structures define smaller secluded spaces for students to break off from the larger group either alone or with an aide to take a moment to decompress and recenter. A series of smaller standalone structures to the west of the outdoor classroom extensions create more focused spaces for small group learning of 4-6 students, further stretching the boundaries of the porous classrooms. The transparency of the structures allows teachers to supervise even as their classroom is expanded outside the traditional building envelope.
Figure 35: Classroom expansion intervention. From top: elevation, enlarged plan, rendered view
**Standalone Outdoor Classrooms**

Distributed to the south of the site are a set of loosely defined standalone classroom spaces (Figure 36). Providing shade and some degree of weather protection, they create outdoor rooms in which a full class can gather outside the boundaries of the traditional classroom for discussion, story time, or other informal learning opportunities. The distributed standalone spaces add a sense of adventure to the day and foster connection to nature.

![Figure 36: Standalone classroom rendered view](image)

**Site Interventions**

Bamboo structures attached to the ceiling at the new passthrough and at the interior of the cafeteria dining room move out into the courtyard and transform into arched passageways that define and organize the main circulation paths.
Various seating areas and folly structures create a playful environment for students to engage with throughout the site (Figure 37).

![Figure 37: Types of interventions throughout site](image)

**Design Analysis**

The case study alteration and expansion of Morningside Elementary showcases some of the unique characteristics and advantages of the bamboo construction system for this type of application.
**Phased Implementation**

The case study proposes a thorough and expansive intervention for Morningside Elementary School. However, the nature of the system is that it can be deployed incrementally as needed. A diagram shows the possible phasing of the project if it were to be undertaken by the school over time and within potential budget constraints (Figure 38). The structures would not be installed all at once but would more likely pop up organically over a longer period in phases of expansion. The first phase could see a few standalone seating structures and

*Figure 38: Phased implementation*
outdoor classrooms deployed. A second phase could address the existing classrooms, adding the expansion spaces onto the exterior and carving out the secluded interior spaces. The full site intervention shown in the case study would be a final phase in which the campus becomes transformed by the melding of existing buildings with the new bamboo construction language to create an environment of play and engagement throughout.

**Increased Porosity**

The interventions to Morningside Elementary School expand the boundaries of the existing buildings, blurring the lines between traditional indoor and outdoor (Figure 39). The classroom learning environment is extended.

*Figure 39: Increased porosity*
outside the confines of the traditional classroom, while the opening of the façade at the entrance brings the outside into the interior of the existing building. In good weather the school is able to open up and expand outside the boundaries of the traditional building envelope, while still being able to retreat back indoors and close up when the weather gets inhospitable. A spectrum of different environments is created for an ongoing outdoor learning program and a new type of school is imagined in symbiosis with the surrounding environment and ecosystem.

**The System as a Learning Opportunity**

The bamboo structures also offer a unique learning opportunity in themselves. The simple design of the joint system allows students to understand and engage with the structure and gain a sense of empowerment and control over their built environments. Utilizing bamboo for these structures teaches students about the ecosystems and species around them and models an innovative form of building material.
CHAPTER 6
DISCUSSION AND CONCLUSION

Reflecting on the Case Study
The case study explores one way to address the needs of an existing school. However, the open nature of the system is designed to allow a vast range of different forms and spaces to be built to suit the needs and desires of the user, while still reflecting the specific characteristics and patterns inherent in the system. Though the case study does model a possible way of deploying the system for an existing school and how it can provide a variety of different spaces for outdoor learning and engagement, proposing a large-scale intervention as an outside designer is not the ultimate intended purpose of what has been conceived of as a rhizomatic system to be built, rebuilt, altered, and appropriated by the users themselves. Ultimately the design is for a kit-of-parts style system in which the user(s), having identified a local source of bamboo, could buy a set of connection hardware and start building structures on their own as needed or desired. In this way the system is intended as a bottom-up, user driven intervention that could be designed and adapted as it is being built, rather than a top-down predesigned project.

Next Steps for the System
The bamboo construction system would lend itself to the development of a full catalogue of different forms, uses, and scenarios. Exploration of the variables
within the system—bamboo segment lengths, varied spacing of the material for shading or other effects, and irregularity of form—could all be pushed further than was covered in the scope of this project. The next step in testing the system would require full size mockups of all the joints and test builds of some of the structures.

**Conclusion**

The COVID-19 pandemic has revealed the limitations of existing buildings and the need for both rapidly deployable outdoor structures and spaces that are more flexible and adaptable over the long-term. The bamboo system designed and described in this thesis aims to address these limitations. The pandemic has also challenged society to rethink our relationship to the outdoors and altered expectations around what types of activities can occur outside, during any season. This project is an opportunity to rethink future education spaces to acknowledge the benefits to students from exposure to nature and the outdoor environment in the school setting. Building structures out of the wild growing invasive bamboos of the U.S. is a pragmatic use of an over abundant plant, but also a proposal for a type of building and inhabitation that creates a beneficial relationship between people and their local ecosystem. While this project proposes a specific application of bamboo structures for educational spaces, the hope is that this system would be adapted and utilized in many different unforeseen and unpredictable ways and new systems and uses would also be
inspired to sprout up creating an ever-expanding rhizome of playful, dynamic spaces.
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