What Comes of Viscous Wood:
Designing Space with Living Architecture

by
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Author’s Declaration

I hereby declare that I am the sole author of this thesis.

This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

What if buildings are *grown* in the future?

In an urban scape of materially static architecture, unsustainable construction methods, and generic spaces designed for speed and scalability, there is incentive to find affinity with nature. One instance is through investigations of biophilic built-up environments. This thesis introduces novel construction methods and alternative spatial typologies as opportunities in architectural design, particularly, the role of living trees as a functional building.

Architecture often places trees amongst buildings, as found in green roofs and living walls, or buildings amongst trees, such as tree-houses or cabins. However, there are very limited examples that propose trees *as* buildings. Although practiced by the ancients, few have investigated living trees as structural and aesthetic systems for building architecture. The research is only exposed through limited international designers, academics, gardeners, and artists.

The purpose of this study expands upon existing knowledge in hybrid structural systems in architectural design by contextualizing *baubotanik (hybrid construction with living trees and artificial structures)* and *arbortecture (general practice of shaping trees to create spatial context)* methods in southwest Ontario, Canada while synthesizing *bonsai (East Asian practice of miniaturizing trees)* and *arborsculpture (living-tree art)* techniques. This thesis outlines general knowledge, influences, and history of tree-shaping. Subsequently, a series of small-scale experiments are designed to demonstrate the potential of shaping, structure, and inosculation qualities in trees as spatial form applications using bonsai techniques. The experiments are conducted using native willow cuttings found in southern Ontario to emulate full-scale structures. Informed from the findings, the thesis illustrates fragments of a possible future to provoke imagination, where living tree structures become plausible spaces.

The hope of this study is to contribute more speculations on the potential of living-tree architecture and to build upon further development in the field of research pertaining to hybrid systems construction, sustainability, and to generate architectural discourse. As space-makers in a world facing rapid growth and sustainability challenges, what if we become space-growers instead? Let's go outside and plant some buildings.

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164 Fig. 4.106. Three images of 2A after 1 month. Three of four cuttings were still in good health with green stems. All the leaves had fallen while one cutting showed signs of drying. The connections from insertion did not fail. Small white fluff seen in the images indicate pest infection.

165 Fig. 4.107. Sketch of 2B

165 Fig. 4.108. Three images of 2B after 1 month. All cuttings were still green and alive. Most leaves had fallen while a few remain. The soft cuttings were reacting well with zip-ties and frame structure. Pale patches on leaves indicated infection or disease.

166 Fig. 4.109. Sketch of 2C

166 Fig. 4.110. Three images of 2C after 1 month. One of four cuttings showed signs of the top half drying while all other cuttings were still green. Friction and zip-tie connections did not cause damage the bark of the cuttings, indicating that the cuttings responded well.

167 Fig. 4.111. Sketch of 2D

167 Fig. 4.112. Three images of 2D after 1 month. Both cuttings were still alive with green stems. Portions of the thinner cutting showed signs of drying. The hole drilled into the wider cutting did not cause visible damage around the cutting. A flush of new leaves sprouted and fell three weeks after conducting experiments.

168 Fig. 4.113. Sketch of 2E

168 Fig. 4.114. Three images of 2E after 1 month. Both cuttings were still alive with green stems. Small portions of both cuttings were showing signs of drying, however, a new bud was spotted in the middle image.

169 Fig. 4.115. Sketch of 2F

169 Fig. 4.116. Three images of 2F after 1 month. The cutting's health was not determined at time of photograph. The newer shoots dried while the main bark appeared still alive. 2F at this moment was too soon to determine if shaping was successful.

170 Fig. 4.117. Sketch of 2G

170 Fig. 4.118. Three images of 2G after 1 month. Many cuttings showed signs of drying. All leaves dropped but there were still green stems. No signs of inosculation were seen at zip-tie connections though there were some signs of new buds forming on some cuttings.

172 Fig. 4.119. Workbench for setting up black willow cuttings.

173 Fig. 5.1. Illustration of tree leaves, 2024, by author

177 Fig. 5.2. Sketch of 2C

178 Fig. 5.3. Drawing 1 Sectional

180 Fig. 5.4. Drawing 1 Elevation

181 Fig. 5.5. Sketch of 2G

181 Fig. 5.6. Sketch of 2E

182 Fig. 5.7. Drawing 2 Elevation

184 Fig. 5.8. Drawing 2 Elevation zoom-in

185 Fig. 5.9. Sketch of 2A

186 Fig. 5.10. Drawing 2 Elevation

187 Fig. 5.11. Drawing 3 Elevation details

194 Fig. 6.1. Set of three final aspirational drawings printed for thesis defence

196 Fig. 6.2. Photographs documenting some work displayed at thesis defence

197 Fig. 6.3. Photographs of process work fixing broken walnut frames to display drawings

198 Fig. 6.4. Photograph of some artifacts displayed at thesis defence

200 Fig. 6.5. Work in progress stages of two final drawings

202 Fig. 6.6. Early drafts of the three final drawings as exported from CAD software

204 Fig. 6.7. Series of tamarind bonsai progress illustrations including the root system

205 Fig. 6.8. Tamarind bonsai elevation drawing initial stage

206 Fig. 6.9. Tamarind bonsai elevation drawing imagined end stage

Preface

Little leaves, big roots.

Over the final year of the pandemic, I found myself working a remote office job inside a small studio apartment on the second floor of a late 1900's Victorian house. It was a large brick house with each room converted into a rentable unit, thus making it a multiplex. I was lucky enough to have an outdoor patio, which was a wooden decking built onto the main porch's roof. I mention this because the house was never designed to have a second-floor patio. From the street, the original pitch of the porch roof can be seen cutting into the leveled wooden deck. On top of this deck, wrapped a wooden railing more akin to a fence as it was over two meters tall. This was my outdoor space. A two by three-meter square with only views straight up into the sky. This is where I built my urban bonsai garden.

After buying a young juniper cutting from a little garden shop in Chinatown the year prior, it survived and started growing as spring arrived. It was the first and only tree in my patio and I was thrilled to see it sprout after a Canadian winter. This spurred me to obsessively research and consume bonsai related content. As the spring growing season arrived, I started to collect trees in any way I could, imagining different designs and styles for different trees, as bonsai trees even infiltrated my dreams. I started visiting garden centers and became acquainted with many local flower shops that occasionally carried bonsai trees. Discount landscaping trees were prime material as often the upper parts of the tree had died, but since I was making bonsai, the dead parts were cut off and a two-foot living tree would remain healthy. Many convenience stores and flower shops owned by elderly Chinese couples would also carry bonsai trees as cultural novelties. I would share conversations about my passion for art, which would often lead to me buying their trees. I ended up with a wide collection of species including elm, ginkgo, Japanese maple, tamarind, and larch to name a few.

After my nine-to-five job, it became ritualistic to re-pot, prune, and work on bonsai. It was a meditative act that helped me process a stressful day. I found great satisfaction to watch a tree successfully bloom and take shape, but equally nervous anticipation in hoping it survives. Sometimes, the only thing to do is to be patient and fully enjoy the entire journey in developing a bonsai. Like the ancient Taoist monks, I brought in nature around me and turned the patio into my sanctum.

In a fundamental view as someone who designs space -- miniature dioramas and models are a familiar, if not quintessential part of the architecture discipline. Miniaturization is a tool which allows for the visualization of design proposals in three-dimensional space, creating a chance to observe spatial relationships and improve upon them in real time. The scale of bonsai is familiar in that aspect, similar to a diorama or a spatial vignette. In turn, it gives me great fascination and satisfaction.



Fig. 1.1. Plane Tree Cube, facade built from plane trees. Designed by OLA and built in Nagold, Germany, 2012.

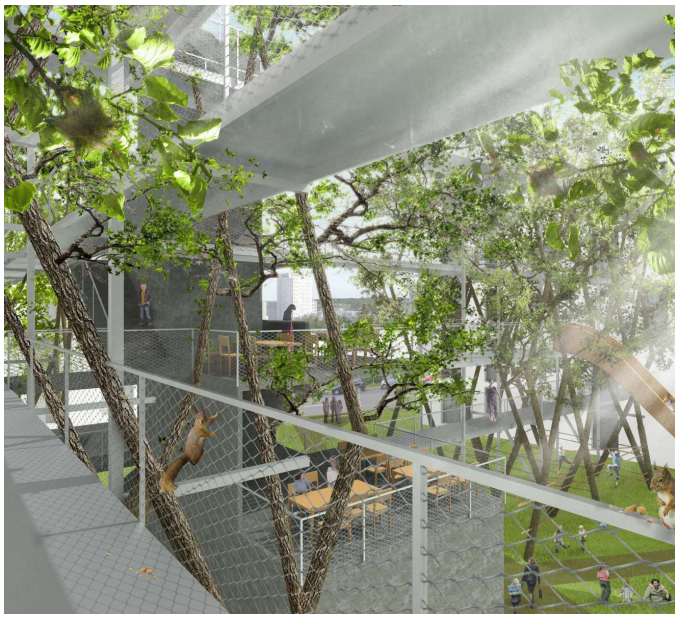


Fig. 1.2. Residential Trees, a proposal study set in Stuttgardesigned by OLA in 2013.

1.0 Introduction: The Seed

Architects engage in the act of “space-making;” designing structural and sculptural compositions that capture a physical experience. Equally so, the act of space-making actively curates a psychological experience that is intrinsically human—a record of human lives and history. The architecture around us constructs our collective identities and our unique cultures as social creatures. The daily lives of individuals are ever more defined by the built-up spaces around us. In the modern world, this is more important than ever. Having good architecture that defines us culturally as individuals, and as a society.

As metropolises become ever-expansive, continuously growing with the urban sprawl that multiply around them, the spaces that define us are increasingly dull, mundane, and unsustainable, focusing on speed, efficiency, and repetition. With rapid growth and high infrastructure demand, more pleasant cultural, public, and green spaces with vegetation are needed. Despite frequent negligence in developments, green urban spaces yield high benefits in purifying air, flood and rain protection, mental health, temperature regulation, and climate change mitigation.[1] Acknowledging such, this thesis takes the opportunity to explore alternative methods in construction with the intention of improving urban scapes, generating green islands, and building sustainably. The angle of sustainability through this study is pursued through reducing material waste, material performance, and providing opportunities for urban green islands.

These ideas are investigated through the subject of trees. Trees have always been an important element in healthy and pleasant neighborhoods with numerous benefits for quality of life and the environment. Scattered in public parks and used as shade, they are frequently planted as an easy response to improving streetscapes. Considering the advantages of trees, this thesis seeks to introduce the idea of merging them as part of the built environment, imagining “trees as building.”

While reviewing the social and environmental benefits of trees and their roles in cities, novel concepts such as *arbortecture* (arbor + architecture), the use of living trees to construct architecture, and *baubotanik* (house + botany) architecture, hybrid structural joinery with living trees, are brought to the forefront of discussion. This thesis introduces arbortecture and within it, baubotanik architecture as an alternative construction method worth investigating, exploring its potential, its state-of-the-art, and finally, how it performs in practice.

1 Park People, “Sharing the Benefits of Green Space,” Canadian City Parks Report 2021, accessed November 4, 2024, https://ccpr.parkpeople.ca/2021/sections/nature/stories/sharing-the-benefits-of-green-space.

1.1 Trees and the City

1.1.1 Sustainability and Vegetation

Sustainability is a monumental task and responsibility in Architecture and city building. According to a UN Environment Programme report published in 2023, the building and construction industry accounts for 37% of all global emissions of greenhouse gasses[2]. It is by far the most significant contributor to emissions above vehicles and agriculture. Much of the carbon footprint is due to material manufacture like concrete, steel, and aluminum, in addition to building operational energy consumption and costs. As a direct response to construction and material pollution, this thesis proposes the application of living trees as a building material substitute since it is one of the few materials that could be carbon negative. Being a self-sustaining structure, there is no need for additional manufacturing or industrial factories for production. Trees can easily be grown in the wild with just water, substrate, and sunlight. While trees themselves are also capable of healing, strengthening, and anchoring. Considering its material properties, trees as architecture is an appropriate and highly viable method for sustainable construction with a high potential ceiling.

Since architecture defines us as a people, emotionally, intellectually, socially, economically, and morally, we must build better spaces. As architects, we have a responsibility to design and promote pleasant, beautiful, and dignifying spaces. With the ever-expanding concrete jungles many urbanites find themselves in, greenspace has become highly contentious yet imperative. According to the World Economic Forum and other reports, tree coverage in urban areas provides many benefits:

→ Trees are very good at absorbing carbon dioxide and producing oxygen. A single mature tree can remove up to 22 tonnes of CO2 in its lifetime[3] while producing about 100,000 liters of oxygen annually, this is enough to sustain two average adults for a year[4].

→ Tree canopies act as natural heating and cooling strategies with heat island effect. In summers, tree shade surfaces can be cooler by 11-25°C and ambient shaded temperatures can be cooler by 5-10°C[5].

→ General human health is also improved by trees. A big contributor is their ability to clear pollutants, dust, and harmful particles from the air and water while also decreasing sun radiation.[6]

→ Roots of trees and plants act as flood mitigation. The roots can retain loose soil and preventing landslides, while their absorption of water prevents ground erosion and flash flooding especially in cities with large impermeable surfaces[7].

2 U. N. Environment, “Building Materials And The Climate: Constructing A New Future | UNEP - UN Environment Programme,” September 12, 2023, https://www.unep.org/resources/report/building-materials-and-climate-constructing-new-future.

3 “5 Reasons Why Cities Need a Healthy Tree Cover,” World Economic Forum, June 29, 2022, https://www.weforum.org/agenda/2022/06/cities-urban-trees-climate-change/.

4 One Tree Planted, “How Much Oxygen Does A Tree Produce?,” One Tree Planted, accessed September 23, 2024, https://onetreeplanted.org/blogs/stories/oxygen-tree.

5 “5 Reasons Why Cities Need a Healthy Tree Cover.”

6 “Trees in Our Cities: 10 Reasons We Need to Plant More,” Trees for Cities, September 19, 2024, https://treesforcities.org/stories/trees-in-our-cities-10-reasons-we-need-to-plant-more.

7 “Trees in Our Cities.”

→ Having green space in cities promotes biodiversity in fauna and flora. It acts as habitats for many animals, helping to preserve native species and keeping balance in ecosystems[8].

→ The presence of trees in a neighborhood increases property value and shows correlation to reductions in crime while also acting as natural traffic control. It attracts people, economy, and business[9].

→ People simply like trees and greenery. Proximity to nature improves mental health, anxiety, and stress. Green spaces also build communities by creating spaces of outdoor socialization.[10] Trees also provide irreplaceable aesthetic qualities improving streetscapes and cityscapes.[11] People want to be near trees.

To summarize, trees are an important part of a community's identity and wellbeing, both socially and economically. As such, the importance of green space and trees in cities is irrefutable. People need trees. However, we need trees not only through the environment, but we need them even through the consideration of materiality.

8 "5 Reasons Why Cities Need a Healthy Tree Cover."

9 "03. Benefits of Urban Forests," Tree Canada (blog), accessed September 23, 2024, https://treecanada.ca/resources/canadian-urban-forest-compendium/3-benefits-of-urban-forests/.

10 "5 Reasons Why Cities Need a Healthy Tree Cover."

11 "Why We Need Trees in Our Cities | Smart Cities Dive," accessed September 23, 2024, https://www.smartcitiesdive.com/ex/sustainablecitiescollective/why-we-need-trees-our-cities/1100050/.



Fig. 1.3. Cité Des Habitarbres, 2019, Luc Schuiten. Painting of a utopian society where architecture is made of vegetation and its inhabitants are actors in its ecosystem. https://www.vegetalcity.net/en/cite-habitarbres/.

1.1.2 Tree as Building

A predominant and historical construction resource in North America is wood. Considering the material properties of milled lumber, similar qualities can be found in its source, a living tree. However, unlike milled lumber, living wood has a unique quality that could be harnessed in specific material applications. A tree's ability to grow allows it to act as a remarkably viscous liquid that has properties of physical memory over long periods of time. As a tree's woody outer material continuously expands in diameter, it behaves like a thick liquid flowing around, encasing, and taking shape of surrounding objects despite its solid woody appearance. As a tree ages, the wood structurally solidifies, fully incorporating objects or other branches within its trunk. This means a tree's load bearing potential increases proportionally with age, and its patterns of growth are highly adaptable to its physical environment.

Interestingly, this introduces the dynamic elements of change and growth in material building science. To build on this concept, German architect Dr. Ferdinand Ludwig from University of Stuttgart coined the term "*Baubotanik* Architecture"[12]; it is defined as an art and science of shaping structures and technical joinery from live plants[13], inspired and derived from arbor-sculpture.[14] While the terms *arborsculpture* and *arbortecture* were only defined by artists Richard Reams and Barbara Delbolin in 1995,[15] the general practice of tree shaping for functional and aesthetic purposes has existed since the knowledge of horticulture. The potential applications of baubotanik architecture brings new models for ecological and social sustainability.[16]

The use of arbor-sculpture and tree shaping in architecture has been largely unseen in North America with very little local precedence by western metrics. By learning from existing global practices, there are opportunities to modernize and evolve primitive construction techniques to benefit and enhance cultural identity and sustainable city-building.

Stepping back, some insight can be found through the artistry of arbor-sculpture, particularly the art of bonsai. Through pruning, wiring, grafting, and other shaping techniques, the growth of trees can be manipulated with general predictability. The art celebrates the ability to artificially control natural growth. Processes of inoculation, grafting, and strategic pruning present potential to develop custom high-strength sections using natural growth. It could be thought of as traditional woodworking joinery embedded into the growth of a living tree. When considering the requirements of tree branch forms, certain techniques used to shape smaller trees can be implemented early in the design process to fully refine design and structure.



Fig. 1.4. Le Panorama Vegetal City, a utopian vision of ficticious green city illustration by Luc Schuiten.

12 "Baubotanik: The Botanically Inspired Design System That Creates Living Buildings," ArchDaily, October 23, 2015, https://www.archdaily.com/775884/baubotanik-the-botanically-inspired-design-system-that-creates-living-buildings.

13 Ferdinand Ludwig, Hannes Schwertfreger, and Oliver Storz, "Living Systems: Designing Growth in Baubotanik," Architectural Design 82, no. 2 (March 2012): 82–87, https://doi.org/10.1002/ad.1383.

14 "Baubotanik: German Botanical Architect Grows Buildings Out of Trees," WebUrbanist (blog), January 3, 2017, https://weburbanist.com/2017/01/03/baubotanik-german-botanical-architect-grows-buildings-out-of-trees/.

15 "Pacific Horticulture | Arborsculpture," Pacific Horticulture (blog), accessed October 22, 2024, https://pacifichorticulture.org/articles/arborsculpture/.

16 Ferdinand Ludwig, Daniel Schönle, and Sonja Duempelmann, Growing Architecture: How to Design and Build with Trees (Basel: Birkhäuser, 2023).

1.1.3 Conclusion



Fig. 1.5. The Basket Tree, made of sycamore trees is an example of arborsculpture by Axel Erlandson for the Tree Circus in 1947. Photo by pigatschmo of Adventure Talgache.



Fig. 1.6. Arena Salix, completed by the Sanfte Strukturen Group in 2004 is a large scale willow construction project.

Through usage of tree shaping, what if our buildings could be combined with the trees? What if architecture can also be greenspace? While many projects of modern times feature green roofs or urban gardens incorporated as sustainability methods are just *trees in buildings*, this thesis investigates the slightly different approach of *trees as buildings*.

This thesis documents a comprehensive collection of knowledge in the fields of baubotanik, arbortecture, arborsculpture, and disciplines at their intersections. Along with a lineage of visionary predecessors who dreamed of utopian tree cities, this thesis invites engagement and speculation about how built spaces could exist.

What if we could literally grow the buildings that make up our cities?

1.2 Research Outline

The scope of this research is an exploration of form and architectural construction. It is a detailed documentation on how tree shaping techniques with horticultural practices through arborsculpture may be applied to design physical spaces. The objective is to build new observations based on the synthesis of existing and established research to further legitimize construction methods that have potential to push the boundaries of architecture and bring sustainability to the forefront of architectural discourse.

Instead of *space-making*, designers could engage in *space-growing*.

Chapter 1 introduces the need for engagement with tree shaping and architecture by highlighting sustainability issues that cities face while emphasizing the need for healthier green spaces and urban vegetation. By reviewing the societal benefits of trees in urban spaces, and its environmental factors, the chapter offers not a solution, but a response. It frames tree shaping in architecture including *arbortecture* and *baubotanik* as a thought experiment in modern construction methodology worthy of continued research.

Chapter 2 seeks to understand and contextualize tree shaping. The chapter briefly reviews the prominence of tree iconography in literature and early depictions of tree shaping. The practice of tree shaping is examined through its historical applications as aesthetic and functional, including agricultural, horticultural, and artistic uses. It also presents a deeper dive into the art of bonsai as a method to learn how living trees can be shaped and manipulated through a designer's intent. This helps explain the botanical properties that allow for arbortecture and tree shaping in general to be conducted.

Chapter 3 presents the research and the state-of-the-art in the practice of *arbortecture* and *arborsculpture*; terms used to describe tree-shaping as space-making and as art making. This helps contextualize the inspiration of early-day tree shaping practitioners and its eventual clarification as a field of research in academics in the last century, introducing novel terms such as *biotecture*, then later *arbortecture* the *arborsculpture*.

The chapter further outlines historical case studies frequently referenced by scholars of *arbortecture*, and case studies of works by many prominent designers over the past century. More specifically, the hybrid construction method of *baubotanik* architecture, by OLA and the Baubotanik Group, is introduced as a modern leader in advancement of living-tree architecture. Throughout, a wide range of potential tree shaping applications are cataloged, and many previously conducted works are presented. This chapter seeks to provide an informed overview of the present research and provoke new approaches to design by understanding its potentials and limitations.

Chapter 4 outlines methodology. It proposes different iterations of simple experiments conducted on a small scale and designed to test simple architectural connections. The experiments are presented through instructional illustrations and serve to visualize results. Photographs document applications of tree shaping techniques and process work. Two series of experiments are performed using garden center willows and a species of native black willow cuttings, first documenting the process of collection, preparation, and propagation, then the completion of experiments after setup and their progress. It also follows the experiments and examining results, including failures, learnings, and analysis. The goal of this chapter is to learn through application of theory into practice using small scale experiments and visualization with intent of employing lessons to larger scale experiments.

Chapter 5 reflects limitations of scope, scale, budget, timeline, and resources. It highlights successes, improvements, and alternatives for future reference are further highlighted with hopes of applicable findings to full scale architecture. The chapter also illustrates three arbortectural objects, designed with the purpose of generating architectural discourse and inspiration for a possible future.

This chapter concludes the scope of this thesis. It attempts to answer questions raised throughout the research and experiment, revisiting the initial motivations and goals of this research. In the end, the thesis asks, how can designers re-think the way spatial design is approached? Could arbortecture be a viable alternative construction method for the future of city-building?



Fig. 2.1. Illustration of tree roots, 2024, by author

2.0 State of the Art: The Roots

This chapter examines the state-of-the-art in tree shaping as a general practice through agriculture, horticulture, and the art of bonsai. It reviews the cultural importance of trees and the early influences of tree shaping, outlining techniques of shaping through historical applications and its eventually lead up to architectural uses.

Foundational bonsai techniques are outlined along with horticultural practices in grafting and shaping using botanical understanding of plant behaviour. Many of these techniques are explained through bonsai, as the art of bonsai is highly applicable to the experiments later conducted in this thesis due to the scale of work required to shape living trees. This chapter provides an overview of how tree shaping is done and why it's used, discussing factors that allow tree shaping techniques are functional in both art and architecture.

2.1 Trees and Art

Trees hold a significant value to almost every culture in the world. It is often a symbolic representation of mother nature and the "miracle of life" on Earth. The fundamentality of human's relationship with trees is reflected as a powerful archetype *"the tree of life"* found in mythological, religious, and philosophical motifs around the world: *Yggdrasil* (tree of knowledge) of Norse mythology which connects heaven and the underworld, the *tree of the knowledge of good and evil* from Christianity bearing the forbidden fruit mentioned in the book of Genesis, and the world tree or cosmic tree as a prominent motif found in Haitian, Finnish, Lithuanian, Hungarian, Indian, Chinese, Japanese, Norse, Siberian, northern Asian and Native American folklore.[1] In art, the range of tree symbolism is so widespread and common, they can are identified as subjects from the landscape watercolours of dynastic China to ancient carvings from the mediterranean, to modern landscape paintings by the Canadian artist Tom Thompson. Other significant mentions of trees can be found in literary epics such as Homer's *Odyssey* in the form of an olive wedding bed. Odysseus' wife Penelope tests Odysseus' true identity by asking him to move their bed - an impossible task only Odysseus would know.[2] In this instance, it is an early depiction of tree shaping in literature.

When investigating the early renditions of tree shaping, one reference often mentioned is a painting titled *La Complainte de Nature à l'Alchimiste Errant* (The Lament of Nature to the Wandering Alchemist) by Jean Perréal in 1516,[3] which depicts a standing alchemist beside a stone tower conversing with a winged figure seated on a tree stump. The tree stump is shown with a fire burning at its base and long live shoots emerging as the back of a chair. These shoots have been weaved and shaped into a symmetrical floral design spanning two stories tall behind the winged figure. It is a painting whose message is not yet clear and open for interpretation; however, it has become a common inspiration for many arborsculptors who began their journeys by shaping furniture.

In other realms of fiction, philosophy, and mysticism, Emanuel Swedenborg, a Swedish scientist, engineer, mystic, and theologian published a book, *Earths in the Universe* in 1758 which tells the story of another planet where its people resided within trees that were planned and shaped into spaces of dwelling.[4] Another mystic was Styrian Christian mystic, Jakob Lorber of the mid 1800's who published *The Household of God*. His book tells of planting trees in a circular formation, having them grow together over time to become a better house.[5] Many of these works of art and fiction became the bases of influence in many tree shaping artists' and designers' practices.

1 "Perceptions of Forests," accessed September 23, 2024, https://www.fao.org/4/y9882e/y9882e08.htm.

2 Homer, E. V. Rieu, and D. C. H. Rieu, The Odyssey, Penguin Classics (London ; New York: Penguin Books, 2003).

3 "La Complainte de Nature à l'Alchimiste Errant by PERRÉAL, Jean," accessed September 23, 2024, https://www.wga.hu/html_m/p/perreal/miniatur.html.

4 Joshua Foer and Richard Reames, "How to Grow a Chair: An Interview with Richard Reames | Joshua Foer and Richard Reames," accessed September 6, 2024, https://cabinetmagazine.org/issues/20/foer_reames.php.

5 Reames.

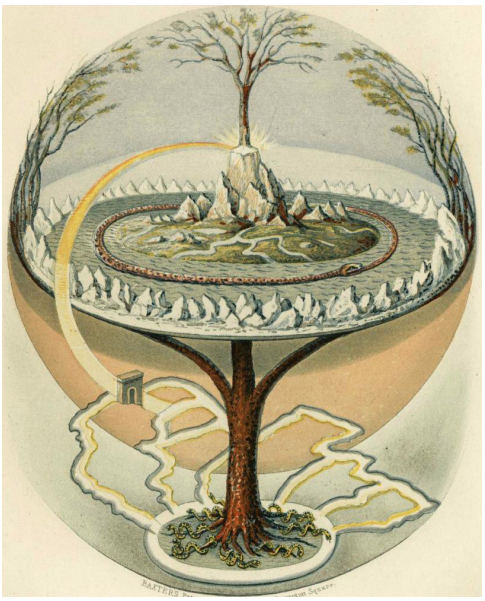


Fig. 2.2. Illustration of Yggdrasil from *Prose Edda* by Oluf Olufsen Bagge, 1847.



Fig. 2.3. Detail of *Paradise, the fall of man* by Lucas Cranach the Elder, 1530.

2.2 What Comes of Viscous Wood: To Sculpt a Tree

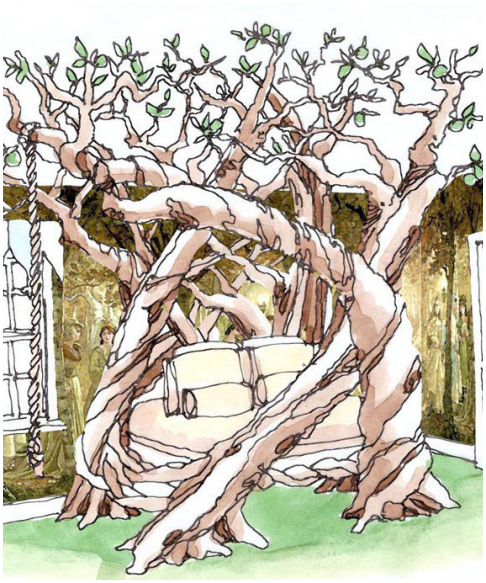


Fig. 2.4. Illustration of Odysseus and Penelope's unmovable bed crafted from olive trees, "Bed Concept Sketch II", unknown artist, 2003.



Fig. 2.5. La Complainte de Nature à l'Alchimiste errant, Jean Perréal, Miniature on parchment 1516.

The use of woody plants as a medium for creating structures has long been seen in human history. Being part of cultural, horticultural, and agricultural practices, some examples of techniques we find often within this medium such as *pleaching*, *espalier*, and *bonsai* focus on harnessing the properties of woody growth.[6]

The trait which makes tree shaping possible is a naturally occurring phenomenon called *inosculation*. This occurs when the woody tissue of a tree, such as the roots, trunks, or branches make contact with itself, or another tree and grafts together through growth.[7] Through prolonged contact, the cambium layer beneath the bark and phloem will generate more cells, effectively fusing through their growth in diameter and forming a connected flow of moisture and nutrients.[8] The cambium layer is responsible for producing new cells to widen tree girth and phloem to deliver water and nutrients up a tree.[9] As nutrients are delivered in the shortest and most direct route of travel, inosculation often allows for nutrients to move more efficiently. This is a frequent occurrence in nature between trees of the same species but is also possible interspecies. Multiple trees that have inosculated together at certain points will share root functions and become a single tree system. In nature, redwood and sequoias trees have shallow roots which intertwine, providing stability and allowing for the sharing of nutrients.[10] The banyan tree in tropical climates grows aerial roots to absorb moisture from the air, these roots also graft through inosculation with the tree's other appendages and trunks forming large clusters often the size of a building or even city block.[11]

6 Science Connected, "Tree-Shaping: The Artful Science of Arborsculpture," Science Connected Magazine (blog), March 23, 2021, https://magazine.scienceconnected.org/2021/03/tree-shaping-the-artful-science-of-arborsculpture/.

7 Matt Kelly and Cheshire County Extension Forester, "Inosculation: Making Connections in the Woods," Extension, February 2, 2022, https://extension.unh.edu/blog/2022/02/inosculation-making-connections-woods.

8 Kelly and Forester.

9 "Anatomy of a Tree," US Forest Service, February 1, 2016, https://www.fs.usda.gov/learn/trees/anatomy-of-tree.

10 "Redwood Facts," Sempervirens Fund, accessed June 7, 2024, https://sempervirens.org/learn/redwood-facts/.

11 "The Mighty Banyan Tree Can 'Walk' and Live for Centuries," HowStuffWorks, January 1, 1970, https://science.howstuffworks.com/life/botany/understanding-roots-banyan-tree.htm.

2.2.1 Inosculation Techniques

Some traditional applications of inosculation in tree shaping include *pleaching* and *espalier*. Pleaching is a method of weaving using living branches to create interlocking lattices. Often this method is used to construct natural walls, fences, hedges, or arches, where groups of plants inosculate together overtime due to the proximity within the lattice.[12] In a historical context, pleaching was frequently used in European gardens between the late medieval era to the early eighteenth century. Typically, deciduous trees or shrubs were planted in lines and woven together to form shaded pathways and fences.[13] Pleaching would create stronger barriers and hedge rows when compared to trees simply planted in a row, while often being more aesthetically desirable than artificial barriers. In 60 B.C, pleaching was also used as a defensive strategy to create anti-cavalry barriers by the Gallic tribe of Nervii as stated by Julius Caesar.[14] The use of pleaching was a choice informed by aesthetics as much as utility.

Espalier is another ancient practice in agriculture. It is done for the production and harvesting of fruit from woody plants. Branches are pruned and secured to a vertically standing flat frame, such as a fence or trellis.[15] Shaped in symmetrical, regular, and two-dimensional forms, espalier trees provide decorative properties while maximizing space efficiency and ease of fruit harvest. The flat trellis formation also provides better sunlight exposure, allowing extended fruiting season and better fruit production. “The techniques used in espalier are similar to some used in bonsai; the branches of a tree grown outside of the two-dimensional plane are pruned away, while branches that maintain the expected shape along the frame are kept and continuously shaped to grow more horizontally. It was also practiced from the time of ancient Rome and in the Middle Ages of Europe.[16] Espalier is an effective use of vertical green coverage akin to living walls.

In addition to these two, another notable technique is grafting. While inosculation is a process that takes place during grafting, it describes the naturally occurring process between two or more formed branches, trunks, or roots growing together through contact. Grafting can be performed artificially by intentionally wounding or exposing the cambium layers of two different tree tissues, placing them in contact, and securing them to inosculate. In agriculture and horticulture, grafting frequently consists of the inosculation of the scion and the rootstock as a method of asexual propagation.[17] The scion is the upper part of a combined plant, having desirable stems, foliage, or fruit, while the lower part is the rootstock, a different cultivar chosen for the properties of its roots.[18] Usually, the grafting point between the scion and rootstock is at or above the soil line. Most cultivars of trees found in garden centers and nurseries for

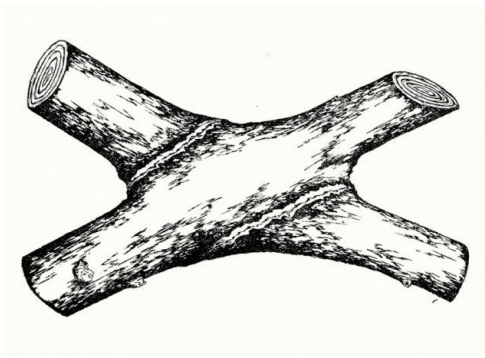


Fig. 2.6. Illustration of intergrowth, Arthur Wiechula, *Growing Houses Created from Living Trees*, 1920.



Fig. 2.7. Photographs of a series of sections through inosculation, Ferdinand Ludwig, 2012.



Fig. 2.8. Hedging competition, an example of pleaching, photography by Penny Mayes, 2009.

12 K Chithra and K. Amritha Krishnan, Implementing Campus Greening Initiatives (New York, NY: Springer Berlin Heidelberg, 2015), 113–24.

13 Chithra and Krishnan, Implementing Campus Greening Initiatives.

14 Julius Caesar, The Gallic Wars, trans. John Warrington, vol. II (New York: The Heritage Press, 1955), 52, 228.

15 Erv Evans, “Espalier,” North Carolina State University, Horticultural Science Department, February 2003, http://www.ces.ncsu.edu/depts/hort/consumer/quickref/general/espalier.html.

16 Sydney Park Brown, Thomas H. Yeager, and Robert J. Black, “Espaliers: CIR627/MG273, Rev. 9/2007,” EDIS 2007, no. 19 (October 18, 2007), https://doi.org/10.32473/edis-mg273-2007.

17 “Graft | Description, Types, & Uses | Britannica,” October 11, 2024, https://www.britannica.com/topic/graft.

18 “Grafting and Budding Nursery Crop Plants | NC State Extension Publications,” accessed June 13, 2024, https://content.ces.ncsu.edu/grafting-and-budding-nursery-crop-plants.



Fig. 2.9. Photograph of a "*Pear Tree Espalier Near Paris*", uploaded by Guido Frilli in 2016.

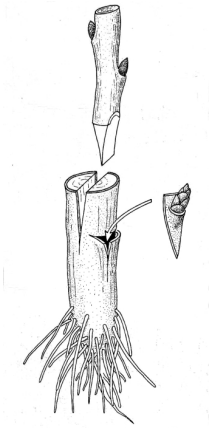


Fig. 2.10. Example of grafting, a section of stem is inserted into a rootstock. D. G. Mackean, No date.



Fig. 2.11. Illustration of approach grafting, George Nicholson, from The Illustrated Dictionary of Gardening, Div. IV, 1884.

landscaping, decoration, and fruit production are grown using the scion and rootstock graft, as it allows for reliable mass production of trees and hybrid breeding.

Within grafting, there are more specific techniques that are used in horticulture. For plants that are difficult to graft, "approach grafting" is where two plants grown in close proximity are secured together along the trunk or branches while both plants' roots and shoot system are undisturbed. When inosculation occurs at the secured point, one plant's rootstock may be removed, and the remaining shoot system becomes the new scion to the other plant's rootstock. This allows for a soft approach to inosculation as both plants still receive nutrients from their independent roots before both plants are able to rely on one rootstock. *Bud grafting* is another option that uses buds in place of stems or branches. Buds can be removed from one plant, then inserted at the base underneath the layer of bark at the stem of a stock plant.[19] The rest of the stock plant's shoot is cut so nutrients will redirect and integrate with the new grafted bud. This is often done with roses to produce more flowers and with fruit trees to increase fruit yield. *Cleft grafting* is a simple and common technique for combining a scion and rootstock and may be used to propagate plants that are difficult to root. The rootstock stem is cleanly cut horizontally, then split two to three inches down the middle to create a cleft. The scion contains three or four buds and is cut into a wedge shape one to two inches long beneath the lowest bud, then inserted into the cleft on the rootstock.[20] There are many more techniques for different instances and use cases in successful plant grafting. Most of these involve exposing the cambium tissue of both the scion and rootstock plants, then placing them in contact through various cuts and attachment methods. This subchapter provides only a brief overview of possibilities and an introduction to the basics of grafting in horticulture.

19 "Grafting and Budding Nursery Crop Plants | NC State Extension Publications."

20 "Grafting and Budding Nursery Crop Plants | NC State Extension Publications."

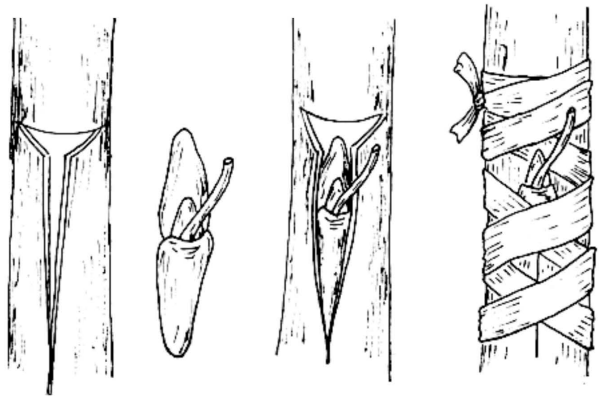


Fig. 2.12. Bud graft illustration, retrieved from the Maine Organic Farmers and Gardeners Association.

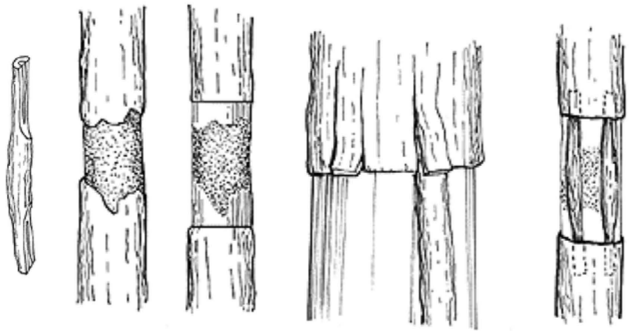


Fig. 2.13. Bridge graft illustration, retrieved from the Maine Organic Farmers and Gardeners Association.

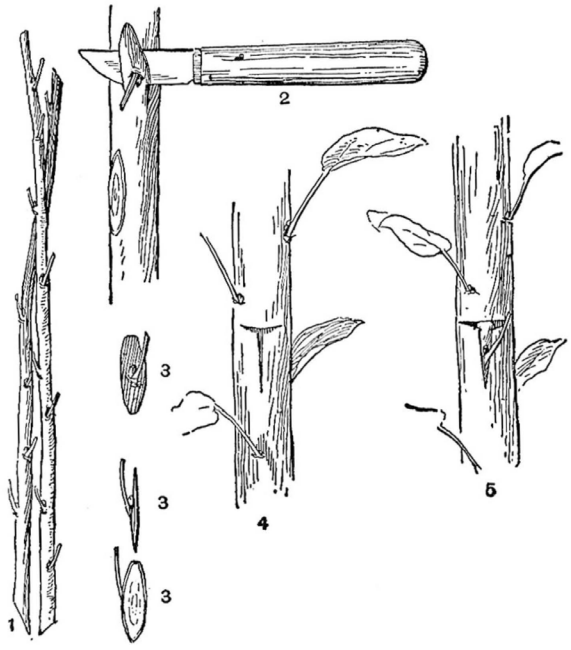


Fig. 2.14. Another bud graft illustration, retrieved from the Maine Organic Farmers and Gardeners Association.

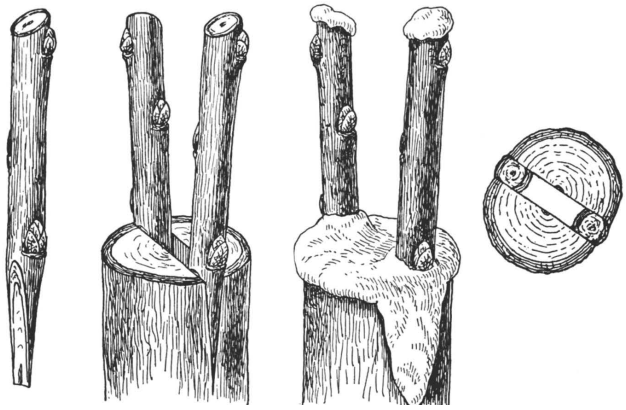


Fig. 2.15. Cleft graft illustration, retrieved from the Maine Organic Farmers and Gardeners Association.

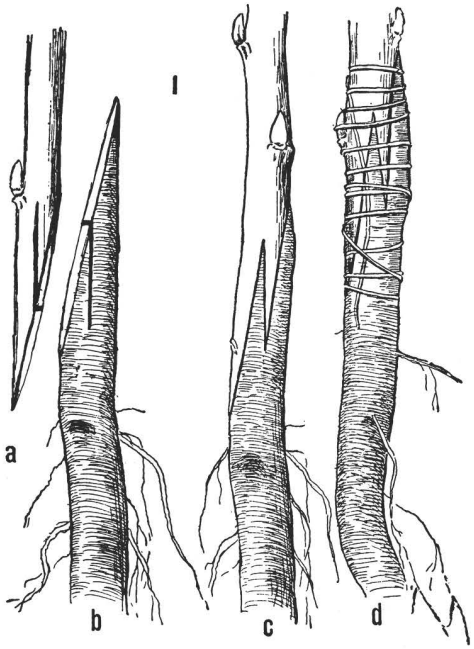


Fig. 2.16. Root graft illustration, retrieved from the Maine Organic Farmers and Gardeners Association.

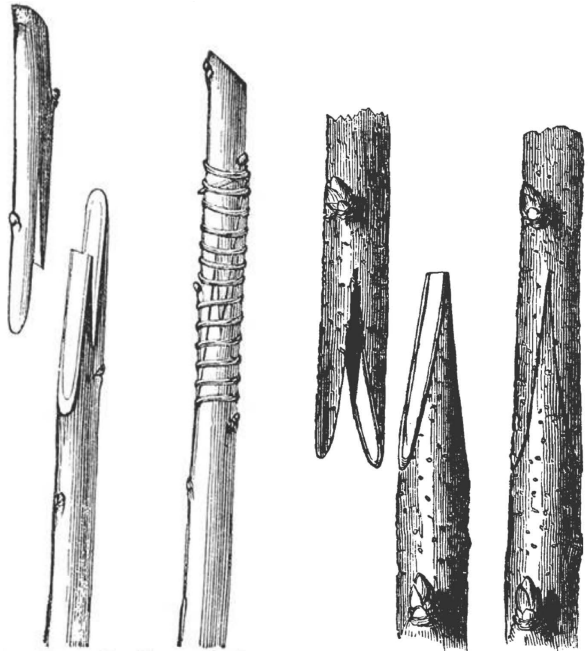


Fig. 2.17. Tongue and whip graft illustration, retrieved from the Maine Organic Farmers and Gardeners Association.

2.2.2 On Bonsai

As spatial designers and "architects," much can be learned from the little trees, called bonsai. Bonsai themselves are not a separate genus, species, or genetically modified plant, but rather are no different from normal trees. Any elm, oak, maple, pine, or even apple tree can theoretically be trained—so long as the plant naturally generates a woody stem, it is capable of becoming bonsai. The feat of their size and transformation, however, is a culmination of multiple generations of mastery in artistry, technique, horticultural knowledge, and trial. All of this provides valuable insight into horticultural design thinking, patience, and sustainable space making.

The earliest known renditions of *bonsai* originated from ancient China as "*penzai*" or "*penjing*", translating to "landscape in a pot or tray."[21] The conception of the "miniature landscape" was first recorded in text during the Tang dynasty, and graphically depicted around 700 B.C.[22] However, it was likely that Taoist monks were practicing some form of penjing even centuries before.[23] It is said that ancient monks living upon mountaintops fell in love with the diverse landscapes and scenery around them as they believed landscapes held cosmic forces harmonizing heaven and earth.[24] Their adoration led them to reconstruct these landscapes in miniature to bring back to their temples.[25] With the expansion of Buddhism and the ancient Chinese traditional' theory of five elements (that everything could be reduced to wood, fire, earth, metal, and water.)[26] There was a belief that natural landscapes hold great power and mysticism. By replicating these landscapes in miniature, "a student could focus on its magical properties and gain access to them."[27] The smaller the scale, the greater the mystic potency. It became both an artform and a spiritual practice. Over time, bonsai became an enormous influence in Chinese garden design; supported by the belief that there were divine powers within the miniature. The progress in Chinese ceramics also evolved the practice, ushering in dynasties of fascination with miniature dioramas of natural sceneries in picturesque little pots.

21 Qingquan Zhao, Penjing: A Pictorial Exploration of Its History, Aesthetics, Styles and Preservation (Chicago: Shanghai Press, 2021).

22 Yunhua Hu, Chinese Penjing: Miniature Trees and Landscapes (Portland, Or: Timber Press, 1987), 128.

23 "The History of Bonsai | Berea Bonsai Studio & Nursery," April 28, 2015, https://bereabonsai.com/the-art-of-bonsai/hello-world/.

24 The Epoch Times, "Chinese Shan Shui Painting Through the Yuan Dynasty," The Epoch Times (blog), January 15, 2019, https://medium.com/the-epoch-times/chinese-shan-shui-painting-through-the-yuan-dynasty-a725383e865c.

25 Bonsai Boy Catalog, "Detailed History of Bonsai," Bonsai Boy Catalog, accessed May 25, 2024, https://www.bonsaiboy.com/catalog/historyofbonsai.html.

26 "Wuxing | Five Elements, Yin-Yang, Taoism | Britannica," October 30, 2024, https://www.britannica.com/topic/wuxing.

27 "History of Bonsai," Bonsai Empire, accessed May 25, 2024, https://www.bonsaiempire.com/origin/bonsai-history.



Fig. 2.18. Drawing of the Garden of a Chinese Merchant, British Library/Bridgeman Images, unknown artist, 1800.



Fig. 2.19. An illustration of a Chinese garden, from the book *Oriental Gardens* by Norah Titley and Frances Wood, 1991.

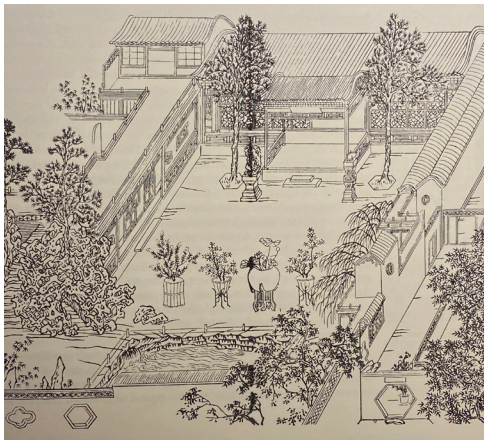


Fig. 2.20. Another illustration of a Chinese garden, *Oriental Gardens* by Norah Titley and Frances Wood, 1991.



Fig. 2.21. Travelers among Mountains and Streams, Fan Kuan, Song Dynasty, 960-1279.

"Bonsai" is the Japanese localization of the older Chinese term "penzai" and both terms share the definition of "tray planting."[28] During the sixth century, Japanese traders, diplomats, monks, and nobles would visit China and its mystical gardens. They would see grand mountain-scapes, roaring waterfalls, and seemingly vast forests displayed in very modest courtyards.[29] They would see hunting grounds fabricated to showcase expansive terrains as if to provide a sampling of the land's varied riches. They would also see tiny dioramas in terracotta pots–perfectly packaged to take home with them as souvenirs for their families across the sea[30]. At this point, the art of penjing branched out into Japan and evolved into the artform of bonsai that we know today.

As the art diverged between the two cultures, what is the difference between the two? Penjing typically focused on the expressive recreation of grand landscapes with rocks, grass, water, and trees. However, they could be separated into three main categories; *shumu*, depicting one or more trees as the subject, *shanshui*, depicting miniature landscapes using mostly rocks, and *shuihan*, depicting water and land with trees, rocks, and figures.[31] Although bonsai covers a spectrum of all penjing categories, Japanese bonsai eventually focused and evolved towards the presentation of trees in shallow containers. More specifically, the art honed in on the expression of the tree's form itself. The subject detracted from the immovable mountain or monumental landscape and instead became the living tree that sits atop the mountain. Its beauty is found within the expression of a tree's trunk, its branches, and its foliage, sculpted and shaped by forces of nature. Over centuries, bonsai artists trained trees to *look like* they were formed by natural elements, such as trees moulded by windy cliffs, or high-tide flooding. Bonsai trees are living sculptures representing natural beauty expressed with human interventions in unnatural forms.

A different aspect of the art exists in the practice of "*yamadori*", meaning "collecting plants in the mountains."[32] Often thought of as a spiritual journey, it is the act of collecting unique wild specimens and training them as bonsai trees. While some collect, many other bonsai artists also prefer to plant their trees from seed rather than collecting as a test of patience and persistence. Many renowned bonsai artists planted their first trees in their youth to see the fruits of their labour as elders in the craft. The allure of this bonsai training method is its predictability and control. However, such a granular level of control is not always possible nor desired as some artists find greater beauty and meaning behind characteristics designed by nature itself.

28 "Top 10: Greatest Bonsai Trees - Bonsai Empire," accessed December 7, 2022, https://www.bonsaiempire.com/inspiration/top-10/great-bonsai.

29 Norah Titley and Frances Wood, eds., Oriental Gardens (London: British Libr, 1991).

30 Titley and Wood.

31 Hu, Chinese Penjing, 11–12.

32 Diana Lang, "Foraging for Yamadori," Calgo Gardens, October 4, 2018, https://calgogardens.com/foraging-for-yamadori/.

At the scale of a bonsai tree, human intervention and training can emulate most effects of weathering and natural forces found on wild trees. Bending a branch by binding it with wire will force the branch to adapt to that shape overtime. Cutting off a branch will cause more nodes to grow and leaves to sprout. Adjusting fertilizer ratios will affect growth rate and distance between leaf nodes. Pruning the foliage will encourage a new flush of leaves to grow at a smaller size. Pruning the roots assists in maintaining the tree's size and encourages better root structure. The rate and repetition these operations of which are performed on a tree will vary widely by species, hardiness, climate, substrate, and the tree's health. Overall, these are basic techniques that have been adopted by bonsai artists, and in many cases, are knowledge shared in other fields of horticulture.

Throughout the bonsai's lifespan, binding and branch pruning can be performed numerous times, with light work multiple times throughout a year, and heavy pruning once every one to two years. It is also possible to cut down wider branches or the trunk as this can encourage more sprouting throughout the tree and at the cut lines, though more advanced in technique. Various degrees of pruning is performed to spur new branching in desired places and to establish denser branches with foliage, further driving the illusion of a larger old tree. This process of pruning contributes to *ramification*, a subdivision of complex branch structures which is critical in successful bonsai. In situations where branches do not grow in the artist's desired form, different gauge wires are wrapped around the branches to bend and bind them into shape. In healthy and older trees, it is possible to defoliate all leaves to force a new flush of foliage which will emerge smaller than its original leaves. All these methods are used throughout the bonsai's lifespan. As a bonsai reaches its final intended design, the artist then focuses on maintenance and preserving the tree's form. Major pruning and root work will become scarcer and most of the work becomes pruning unwanted shoots and leaves and ensuring the tree's health.

The processes discussed only scratch the surface of bonsai techniques and serve to provide an overview of some basic methods that bonsai artists have employed for centuries. In the modern age, new methods are introduced as bonsai becomes a more globally practiced artform. With the introduction of more tree species and the implementation of power tools, more flexibility and possibilities can be introduced into the art of bonsai.



Fig. 2.22. Japanese Cypress Forest, Masahiko Kimura, unknown date.



Fig. 2.23. The Thousand Year Old Ficus Retusa Linn, brought to Crespi Bonsai Museum from China in 1986.

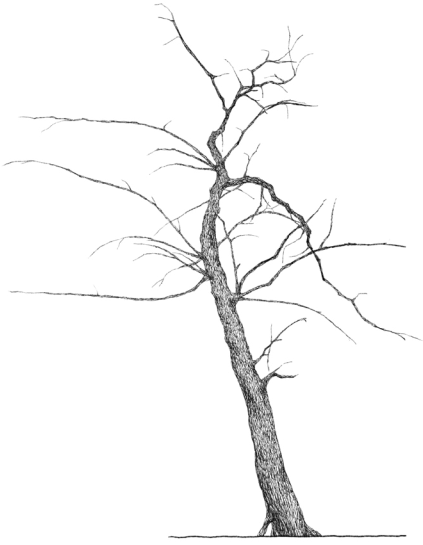


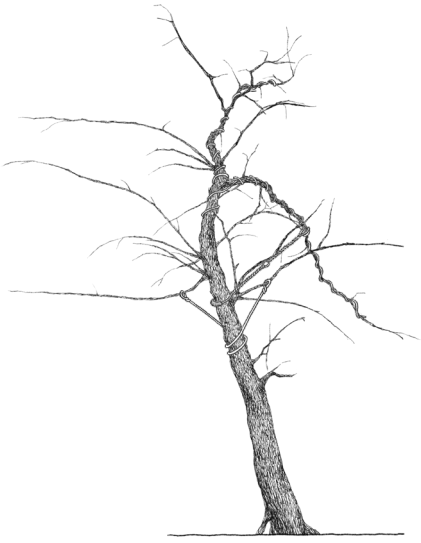
Fig. 2.24. 400 year old Yamaki Pine, donated to the National Bonsai Foundation in 1972 by Masaru Yamaki.

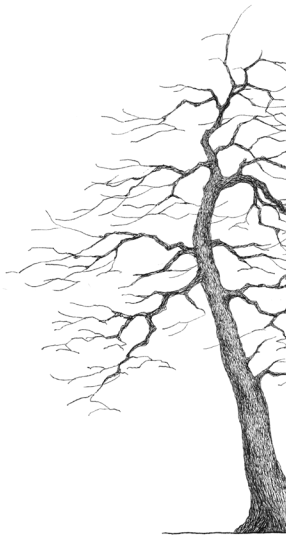












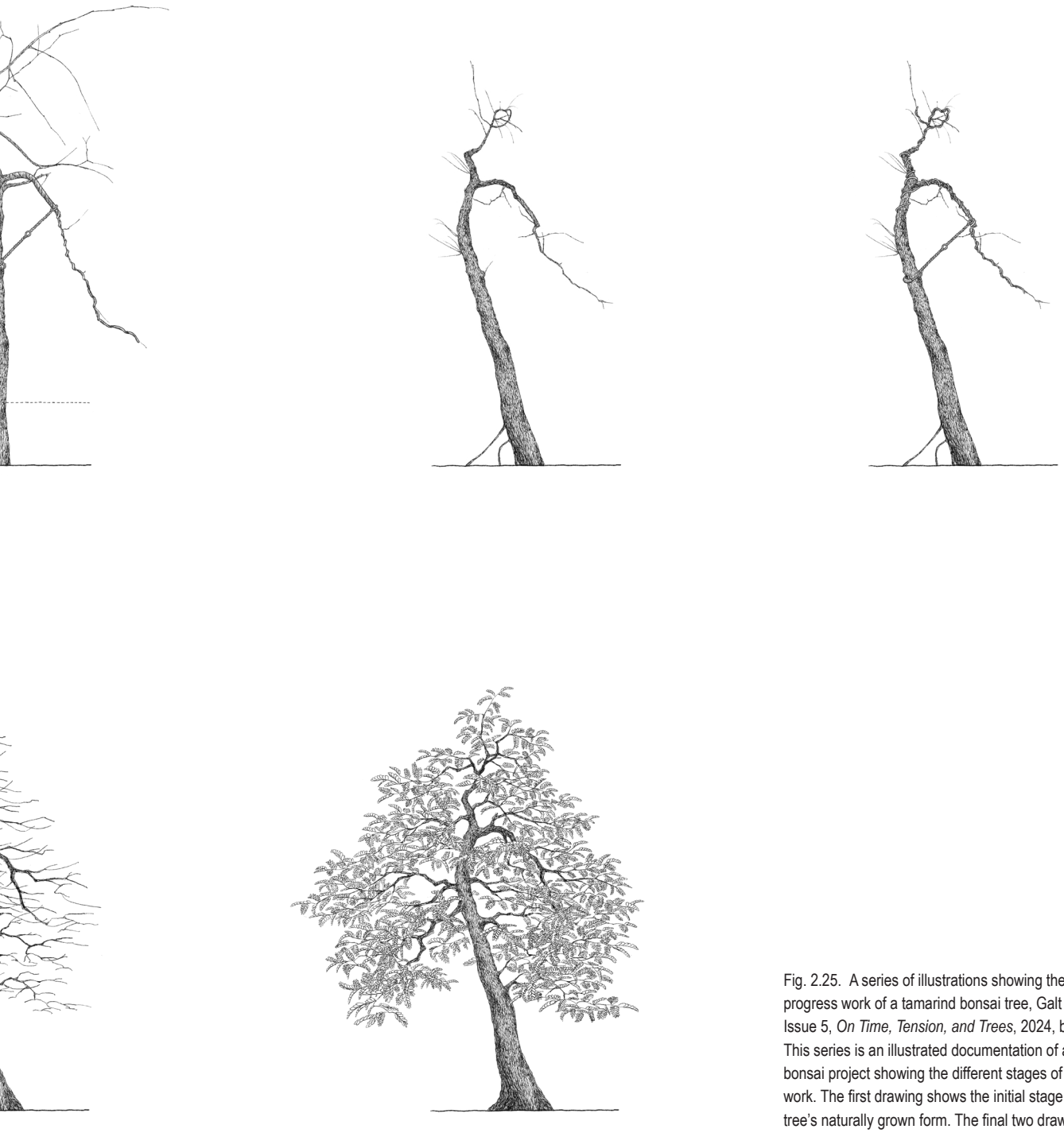


Fig. 2.25. A series of illustrations showing the steps of progress work of a tamarind bonsai tree, Galt Publications Issue 5, *On Time, Tension, and Trees*, 2024, by author. This series is an illustrated documentation of a tamarind bonsai project showing the different stages of progress work. The first drawing shows the initial stage of a young tree's naturally grown form. The final two drawings show future predictions of the tree as a bonsai project.



Fig. 2.26. Illustration of a tamarind bonsai project with projected goal imposed over the original tree form, Galt Publications Issue 5, *On Time, Tension, and Trees*, 2024, by author.

2.3 Conclusion

Living plants adapt and grow; this is key to bonsai, arbortecture, and arborsculpture as living objects. It can be useful to imagine living wood as an almost viscous material that has remarkable properties of physical memory and adaptability. Over the course of many years, woody material grows in diameter, enveloping anything within its growth path and helping stabilize the tree. When restrained at a static form for some time, the flexible and soft live wood will grow thicker and harden to retain that shape in place. This property is quintessential in the ability manipulate form in tree shaping. It is also why consistent pressure and force from wind or water will cause some trees to grow at an angle or in warped shapes. Trees are exceptionally resilient yet sensitive to external stimuli; the natural growth of wood becomes a living sculpture for the bonsai artist to shape and control.

Setting the premise for tree shaping in architecture; being arbortecture, it is essential to understand tree and its growth patterns to begin manipulating them as a design method. These are patterns that trees biologically follow at any scale, from houseplant to sequoia. By taking advantage of inosculation, comes different methods of grafting and imposing woody growth for the benefit of structural, aesthetic, or functional purposes. This sets the premise to how trees are applied to larger scales of space making and architectural objects.

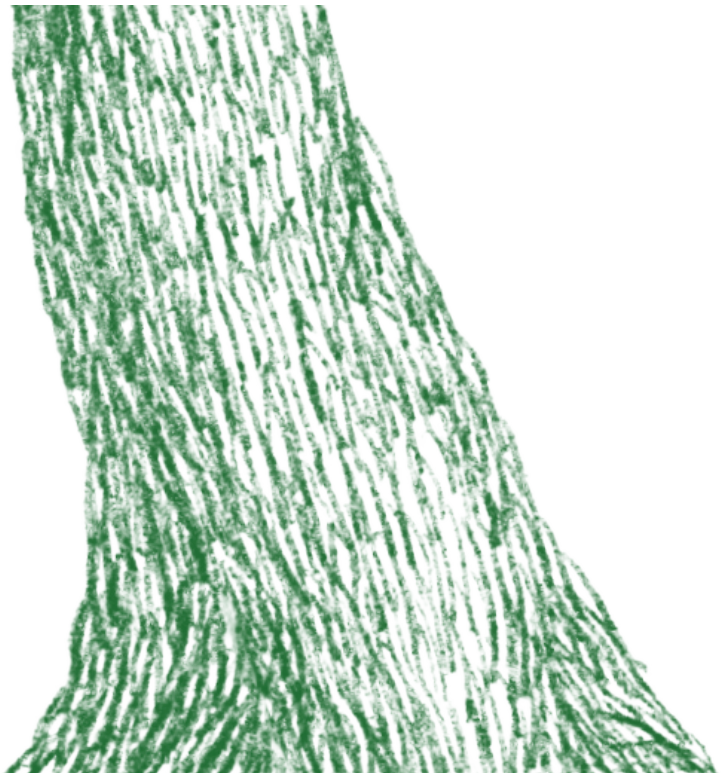


Fig. 3.1. Illustration of a tree trunk, 2024, by author

3.0 State of the Art: Trunk

Chapter 3 continues examining the state-of-the-art in tree shaping specifically through its key historical and developmental appearances both in ancient and modern architectural uses. Synthesizing techniques from agricultural, horticultural, and artistic applications, the chapter reviews the influences of tree shaping on space making, design, and engineering.

With the introduction of living plant architecture through sustainability-driven bio-architecture and naturalist utopian visions in the world of academics, it influenced a world, albeit limited, of designers, artists, and practitioners who continuously test the potential of tree shaping. Furthermore, the chapter reviews current prominent researchers in the hybrid practice, baubotanik architecture, their projects, and philosophy.

The chapter positions how modern movements are shaped through its practitioners. From art to agriculture to architecture and furniture, shaping trees for human needs and interests have existed since antiquity. Trees have become a familiar material to many cultures and curious designers with patience and a green thumb.

3.1 Historical precedence

From the various historical applications of tree shaping, there exist many case studies of furniture, sculpture, and utopian visions of biotecture possibilities from ambitious architects and designers.

As referenced in numerous sources investigating tree sculpture and biotecture, the living bridges of the Khasi people and the dance linden trees of Germany are prominent and important examples of living architecture systems or *biotecture*, a term first used by German landscape architect, Rudolf Doernach, whose research in the 1970's and 1980's heavily focused on bioengineering and integrated systems of biology and architecture.[1]

1 Rudolph Doernach, "Biotecture," Whole Earth Review, no. 64 (September 12, 1989): 1–2.

3.1.1 Living Bridges

In Meghalaya, northeast India, living root bridges can be found around the town of Cherrapunji and the villages of Laitkynsew and Nongriat. Built and used for centuries by the indigenous Khasi and Jaintia people, these suspension bridges are constructed from rubber tree roots (a species of ficus plant along with banyan trees) spanning across rivers and gorges. The dense root structures are hand weaved and shaped with other roots, twigs, and stones until they root into the ground across the riverbank. To bear loads, the bridges are reinforced using temporary natural materials and are removed once ideal growth is achieved, a process that can take around fifteen years.[2] Overtime, the roots merge and thicken, continuously building stability and strength. As a result of the lattice form and living nature of the roots, the bridges hold structural characteristics of cables, arches, trusses, and simple supported beams. As a particularly fast-growing and flexible plant, the Ficus tree develops vine-like aerial roots as a tool to anchor itself to rocky or unstable terrain, thus also making them suitable for this method of construction. As the structures grow, roots are continuously knotted and weaved by generations of the tribes who built them. It can take decades for a root bridge to usefully sustain consistent loads and can be seen as a testament of incredible foresight and long-term planning for the betterment of the future. The maintenance and development of these artifacts transcend generations as an immovable example of architectural resilience and ecological sustainability.[3]

While the living-root bridges are the most notable examples of living architecture in Meghalaya, the techniques from root shaping have also found applications in other functional structures including ladders, steps, platforms, and retaining structures in various levels of hybrid construction. Horizontal paths wrap around steep slopes stabilized by banyan tree roots, while steps grown from the roots create stairs to scale up terrain. Larger terraforming and landscaping projects are also done using the same roots to protect villages from

2 Russ Baker, "Re-Envisioning Our Environment," Business Insider, accessed November 24, 2024, https://www.businessinsider.com/re-envisioning-our-environment-2011-10.

3 "Baubotanik · OLA Office for Living Architecture," accessed March 26, 2023, https://www.o-l-a.eu/baubotanik-en/.



Fig. 3.2. The Great Bridge of Kudeng Rim, photo by Patrick A. Rogers, 2015.



Fig. 3.3. Padu 1 root bridge, photo by Patrick A. Rogers, 2015.



Fig. 3.4. Pongtung living root ladder, photo by Patrick A. Rogers, 2015.



Fig. 3.5. Kongthong living root ladder, photo by Patrick A. Rogers, 2015.

rockslides and hold land for farming purposes, acting as retaining walls.[4] In paths where slopes are too steep for stairs, roots can also be constructed into ladders by growing horizontal rungs or cutting footholds into thicker established roots where the cuts will grow into larger openings. Amongst the tree trunks higher up, platforms weaved from aerial roots are also found as coverage or hunting platforms, though their exact purposes are unknown. Another example is a large banyan tree in the village of Kuden Rim, overlooking a football field. Its aerial roots are trained around its own branches and trunk forming ledges to climb and sit on, while higher up, the roots are weaved into nets between branches for people to sit and stand in. The structure acts as bleachers to lookout at games while providing seating and shade. Many of these unique structures are camouflaged from overgrowth and their locations are not fully known or recorded. The lack of documentation indicates that many living root structures remain undiscovered by those outside of the Indigenous tribes, while the purposes of many documented structures are still uncertain.

4 Patrick A. Rogers, "Evenfewergoats: The Undiscovered Living Root Bridges of Meghalaya Part 4: Living Root Ladders and Other Uses for Living Root Architecture," Evenfewergoats (blog), October 1, 2015, https://evenfewergoats.blogspot.com/2015/10/the-undiscovered-living-root-bridges-of.html.



Fig. 3.6. Up on one of the platforms, photo by Patrick A. Rogers, 2015.



Fig. 3.7. The Living Root Bleachers, photo by Patrick A. Rogers, 2015

3.1.2 Dance Linden Trees

In the Germanic areas of the Holy Roman Empire, “Gerichtslinden” meaning “court linden,” were linden trees planted outside of villages and towns where assemblies or courts are held.[5] Similar to treehouses or gazebos, these linden tree structures planted within the village and town squares would be known as “Tanzlinden”, the “dance linden” and have persisted as gathering or celebratory spaces for centuries.[6] Bearing social significance and communal traditions, these trees still remain at the heart of many settlements in Germany. As a hybrid structure, the Tanzlinde (*Tilia platyphyllos*) is constructed from a central linden tree with its radial branches trained horizontally. These horizontal branches would make up the support beams for an elevated platform built on top used for dancing and festivities. The space below would also function as a shaded gathering space and would be held up by columns as the tree branches got too heavy. Stones or bricks were placed around the structure to further provide bracing support. Branches that wrap up around the platform edges would be shaped as leafy walls, surrounding the platform and becoming dense foliage at the top of the tree, turning the tree into facades of a building.[7] Similar to a backyard treehouse where a building sits within a tree, however, unlike a treehouse, the Tanzlinden uses an integrated building technique where the tree itself plays a role as one of the critical construction materials.

Many of the Tanzlinden trees have lasted for hundreds of years and possibly even 1000 years according to carbon dating estimates.[8] This is a testament to the hybrid process of consistent development and maintenance required for a structure like this to exist. As trees are ever changing, their structural supports and construction materials must change and adjust with it. While most Tanzlinden no longer exist and have fallen apart due to neglect, few persist with restoration and upkeep through community efforts. Some, like the Tanzlinde in Peesten, are still used for festivities, lectures, and concerts.

5 Georg-August-Universität Göttingen- Öffentlichkeitsarbeit, “Thing- Und Gerichtslinde - Georg-August-Universität Göttingen,” Georg-August Universität Göttingen, accessed November 24, 2024, https://www.uni-goettingen.de/de/thing-+und+gerichtslinde/41768.html.

6 “The Dance Linden,” Atlas Obscura, accessed January 9, 2023, http://www.atlasobscura.com/places/the-dance-linden.

7 “The Dance Linden.”

8 Hans Joachim Fröhlich and Hans Joachim Fröhlich, Wege zu alten Bäumen. 2: Bayern (Frankfurt / [Main]: WDV-Wirtschaftdienst, 1990), 24.

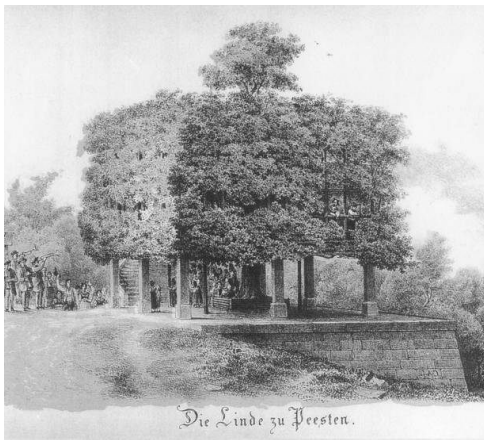


Fig. 3.8. The Tanzlinde of Peesten, Carl August Lebschée, 1850.



Fig. 3.9. Tanzlinde of Peesten, in modern times, photo by Henry Kuppen, 2020.



Fig. 3.10. Stamm der Effeltricher Linde, base of tanzlinde, photo by Schubbbay, 2006.



Fig. 3.11. Village lime tree in Effeltrich, Reinhold Möller (Stamm der Effeltricher Linde), 2019.

3.2 Plant Architecture

Architecture and structures built of living trees feature many traits that have contributed to functionality and reliability. Its simplicity in construction has yielded many historical examples from garden walls to bridges without the need for advanced tools. With these structures, a long lifespan can also be achieved. In many applications, timber would rot due to humidity and weathering within a few years, alternatively, living trees are protected by a bark layer capable of environmental protection and healing from minor injuries. Many of these structures are capable of their designed functions for hundreds of years. Beneath the ground, roots also grow thicker and increase structural stability with time. Acting as foundations, the roots help support structural loads and stabilize the soil without large excavations or soil displacement. Living tree architecture in its pure form does not consume non-renewable resources and instead, generates more. It is a method of highly sustainable construction that produces minimal pollution while naturally filtering carbon from the air. Furthermore, living architecture can create desirable greenery and improve aesthetic qualities in urban spaces, offering an alternative to manufactured and unsustainable materials. Nonetheless, it is an idealistic method of architectural space making that requires time, foresight, long-term planning, care, and maintenance—qualities that modern architecture lacks focus in and are difficult to ensure. However, it is possible to shift the praxis of architecture to a practice of patience, care, maintenance, and change in the environments that we build and cohabitate within. It is useful to reframe our relationship with architecture not as an end product, but as a symbiotic process between people and their environments.

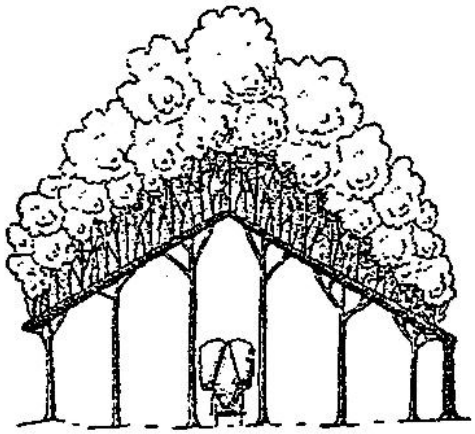


Fig. 3.12. Doernach's illustration of a trellis structure made of trees, published in the Permaculture Journal No. 7, 1989.

3.2.1 Biotecture

Plant architecture is a discipline at the crossroads of many paths. It is a sum of agricultural, botanical, horticultural, artistic, environmental, cultural, and technical construction knowledge. Though perhaps it is best attributed to German architect Rudolf Doernach as one of the first designers to draw a line from living plants to architectural design and construction. Featuring many publications and writings in the late 1970s to late 1980s, Doernach saw living-plant architecture, or "biotecture" as he had defined it, as a viable basis for a new vision of sustainable architecture.[9] With an education in architecture from the University of Stuttgart, and a Fulbright scholar in the United States, Doernach was a project partner of Buckminster Fuller working with geodesic domes.[10] During his practice in the States, he specialized in material science and systems of construction.

Upon returning to Germany, Doernach founded *Bioversität*, an institute and education center dedicated to research in "biotecture" as a "biotekt". Instead of building architecture, he lets the buildings "grow" through systems of geodesic domes and lattice structures as a framework for plants to anchor and grow along. He was also known for using willows in his designs for their flexibility and fast growth. Doernach's biotecture mainly used networks of plants as an envelope or skin to a built supporting structure. Frequently the plants existed as walls, facades, or roof structures with properties of energy production and

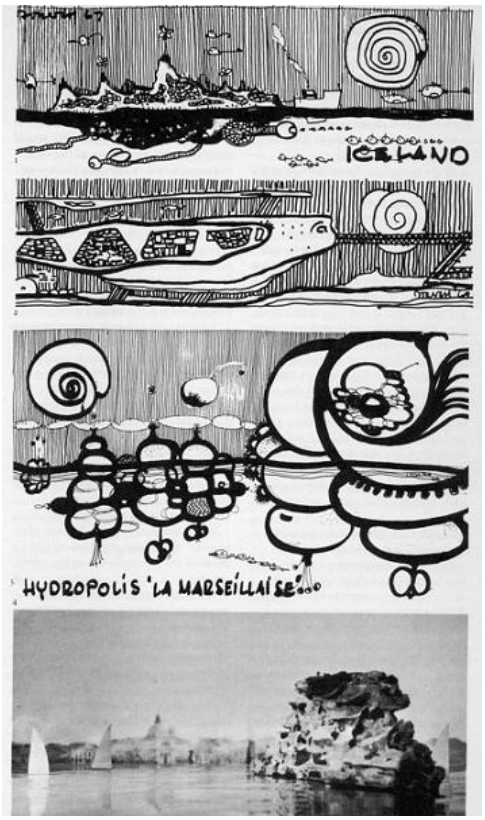


Fig. 3.13. Illustrations of experimental proposals featuring organic and ecological city scapes by Doernach. No date.

9 Ferdinand Ludwig, Daniel Schönle, and Sonja Dümpelmann, Growing Architecture: How to Design and Build with Trees (Basel: Birkhäuser, 2023), 18, https://doi.org/10.1515/9783035603392.

10 "Ecotecture," Thomson | Architecture Inc. (blog), November 8, 2015, https://www.thomsonarchitecture.ca/ecotecture/.

insulation using biomass.[11]

From Doernach's article published in 1989's Permaculture Journal Issue 7, "On the Use of Biotectural Systems," he outlined a lecture explaining early concepts of environmental and health benefits with the use of biotecture.[12] He argued that many diseases, particularly cancer, may be the result of increased carbon dioxide and lack of oxygen which can be remedied by bringing more plants within our urban environments.[13] Although modern medicine does not necessarily indicate oxygen deficit as a cause of cancer, Doernach rightfully proposed that increased oxygen production with decrease of carbon dioxide is better for human health in dense urban areas, countering some effects of pollution and improving air quality. The article also presented trees as a solution to many environmental issues that cities and towns are confronted with. Capable of reducing noise through dissipation and reducing air contaminants such as dust, Doernach also posed trees as an energy saving strategy. He explained that trees are further capable of providing passive cooling in the summer through while their biomass while also providing warmth and breaking winds in the winter, thus, saving energy costs on building operations.[14] His concept of living-plant envelopes or external cladding systems used biomass as a method of insulation, protecting the structure underneath. Despite Biotecture was a rather novel concept in architecture of the time, Doernach proposed to harness the benefits of trees and plants by integrating them into architecture as envelopes and facades, even suggesting different trellis systems and plant species for every facade orientation in relation to sun exposure. It is fair to say that even though Doernach had not produced many currently existing pieces of biotecture, it was his influence that formed the basis of study and research beyond the 1980's for living plant architecture.

11 Mark Primack, "PLEACHING," Living Structures, accessed November 24, 2024, https://www.rainforestinfo.org.au/good_wood/pleachng.htm.

12 "BIOTECTURE I: LIVING HOUSES," accessed September 5, 2024, https://www.rainforestinfo.org.au/good_wood/biotctl.htm.

13 "BIOTECTURE I: LIVING HOUSES."

14 "BIOTECTURE I: LIVING HOUSES."

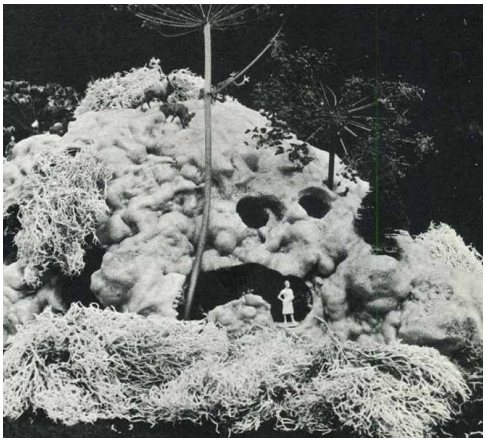


Fig. 3.14. Diorama of a bio-architecture proposal by Doernach. No date.



Fig. 3.15. A living-plant dome designed by Doernach. No date.

3.2.2 Tree Shaping

The flexibility and potential of using living trees as architecture had also inspired many more contemporary applications. In the early 20th century, German gardener and landscape engineer Arthur Wiechula published the book, *Wachsende Häuser aus lebenden Bäumen entstehend* (Growing Houses from Living Trees).[15] He produced a series of detailed illustrations demonstrating the use of living trees as residential and commercial buildings. Wiechula explains his visionary building method,

> "Here it is not a question of forming buildings out of foliage, but of letting the wood itself grow into such forms where it constitutes structural enclosures, structures that have solid walls, doors and windows, and which, like any other house, can be used for purposes of all kinds without fear of snow, rain, wind, cold or heat getting in."[16]

To achieve this, he applied horticultural techniques for tree growth to use in architecture. By planting trees in grid formations and in close proximity to each other, the trees would thicken and close the gaps between, effectively forming continuous "walls".[17] This theory of creating merged wooden surfaces through trunk thickening would further be applicable to roofs and floors. His illustrations also depicted bending, weaving, and lattice structures to further develop facades as part of a building. Windows and doors would have larger openings between trees and the interior would be lined with wood finishes or drywall. As Wiecula's proposals were utopian with minimal downsides, he believed that it was a likely sustainable future. However, outside of his illustrations, no tangible buildings or architecture had ever been produced using his documentations.[18]

Though idealistic and progressive, it is understood that Wiechula's proposals had biological limitations. Mainly, trees could not grow in such close proximity at regular intervals needed for their trunks to merge. The density causes competition for resources and nutrients, stunting tree growth and producing highly inconsistent growth rates between trees.[19] Due to this fundamental biological impossibility, *Wachsende Häuser aus lebenden Bäumen entstehend* was highly criticized, and in the end, fell into relative obscurity. Although no buildings were ever made in his time, Wiechula's book visualizes a framework for a sustainable construction that is still worth revisiting today.

In the 1980s, then architecture student Konstantin Kirsch and experienced gardener Hermann Fritz Block rediscovered the works of Wiechula independent of each other. They met through their mutual interest and together, eventually designed and grew numerous full-scale buildings using Wiechula's proposals as a basis. In addition to Wiechula's designs, they also developed their own techniques through experimentation with sculptures and building-like structures. Many of their experiments can still be actively found today in *Waldgartendorf* or *"Forest Garden Village"* near Nentershausen in Germany now under the care of Kirsch.[20] Due to the lengthy timescale of such construction, many of Kirsch's experiments are in various stages of completion.



Fig. 3.16. Design for a hunters' lookout, Arthur Wiechula, 1926.

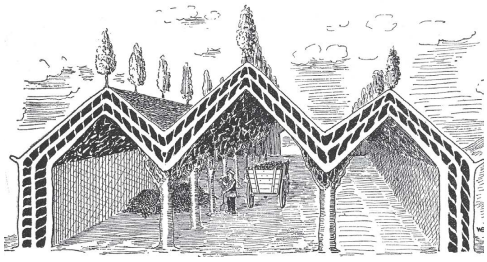


Fig. 3.17. Design for a farm building with triple layer living wall for insulation, Arthur Wiechula, 1926.

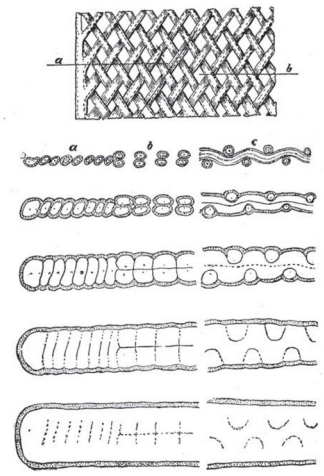


Fig. 3.18. Schematic drawing of the theoretical cross-connected shoots fusing into closed walls, Arthur Wiechula, 1926.

15 Ludwig, Schönle, and Dümpelmann, Growing Architecture, 174–76.

16 Arthur Wiechula, Wachsende Häuser aus lebenden Bäumen entstehend, [Nachdr. der Ausg.] Berlin-Friedenau, Verl. Naturbau, 1926 (Osnabrück: Packpapier-Verlag, 2012).

17 Ludwig, Schönle, and Dümpelmann, Growing Architecture, 174–76.

18 Ludwig, Schönle, and Dümpelmann, 174–76.

19 Ludwig, Schönle, and Dümpelmann, 174–76.

20 "Forest Garden Village," accessed July 3, 2024, https://www.naturbauten.org/waldgartendorf.html.

Like the structures in Waldgartendorf, Hermann Block also independently created structures in the gardens of Hohen Schloss of the Unterallgäu district in 2001 using some differing species than that of Kirsch's. The level of development found at both sites are rather comparable as in Wiechula's original designs, he over projects the trees' growth rate. In practice, the overwhelming competition between plants within close proximity significantly stunts the growth and thickness of their branches.[21] As roots beneath soil require a similar material mass as branches above ground in order to sustainably absorb nutrients, closely rooted plants find extreme competition resulting in reduced rate of nutrient intake. Nonetheless, Kirsch and Block are some of the first designers legitimizing Wiechula's utopian vision of sustainable plant-based architecture.

Around the same time that Arthur Wiechula was publishing his book, Axel Erlandson, a Swedish American farmer, began his own development of sculpting living trees. Seen as an early pioneer of "arborsculpture", Erlandson started experimenting with inosculation on the hedgerows of his California farm in 1925 as a hobby. By applying tree shaping techniques and designing patterns, he became masterful shaping trees and controlling their growth.[22] Erlandson eventually opened up the roadside attraction *"The Tree Circus"* in 1947 featuring some of his most notable works: *"The Basket Tree,"* consisting of six American Sycamores, and *"The Four-Legged Giant,"* from four American Sycamores.[23] Many of Erlandson's arborsculptures are currently rehomed in Gilroy Gardens due to the changing land ownership of the original Tree Circus. While his work showcased possibilities of manipulating tree growth in complex patterns, Erlandson mostly featured sculptural oddities and objects, with no strong intent towards sustainable construction or architectural design.

A contemporary to Konstantine Kirsch, Richard Reames, is an American artist who founded *"Arborsmith Studios"* in 1993, establishing the term "arborsculpture" and bringing the practice into international attention.[24] With an education in horticulture, biology, and log-house construction, Reames had a strong connection and interest in ecology and nature. While working as a landscaper, he started growing and shaping trees while writing about his knowledge. Though he was influenced by figures like Wiechula, Reames's major inspiration comes from arborsculpture pioneer, Axel Erlandson. Having grown up in proximity to The Tree Circus and supported by his interest in Frank Lloyd Wright's organic architecture, Reames was encouraged by the potential of arborsculpture within the world of space making and sustainability.[25] He also attributes his influences from 18th and 19th century naturalist mystics. Reames's intellectual work followed and succeed Erlandson's projects, exhibiting sculptural artifacts and testing complex formwork at scales more varied than that of The Tree Circus, including chairs, boats, and buildings.[26] Reames' portfolio included environmental installations such as the *"Laughing Happy Tree Park"* in Jokoji, Japan, and

21 Ludwig, Schönle, and Dümpelmann, Growing Architecture, 174–76.

22 Wilma Erlandson, My Father "Talked to Trees" (S.l: W. Erlandson, 2001).

23 "The World-Famous Circus Trees | A Must-See at Gilroy Gardens," accessed September 6, 2024, https://www.gilroygardens.org/play/circus-trees.

24 Richard Reames, Arborsculpture: Solutions for a Small Planet, 2. print. with rev (Williams, Or: Arborsmith Studios, 2007).

25 "Life and Limbs - AGCO FarmLife," December 6, 2012, https://myfarmlife.com/2012/life-and-limbs/.

26 Joshua Foer and Richard Reames, "How to Grow a Chair: An Interview with Richard Reames | Joshua Foer and Richard Reames," accessed September 6, 2024, https://cabinetmagazine.org/issues/20/foer_reames.php.

arborsculpture exhibitions at the Growing Village Pavilion at the World Expo 2005 in Nagakute, Japan, in collaboration with colleague John Gathright.[27] After his appointment as the international arborsculpture coordinator, Reames presented international lectures on arborsculpture, from growing chairs to building structures, and oversaw many global artists.[28] With such, Reames did not attempt to propose academic solutions nor facilitate new methodologies and frameworks of sustainable building construction, but rather, his work still currently remains in the realm of speculative art and gardening.

27 "Bio," Arborsmith Studios, accessed November 24, 2024, http://www.arborsmith.com/bio.

28 "Life and Limbs - AGCO FarmLife."



Fig. 3.19. Konstantin Kirsch's Eschenhaus, drawn by Susanna Feldmann, unknown date.



Fig. 3.20. Eschenhaus designed by Konstantin Kirsch. Naturbauten.



Fig. 3.21. Eschenhaus lattice designed by Konstantin Kirsch, Naturbauten.



Fig. 3.22. Buchenhaus Wird Gruen by Konstantin Kirsch, Naturbauten.



Fig. 3.23. Lindenhaus by Konstantin Kirsch. Naturbauten.



Fig. 3.24. Ahornwand Wall by Konstantin Kirsch, Naturbauten.



Fig. 3.25. Eschenhaus by Konstantin Kirsch, Naturbauten.



Fig. 3.26. Chairs Growing in Place by Konstantin Kirsch, Naturbauten.



Fig. 3.27. The Ash House by Konstantin Kirsch, Naturbauten.

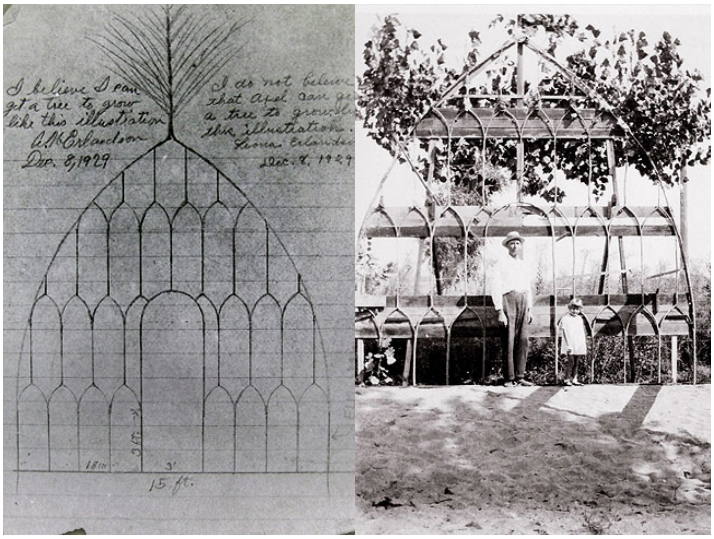


Fig. 3.28. Schematic design of a tree sculpture curiosity and photograph, Axel Erlandson, 1929.

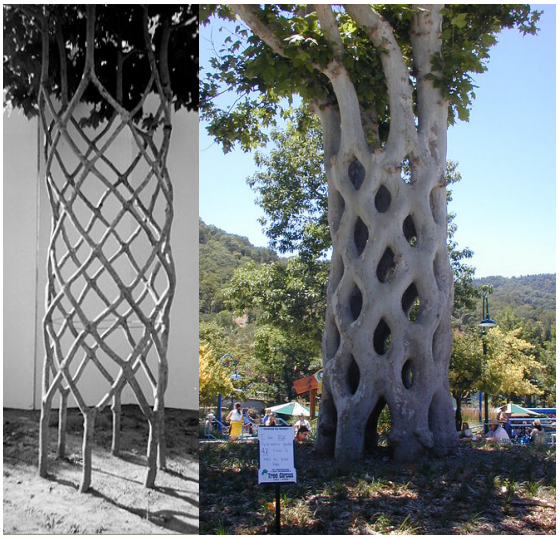


Fig. 3.29. The Basket Tree from the Tree Circus, Axel Erlandson, 1945.

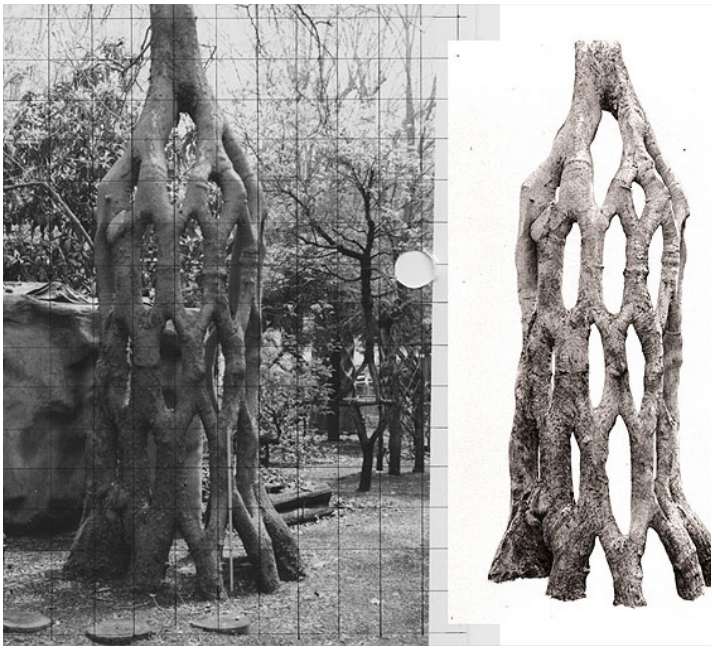


Fig. 3.30. Curiosities from The tree Circus by Axel Erlandson, recorded by Mark Primack, unknown date.



Fig. 3.31. Curiosities from The tree Circus by Axel Erlandson, recorded by Mark Primack, unknown date.

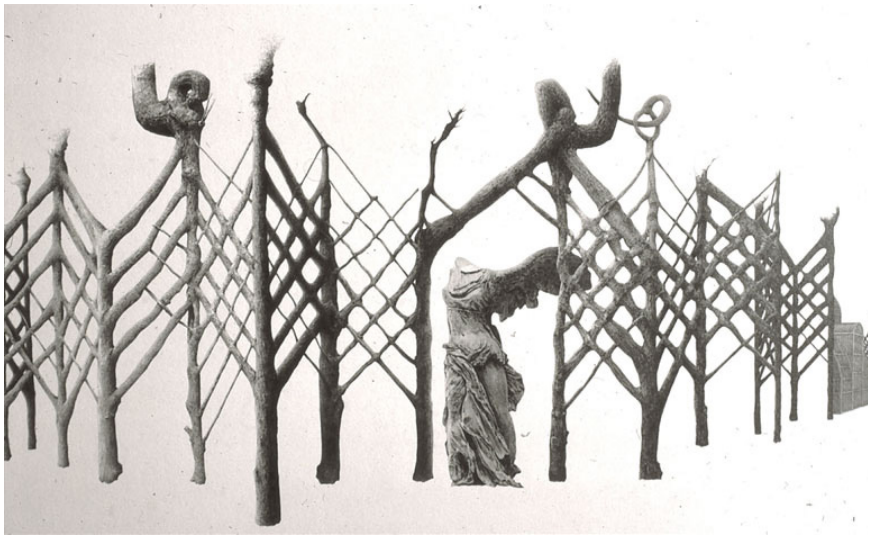


Fig. 3.32. Curiosities from The tree Circus by Axel Erlandson, recorded, illustration, by Mark Primack, unknown date.



Fig. 3.33. Curiosities from The tree Circus by Axel Erlandson, recorded, illustration, by Mark Primack, unknown date.



Fig. 3.34. Cathedral Entry by Arborsmith Studios, Richard Reames, unknown date.



Fig. 3.35. Sequoia Sactuary by Arborsmith Studios, Richard Reames, 2023.



Fig. 3.36. Moving tree to world expo 2005, Arborsmith Studios, Richard Reames, 2005.

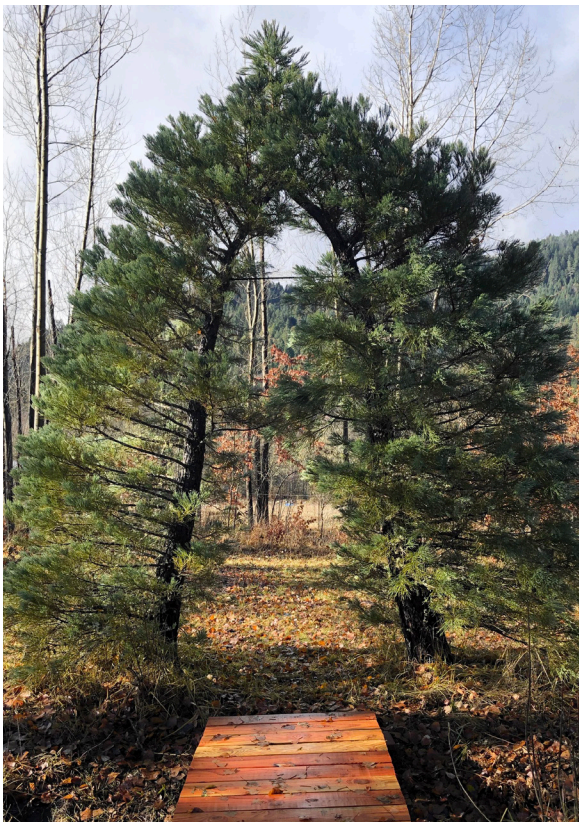


Fig. 3.37. Sequoia Arch by Arborsmith Studios, Richard Reames, unknown date.



Fig. 3.38. Tree House by Arborsmith Studios, Richard Reames, unknown date.

3.2.3 Catalog of Other Influences in Living Architecture and Adjacent Disciplines

Architecture: Practitioners and their projects that use living trees as form to design human scale spaces

Sanfte Strukturen - Art/architecture studio founded by Marcel Kalberer and Dorothea Kalberer 1973 in Germany. Inspired by Rudolf Doernach's visions of biotecture, Kalberers developed a technique using bundled live willow rods as construction.[29] Influenced by the Land Art movement, Sanfke Strukturen has built many pavilions and domes using the fast-growing system of willow bundling.[30] Sanfte Strukturen's most recent project was made in 2023.

Fab Tree Hab - A theoretical eco-house proposal from MIT designed in 2006 by Mitchell Joachim, Javier Arbona and Lana Greden. Using "pleaching" as the framework, the project proposes young trees woven into shapes and forms that would create a model for a sustainable living home.[31]

Bonnie Gale self-described as a "Willow artist." With an education in City Planning and Landscape architecture, Gale works with willow trees as a medium. Her work consists of art installations and exhibitions of varying scales in public parks, museums, and private gardens.[32] Gale has been working on a new willow project since 2021.

Giuliano Mauri defined himself as "a sculptor of art in nature."[33] Having featured works in many international galleries including the Venice Biennale in 1976, in the context of arborsculpture and biotecture, he is most known for his piece, *"Cattedrale Vegtale"* in Northern Italy. The installation replicates a five-aisle basilica by using scaffolding made of branches and pieces of wood, supporting the growth of eighty hornbeam saplings. Overtime, the hornbeams would grow along the scaffolding, forming arches and completing the basilica.[34]



Fig. 3.39. Fab Tree Hab by Mitchell Joachim, Javier Arbona and Lara Greden at MIT, 2005.



Fig. 3.40. Living Willow Tunnel by Bonnie Gale, 2011.

29 "Marcel Kalberer: Venus Architecture," accessed September 9, 2024, https://venusarchitecture.com/en/marcel-kalberer.html.

30 "Willow Construction," Sanfte Strukturen (blog), accessed September 9, 2024, https://sanftestrukturen.com/en/willow-construction/.

31 "Three from MIT Envision Grow-Your-Own Home," MIT News | Massachusetts Institute of Technology, August 1, 2006, https://news.mit.edu/2006/house.

32 "PROJECTS," Living Willow Structures by Bonnie Gale, accessed September 9, 2024, https://www.livingwillow.info/projects.

33 "BIOGRAFIA," Giuliano Mauri, accessed September 10, 2024, https://www.giulianomauri.com/test/biografia/.

34 Audra, "Magnificent Cathedral In Italy Formed By Real Growing Trees," Demilked, December 4, 2014, https://www.demilked.com/cattedrale-vegetale-tree-cathedral-giuliano-mauri/.



Fig. 3.41. Auerworld Palace by Sanfte Strukturen, 1998.



Fig. 3.42. Vegetable Cathedral by Giuliano Mauri, 2016.

Furniture: Shaping roots and branches have also allowed designers to "grow" furniture

John Krubsack, known for his curious piece dubbed *"The Chair That Grew"*, planted 32 box elder trees in 1903 and shaped them into a chair over the course of 14 years.[35] After harvesting the chair, it was later exhibited at the 1915 World Fair. Krubsack could be considered one of the early pioneers of modern day arborsculpture. The descendants of the Krubsack family now privately keep the chair.[36]

Peter Cook and Becky Northy founded the company *"Pooktre."* They were invited as featured artists in the Growing Village Pavilion at the 2005 World Expo in Japan. They have since been growing many pieces of art and furniture, while also taking commissions and providing consultation for living furniture.[37] Unlike Krubsack's chair, Pooktre has many projects which remain living and planted past completion.

Alice and Gavin Munro are furniture designers. Having studied furniture design in college, Gavin Munro started making driftwood furniture while also working in construction. He started the company *"Full Grown"* in 2006 as a platform to mass grow furniture. Using only one willow tree per chair, Munro shapes them with frames on a two acre field and cultivates them when completed.[38] Having been featured in many galleries and collaborations with companies including Louis Vuitton, Munro is working towards mass-producing plant furniture, as he calls "bio-facture," a play on the word "manufacture."[39] Hundreds to thousands of trees are planted in order to conduct design experiments with hopes that some may succeed.[40]

35 "1908 John Krubsack," treeshapers.net, April 13, 2011, https://www.treeshapers.net/john-krubsack.

36 "The Chair That Grew," Atlas Obscura, accessed September 10, 2024, http://www.atlasobscura.com/places/chair-grew.

37 "Pooktre Creating Living Art with Trees," Pooktre, September 30, 2022, https://www.pooktre.com/.

38 "The Chair Orchard: How Gavin Munro Shapes Furniture from the Ground up - CBS News," March 10, 2019, https://www.cbsnews.com/news/gavin-munro-full-grown-shaping-nature-into-furniture/.

39 "Front Page," Full Grown, accessed March 28, 2024, https://fullgrown.co.uk/.

40 "About Us," Full Grown, accessed September 10, 2024, https://fullgrown.co.uk/about-us-full-grown/.

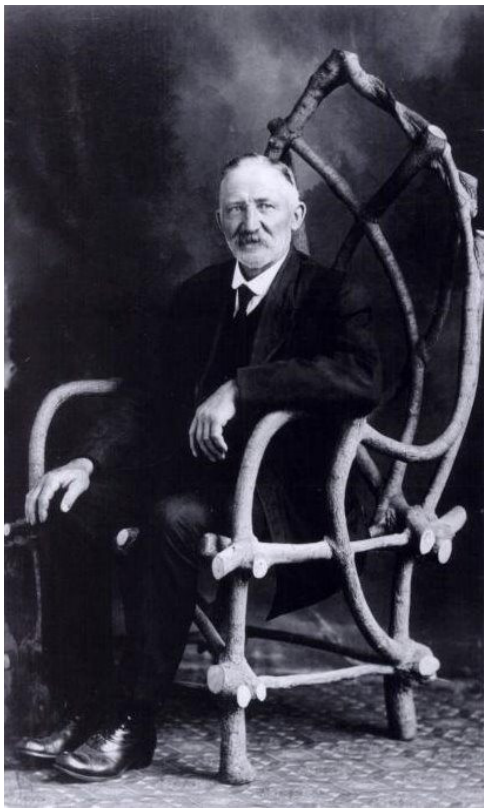


Fig. 3.43. The Chair that Grew by John Krubsack, 1915.



Fig. 3.44. The Living Chair by Pooktre, 1998.



Fig. 3.45. Gavin Munro's chair orchard, 2019.

3.3 Baubotanik

"Baubotanik" architecture is a term introduced at the Institute for Architectural Theory and Design (IGMA) of the University of Stuttgart in 2007 through research work done under the guidance of Professor Ferdinand Ludwig.[41] Ludwig later co-founded the Office for Living Architecture (OLA) with Daniel Schönle and Jakob Rauscher to continue practicing architecture, landscape, and urbanism[42].

Baubotanik, "bau-" meaning "building," and "-botanik" meaning "botany" in German, is used to define architectural structures created of technical joints and living plant growth as a hybrid construction method.[43] The architectural concept re-approaches classic design-thinking by using rules of plant growth as guiding principles. It can be categorized under the umbrella term "biodesign" or "biotecture" as introduced by Rudolf Doernach, using living plants as a technical joinery and structural elements. Primarily focusing on material use of wood producing plants, the method seeks to adopt the structural and growth properties of living plants as substitution and supplementary to artificial frameworks. Currently, this field of study can be found at the Professorship for Green Technologies in Landscape Architecture and is expanding as an interdisciplinary practice.[44]

As demonstrated, trees can be grown, grafted, and adapted as structural elements in summation of a "building" or "architecture", presenting spatial properties akin to our built environment. As an interdisciplinary practice, it integrates design, structural engineering, bio research, and horticultural procedure. By bringing spatial qualities of nature, ecological benefits of local long-standing trees and interdisciplinary research, it offers a profound architectural opportunity to explore as facets of sustainable urbanism and progressive design.[45]

To understand baubotanik architecture productively as a construction method, we must understand that there are two main techniques to manipulate the horticultural properties of woody-plants. Everything else builds upon these techniques.

41 "Baubotanik," accessed January 10, 2023, https://www.arc.ed.tum.de/gtla/forschung/baubotanik/.

42 "Office · OLA Office for Living Architecture," accessed November 4, 2024, https://www.o-l-a.eu/office/.

43 "Baubotanik · OLA Office for Living Architecture."

44 "Baubotanik · OLA Office for Living Architecture."

45 "Baubotanik · OLA Office for Living Architecture."



Fig. 3.46. The Baubotanik Footbridge, by OLA and Baubotanik Group, Ludwig Ferdinand, 2005.



Fig. 3.47. Baubotanik Arbor Kitchen, TUM School of Engineering and Design, 2022.

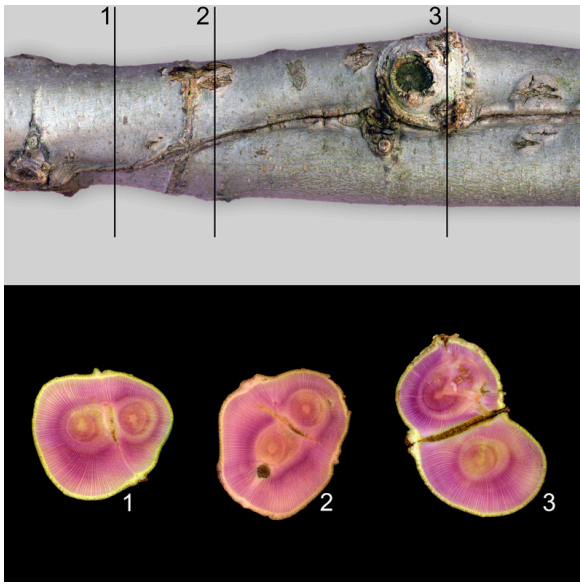


Fig. 3.48. Series of sections through inosculation, Ferdinand Ludwig, 2012.



Fig. 3.49. Test field with inosculations, photo by foto chira moro, unknown date.



Fig. 3.50. Plane trunks intergrown evenly at crossing point, *Growing Architecture*, Ferdinand Ludwig, 2023.



3.3.1 Inosculation and Grafting Technique

Akin to existing tree-shaping and arbortecture techniques, inosculation is also a key factor in creating hybrid joints in baubotanik structures. It is used to create strong organic junctions. By pressing multiple plant members together or around abiotic structures, separate plant appendages can organically fuse over time as the plant thickens and the bark callouses, holding itself or other connected structures in place.[46] A successful inosculation operation results in multiple stems or branches combining into one organism at one or more points of contact.

Through the Baubotanik Research Group's experimentations, cross sections through branch material are documented on a segment of parallel grafts. This was done to evaluate and document the process and efficacy of inosculation between two branches. When referring to the sectional cuts through the inosculated branches (fig. 3.48), in cases of 1, 2, and 5, a continuous growth ring begins to form as indicated by the purple dye. This signifies successful inosculation as the woody part of the plant becomes a unified body.[47] 3 and 6 however, still show remnants of bark callous between the individual members.[48]

In the figures to the right, we can see instances of inosculation occurring in nature as multiple living plants sharing flow and supply of nutrients; thereby becoming one organism with unique form properties. When a strong connection is established, the two organisms become a symbiotic system.

46 Ferdinand Ludwig, Hannes Schwertfreger, and Oliver Storz, "Living Systems: Designing Growth in Baubotanik," Architectural Design 82, no. 2 (2012): 82–87, https://doi.org/10.1002/ad.1383.engineers and biologists it aims to synthesise architectural qualities, constructive requirements and biological properties in living structures. In this article, Ferdinand Ludwig, Hannes Schwertfeger and Oliver Storz of the Baubotanik research group at the Institute for Architectural Theory and Design (IGMA

47 Ludwig, Schwertfreger, and Storz.engineers and biologists it aims to synthesise architectural qualities, constructive requirements and biological properties in living structures. In this article, Ferdinand Ludwig, Hannes Schwertfeger and Oliver Storz of the Baubotanik research group at the Institute for Architectural Theory and Design (IGMA

48 Ludwig, Schwertfreger, and Storz.engineers and biologists it aims to synthesise architectural qualities, constructive requirements and biological properties in living structures. In this article, Ferdinand Ludwig, Hannes Schwertfeger and Oliver Storz of the Baubotanik research group at the Institute for Architectural Theory and Design (IGMA

3.3.2 Adaptive Growth

The second key baubotanik method is integration of technical building elements with live plant structures. Generally, this consists of additive artificial frameworks within a plant fabric. This can include securing components to “Y” spits of branching, embedding components within an established branch by drilling/cutting, or bending and wrapping a branch around the component and allowing the organic material to grow.

When the surface of a tree comes into contact with a secondary material, either plant or artificial, the tree expands its surface to increase the point of contact, forming an anchor point.[49] The “fluid-like” form-fitting growth around foreign objects can be used in baubotanik construction as a method of stabilization.[50] The contact of other objects is met with excess wood production to reduce risks of breakage and weakness.

By harnessing natural properties of trees, adapting scaffolding and artificial material into organic growth patterns supports durable and form fitted joints that are designed by nature itself.

49 Ludwig, Schwertfreger, and Storz.engineers and biologists it aims to synthesise architectural qualities, constructive requirements and biological properties in living structures. In this article, Ferdinand Ludwig, Hannes Schwertfeger and Oliver Storz of the Baubotanik research group at the Institute for Architectural Theory and Design (IGMA

50 Ludwig, Schwertfreger, and Storz.engineers and biologists it aims to synthesise architectural qualities, constructive requirements and biological properties in living structures. In this article, Ferdinand Ludwig, Hannes Schwertfeger and Oliver Storz of the Baubotanik research group at the Institute for Architectural Theory and Design (IGMA



Fig. 3.51. Connection detail, Ferdinand Ludwig, 2012

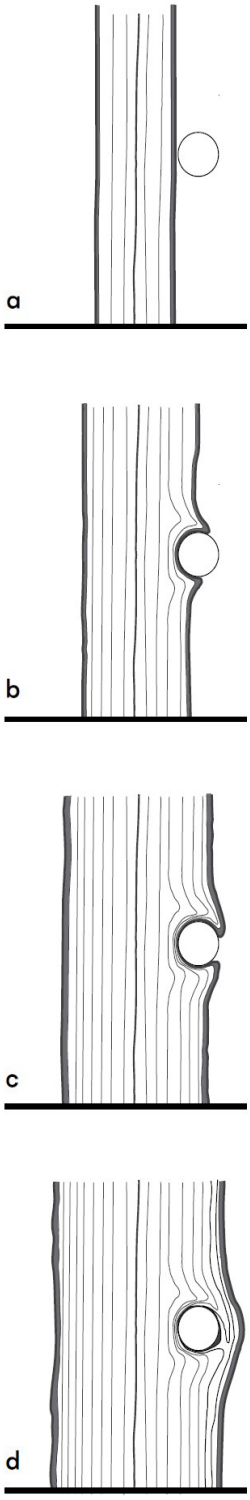


Fig. 3.52. Incorporation of a tube (schematic section), *Growing Architecture*, 2023.

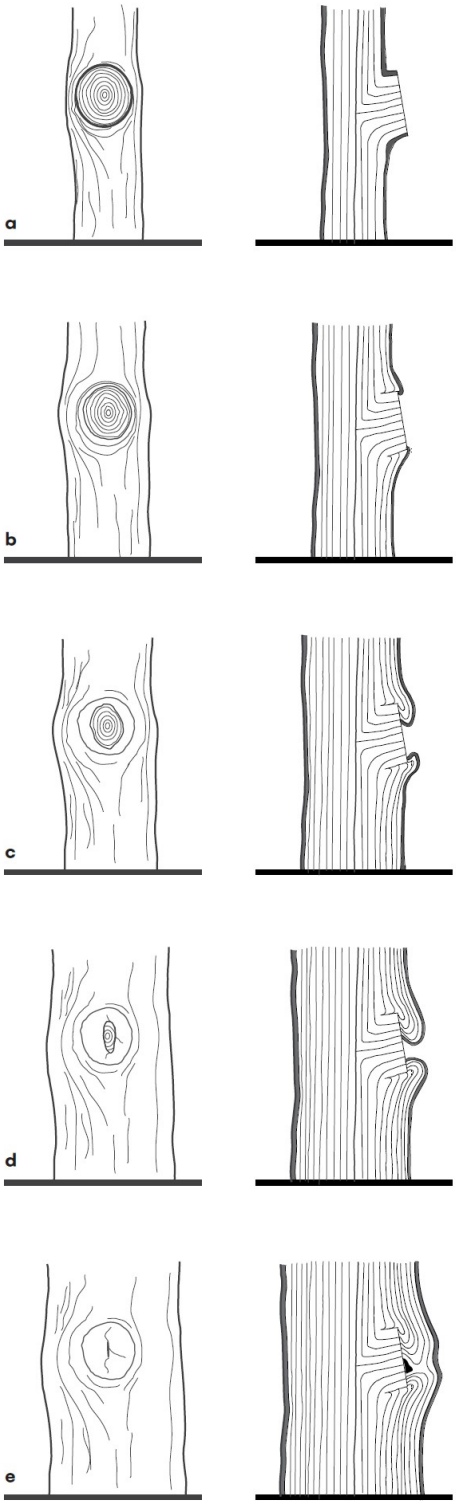


Fig. 3.53. Process of wound healing, *Growing Architecture*, 2023.

3.3.3 Adaptive Examples

Examples of such occurrences are common to find amongst our built environment. Trees and shrubs growing either intentionally or accidentally near signs, fences, or public outdoor amenities often absorb other objects should contact occur. It can be observed that as permanent or prolonged contact with a foreign object is made, a tree's cambium tissue grows to surround and absorb the object as a stabilizer for the tree against external forces.

A good example of a baubotanik building is the *The Baubotanik Tower* located in Wald-Ruhestetten, Germany. It was a project designed and built as a test by the Baubotanik Research Group in 2009.[51] The tower is a nine-meter-tall building with an eight square meter footprint. The living components consists of several hundred white willow (*Salix alba*) trees, each tree around two meters tall at initial construction. The lowest level of trees is rooted within the ground, while trees above are suspended and interwoven diagonally in layers forming a diagrid structure.[52] As the plants age, the intersections between different trees have fused and thickened. When the trees obtained a sufficient size to self-sustain loads, the initial temporary scaffolding was removed from the tower.[53] After removal of the temporary steel frames, the trees fully support forces of the building with its "truss-like" structure braced by its horizontal platforms.[54]

It is also important to note, in 2017, swamp birch (*Betula Pubescens*) trees were used to replace existing willow trees for better site adaptation. This switch reduced branch density, allowing more even spacing for tree trunk growth and thickening.[55] In this instance, localization of tree material is important to factor into the success of the design.

The Baubotanik Tower's design successfully proposes a use case for baubotanik construction methods while acting as a working experiment testing construction with plant growth in mind, a designer must understand and respect the plant's rules and guiding principles to create effective structures. A method to develop complex structures often requires a system of multi-plant arrangements with separate sources of substrate and water. In this process, the individual plants are arranged as beams and columns in a traditional building with connection points being either mechanical-adaptation or natural inosculation. Upon successful fusion, support, scaffolding and excess points of substrate and water are removed, leaving behind a unified structure sharing a root system anchored to the ground.

51 "Baubotanik Tower · OLA Office for Living Architecture," accessed April 17, 2023, https://www.o-l-a.eu/project/baubotanischer-turm/.

52 "Baubotanik Tower · OLA Office for Living Architecture."

53 "Baubotanik Tower · OLA Office for Living Architecture."

54 "Baubotanik Tower · OLA Office for Living Architecture."

55 "Baubotanik Tower · OLA Office for Living Architecture."

3.3.4 Fragility as Design Strategy

When designing growth, one must remember the principal nature of plants—effectiveness. This means two things:

→ 1. A plant will prioritize the shortest path of nutrient transfer; therefore, designs must avoid redundancy in plant structure.[56]

→ 2. A plant will thicken at points of stress and external force, therefore, creating advantageous properties for structure design.[57]

With this design principle in mind, the completion of construction does not indicate the finalization of design. Instead, it is only one step in an involved process where the architect must be considerate of designing not only the static plans but also the growth process of a building. In Ludwig's writing, he refers to two new roles that an architect must play—engineer of a tree, and designer of growth. "In this new role, the architect must consider that the ecosystem of plants is now playing a major role in the contextuality of architecture."[58] We can reframe "uncertainty" to become a part of architecture's becoming rather than a byproduct of its construction phases. As Ludwig also writes:

> "Since baubotanik is an ecologically embedded architecture, the designer needs to understand the plant as a profound yet fragile architectural opportunity."[59]

In this way, fragility can be a design strategy.

Reviewing the history of living construction architecture, the Baubotanik Research Group and OLA are some of the current leaders of the practice. Their works, however, are confined to cities in Germany, and therefore, limited to their ecology, climate, and environments as well. Methods of baubotanik architecture have rarely been explored in a North American context—despite America having a remarkably diverse range of climates and plant hardiness zones. Additionally, we find a collection of biodiversity very distinct from those found in Europe. This provides ample opportunity to research and explore more localized situations in living systems beyond simple designs that integrate living walls in offices or malls.

56 Ludwig, Schwertfreger, and Storz, "Living Systems."

57 Ludwig, Schwertfreger, and Storz.

58 Ludwig, Schwertfreger, and Storz.

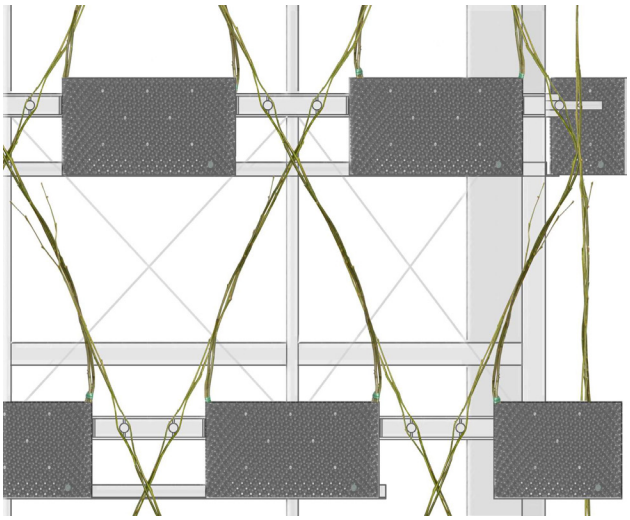
59 Ludwig, Schwertfreger, and Storz.



Fig. 3.54. Baubotanik tower, Wald-Ruhestetten, Office for Living Architecture, 2009.



Fig. 3.55. Baubotanik tower, after 2017 replacement, TUM School of Engineering and Design. Unknown photograph date.



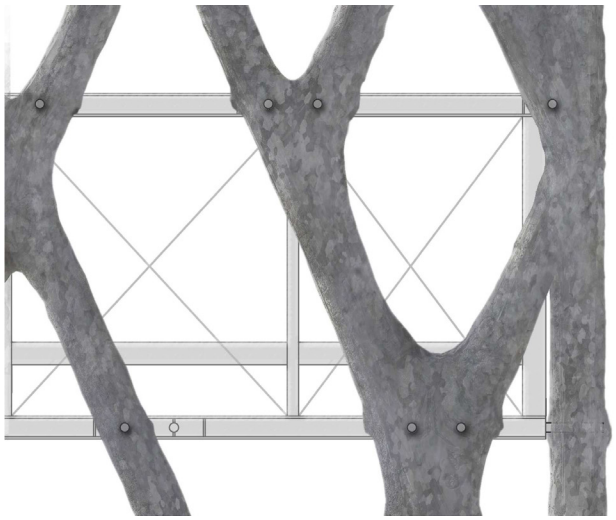


Fig. 3.56. detail after completion and projection of detail after 20 years, Plane Tree Cube, Office for Living Architecture, 2012.



Fig. 3.57. Baubotanik tower, willow connection detail, Office for Living Architecture, 2009.

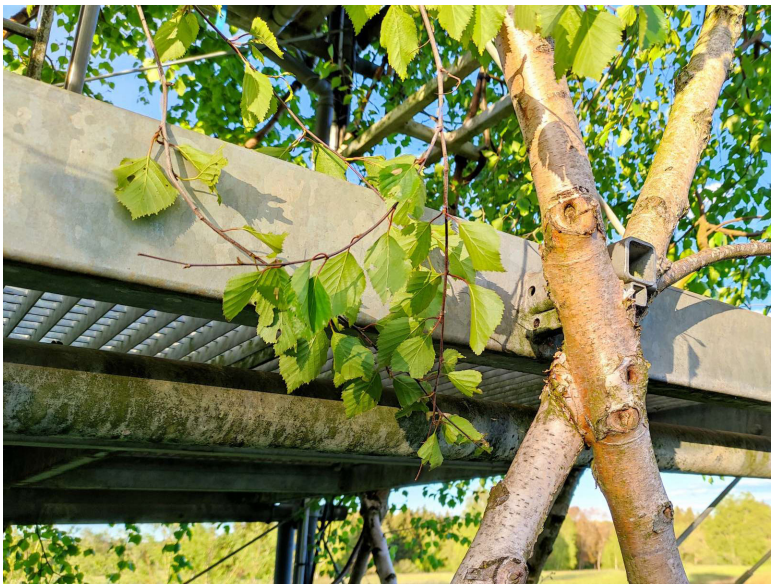


Fig. 3.58. Baubotanik tower, birch connection detail, Office for Living Architecture. Unknown date.

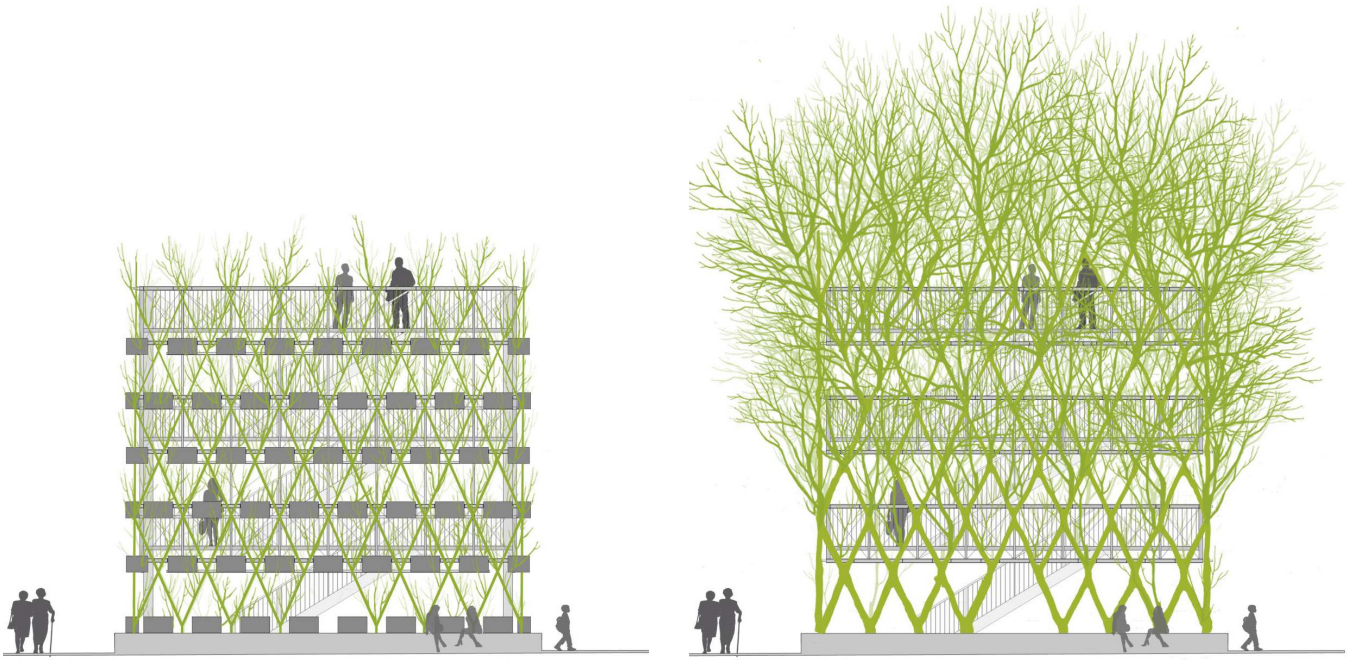


Fig. 3.59. Elevation drawing of completion, and projection after 20 years, Plane Tree Cube, Office for Living Architecture, 2012.

3.4 Conclusion

From the living-root bridges of ancient India to linden treehouses of middle age Germany to the baubotanik buildings of modern-day Germany, living-tree architecture, or arbortecture, is found in many applications as a highly flexible material capable of adapting to its designed purposes. The academic theories of Rudolf Doernach and utopian illustrations of Arthur Wiechula influenced generations of research and experimental works in art, architecture, and furniture. While many examples of tree shaping projects in the modern age are primarily novelty or conceptual, there is great potential for rigorous and continuous research to elevate arbortecture as an alternative approach to architecture as seen exemplified by the work from Ferdinand Ludwig and OLA.

Through review of the existing body of work, the thesis aims to present better understanding of both technique, artistry, and the potential of living trees as an architectural construction method.



Fig. 4.1. Illustration of tree branches, 2024, by author

4.0 Methodology: The Branches

The studies found in this chapter are an important record of process, method, and practice. The goal of this thesis is to explore existing tree-shaping methods and speculate their potential applications in space-making through miniature-scale experimentation. Using existing techniques from bonsai and horticulture, two sets of rudimentary experiments using garden center willows and native willow cuttings collected along the local Grand River's banks are conducted and recorded.

The chapter examines thought process, design iterations, material choices, and setup through drawings and photographs. Sketches are used to iterate through designs while experimentation on cuttings tests the designs. The experiments document an investigation of how architectural elements might exist as living plant construction systems. The work is presented as a conceptual idealization of how society might consider architecture through different lenses. The steps taken in this chapter are exhibited through images of material collection, propagation, designs, and experimentation of two sets of willow cuttings. The results are to compare the processes of both sets and to learn through practice using tree shaping with architectural applications.

4.1 Location and Setting

The nature of living plant construction is highly dependent on environmental factors and influences. Temperature, climate, growing season, soil condition, water quality, and ecosystem (and more) all influence the ability in which a plant can thrive. With unique environments and biomes, comes unique collectives of native plant and tree species. According to plant hardiness data released by Natural Resources Canada, the hardiness zones found in southwestern Ontario roughly range from 7a to 4a.[1] The Canadian plant hardiness map and zone designations are based on the first plant hardiness map released by the USDA in 1960 which encompasses a range of 0 to 11,[2] with higher numbers indicating more temperate climates. Variables which determine regional hardiness levels include plant survival data, minimum winter temperatures, frost period length, rainfall, maximum summer temperatures, and wind speed.[3] This scale is useful in determining a plant's ability to survive in different regions and sorting the hardiness of each plant.

For the premise of experiments performed in this thesis, the location was set in Cambridge, Ontario, with a USDA plant hardiness of 5a-6a.[4] Cambridge sits in southwestern Ontario on the edge of the Carolinian Forest zone, which is characterized by its predominance of deciduous forests and particularly rich biodiversity.[5] The zone's proximity to the Great Lakes produces a unique

1 "Canada's Plant Hardiness Site | Natural Resources Canada," accessed September 22, 2024, https://www.planthardiness.gc.ca/?m=22&lang=en&prov=Ontario&val=C.

2 "Your Hardiness Zone - Landscape Ontario," accessed September 22, 2024, https://landscapeontario.com/your-hardiness-zone.

3 "Your Hardiness Zone - Landscape Ontario."

4 "Canada's Plant Hardiness Site | Natural Resources Canada."

5 "Reaching for the Sky - Woodlands, Forests, and Swamps | Carolinian Canada," accessed November 24, 2024, https://caroliniancanada.ca/sar/reaching-for-the-sky.



Fig. 4.2. USDA Hardiness Zones of Ontario. Map retrieved in 2024 from Natural Resources Canada.

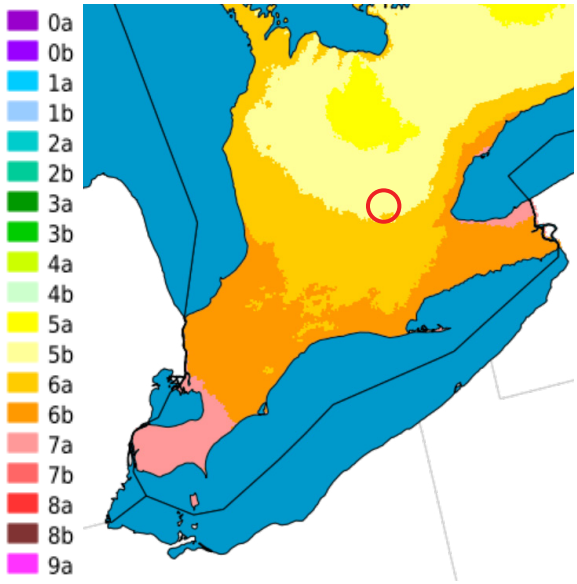


Fig. 4.3. USDA Hardiness Zones of southeast Ontario, highlighting the Cambridge region. Map retrieved in 2024 from Natural Resources Canada.

climate from thermal mass held by the large bodies of freshwater.[6] This effect results in high humidity, warmer temperatures, and long frost-free periods. As the smallest forest region in Canada, it can support the largest variety of native tree species.[7]

Cambridge is also located within Canada's Mixedwood Plains ecozone. A site that is characterized by plentiful freshwater lakes, networks of waterways surrounding the Great Lakes and St. Lawrence River, highly fertile soil ideal for cultivation, and mild temperament[8]. These factors make much of southwestern Ontario a highly productive and prosperous land area for biodiversity, land use, and farming. Historically, it has also been home to many indigenous peoples. The benefits presented by its location within both the Carolinian Forest and the Mixedwood Plains indicates very ideal conditions as a test bed to propose arbortecture projects for localization in Canada.

6 "Hinterland Who's Who - Mixed Woods Forest," accessed September 22, 2024, https://www.hww.ca/en/wild-spaces/mixed-woods-forest.html.

7 "Carolinian Forest," accessed September 22, 2024, https://www.natureconservancy.ca/en/what-we-do/resource-centre/forests-101/../../carolinian-forest.html.

8 "Mixedwood Plains Ecozone," accessed September 22, 2024, http://www.ecozones.ca/english/zone/MixedwoodPlains/index.html.



Fig. 4.4. Southeastern Ontario Carolinian Zone. Map retrieved from the World Wildlife Foundation in 2024.



Fig. 4.5. Ecozones of Ontario, showing mixedwood plains in southeastern Ontario. Map retrieved in 2024 from Government of Ontario, 2002.

4.2 Designs

The approach to experiment design was through simple gestures which rely on a tree's inosculation property. When multiple branches or trunks are secured together for long periods of time where the tree experiences growth, the material will inosculate and become a combined element bonded by wood. To manipulate this process, fasteners and anchors can be strategically used.

The initial series of sketches depicted simple techniques to fasten and shape branches. The anchoring was achieved by using stainless steel nails or screws and self-adhering bandages. Stainless steel avoids corrosion and rust from moisture, and when encased within the tree, does not cause living material to rot. Self-adhering bandages are porous and elastic, allowing the tree material to thicken without restraining growth, it can also act as tape without leaving residue to damage bark. Different shaping methods can be done by drilling holes to graft new branches or simple wedge cuts on stiffer branch material to allow for more acute bending angles. The drawings here offer connection and shaping details that are tested on the willow material.

The next iteration of sketches took fastening and shaping strategies and articulated them as architectural elements informed by Leon Battista Alberti's writing, *De re aedificatoria*. This outlines fundamental elements of architecture, focusing on platform, compartition, walling, covering, and aperture, which were selected for categorical simplicity, planarity, and generality in organizing architecture. Each sketched design represents one of Albert's elements as translated through arbortecture. However, the issue arises where arbortecture, made of individually grown trees, lacks planarity since trees grow with depth and dimension. Nonetheless, this set of sketches informs the following design experiments.

The goals of the designs presented are to model potential architectural connections incorporating living trees as a practical test to learn from and to inform future studies. They were designed for the specific scale of the available willow material and for modeling ease with 3D-printing integration.

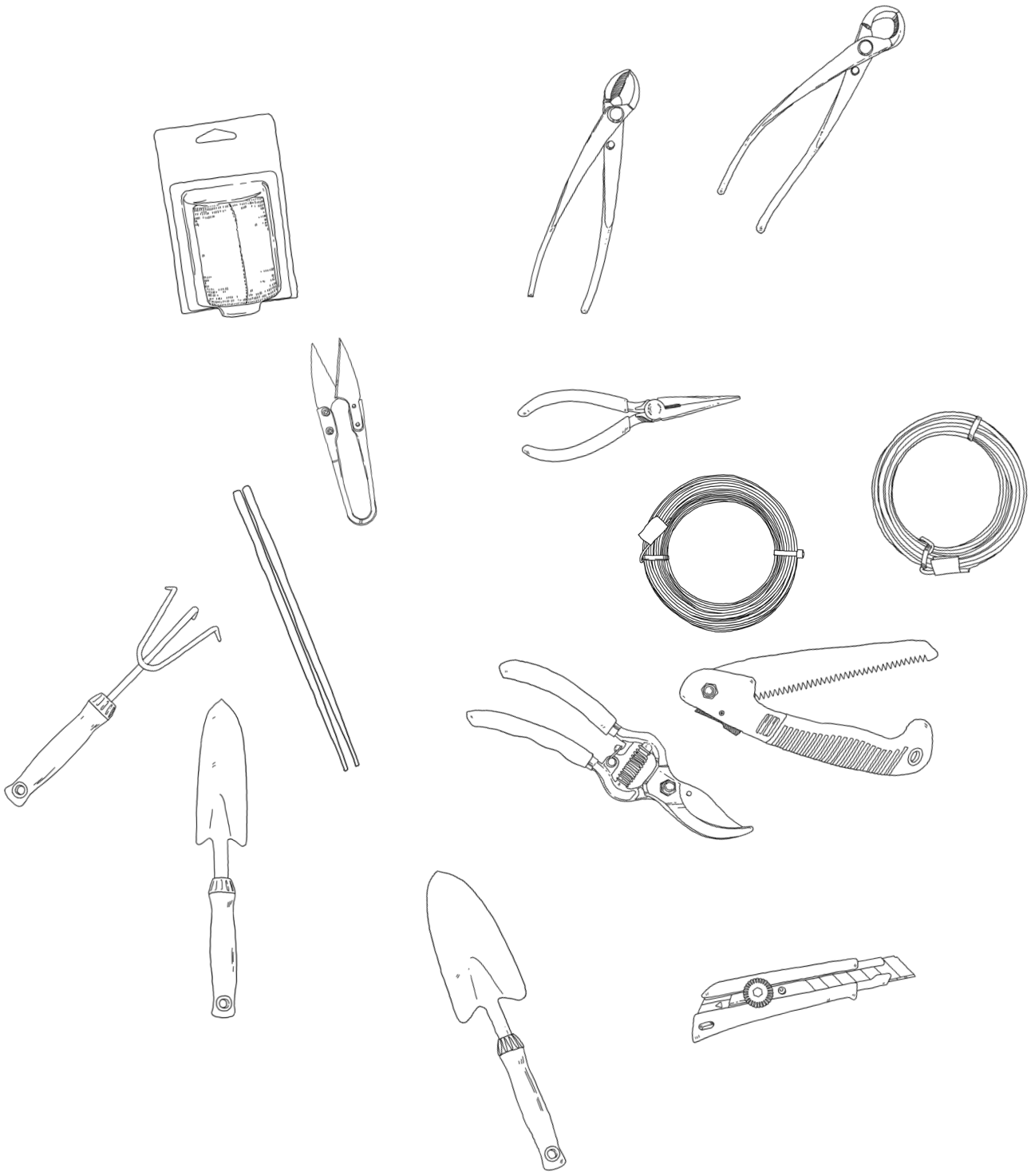
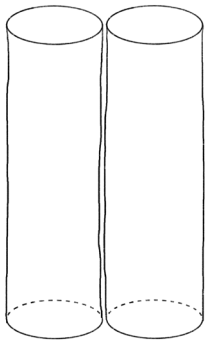
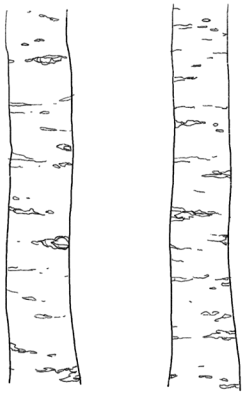
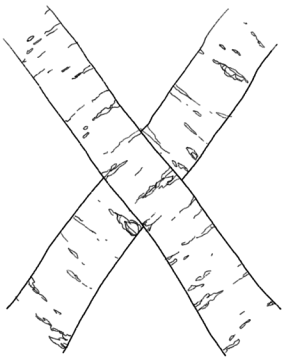


Fig. 4.6. Illustrations of some of tools used for collection and repotting when conducting the experiments.







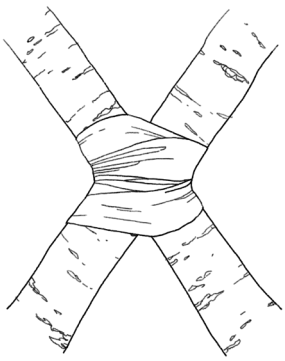
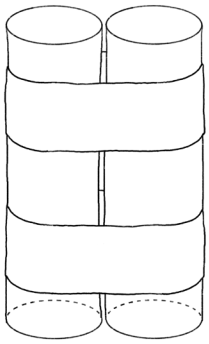
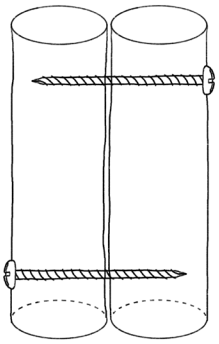
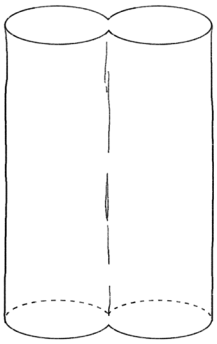


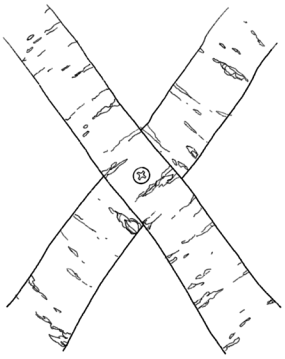
Fig. 4.7. (Upper) Sketches of simple fastening techniques using tape and screws to bind two parallel branches.

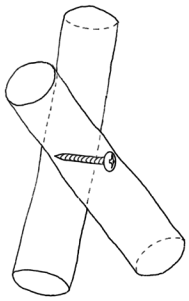
Fig. 4.8. (Lower) Sketches using the same fastening devices to bind cross bracing branches.

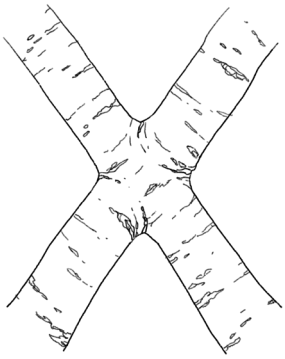












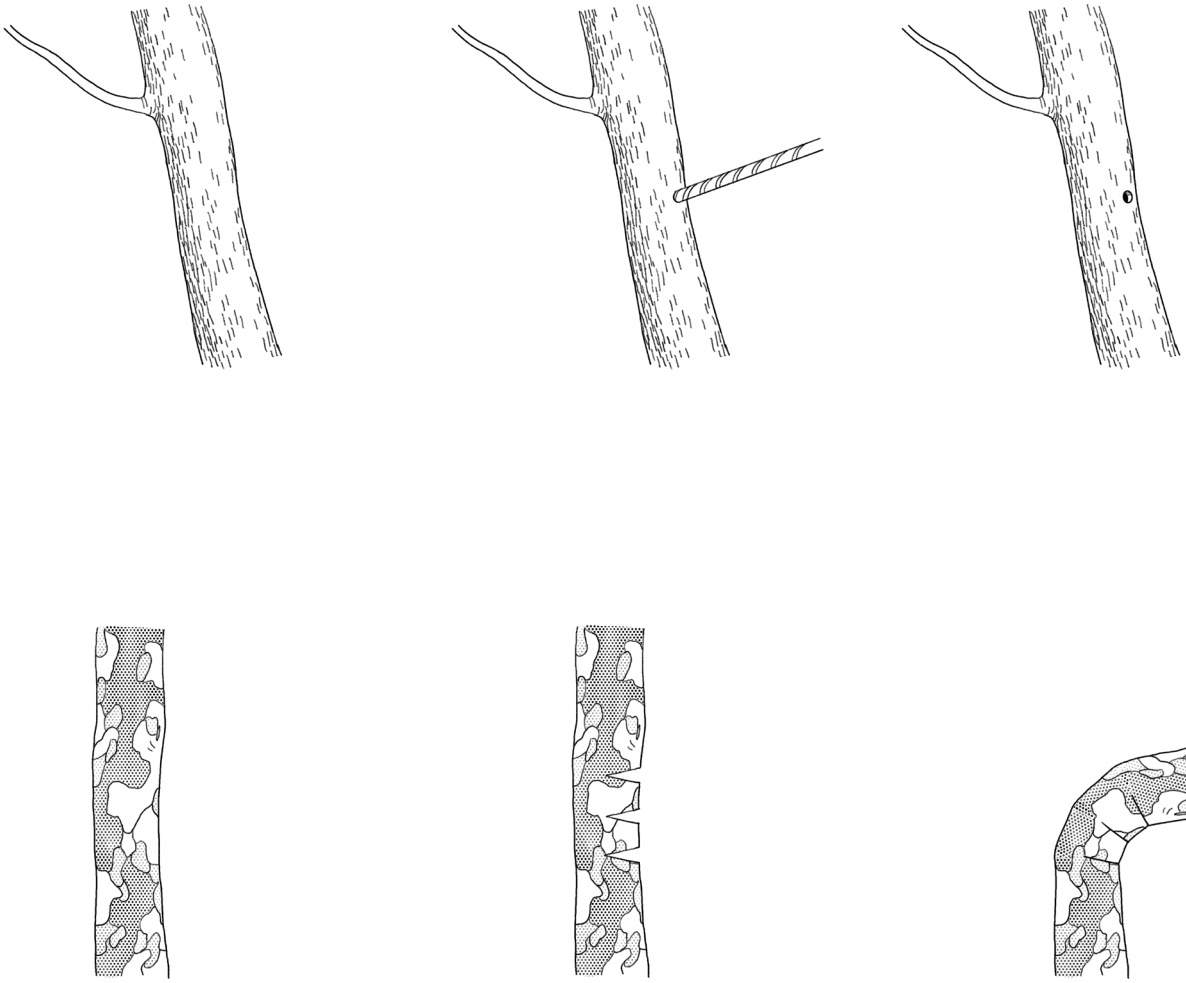
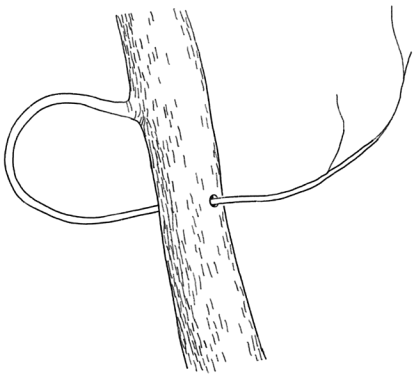
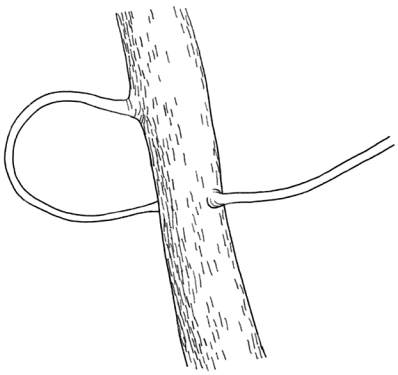
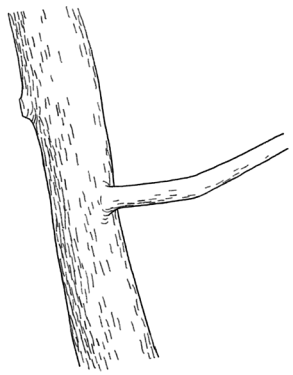


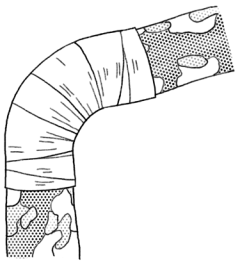
Fig. 4.9. (Upper) Sketches show sequence of drilling hole into trunk and inserting smaller branch to graft together.

Fig. 4.10. (Lower) Sketches show sequence of cutting repeated wedges to allow for sharped bend in branch.









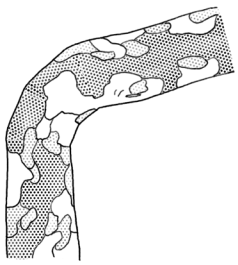
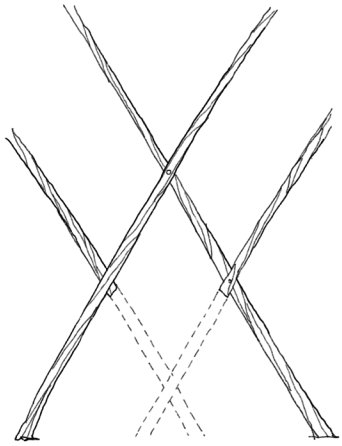
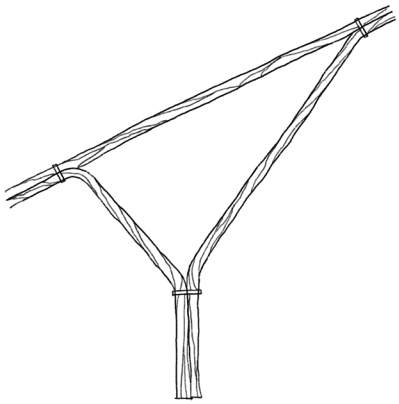
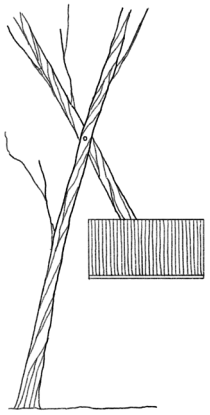
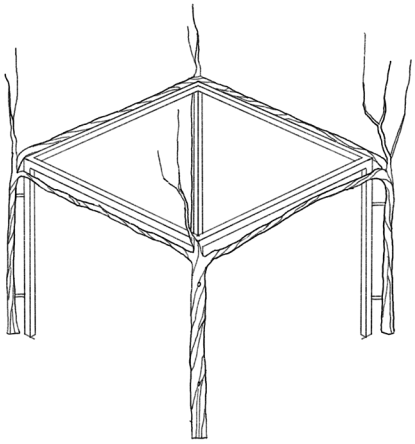


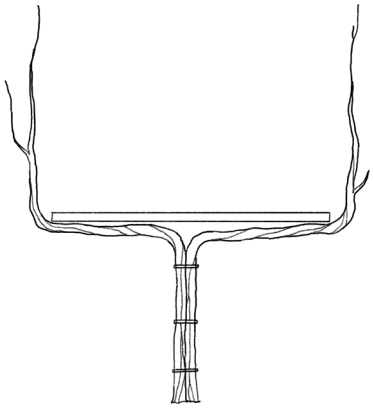
Fig. 4.11. Collection of sketches demonstrating structure and form by combining different fastening techniques. This iteration is inspired by Alberti's elements of architecture in De re aedificatoria.
(Upper from left to right) Aperture 1, aperture 2, compartition 1.
(Middle from left to right) Compartition 2, platform 1, covering 1.
(Lower from left to right) Platform 2, walling 1, walling 2.

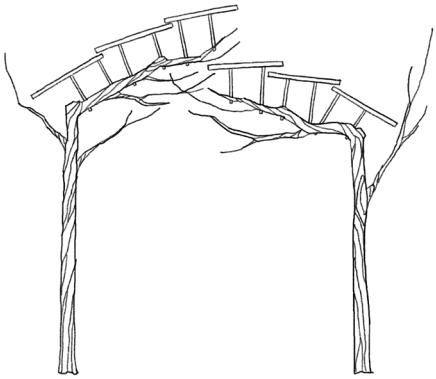


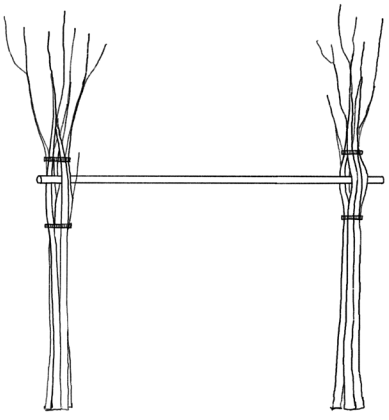


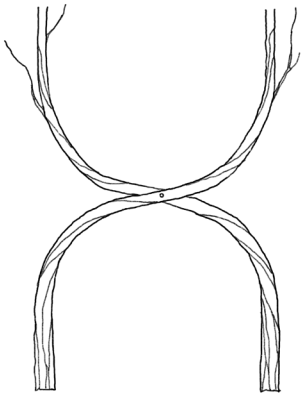


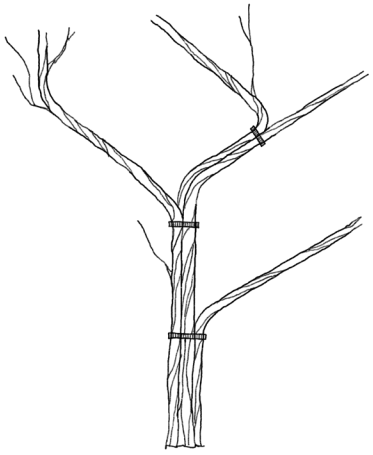












4.3 Series I: The Garden Center Willow

The first group of willow experiments were two pots of ornamental braided willows obtained from the garden center of a major department store. These planters provided 60 willow shoots consistent in length and thickness. At roughly 10mm in diameter and 800mm in length, they were the ideal age and size with a perfect degree of flexibility and rigidity for experimentation purposes. By having 60 fast growing shoots readily available, multiple experiments could be conducted at the same time and with excellent consistency.

The braided willows were given two weeks in their original pots to adjust to climatic changes between the garden center and a semi-shaded patio. They were watered once every two to three days when the top layer of potting mix started drying. During this adjustment period, many new leaves and shoots grew with significantly more rigor than when at the garden center. Likely as a result of more consistent watering schedule and better sunlight exposure.

For preparation, the willows were unbraided and removed from their original pots to be replanted into multiple containers for each experiment. In this process, it was revealed that all the willow shoots were relatively fresh cuttings from a host tree evident from their flat cut base and shorter roots. The original potting mix was also very densely packed garden soil with very little aeration evident by the lack of fine roots. It is worth noting that the existing soil condition may pose carried-over negative effects to successful repotting.

When repotting, 1-8 cuttings were planted per 8-inch pot per requirement of experiment design. This gave more space for each cutting and mitigated the overcrowding the willows faced previously. The substrate used consisted of an even mix of soilless potting mix (perlite, peat moss, coir), mulch, and original soil from the garden center. This aggregate mixture was used to improve moisture retention and aeration, reduce decay and infections, while some of the previous soil to ease the willows' root stress when adjusting. 80% of the leaves were also removed to alleviate their energy consumption and redirected to new root growth. During the repotting, cuttings were kept sufficiently moisturized during the entire process. Once repotted, the willows were generously watered, kept east-facing, and in shade for another week before any additional work for experimentation was performed.

Fig. 4.12. Two braided willow baskets obtained from local department stores, used as material for experiments. Each plant was roughly one meter in height with plenty of green foliage.







Fig. 4.13. Close-up view of the willow shoots, plenty of new growth as well as dead segments



Fig. 4.14. Workspace for setup in the front yard. A blue tarp was used to layout the branches for easy documentation and analysis.





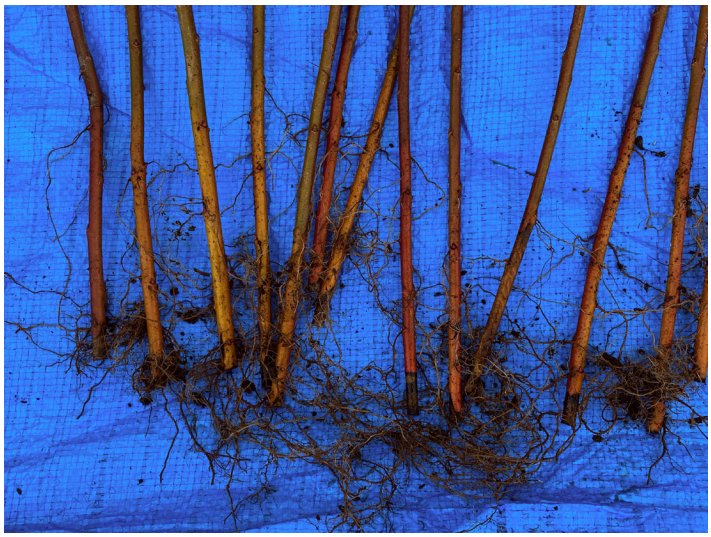




Fig. 4.15.
a. braided willow shoots removed from original pot, separated, washed, and placed flat on a tarp.
b. the existing green foliage.
c. the existing root systems of the shoots.
d. image showing sample of scale and diameter of shoots.

4.3.1 Series 1 Experimentation

In this series, 9 different experiments were designed using miniature hybrid structures in consideration of the garden center willows. They demonstrate different connections, platform support, and walling. At an arbitrary miniature scale, these experiments were designed to exhibit more hybrid structures than initial iterations. Non-organic scaffolding and supports were digitally modeled, 3D printed and secured to plant material using zip-ties two weeks after repotting the department store willows. Nylon zip-ties were used as the main fastening strategy to secure contact between plant material. This allowed for ease of construction with thinner willow branches where drilling holes for nails would impact structural integrity and bandages would be too thick and wide for precision.

While setting up the structures, it was observed that no new growth had occurred above the soil level and many of the cuttings were showing signs of declining health (further speculated in Chapter 4). After shaping the willows, they were returned to the same location outside to allow for recovery after more stress. At the time, the temperature outdoors generally ranged between 18°C and 30°C.

In documenting these sets of experiments, the expected goal was to examine how the willows would continue to grow with and around the 3D printed structures. It was meant to document how young willow shoots may adapt to anchoring, binding, and fastening. Over the course of two weeks, all experiments were supplied with water ensuring the substrate never dried out. The willows stayed in shade and only received morning sun, this was done to prevent new and sensitive growth from burning.

Series 1 Observations to look for:

→ Which experiments had a higher rate of death?

→ Which branches recovered from trauma and where?

→ Which branches exhibited higher rates of growth, and where was the growth located?

→ Did any effects of inosculation occur and after how long?

→ How did plant material react to non-organic components?

→ What worked and what did not?

→ Improvements for next time.

Fig. 4.16. The illustrated collection of series 1 experiments. This demonstrates nine experiments featuring hybrid living tree structures using willows, 3D printed components, stainless steel screws, bandages, and zip ties.



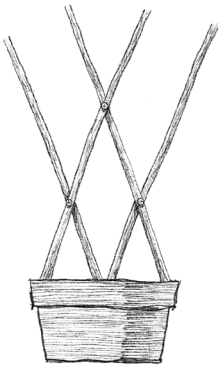
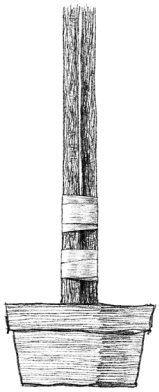
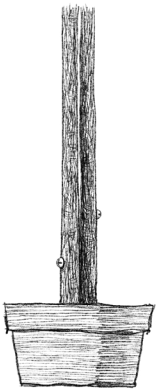
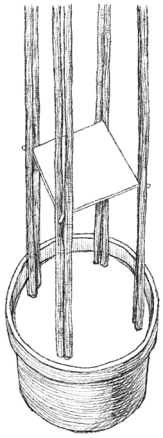
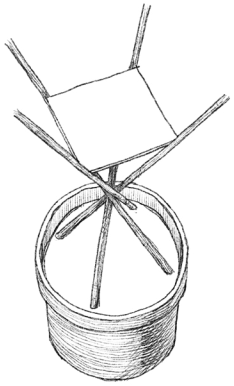
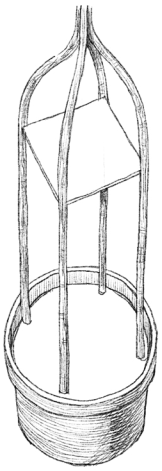
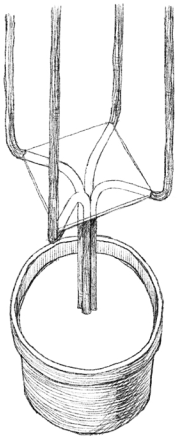










Fig. 4.17. 3D printed components used for series 1 experiments.

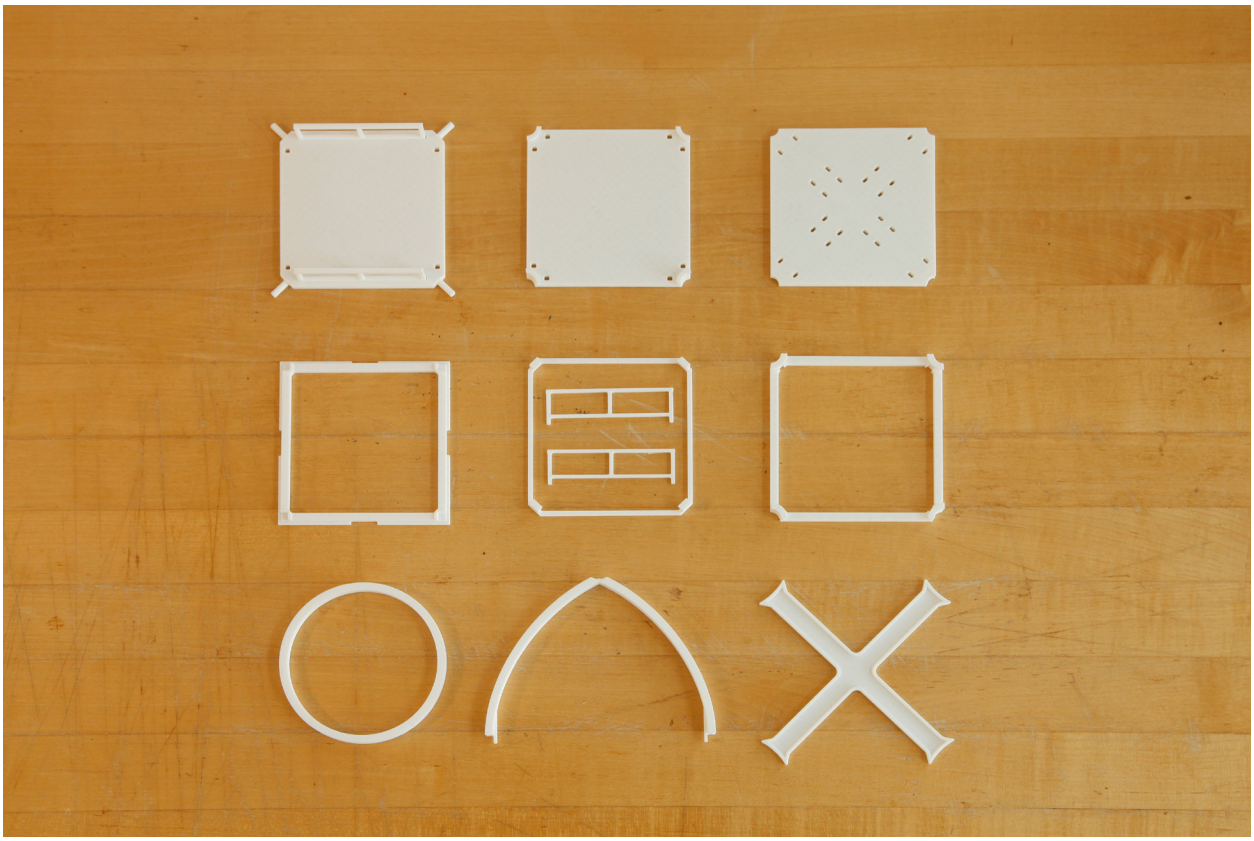


Fig. 4.18. Upper row feature various types of platforms designed for different experiements. Pegs are designed to insert into branches, indents are fitted for trees, while holes are for securing zip ties. Middle row features different braces and railings to keep branches in proper position and for aesthetic purposes. Lower row features a circular shape to push branches apart, an arch frame to guide branches into a dome, and an X shape to brace cuttings at base, preventing movement at soil level.

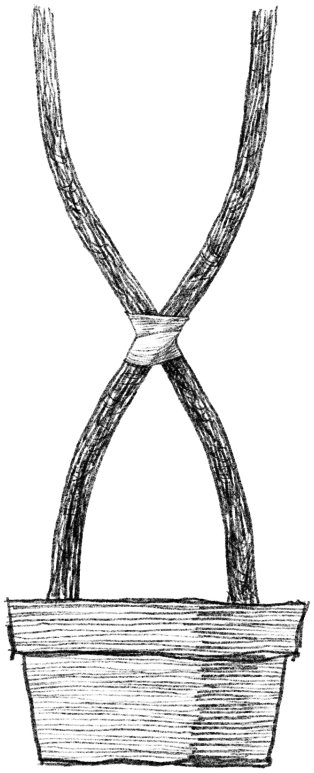


Fig. 4.19. Sketch 1A shows experiment demonstrating cross bracing using bandage to secure contact.



Fig. 4.20. Willow cutting experiment 1A as informed by the sketch. The circular shapes push cuttings apart.





Fig. 4.21. Image a (left) shows two cuttings crossing. Image b (right) shows them secured with bandage.

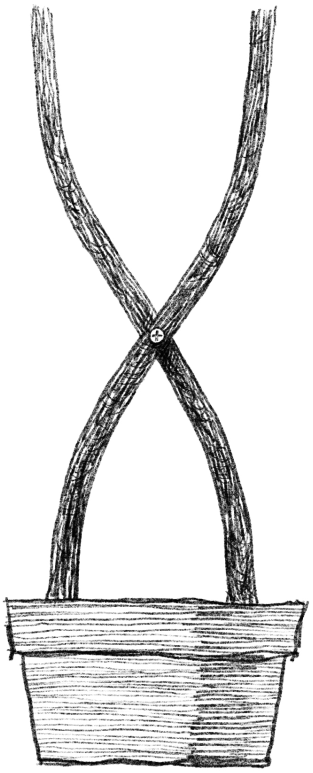


Fig. 4.22. Sketch 1B shows experiment with cross bracing using a stainless steel screw to secure contact.



Fig. 4.23. Willow cutting experiment 1B as informed by the sketch.





Fig. 4.24. Image a (left) shows screw being driven into first cutting. Image b (right) shows the screw secured.

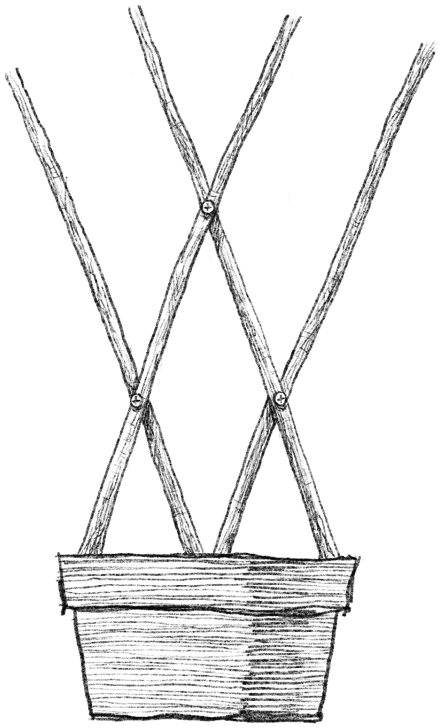


Fig. 4.25. Sketch 1C shows multiple crossing cuttings secured to create a wall



Fig. 4.26. Willow cutting experiment 1C as informed by the sketch. Zip-ties are used to secure contact.

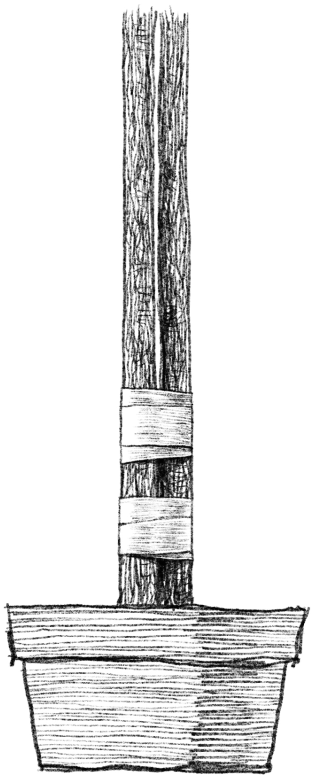


Fig. 4.27. Sketch 1D shows experiment demonstrating cuttings in parallel contact secured with bandages.



Fig. 4.28. Willow cutting experiment 1D as informed by the sketch.





Fig. 4.29. Image a (left) shows two branches planted in proximity. Image b (right) shows the bandages secured.

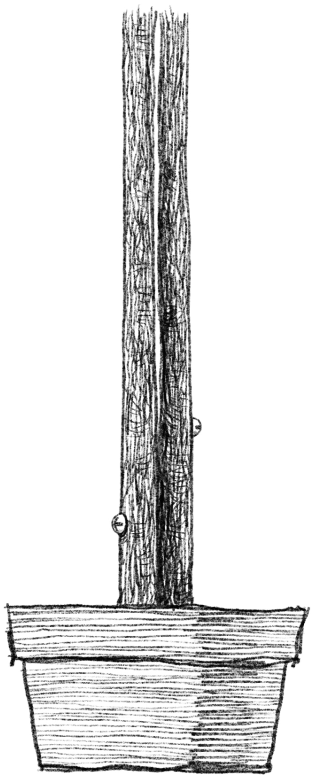


Fig. 4.30. Sketch 1E shows experiment using stainless steel screws to secure parallel cuttings.



Fig. 4.31. Willow cutting experiment 1E as informed by the sketch.







Fig. 4.32. Image a (left) shows two branches planted in proximity. Image b (middle) shows the screws securing the branches together. Image c (right) shows cutting paste applied to seal injuries.

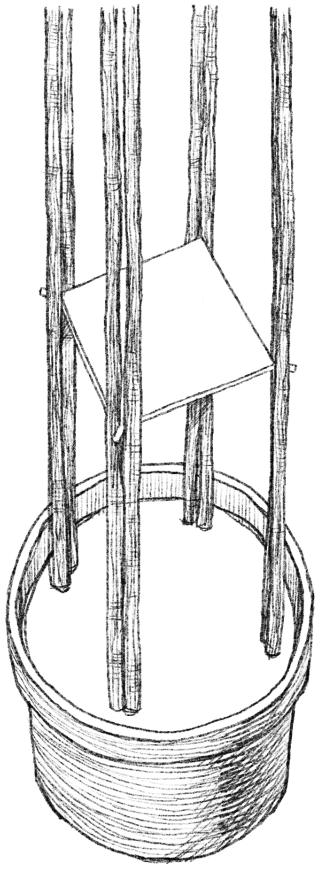


Fig. 4.33. Sketch 1F shows experiment supporting a platform using friction by inserting pegs between cuttings.



Fig. 4.34. Willow cutting experiment 1F as informed by the sketch. A square brace is used to keep cuttings straight.

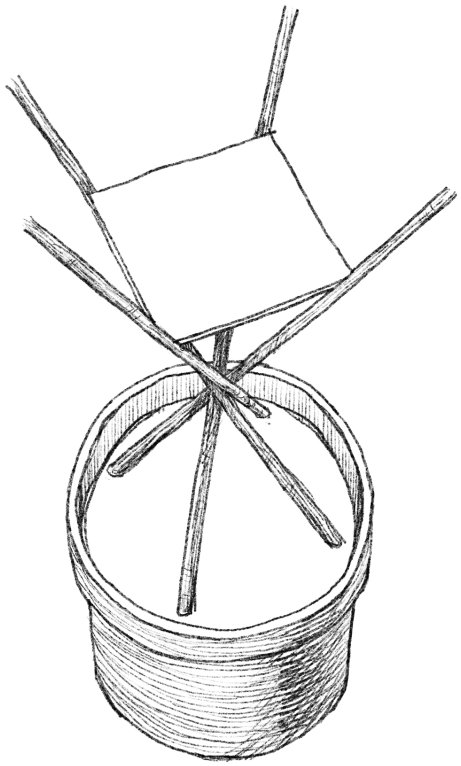


Fig. 4.35. Sketch 1G shows experiment supporting a platform resting on sloped cuttings.



Fig. 4.36. Willow cutting experiment 1G as informed by the sketch. A square brace is used to keep cuttings straight.

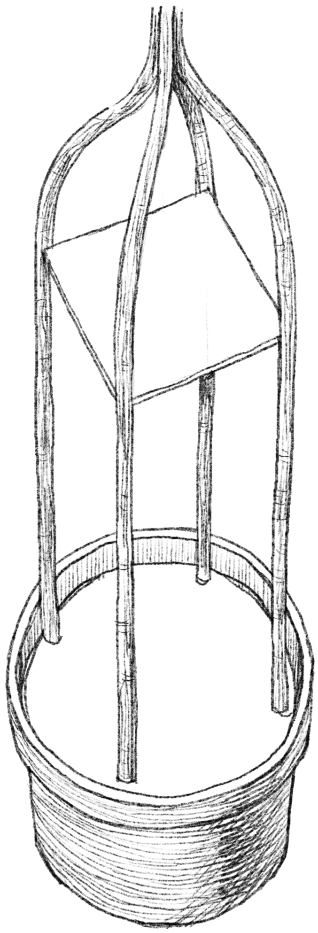


Fig. 4.37. Sketch 1H shows experiment supporting a platform and bound to dome shape by arched frame.



Fig. 4.38. Willow cutting experiment 1H as informed by the sketch. Zip-ties are used to secure the frame.

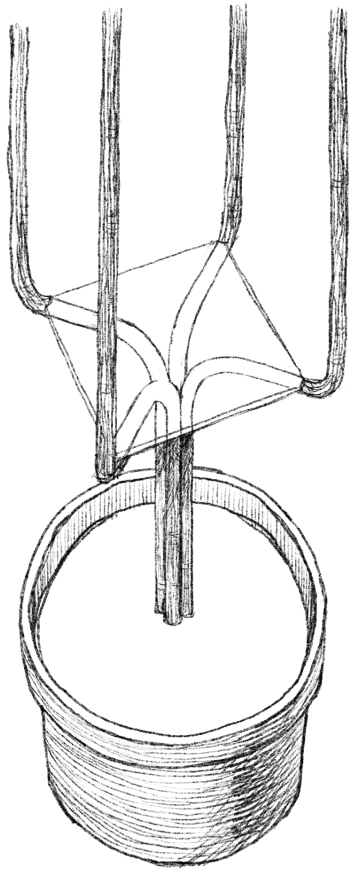


Fig. 4.39. Sketch 1I shows experiment supporting a platform resting on cuttings bent as columns and beams.



Fig. 4.40. Willow cutting experiment 1I as informed by the sketch. Zip-ties are used to secure the platform.

4.3.2 Learnings and Observations: Series I

Initially, the two garden center braided willow baskets were chosen for their quantity and consistent size in length and diameter, featuring 60 individual plants at around 8-10mm in diameter. They were perfect in flexibility as no hardwood or bark developed which provided ease for shaping in experiments. They also seemed quite healthy with plenty of foliage and minimal dead branches, making it reasonable to assume good root health.

When repotting, the braided willow plants were unbraided and extracted from the planters. From this step, the individual plants were carefully separated, revealing that they were all cuttings with very fine roots. The soil appeared to be dense gardening soil, which is not typically preferred for willow cutting propagation. None of the 60 cuttings had strong root systems as it is difficult to grow thicker roots quickly in a densely packed planter. It is possible the willows experienced water supply shortage during their early propagation resulting in the weaker root structure. These observations were only possible after unearthing and cleaning each cutting from its pot. With the root systems already disturbed, it was necessary to promptly repot the willows as the thin roots risked drying out. Since roots and green leaves were still present on every cutting, the repotting carried on with optimism for possible recovery.

In the first week after repotting the cuttings adjusted to the new soil. During this period, the plants were expected to show signs of health decline, then start recovering from the transplant and finally new shoots should start to appear. The experiments were conducted during this timeframe.

A week after the experiments were conducted on the plants, it was observed that over 60% of willow cuttings showed deeper signs of decline. Branches would dry out, turn black, and continue to spread. It is not conclusive that the hybrid structures or the imposition of nails, zip ties, or tape induced the willows' decline as the affected areas did not originate from points of structural contact, but rather seemed random in placement and spread. This means the willows may have declined in health regardless of intervention. It is also likely the connected structures slowed the plants' recovery by causing more strain and injury. Due to the softness of the wood, some branches creased when applied force during bending. Although this is a benign injury to woody plants, it would strain the plant's already limited energy supply. Within two weeks, 57 of 60 willow branches had fully turned black and died. Only three cuttings survived and were able to grow new healthy leaves. No obvious pattern or correlation can be drawn to the surviving cuttings as each one had been set in a different experiment. Severe stress and trauma experienced by the roots likely caused nutrient and energy deficiency, leading to failure of recovery.

Keeping the cuttings fully outdoors may have contributed to the failed experiments. One factor is the presence of squirrels trying to scavenge or hide food. Displaced potting soil was almost a daily occurrence, as squirrels would dig significant holes frequently disturbing willow roots. Actions taken to ward off the squirrels by placing the plants in a large deep tray and isolating them in a greenhouse. Unfortunately, the squirrels continued to dig the soil. Wind and sun were largely unpredictable contributors to the willows. It was frequent to find the willows toppled from wind gusts since the height of the cuttings acted as sails to unstable plastic pots. Although kept in partial shade, late summer sun can be harsh to more fragile plants causing leaf burn, evaporating moisture especially in softer new shoots. Despite none of the experiments from this series being successful in achieving the original mapped goals and intents, their value comes from process work and the ability to learn from mistakes.

A second major contributor to the failures of series 1 was the inability to identify the willow species used in the braided willow plants. Since the cuttings are quite young and do not have the same identifiable physical traits of a larger mature tree. With the exact species unknown, it becomes difficult to provide the necessary and appropriate care to ensure good health and growth. Furthermore, it is possible that this species may not be native to the region and therefore, be more sensitive to local environmental patterns.

Other points of failure could be the insufficient water supply before and after repotting. Since many willows thrive better in flooding conditions, it is possible that a more frequent supply could have improved the overall health.

Possible solutions for the water supply are to treat with aspirin or other methods to support root recovery and health. A rooting hormone could be used to support new root growth. All leaves could be removed to further minimize the cuttings' energy consumption. Netting could be used to shield the soil from wildlife, while more shading devices and thorough monitoring of outdoor temperatures could have eased external factors. Any one or a combination of these suggestions may have been enough to support the roots adequately to allow for recovery. These observations were quintessential to inform the methodology and process of experiments in series 2.





Fig. 4.41. Two photographs of series 1 experiments taken 4 months after being conducted. Soil has been scattered from squirrels.

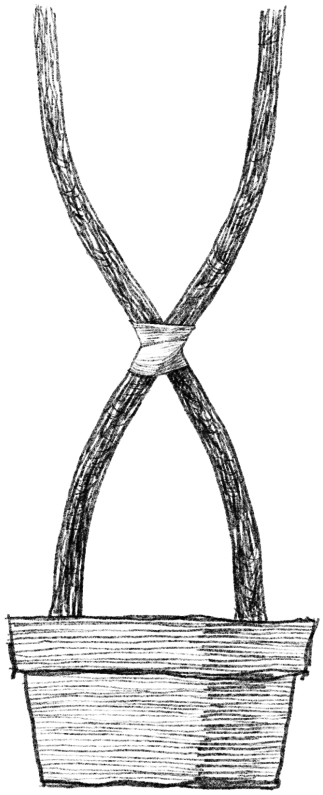


Fig. 4.42. Sketch of 1A

Fig. 4.43. Three images of 1A after 4 months. The two cuttings are dead and inosculation at contact point failed, however the shape of the experiment held.



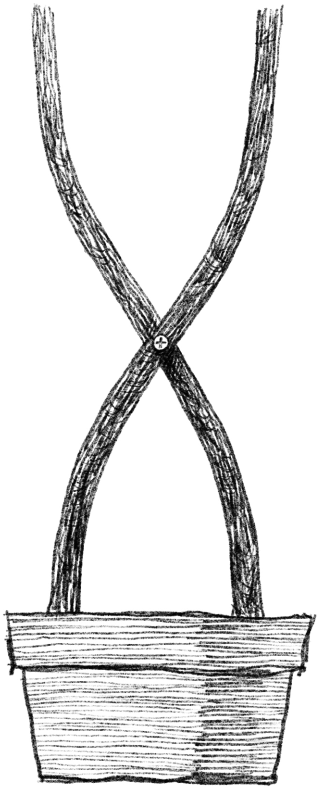


Fig. 4.44. Sketch of 1B

Fig. 4.45. Three images of 1B after 4 months. The two cuttings have dried while inosculation at screw connection point failed. Upper parts of cuttings turned black.







Fig. 4.46. Sketch of 1C

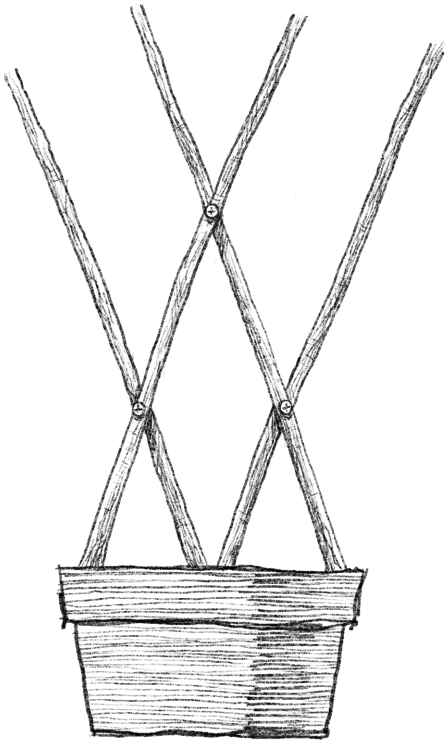


Fig. 4.47. Three images of 1C after 4 months. The zip-tie connections did not inosculate while most portions of the cuttings have turned black.







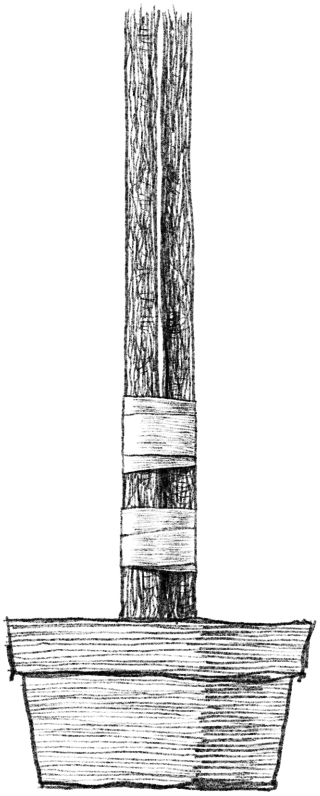


Fig. 4.48. Sketch of 1D

Fig. 4.49. Three images of 1D after 4 months. Squirrels completely unearthed the roots causing failure. However, connection point with bandage showed compression on bark from contact between cuttings.







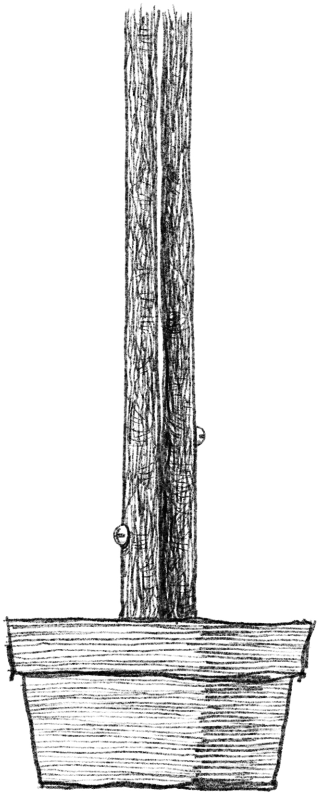


Fig. 4.50. Sketch of 1E

Fig. 4.51. Three images of 1E after 4 months. One cutting dried earlier than the second, turning black first. Both cuttings have failed and screw connections did not inosculate.







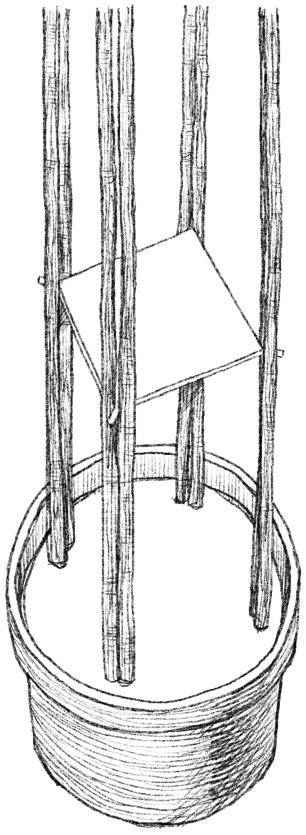


Fig. 4.52. Sketch of 1F

Fig. 4.53. Three images of 1F after 4 months. Two cuttings survived, at the time of photography, the cuttings were entering dormancy in autumn. One cutting grew a separate branch 2 inches above surface soil while its upper portion dried. All other cuttings dried and no inosculation occured.







Fig. 4.54. Sketch of 1G

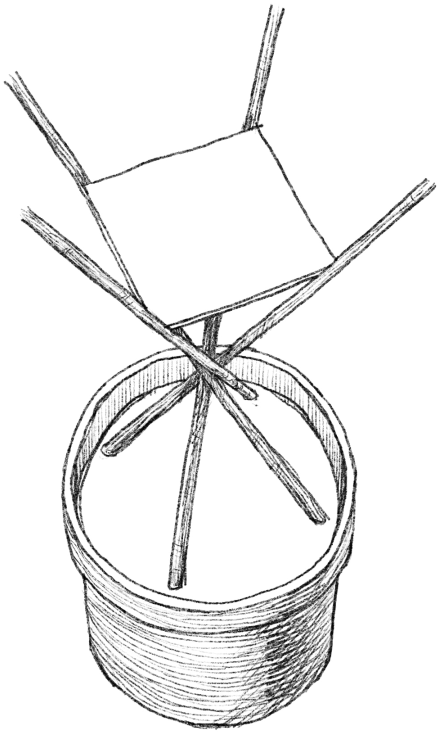


Fig. 4.55. Three images of 1G after 4 months. Some of the cuttings were bent at connection with platform due to their fragility. No cuttings had survived while many portions turned black.







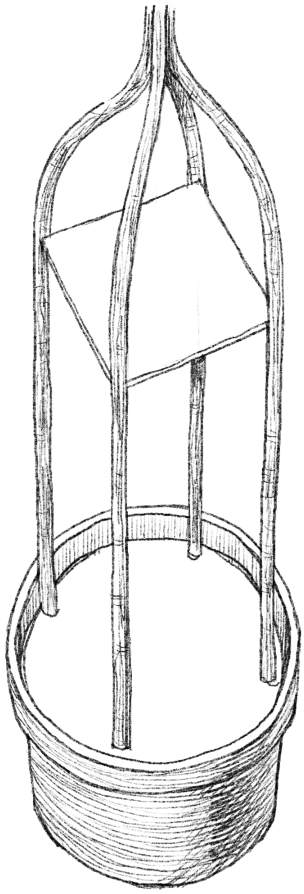


Fig. 4.56. Sketch of 1H

Fig. 4.57. Three images of 1H after 4 months. All of the cuttings have dried and mostly turned black. The shape of the cuttings were held.







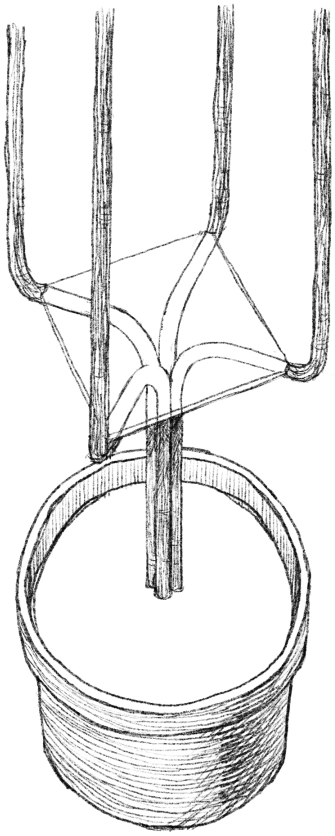


Fig. 4.58. Sketch of 1l

Fig. 4.59. Three images of 1l after 4 months, All the cuttings have failed and dried. Due to the force of the shaping, all the cuttings creased as they were too fragile to maintain structure.







4.4 Series II: The Grand River Black Willow Preparation

Common species frequently used in OLA/Baubotanik Group's experiments and arborsculpture projects (but not limited to) are variations of willow, hornbeam, plane, and ash.[9] All of which would find reasonable success in Cambridge with compatible hardiness zones and similar environmental conditions. However, many of these European trees share a genus with native or naturalized species found in North America. For example, the London plane tree (*Platanus x hispanica*) in some Baubotanik projects shares similarity to the american sycamore (*Platanus occidentalis*) used in many of Axel Erlandson's arborsculpture pieces.[10] Both species are from the deciduous Platanus genus characterized by large muscular trunks, speckled or flaky bark, and tall size. White willow (Salix alba) is another popular species for tree shaping projects found in Europe. Although the white willow commonly found in Germany and Europe would successfully grow in southern Ontario, black willow (Salix nigra), native to eastern North America[11] is an excellent candidate for localized arbortecture projects. Characterized for its large size, rapid growth, flood resistance, and flexible young branches[12], the black willow provides similar and perhaps advantageous traits than white willow. In this series, the experiments use black willow cuttings collected along the banks of the Grand River.

In Cambridge, the Grand River runs through the city and has historically provided manufacturing and agriculture to the region.[13] Concrete floodwalls and tall riverbanks are found in the downtown area, flanking the river where the city is prone to flooding. The soil quality in the region is generally loamy and sandy. These conditions of high-water levels and sandy soils create ideal conditions for black willow to grow. As historical records show, the Grand River is named *"O:se Kenhionhata:tie"* in Mohawk roughly translates to *"the willow river"* or *"willowed banks"*.[14] As the river bank willows are native, plentiful, fast growing, and easily propagated, it is a very logical resource to collect for subject of experimentation and documentation.

Willow trees are one of the easiest species to propagate through cuttings due to two substances found inside willows are Salicylic acid and Indolebutyric acid, both of which encourage rapid rooting to occur[15]. Salicin, the precursor to Salicylic acid, is also found in willow bark and has historically been used for its anti-inflammatory and pain relieving properties as it is chemically very similar to aspirin.[16] In botany, it is common knowledge to use a "willow water" recipe as a natural rooting hormone which takes advantage of their chemical properties. By cutting segments of green stems and new shoots from a willow plant (to ensure

9 Ferdinand Ludwig, Daniel Schönle, and Sonja Duempelmann, Growing Architecture: How to Design and Build with Trees (Basel: Birkhäuser, 2023), 67–74.

10 "The World-Famous Circus Trees | A Must-See at Gilroy Gardens," accessed September 6, 2024, https://www.gilroygardens.org/play/circus-trees.

11 Natural Resources Canada Government of Canada, "Black Willow," December 31, 2013, https://tidcf.nrcan.gc.ca/en/trees/factsheet/468.

12 Government of Canada.

13 "Grand River," accessed November 2, 2024, https://www.thecanadianencyclopedia.ca/en/article/grand-river.

14 galt. and Amy Smoke, "In Conversation With Amy Smoke," Galt. Publication, no. 4 (September 2021): 85.

15 PreparednessMama, "DIY WIllow Water - A Natural Rooting Hormone - Garden Primer Series," PreparednessMama (blog), July 28, 2020, https://preparednessmama.com/willow-rooting-hormone/.

16 "Salicin - an Overview | ScienceDirect Topics," accessed September 14, 2024, https://www.sciencedirect.com/topics/medicine-and-dentistry/salicin.

high concentration of acids), boiling in water, and letting soak for 24 hours, results in a liquid that can be used for rooting new cuttings and strengthening roots of fragile plants. This property of willow is quintessential to ensure higher rates of experiment success.





Fig. 4.60. Two photographs of large black willow trees found along the Grand River's banks.

4.4.1 Collection

To collect material for this thesis, five kilometers along the Grand River running through downtown Cambridge were surveyed and three locations were selected as candidates from the visible presence of multiple large black willow trees. These three locations are all public parks along the riverbank overgrown with dense natural greenery.

The goals for collection excursion:

→ Collect 30-50 cuttings

→ Collect cuttings of varying lengths and diameters

→ Test the growth success of natural wild willows versus store-bought commercial willows

Tools equipped for collection excursion:

→ 1 bucket filled halfway with water and 2 crushed aspirin tablets (acetylsalicylic acid helps root growth)

→ 1 empty bucket for carrying cuttings from tree to water bucket

→ Garden shears

→ Small garden saw

→ Bonsai clipper

→ Scissors

→ Spray bottle filled with water

→ Rope to secure cuttings in bundles

→ Work gloves

→ Work boots

Site 1: Riverbluffs Park

Site 1 revealed two black willow trees along the dirt road leading into the park. Tree “A” was roughly four meters tall and had either fallen or was cut down midway through the trunk. This resulted in many new branches sprouting near the midsection of the trunk, creating a more “bush-like” appearance. At first, tree A could be mistaken for a different species of willow due to its stout height and density of branches. From this tree, 10 narrow long cuttings were collected as this was the nature of the tree’s branches. Tree “B” was closer towards the riverbank down a single-track pathway. This tree was around eight to ten meters in height; however, it had a large branch break off while a small portion remained attached to the trunk. This small connection provided enough water and nutrition for the fallen branch to still thrive and grow. From the fallen branch of tree B, 20 thicker cuttings were obtained that would have been unreachable had the large branch not fallen.

Site 2: Waterworks Park

Site 2 is in a residential neighbourhood. Two fully grown black willows were present along the riverbanks alongside a small trail. However, due to the height of the tree, the lower trunk had no small branches, making any appropriately sized branches unreachable. Therefore, no cuttings were able to be obtained from this location.



Fig. 4.61. Bucket of collected willow branches. Roughly 30 cuttings shown in image.

Site 3: Cambridge to Paris Rail Trail, Trailhead.

The Paris Rail trailhead featured the most naturalization and highest density in trees. On site 3, multiple mature black willows were immediately evident along multiple small trails. Many of which had dense branches within reach. Upon investigation, it appeared that many of the trees were infested with an insect or parasite that was not identified. To avoid risk of infecting other cuttings accidentally, all collected cuttings from this site were discarded. No cuttings were used from Site 3.

In this collection excursion, 30 cuttings were collected from Site 1 in the peak of summer. This is a factor that would potentially affect the propagation process negatively as the growing season approaching an end, however, a few things were done as a countermeasure. A bucket of water was used to hold collected cuttings ensuring that cuttings were never out of water for more than 10 minutes. A spray bottle was used to hydrate cuttings between extraction from the tree and transport to the water bucket. Crushed aspirin containing acetylsalicylic acid was used in the water bucket to immediately stimulate root growth. Cuttings contained in the water bucket were held in shade to minimize moisture loss. 90% of leaves and new shoots were immediately removed to preserve energy stored inside cuttings.

After collection, the willow cuttings were brought indoors in the same bucket and placed in a bright but shaded area with consistent room temperatures.





Fig. 4.62. (Above) Tools used during collection. (Below) Asprin tablets crushed and mixed with water for root growth.

4.4.2 Propagation

To ensure the highest success rate for the propagation of willow cuttings, consider the following factors when harvesting.

→ Season and time: Collecting willow cuttings in early spring when new buds start forming and in autumn after the leaves fall increase rate of rooting. In these seasonal windows, energy is stored inside the branches and not in leaves or shoots.

→ Size and length: Cutting branches roughly from 8 inches to 18 inches and around ½ inch in diameter to propagate is a safe length. Shorter branches may not have enough active nodes while branches too long may be too demanding on energy.

→ Nodes: Include multiple nodes (sections where new buds sprout from) on each branch. Leave an inch above the topmost node as this section may die off. New sprouts grow from nodes and nodes in cuttings ensure new shoots after rooting. A new sprout is also a good indicator of the cutting's health.

→ Leaves: If there are leaves or new shoots, remove all or most of them. Leaves continue consuming stored energy within the cutting, taking away from energy used to grow new roots. One or two leaves may remain at the top ends of a cutting to assess the branch's health.

→ Moisture: Keep the lower ends (end closest to original tree trunk) of the branches moist or wet before propagation process. If a cutting dries out, it will die.

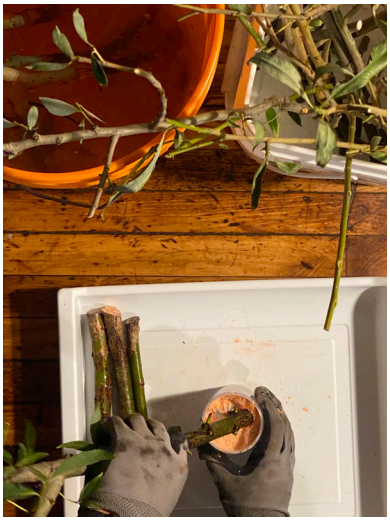
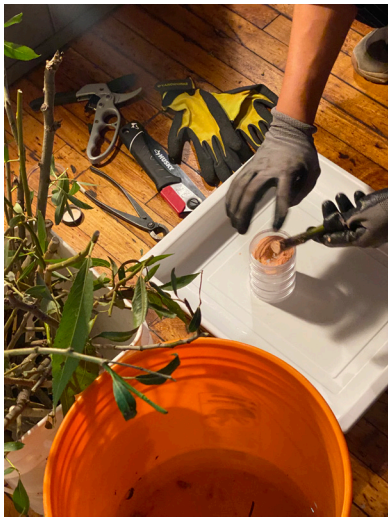
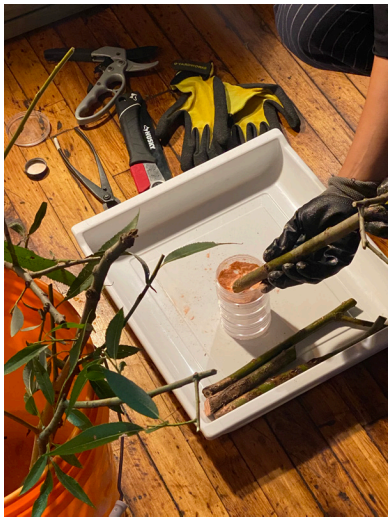
There are multiple ways to propagate a plant cutting but all methods involve supplying plentiful moisture to the bottom end of a cutting. The key component is the substrate or medium that retains the moisture for the cutting to sit in. An effective medium used in bonsai is sphagnum moss, for its aeration and moisture retention, while willows prefer either sand or just water. Different degrees of efficacy are observed when propagating different species of plants.

For the collected batch of 30 willow cuttings, they were left undisturbed in a large bucket submerged in four inches of tap water along with the two crushed aspirin tablets used during collection. They were then placed in a temperature-controlled studio space with a large east-facing window. Fabric blinds diffused direct sunlight and provided shade for the cuttings.

Within the same day of collection, each cutting was individually applied with a horticultural rooting hormone powder containing auxin. A naturally occurring hormone in plants, auxin stimulates the elongation of plant stem cells to become root cells, therefore limiting new replicated cells only as basic root cells.[17] This hormone powder was applied liberally to the lower 2-3 inch section of all cuttings and resubmerged in water.

Three cuttings with wider diameters, around ½-1 inch were individually placed in three separate glass mason jars as control samples to visually document and observe root growth. These cuttings were suspended and secured around the lip of the jars, submerging 3 inches in tap water, and treated the same as the remaining 27 cuttings. The three cuttings were photographed every few days against a white background to compare the root growth progress. Custom lids were designed, and 3D printed to suspend the cuttings upright in the mason jars. The diameter of the cuttings was chosen for their visual clarity and ease of identifying new roots, while their various sizes showed where new buds would emerge.

17 "How to Use Rooting Hormone to Propagate New Plants From Cuttings," HowStuffWorks, May 8, 2023, https://home.howstuffworks.com/rooting-hormone.htm.

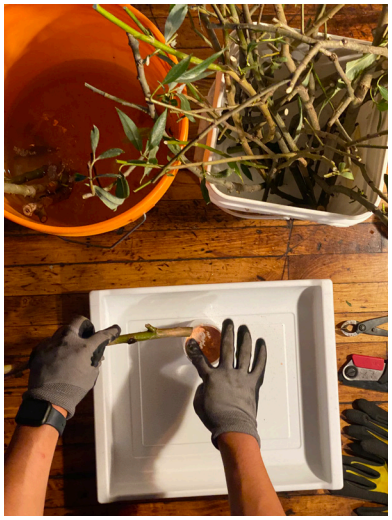


Fig. 4.63. Photos 1-5 demonstrating the application of rooting hormone powder to fresh cuttings in preparation for propagation.

4.4.3 Timeline

Day 2 after collection, based on observation, roughly half of all remaining green stems and leaves started to turn yellow. This was not an indicator of propagation failure or death, but simply, the remaining branches were not able to meet the energy requirements of sustaining mature leaves and new stems as energy are redirected to replicate root cells.

Day 4 all yellow leaves and stems turned brown and started falling from the branches. The bucket remained untouched in a brightly shaded area. No obvious observable changes occured at this point.

Day 7 marked the most significant signs of propagation. Small white bumps start forming on the submerged section of most cuttings. This showed promising signs that the roots were starting to form. New buds showing green tips also started to sprout in the upper portions of the cuttings. These shoots were about 2mm long and only just emerged from the layer of bark. Under half of the cuttings showed visible signs of life, while the majority were still seemingly latent. Water was repeatedly topped up as it evaporated overtime.

Day 9 showed good and rapid progress in all aspects. New roots had emerged around 10mm in length reaching outwards radially around the cutting while in water. Some cuttings had 3-6 emerging roots while others still have none. The buds that appeared on day 7 were also about 10mm length and new small leaves started forming at the base of each shoot. Many cuttings had grown 3-6 shoots, while others still do not show evidence of propagation, however, no cuttings were dry or turned black indicating that none were dead.

Day 11 the remaining still water was replaced with fresh water. When changing the water, all the cuttings were examined for new roots and growth. This revealed that 28 of 30 collected cuttings had successfully grown new roots, all of which were at least 25mm long. Many of the main roots also started growing finer roots indicating that the cuttings could be transferred for repotting in soil or a sandy substrate. Two of the thinner cuttings exhibited no visible changes since collection, but still had green cambium under the layer of bark. This indicated a 93% rooting success in about 10 days of collection.

Day 14, 27 of the 30 cuttings were showing varying stages of new green growth. The more vigorous samples grew over 10 new shoots with multiple leaves sprouting on each. Leaves were about 20-30mm in length and less than 10mm wide. Longer roots extended up to 70mm with more fibrous roots starting to form. As larger leaves developped, the window blinds had been slightly drawn to supply a few hours of direct morning sun. This allowed the plants to perform photosynthesis and continue growing. The two rootless cuttings remained in the same condition with no visible changes. Another outlier was a wider rooted branch, while it had grown multiple roots about 30mm in length, it did not exhibit any green buds or leaves. In addition to the two rootless cuttings, these three samples were separated into mason jars for further observation.

Day 21, 27 cuttings of various sizes from two different trees were safely rooted with over 100mm of main roots and fibrous roots. All cuttings also had over 120mm of new shoots with multiple leaves on each new stem. Many of the leaves have achieved full size measuring roughly 120mm by 35mm, though leaves growing in direct sunlight seem larger than those grown in shade. When compared to the original leaves from the parent willow trees, the new leaves are much thinner with a translucent quality, and lighter green in colour rather than a solid dark forest green. As the new stems mature and increase sun exposure, the colour and texture should match their parent trees. As the level

of growth was quite rigorous, a small amount of liquid fertilizer was added in the water reservoir to supplement missing nutrients. At this current state, the cuttings will easily transplant into the ground or soil in a larger container. Willows are very forgiving with soil conditions so long as there is plentiful water. Of the two unrooted cuttings, one started growing roots about 5mm in length while the other remains the same as previously observed.

The black willow propagation progress was tracked for 3 weeks and resulted in a 90-93% success rate. The cuttings ranged from 15cm to 90cm in length and 1cm to 3cm diameter all proved successful with only water. This documented process of propagation through cuttings helps support black willow as a forgiving species which is both fast growing and adaptive to its surroundings, potentially capable as a native Canadian material for living architecture construction.



Fig. 4.64. Three willow cuttings photographed a week after collection. Small white bumps formed on the submerged half indicate root cells, while light green buds can be seen on the upper half of the cuttings.



Fig. 4.65. The willow cuttings photographed nine days after collection. Clear root growth and new shoots can be identified on each cutting.





Fig. 4.66. (Above) The three willow cuttings after 11 days. Green shoots sprout leaves while fine roots are visible.

Fig. 4.67. (Below) Propagation progress after 12 days. Roots and new shoots continue to grow in length.







Fig. 4.68. A series of photographs showing the fibrous roots of some willow cuttings propagated in a separate bucket of water. These were the roots after 14 days.





Fig. 4.69. (Above) Willow cuttings after 13 days. Significant daily growth is visible in both roots and leaves.

Fig. 4.70. (Below) After 14 days, new roots seem very healthy and new shoots exhibit multiple leaves per stem.



Fig. 4.71. The three cuttings 19 days after collection. Roots continue growing in lengrth and density with steady pace. New leaves start increasing in size.



Fig. 4.72. Progress 21 days after collection. Plenty of thicker roots and fine roots can be seen, while new leaves are approaching full size. Early smaller leaves are falling to make way for larger leaves. The willow cuttings can be repotted with relative ease at this stage.

4.4.4 Series II Experimentation

Series 2 with native black willow as material learns and iterates from series 1 experiments, and were designed shortly after series 1 was conducted. Seven experiments are presented, removing some redundancies from series 1, while further differentiating the connections and components of each experiment. In addition to many of the elements found in series 1, series 2 illustrates two different types of platform connections, a bracing structure, weaved walling, bending, and grafting.

Since the collected material had already been well rooted in water and stable for over three weeks, the repotting and experiments were performed concurrently. This is beneficial as it imposes one moment of stress for the willow cuttings instead of two, allowing for better chances of recovery and stabilization. Furthermore, this puts the cuttings in less physical strain since they can be planted in their final experiment position rather than forcefully bent.

As the collected willow material had varying thicknesses, typically wider in diameter than the department store willows, experiments could be conducted at a slightly larger scale. This means there were less structural consequences to drilling and cutting, while hybridized components could exhibit more sophistication. Newer custom components were digitally designed, and 3D printed. Zip ties were still used as the primary fastening device, while stainless steel nails and 3D printed PLA components were also used.

When preparing for repotting, the willow cuttings were labeled and sorted by shape and size to better suit the nature of each experiment. The wider cuttings were designated for drilling and cutting actions as they had more cambium for recovery and growth. The thinner cuttings were arranged for experiments that tested bending and required flexibility to shape. Taller cuttings were used to support platforms at higher elevations.

The entire setup process was conducted indoors in a temperature-controlled environment. The cutting roots were thoroughly kept damp; however, some signs of drying were identified when photographing the cuttings while removed from water. While potting each plant, most existing leaves were kept since the roots seemed to be in very healthy condition. Drilled holes and cuts that exposed internal wood were covered by bonsai cutting paste or bandages to minimize environmental exposure.

When repotting, the same 8-inch plastic planters were used, while the substrate was a potting mix of sphagnum moss, perlite, composted organic material, and lime. The planters were soaked and placed semi submerged in a large tray with 2-cm of standing water. It was important to keep the substrate highly saturated with water since the cuttings were transitioning from pure water to potting mix. Afterwards, series 2 experiments were kept indoors beneath an east-facing window covered by a translucent cloth blind allowing for some soft diffused light and mostly shade to allow for recovery. After a week, the blinds were opened to allow for a few hours of direct sunlight daily. Water was provided once the standing water from the tray was fully depleted through absorption or evaporation. The indoor temperature at this point stayed at a consistent 22°C.

The expected outcomes were the same expectations for series 1, this time, testing how native black willow grows around abiotic material and how they perform as hybrid structures. The differences are that the willow samples here are thicker in diameter, have stronger roots, are more stabilized, and come from an assumably healthier host tree.

Series 2 Observations to look for:

→ Death in experiments and individual branches?

→ Which branches recovered from trauma and where?

→ Different reactions to different fastening materials.

→ Details of different growth rates.

→ Reactions to more severe trauma, i.e. drilling and cutting.

→ Differences noticed between series 1 and series 2 experiments.

→ Differences of indoor growth vs outdoor growth.

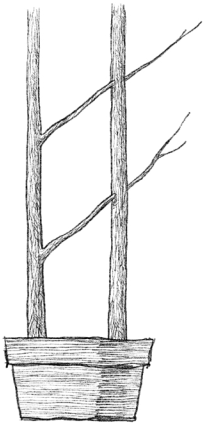
→ Any effects of inosculation

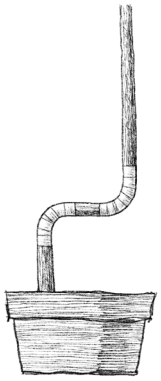
→ What worked and what did not?

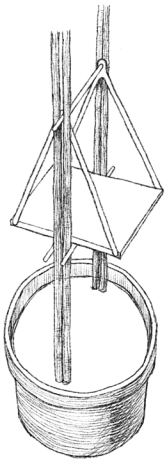
→ Improvements for next time.

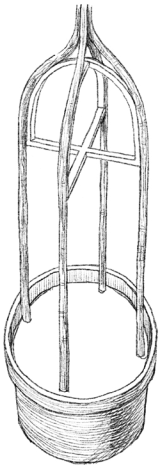
Fig. 4.73. The illustrated collection of series 2 experiments. This demonstrates seven experiments featuring hybrid living tree structures using black willows, 3D printed components, stainless steel screws and zip ties. Drilling and cutting are also used as shaping strategies.

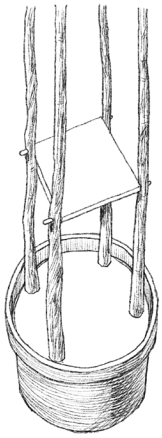


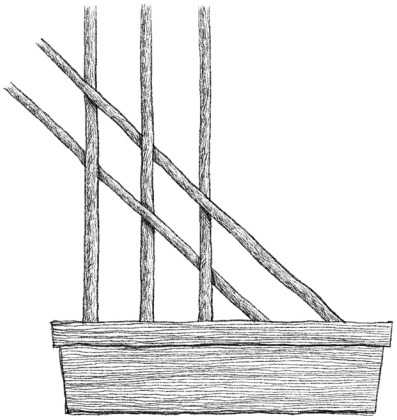













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Fig. 4.74. Photograph of collected willow cuttings after 3 weeks of propagation. Most have grown new roots, stems, and leaves, however a select few have only few roots and no green growth. They are labled to be sorted into the series 2 experiements.

Fig. 4.75. Newly designed 3D printed components used for series 2 experiments.

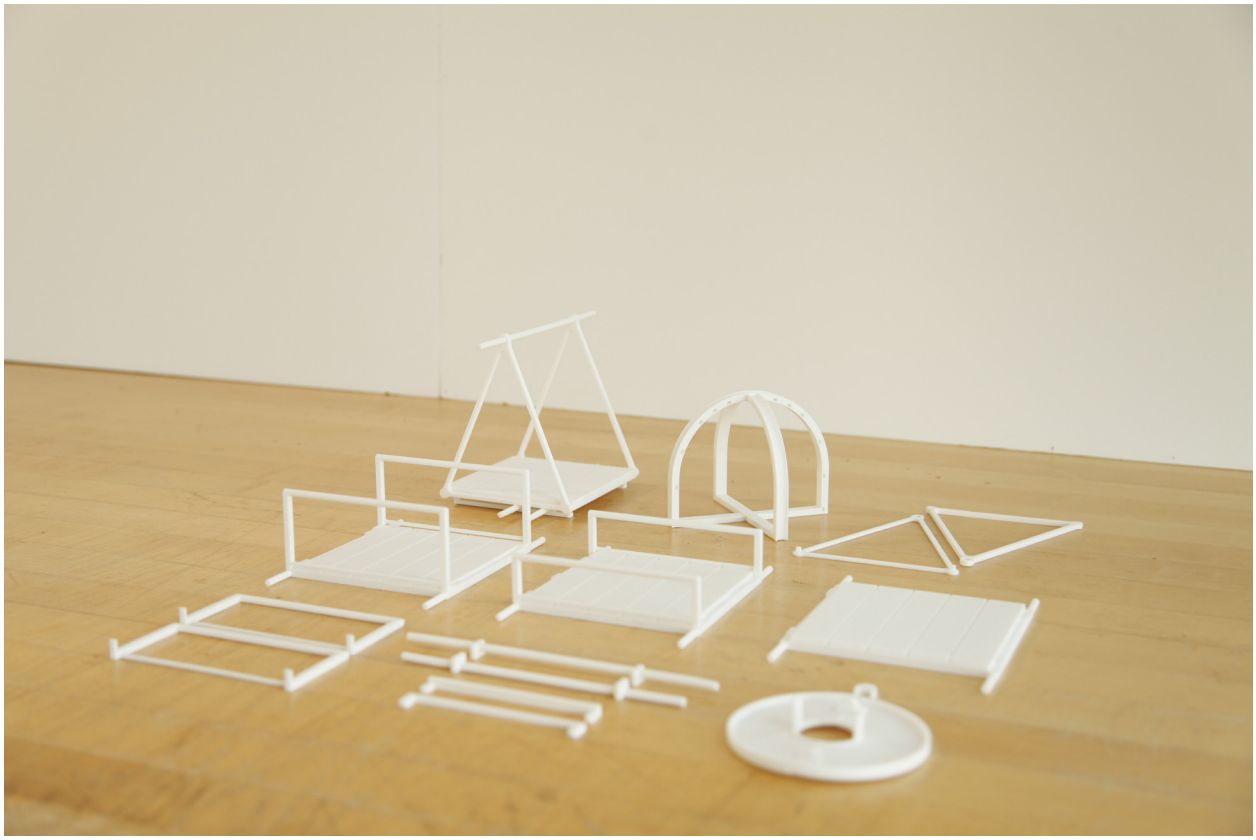
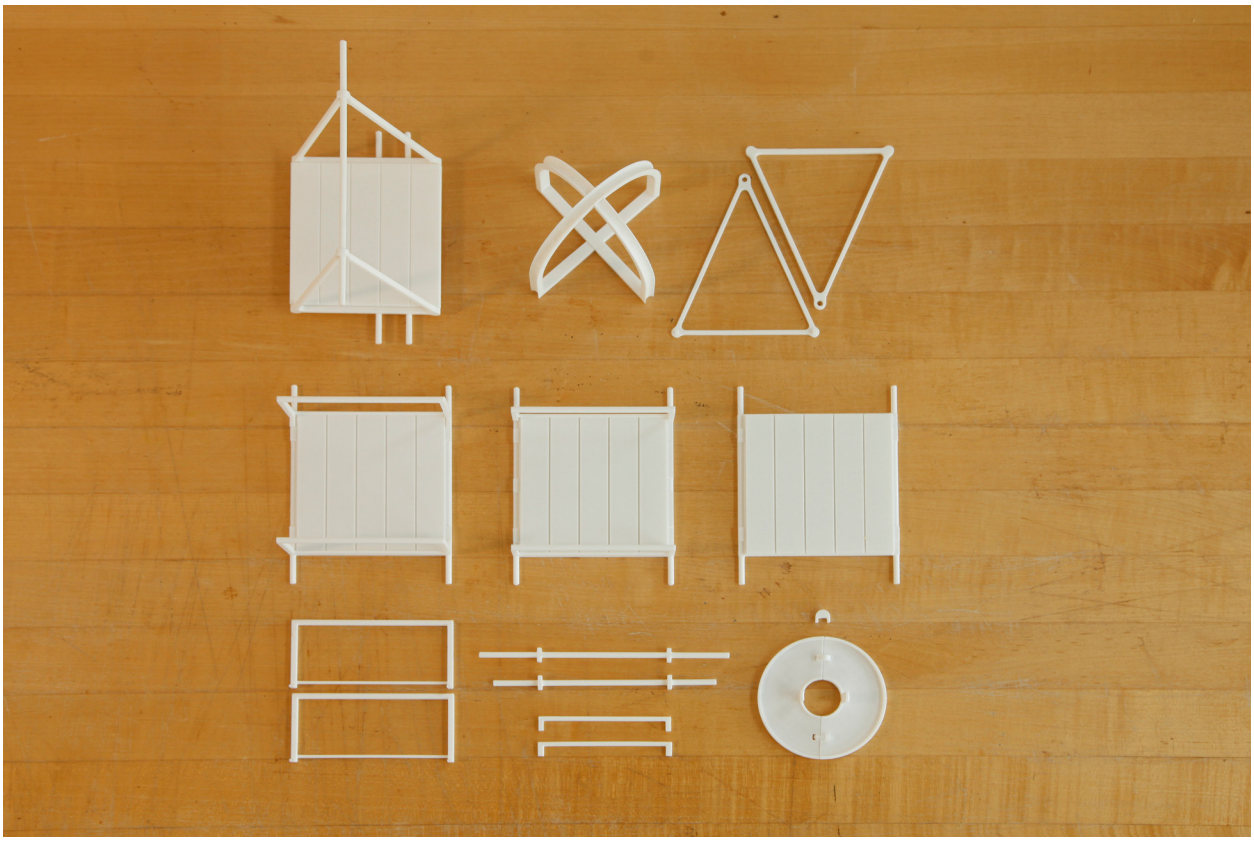


Fig. 4.76. (Upper row left to right) 1. A platform with two types of friction attachment methods. 2. A dome frame for bracing cuttings to shape. 3. Trusses for the first platform. (Middle row) Three iterations of a platform to be supported by drilling pegs into cuttings. (Lower row left to right) 1. Railings for architectural quality and aesthetic purpose. 2. Adjustable beams for the first platform, designed to clamp around custom sized cuttings. 3. A custom mason jar lid made to suspend cuttings upright in jars of water.



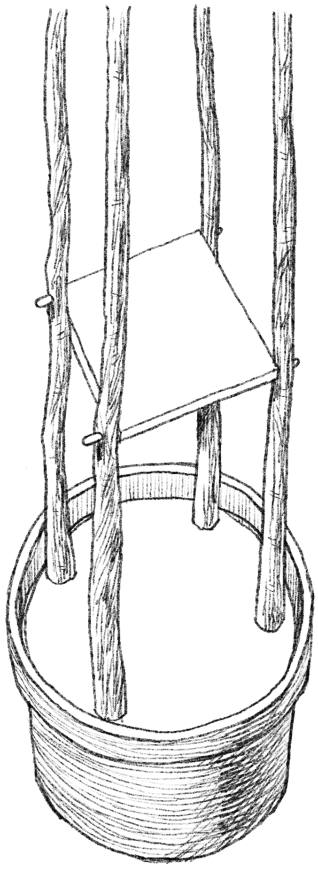


Fig. 4.77. Sketch 2A shows experiment supporting platform by beams slotted into drilled holes on the willow trunks.



Fig. 4.78. Willow cutting experiment 2A as informed by the sketch. No additional fasteners were used.







Fig. 4.79. The work-in-progress while drilling a 4mm hole through the center of the cutting, avoiding damage to areas around the hole.





Fig. 4.80. Four photos showing detailed views of experiment 2A and the hybrid connections used.

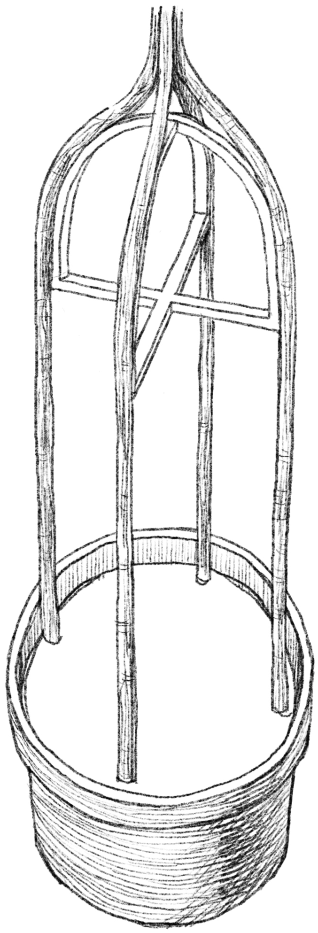


Fig. 4.81. Sketch 2B shows experiment with cuttings braced to arched frame to form a dome shape.



Fig. 4.82. Willow cutting experiment 2B as informed by the sketch. Zip-ties are used to secure cuttings to frame.







Fig. 4.83. Four photos showing detailed views of experiment 2B and the hybrid connections used.

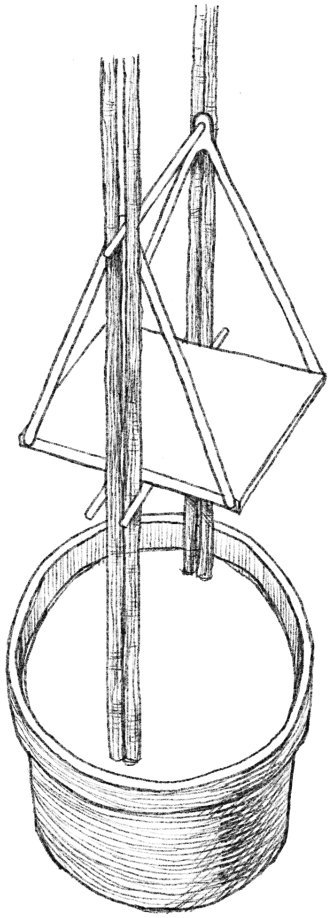


Fig. 4.84. Sketch 2C shows experiment supporting a platform by two friction clamping methods. The upper beam is clamped by cuttings, while lower beams apply clamping force to the cuttings.

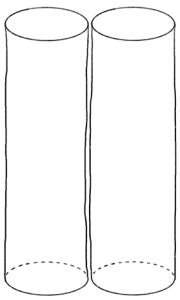


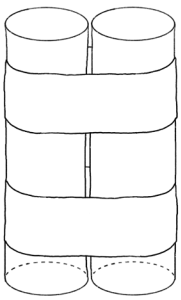
Fig. 4.85. Willow cutting experiment 2C as informed by the sketch. Both connections are tightened with zip-ties.





Fig. 4.86. Sketches of simple inosculation techniques that 2C is designed to experience.





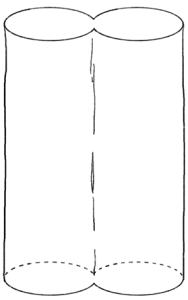




Fig. 4.87. Four photographs showing the 2C platform and clamping beam details. Zip-ties secure around the cuttings in the upper connection and the beams in the lower connection.

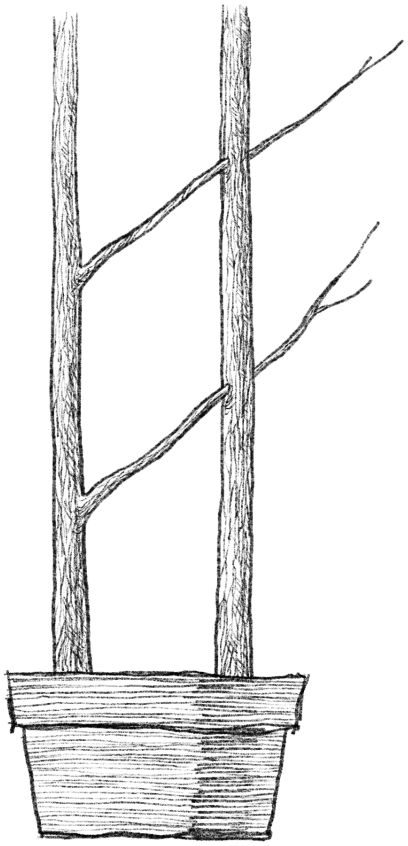
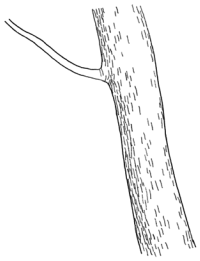


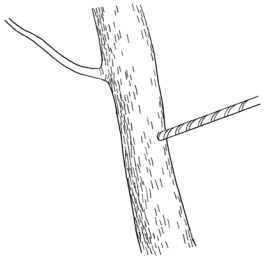
Fig. 4.88. Sketch 2D shows experiment grafting smaller branches of one cutting to another cutting through insertion into a drilled hole. This experiment has potential for planar properties.



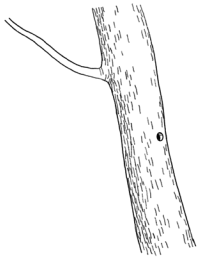
Fig. 4.89. Willow cutting experiment 2D as informed by the sketch. Cutting paste is used to seal exposed injuries.

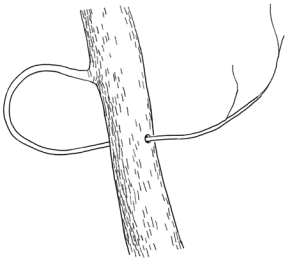












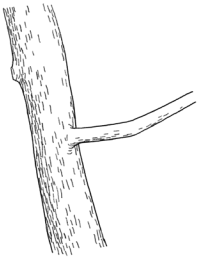






Fig. 4.91. The four images of experiment 2D show details of the connections and applied cutting paste to seal gaps.

Fig. 4.90. The sketches to the left present a simple sequence of grafting through insertion of branch into a hole.

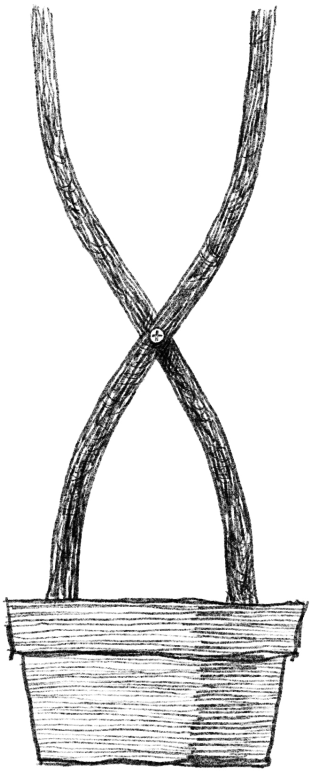


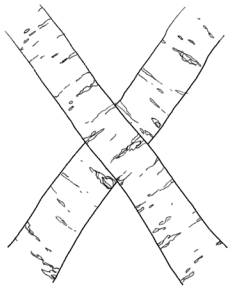
Fig. 4.92. Sketch 2E shows experiment where two branches are secured at a point of crossing using a nail.

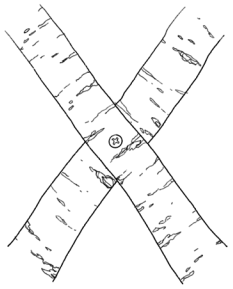


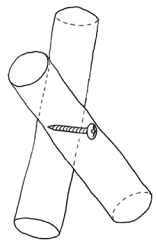
Fig. 4.93. Willow cutting experiment 2E as informed by the sketch. Stainless steel nails are used to fasten branches.











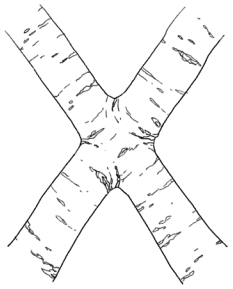


Fig. 4.94. Sketches demonstrating the inosculation expected at nailed contact points.



Fig. 4.95. Photo of work-in-progress, experiment 2E is shown applied to the cuttings before being potted into substrate. Connections are secured temporarily with zip-ties.





Fig. 4.96. Four images of experiment 2E show details using the stainless steel nail connections.

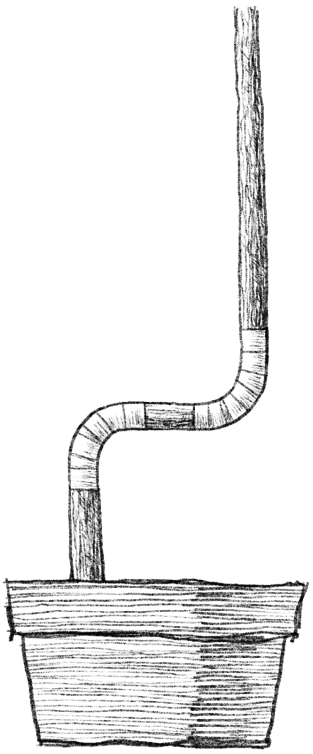


Fig. 4.97. Sketch 2F shows experiment that applies bends through cutting wedges along the side of the cutting.



Fig. 4.98. Willow cutting experiment 2F as informed by the sketch. Bandages are used to cover cuts, braces secured with zip ties apply force on bends, while wires are coiled around cutting to help hold shape.



Fig. 4.99. Image shows detail of the work and fasteners used to brace the shape of the bends in 2F.

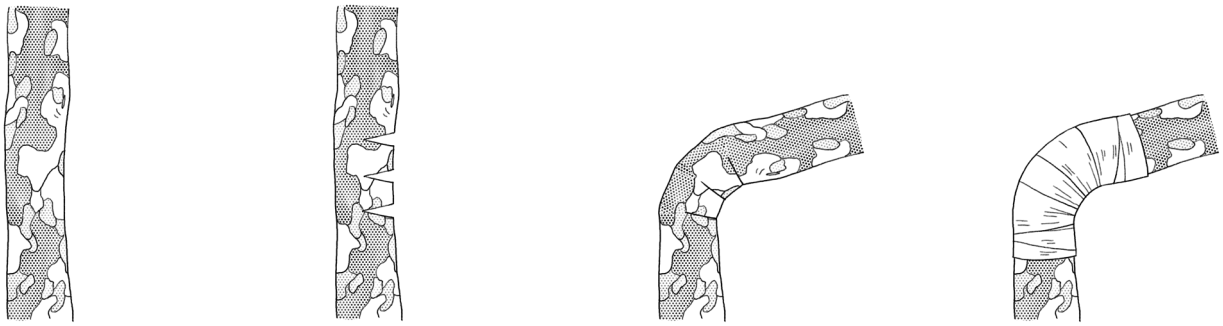


Fig. 4.100. Sketches show the process of how the bending technique is applied.



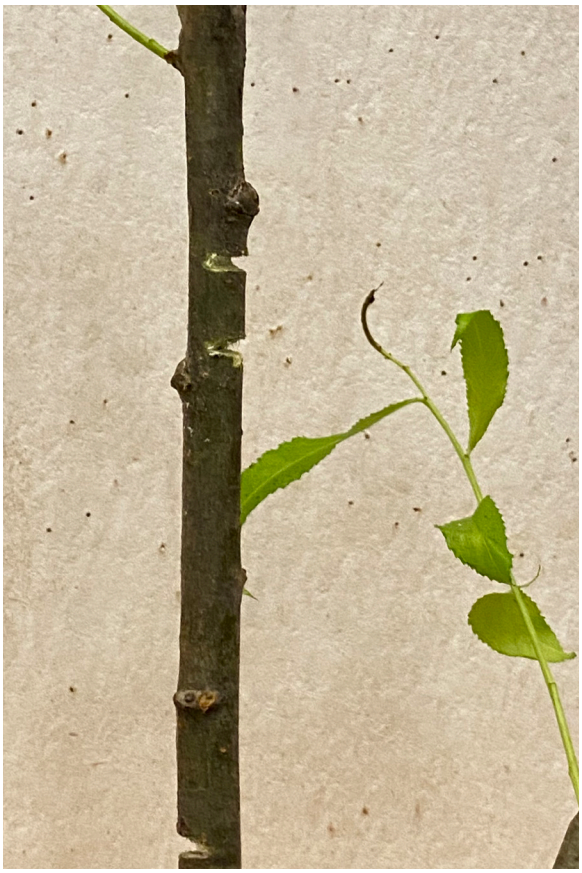


Fig. 4.101. Two images show the cuts applied to the branch before being shaped, bandaged, and potted in substrate.

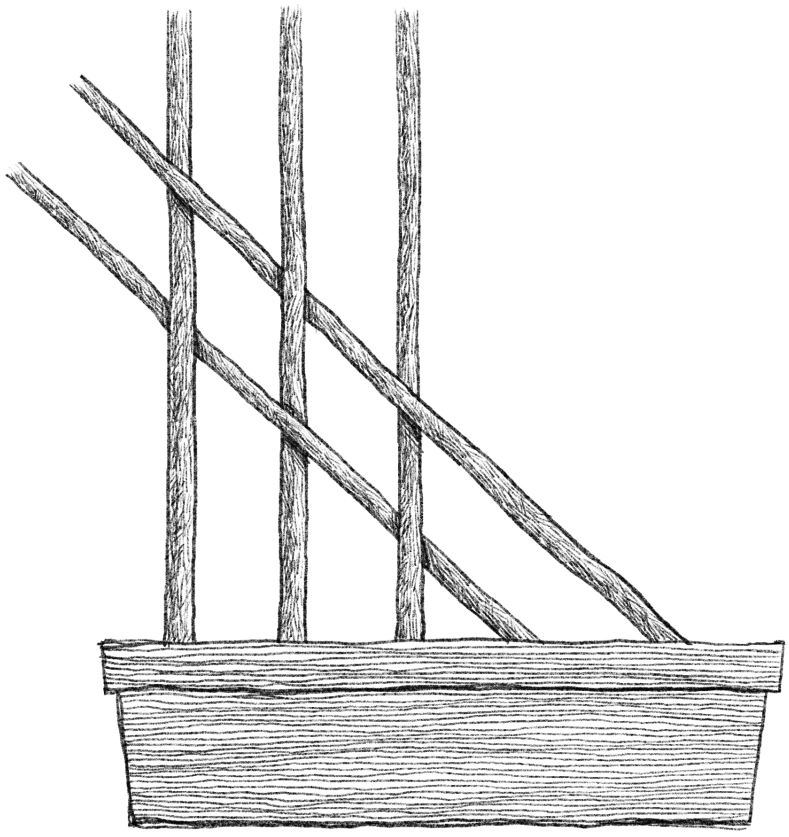


Fig. 4.102. Sketch 2G shows experiment using multiple cuttings to weave a planar surface.



Fig. 4.103. Willow cutting experiment 2G as informed by the sketch. Cuttings are weaved together and secured at contact points by zip-ties.







Fig. 4.104. Four images of experiment 2G showing weaving details and zip-ties as fasteners. The goal is to grow a weaved wall surface using this method.

4.4.5 Learnings and Observations: Series II

In the second round of experiments, the main subject material was the black willow (*Salix nigra*) found native to large regions of eastern North America, including South Ontario.[18] This species was chosen to compare against the braided willow for its features of rapid growth, ease of propagation, adaptability to environment, and availability.

Since the Grand River is prone to flooding and changing water levels,[19] it was easy to locate multiple locations along riverbanks that had large naturally grown black willow trees suitable for material collection. Typically, the newer and thinner branches suited for cuttings are found higher up in mature trees. Unfortunately, these were unreachable in most of the trees surveyed without ladders or heavy equipment. Two trees, however, had plenty of new shoots along the lower trunk as a direct result of damage to their upper trunks. One was cut down mid-trunk causing new branches to regrow on the lower portions. The second tree had a large split branch which had rooted independently after contacting the ground from storm damage, causing plenty of smaller branches to sprout on the fallen limb. During this excursion, 30 cuttings were collected primarily from two trees that had plenty of lower branch growth.

A different group of willow trees were unused due to the presence of insect infection. During collection, a high volume of small insects was identified on the smaller branches of these willows. To avoid risk of infection to other collected willows, cuttings from these trees were discarded and no more cuttings were collected.

Learning from Series 1 experiments, many assurances were applied to Series II to optimize propagation and successful rooting rates. Crushed aspirin was mixed with water during collection to decrease shock and stimulate root cell generation. A rooting hormone powder was added at propagation setup, while tap water was left to dechlorinate for a couple days before being used. The whole process occurred in a bright space indoors to avoid effects of external factors and placed away from direct sunlight with daily monitoring. No wind, wildlife, or temperature fluctuations affected the cuttings. These actions over the course of a three-week propagation period resulted in minimal propagation failure, yielding a 93% rooting rate leaving only two cuttings without roots.

Observing the cuttings after three weeks of root growth, it was noted that while 93% of cuttings grew roots, only 83% (25 cuttings) sprouted new leaves. While this is not an indicator of propagation failure, it does indicate a weakened state of cutting health. Upon checking by scraping off a small piece of bark, green cambium was still present indicating that the cuttings were alive at this point. A major drawback of conducting the experiments through propagation is the two stages of stress that the plants are subjected to. Once when consuming stored energy to grow roots after removal from the host tree, and second when adjusting to new substrate during repotting after propagation. Additionally, this two-step process is more time consuming, requiring cuttings to grow strong roots before experiments are conducted.

When repotting and conducting the series 2 experiments, many obstacles were discovered. In photographing the repotting process, many of the fine roots dried within ten minutes of being placed outside of water. The roots at this stage were particularly fragile and prone to drying. This damage might have

18 Natural Resources Canada Government of Canada, “Black Willow,” December 31, 2013, https://tidcf.nrcan.gc.ca/en/trees/factsheet/468.

19 “Flooding,” Grand River Conservation Authority, accessed November 5, 2024, https://www.grandriver.ca/our-watershed/flooding/.

been avoidable if less photos of cuttings were taken outside of water, or if the roots were misted every few seconds.

Organizing the cuttings to designate experiments proved to be a challenge. Since the designs were not fully resolved during the material collection, a variety of diameters, lengths, and shapes of willow branches were collected to provide a range of flexible options. However, after finalization of ten design sketches, only 28 cuttings were usable. Of the 28 available, roughly 21 cuttings were suitable for usage in the designs. Some were too short while others had inconvenient shapes, rendering only 70% of cuttings usable for experiments. Even with 21 cuttings, the range and quantity of different sizes were greatly reduced, limiting the quality of some experiments. Although this resulted in a decrease of experiments in series 2, it was addressed by combining some experiments together to test multiple connections. While willow material was a significant limiter, the existing seven were successful in showcasing various joinery.

Although an attempt was made to avoid external factors, series 2 was still affected by temperature. In the day following experiment setup, the heating system of the studio space failed. This caused indoor temperatures to reach 10°C overnight for two weeks while awaiting repair. The studio walls are made of brick with no insulation and offer no heat retention, causing interior and exterior temperatures to match. It was not possible to move the experiments to a separate location due to logistics of transportation, space availability, and additional plant stress. Unfortunately, the week immediately following transplant plays a critical role in plant recovery. Root growth thrives best in a moist and warm environment, which could not be fully satisfied.

In observation, the effects of root shock and temperature effects were visible immediately on the second day from wilting leaves. Over 60% of the plants showed signs of decline. While alarming, this was also an anticipated reaction indicating energy redirection to root recovery. Diffused sunlight was available daily and dechlorinated tap water was provided once every 3-4 days to maintain damp soil. Signs of decline for all series 2 experiments continued for the ensuing two weeks.

The connections with 3D printed structures also present a sensitivity to the plants' overall health as many of the connections are secured with zip-ties, insertion, or friction. This applies pressure, external forces, and some exposure from damaged bark to the cuttings. While these factors seldom compromise a healthy tree, the willow cuttings are weakened at this stage. Most exposed areas were covered proactively with cut paste for added protection. Over two weeks, no visual signs of rot or decline formed around points of connection, indicating that the connections had not immediately failed.

About 3 weeks into the series 2 experiments, most leaves have wilted and fallen, however, most plants still have green shoots. Two willows fortunately started showing signs of new sprouts. At this stage, the results of series 2 showed greater signs of success than the willow cuttings of series 1.

During week 4, the willows became infected with spider mites and potentially cixiid eggs. The cause of infection is unknown but theorized to have been carried over dormant during collection, then further aggravated from the willows' weak health, environmental dry air, and insufficient air circulation. New sprouts on the plants have wilted due to the infections. To combat this, a combination of fungicide, insecticide, and miticide garden was sprayed thoroughly twice a week. This is an unfortunate setback of growing the experiments indoors with

no rain, wind, or natural predators to displace pests.

While series 2 willows are still alive, they have not thrived in the first 4 weeks after experimentation and transplant. The successes of their 3 weeks propagation after collection were not fully reflected in the experiments. In this whole process, many factors have affected the state of the willows including cold temperatures, root shock, connections of 3D printed structures, pest infestation, water quality, soil quality, and sunlight exposure. Additionally, series 2 was conducted in early autumn, deciduous trees like willows naturally drop leaves, slow down growth, and to store latent energy for winter. This could also contribute to the slower and weaker progress seen in the cuttings. To differentiate which factor definitively impacted recovery is difficult given the thesis scope and can only be confidently confirmed with many more iterations of experiments, testing each factor individually.

In summary, there are obvious benefits of using the native black willow in the series 2 experiments. It is an accessible, plentiful, and regenerative resource found near bodies of water in south Ontario, making the experiments repeatable and iterative. Future experiments using black willows can be repeated at larger volumes. Although hardy by nature, the native willows are not fully adjusted to indoor environments, dry air, or treated tap water. They come with their own sets of challenges different than garden center braided willows.

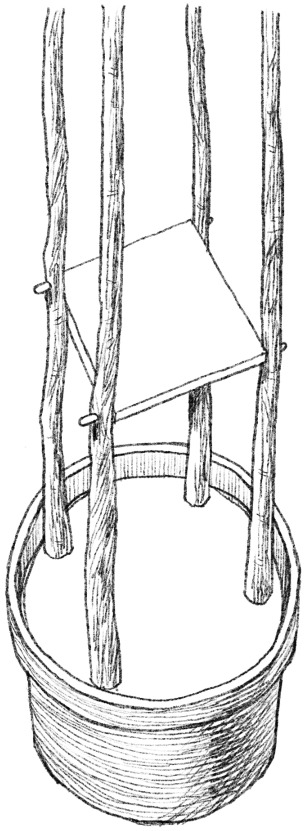


Fig. 4.105. Sketch of 2A

Fig. 4.106. Three images of 2A after 1 month. Three of four cuttings were still in good health with green stems. All the leaves had fallen while one cutting showed signs of drying. The connections from insertion did not fail. Small white fluff seen in the images indicate pest infection.







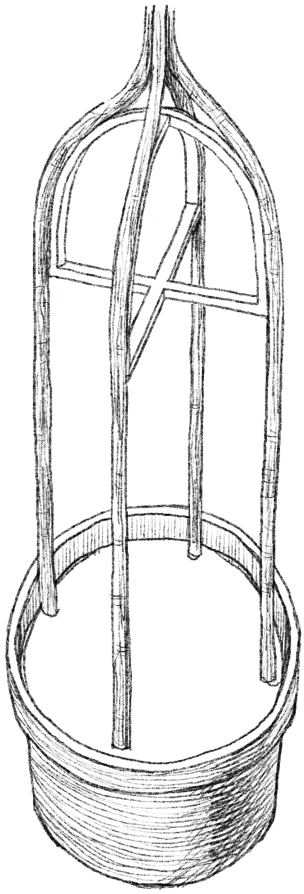


Fig. 4.107. Sketch of 2B

Fig. 4.108. Three images of 2B after 1 month. All cuttings were still green and alive. Most leaves had fallen while a few remain. The soft cuttings were reacting well with zip-ties and frame structure. Pale patches on leaves indicated infection or disease.







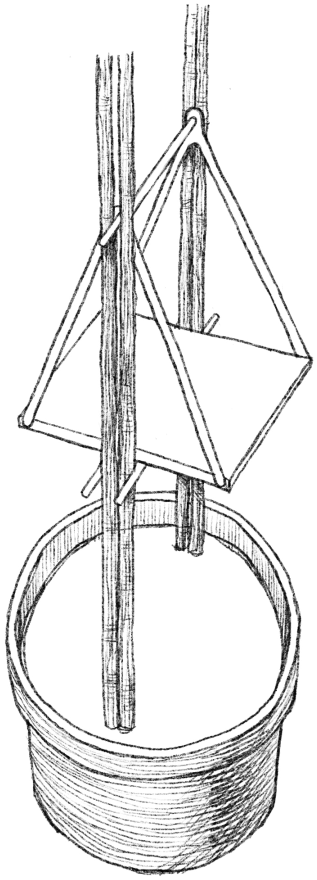


Fig. 4.109. Sketch of 2C

Fig. 4.110. Three images of 2C after 1 month. One of four cuttings showed signs of the top half drying while all other cuttings were still green. Friction and zip-tie connections did not cause damage the bark of the cuttings, indicating that the cuttings responded well.







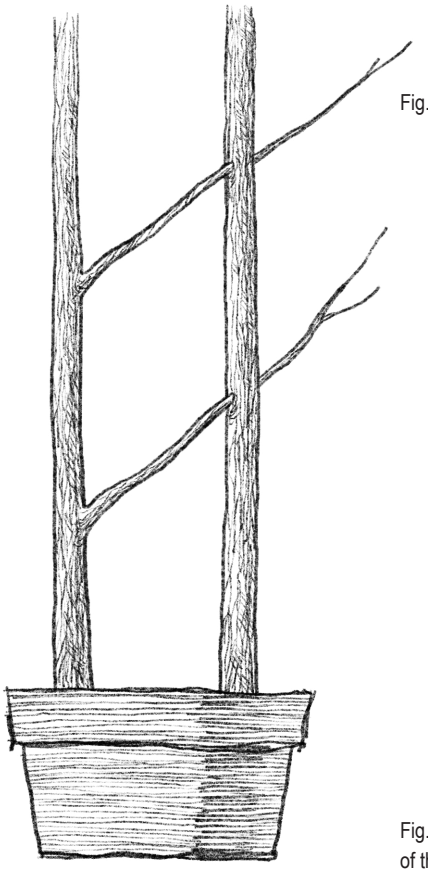


Fig. 4.111. Sketch of 2D

Fig. 4.112. Three images of 2D after 1 month. Both cuttings were still alive with green stems. Portions of the thinner cutting showed signs of drying. The hole drilled into the wider cutting did not cause visible damage around the cutting. A flush of new leaves sprouted and fell three weeks after conducting experiments.







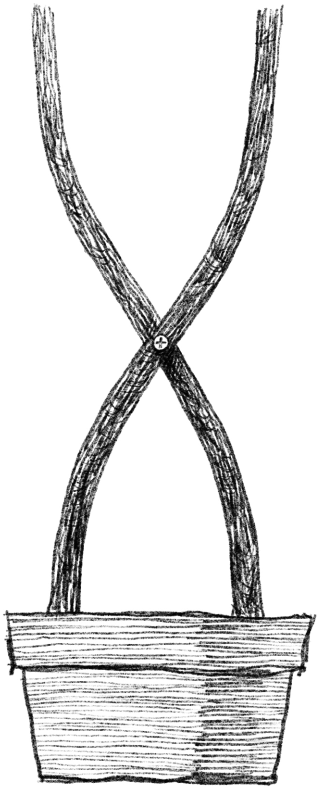


Fig. 4.113. Sketch of 2E

Fig. 4.114. Three images of 2E after 1 month. Both cuttings were still alive with green stems. Small portions of both cuttings were showing signs of drying, however, a new bud was spotted in the middle image.







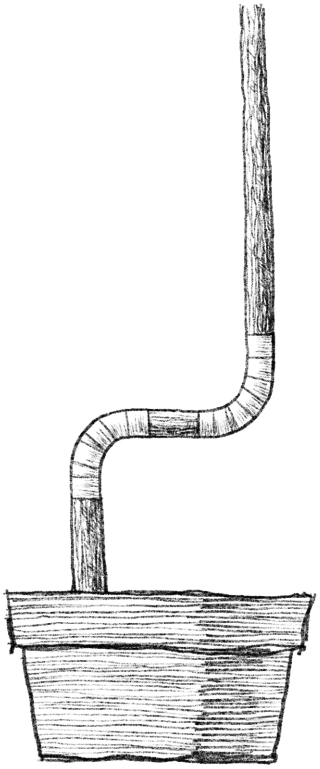


Fig. 4.115. Sketch of 2F

Fig. 4.116. Three images of 2F after 1 month. The cutting's health was not determined at time of photograph. The newer shoots dried while the main bark appeared still alive. 2F at this moment was too soon to determine if shaping was successful.







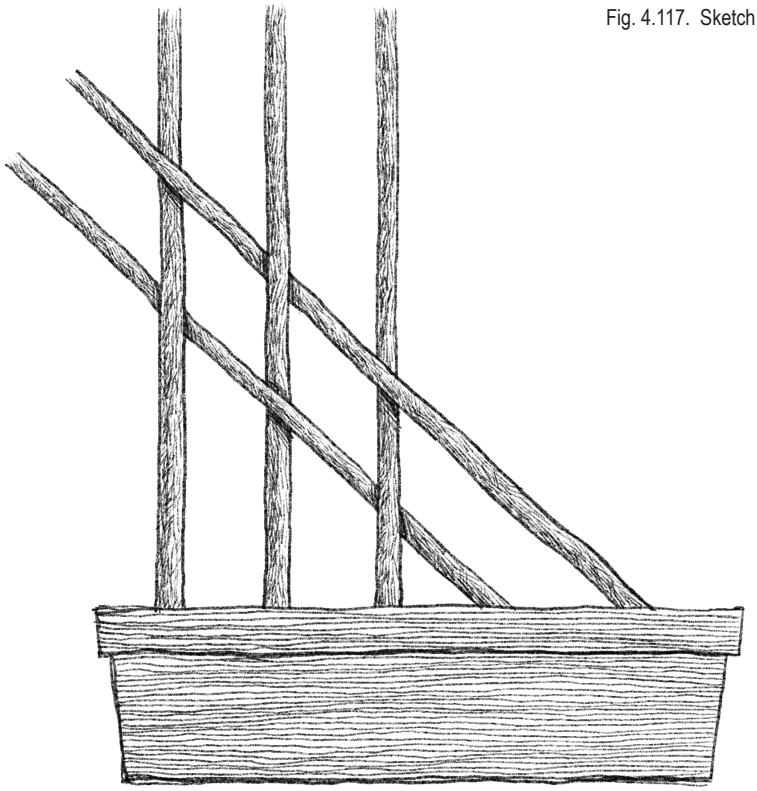


Fig. 4.117. Sketch of 2G

Fig. 4.118. Three images of 2G after 1 month. Many cuttings showed signs of drying. All leaves dropped but there were still green stems. No signs of inosculation were seen at zip-tie connections though there were some signs of new buds forming on some cuttings.







4.5 Conclusion

The goals of this chapter were to demonstrate simple connection designs using living plants and to learn tree shaping techniques through practice while set in Cambridge, Ontario. Simple designs are iterated through sketches and are then applied through two separate series of experiments using garden center willow cuttings and locally collected native black willow. Nine experiments are conducted with series 1 garden center willows, while series 2 proposed seven more revised experiments. It documents collection, preparation, propagation, experimentation, and maintenance of all the willow material. From this, the chapter compares the preparation process while documenting and learning from each series to better inform future studies and larger scale modeling.

The chapter also presented findings from the two series of conducted experiments. It highlighted the results and compared the performance of experiments to expectations. The findings were explained along with a review of active and environmental factors' contributions to the successes and failures of each series. Obstacles and problems were discussed to theorize how they could have been avoided to minimize impact on the outcomes. These documentations act as lessons to learn from in potential future iterations.



Fig. 4.119. Workbench for setting up black willow cuttings.



Fig. 5.1. Illustration of tree leaves, 2024, by author

5.0 Findings: The Leaves

Chapter 5 reflects on the two series of experiments. It revisits the scope and limitations of research and proposes potential iterations for future experiments.

Furthermore, architectural illustrations are presented as a response to the work and research. The illustrations depict vague, yet detailed architectural objects and structures. The translations to physical manifestations are flexible with interpretation, provoking ideas of possible structures made of living trees. They are designed to celebrate change and growth in architecture and show appreciation for the research around the fields of baubotanik and arbortecture.

This chapter concludes with benefits and drawbacks of living plant construction and factors to overcome when posing arbortecture as a commonplace method in practice. It further speculates how future cities could be and how we might live amongst the trees. In the end, is it a viable approach to construction and the way designers interpret space?

5.1 Limitations and Future growth

The scope of the experiments found in this thesis faced massive limitations in many fronts. Budget, space, scale, time, resources were all consequential drawbacks. Given the conditions, the thesis presents a set of experiments and documenting the work taken to achieve it.

With an increased budget, future iterations of this research could expand significantly, featuring a wider variety of both native and non-native tree species. Plants sourced from garden and landscape nurseries such as sycamore, hornbeams, ash, oak, and other various willows would allow for broader exploration. Their branches could be collected for propagation as eventual small-scale experiments while the trunks could be used for larger scale tests.

Space limitations shaped the size and scale of the experiments of this research. Series 1 was conducted in plastic two tubs on the front steps and back porch of a townhouse, while series 2 was conducted on a workbench in the university studio space. This restrained experiments to 8-inch plastic planters that could be placed in plastic storage tubs and standard wagons or trolleys. Moving forward, access to larger spaces like garden beds, a greenhouse, or a backyard would enhance the setup, allowing the ability to monitor growth for larger and more resilient plants in a more stable environment.

Larger scale materials and studies would translate better to modeling real-world applications of arbortecture connections. At their current rough 1:15 scale, the experiments are best seen as representational artifacts. Connections and joints designed to be modeled at 1:1 to 1:5 scale would allow for a higher resolution and more sophistication of details that can better show the process of inosculation and the interaction between plants and artificial components. This would also open the opportunity for custom designed parts to be manufactured for arborsculpture applications. However, as the scale of experiments increases, the time required for inosculation and growth also proportionally increases.

Time is perhaps the most crucial consideration in this thesis and in the study of arbortecture. Woody plants are slow growing and seasonal, being highly dependent on the warm growing season for progress in height, diameter, and density. Designs cannot simply be built; they are instead prepared, set up, then maintained over time to achieve a point of predicted growth. A longer timeline would allow for more complex experiments and more time to make plant healthy decisions. Working at smaller and slower intervals would reduce the stress and damage afflicted on the plant material. This means more time between propagation, repotting, and conducting of designs during more ideal seasons where plants can store more energy. A third series of experiments would be performed combining lessons learned from previous willow experiments. Some changes would include collecting cuttings in early spring, collecting double the quantity of cuttings, using filtered water or water from the Grand River, propagating in warmer environments, and more complex connection designs. Series 3 would also feature one or two experiments that are more architecturally formal, as a composition or system or connections that make up a building model.

Experiments are always an iterative process, and every set has lessons to learn from. The more experiments that can be performed, the more resolute and refined their goals and designs will be.

5.2 Drawings

Speculative drawings are common tools used in architecture to deliver ideas outside the realm of physics and budget to push creative boundaries and generate thought.[1] This thesis takes the culmination of research and experiments to generate three speculative illustrations.

The goals of the following drawings are to demonstrate change and organic growth through formal architectural representation. While blueprints and construction documents provide precise instruction and visual index of the while building, with arbortecture, the documents must also record a timeline showing setup and future change. They visually describe the structures' technical composition and integrate flexibility and unpredictability through their living components. With the use of digital drafting and hand rendering, they aim to capture change and growth through static drawings. These drawings act as instruction through documentation. Like the hybrid nature of the architecture, the drawings are also hybrid.

Each illustration depicts drawings of architectural objects. These objects are designed with spatial properties and serve to showcase the construction potential of living tree architecture.

Drawing 1 suggests an enclosed elevated walkway supported by living willow columns. This walkway is designed with modularity and can span various lengths as desired. The side walls between the willow columns are operable folding panels which allow for full control of shade and natural light onto its 1.5m wide wooden deck.

Drawing 2 presents a tower made of modular steel scaffold framing with a "second skin" envelope which wraps and supports the tower. It measures 6.6 meters by 4.5 meters and stands 10 meters tall. The living envelope can be built of willow, hornbeam, ash, or sycamore, growing wider and stronger over time to act as the tower's structural support.

Drawing 3 depicts a covered pavilion with its light wood-and-steel frame canopy supported by large mature sycamore trees in the center. The trunks act as columns while its branches act as beams. This assembly can be installed on existing mature trees or constructed around a younger tree with temporary supports which can be removed after it reaches the desired size.

In the three drawings, manufactured technical components such as platforms and steel beams are digitally drafted, while the living tree elements are hand rendered. Most importantly, these drawings are created to be pleasing and engaging to look at.

As the timescale to construct the drawn architecture far exceeds the effective timeline of this thesis, the drawings serve as a projection into a possible future, visualizing what architectural details may evolve to be, and where the use of living architecture may be commonplace. These drawings aim to inspire imagination and conversation of how arbortecture might be realized in the world and how they could be applied in other architectural opportunities.

1 "Idea-Building," Architecture Now, accessed November 5, 2024, https://architecturenow.co.nz/articles/idea-building/.

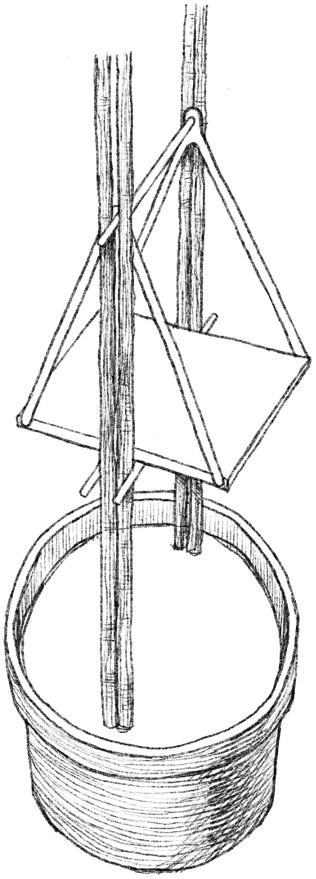


Fig. 5.2. Sketch of 2C

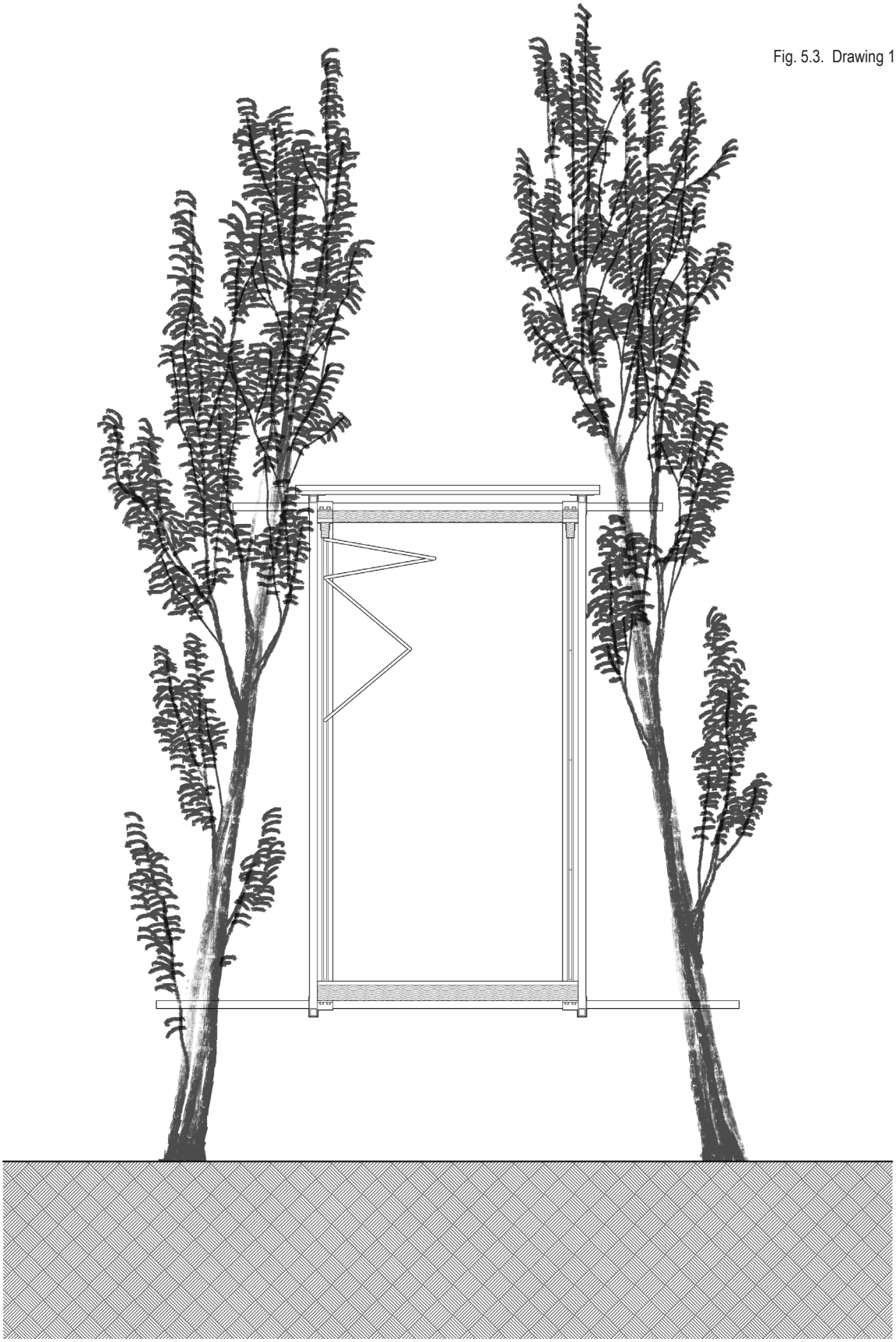
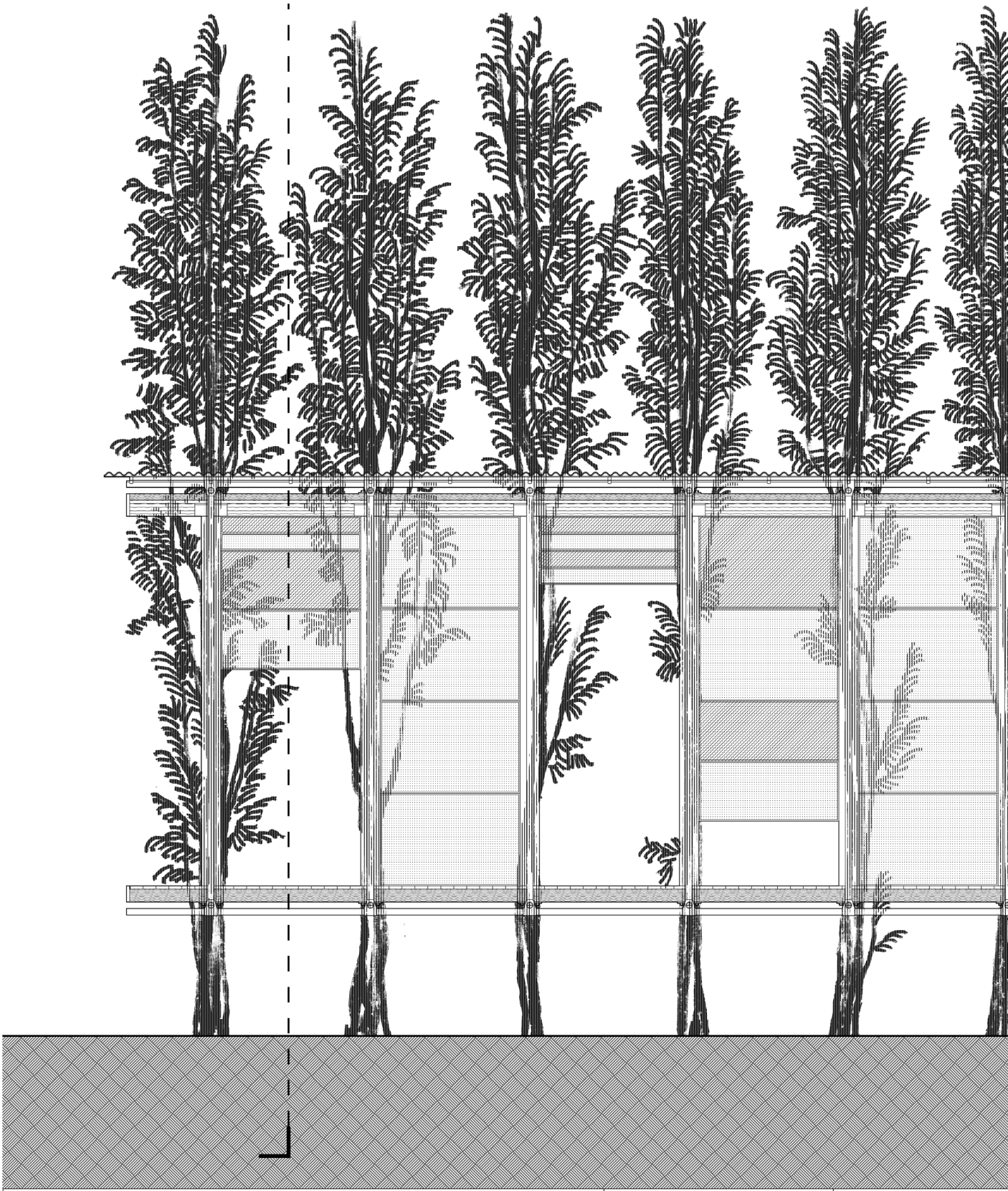
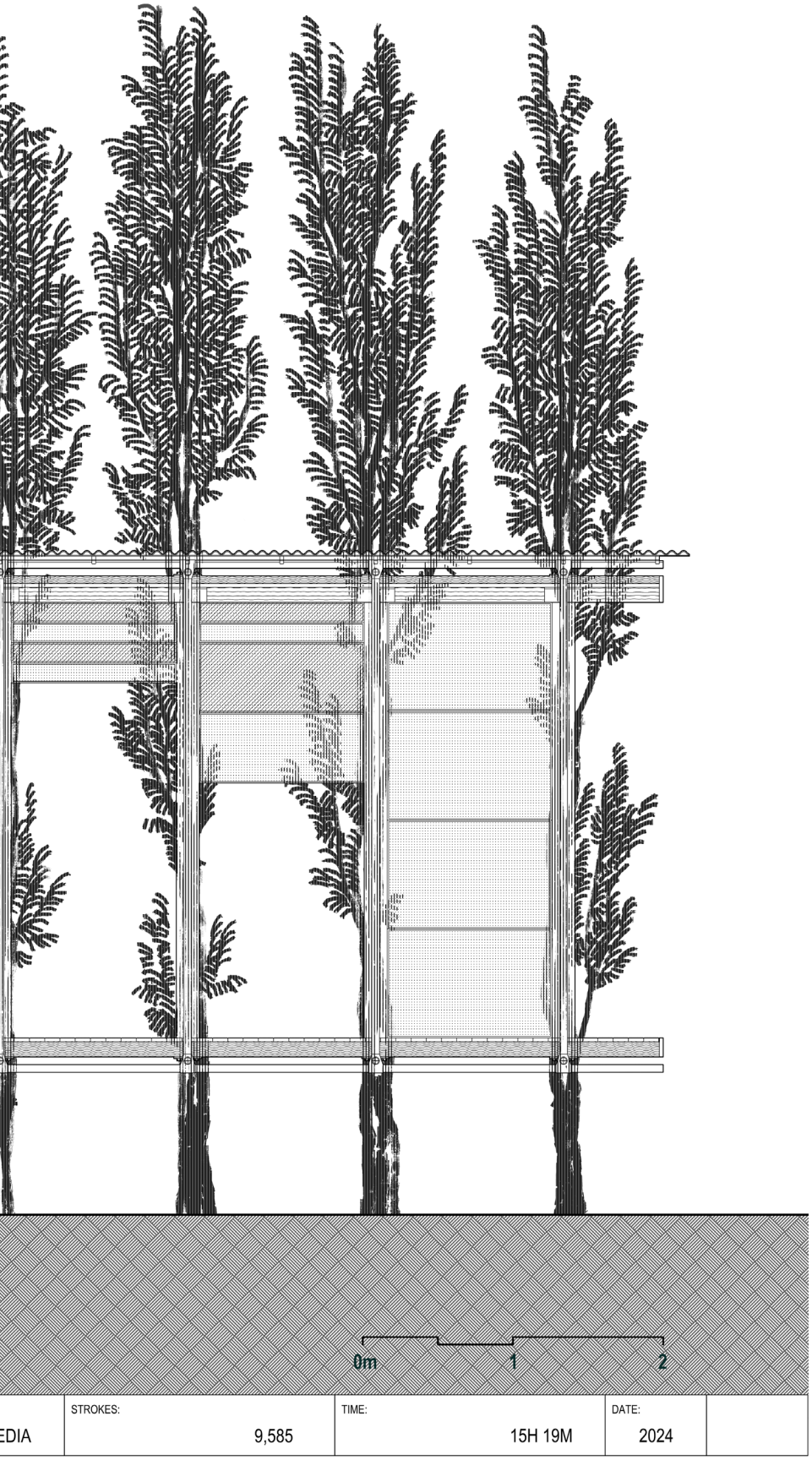


Fig. 5.3. Drawing 1 Sectional



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Fig. 5.4. Drawing 1 Elevation

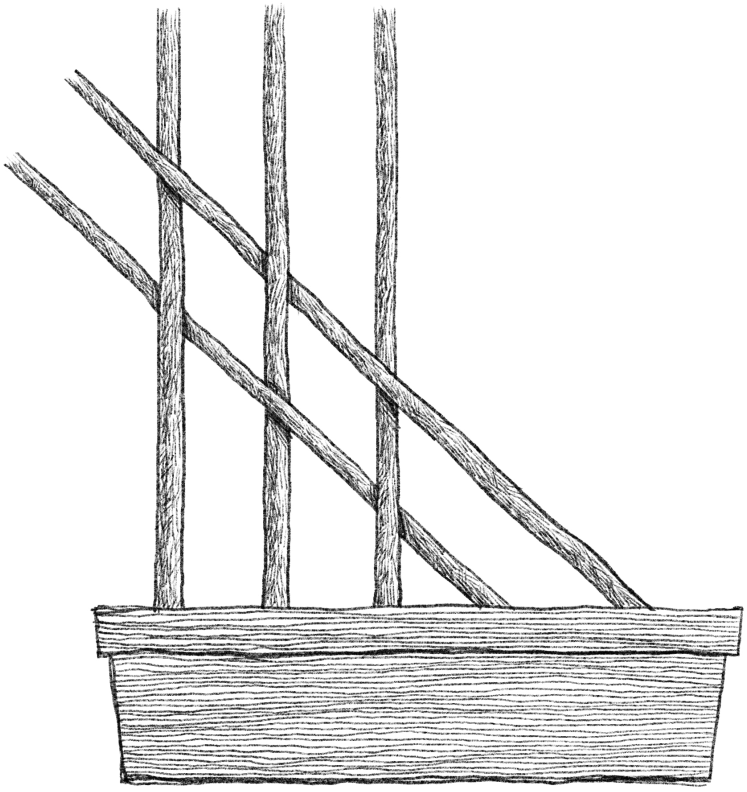


Fig. 5.5. Sketch of 2G

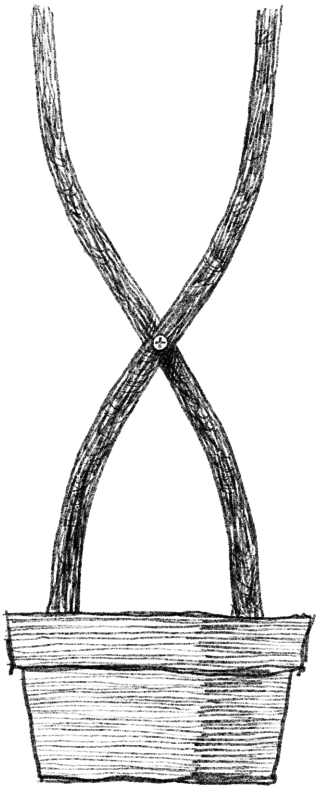
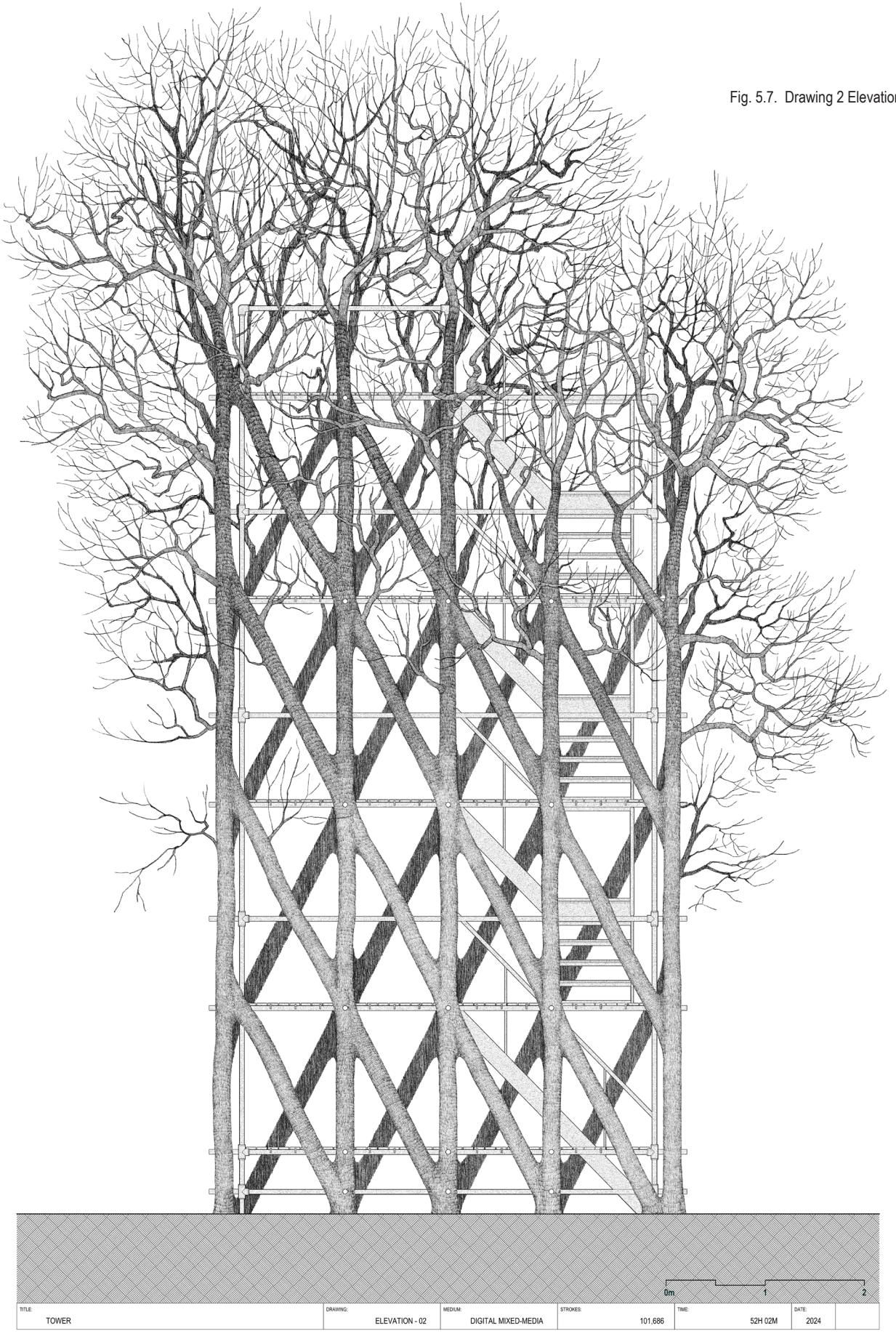
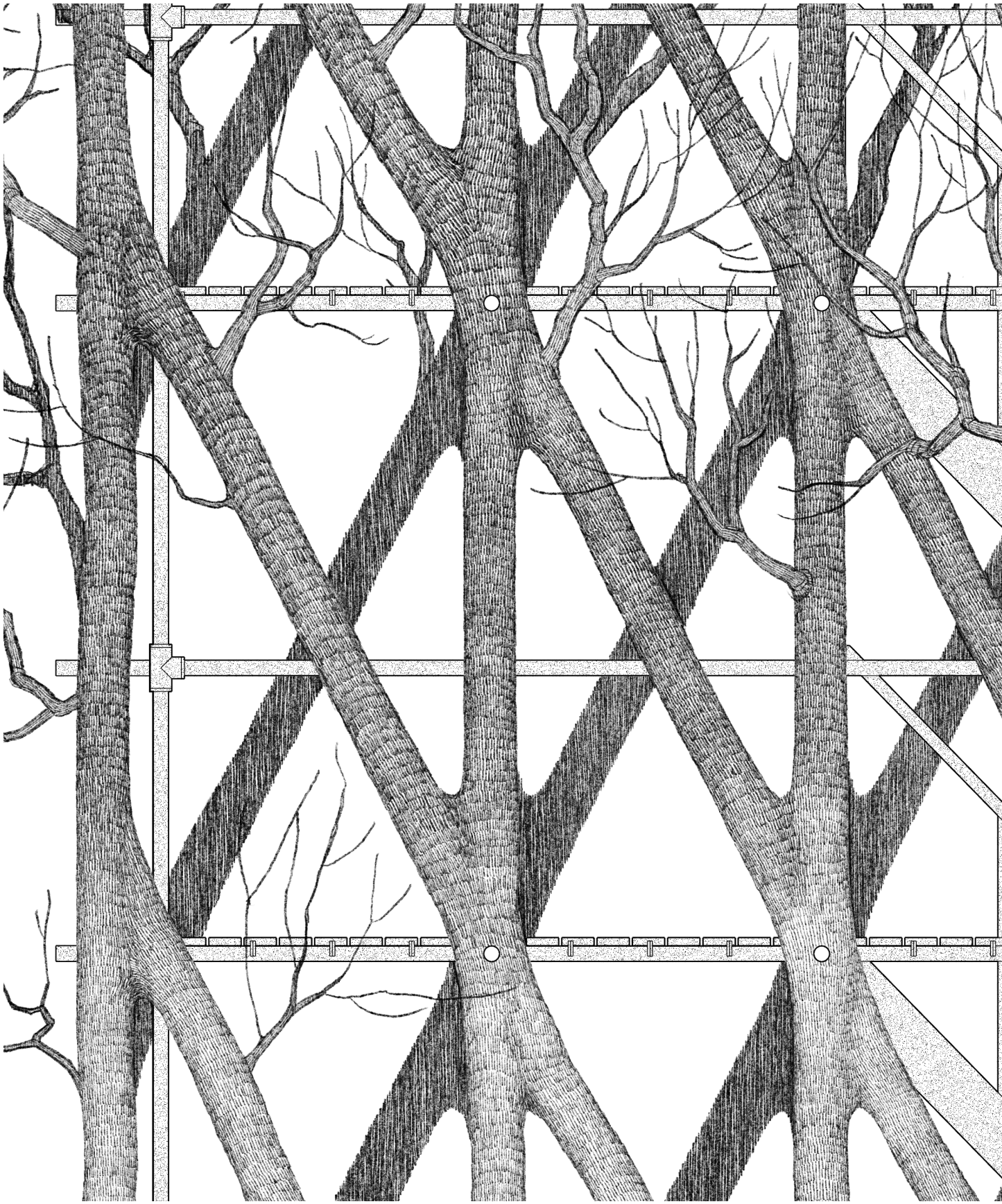


Fig. 5.6. Sketch of 2E

Fig. 5.7. Drawing 2 Elevation





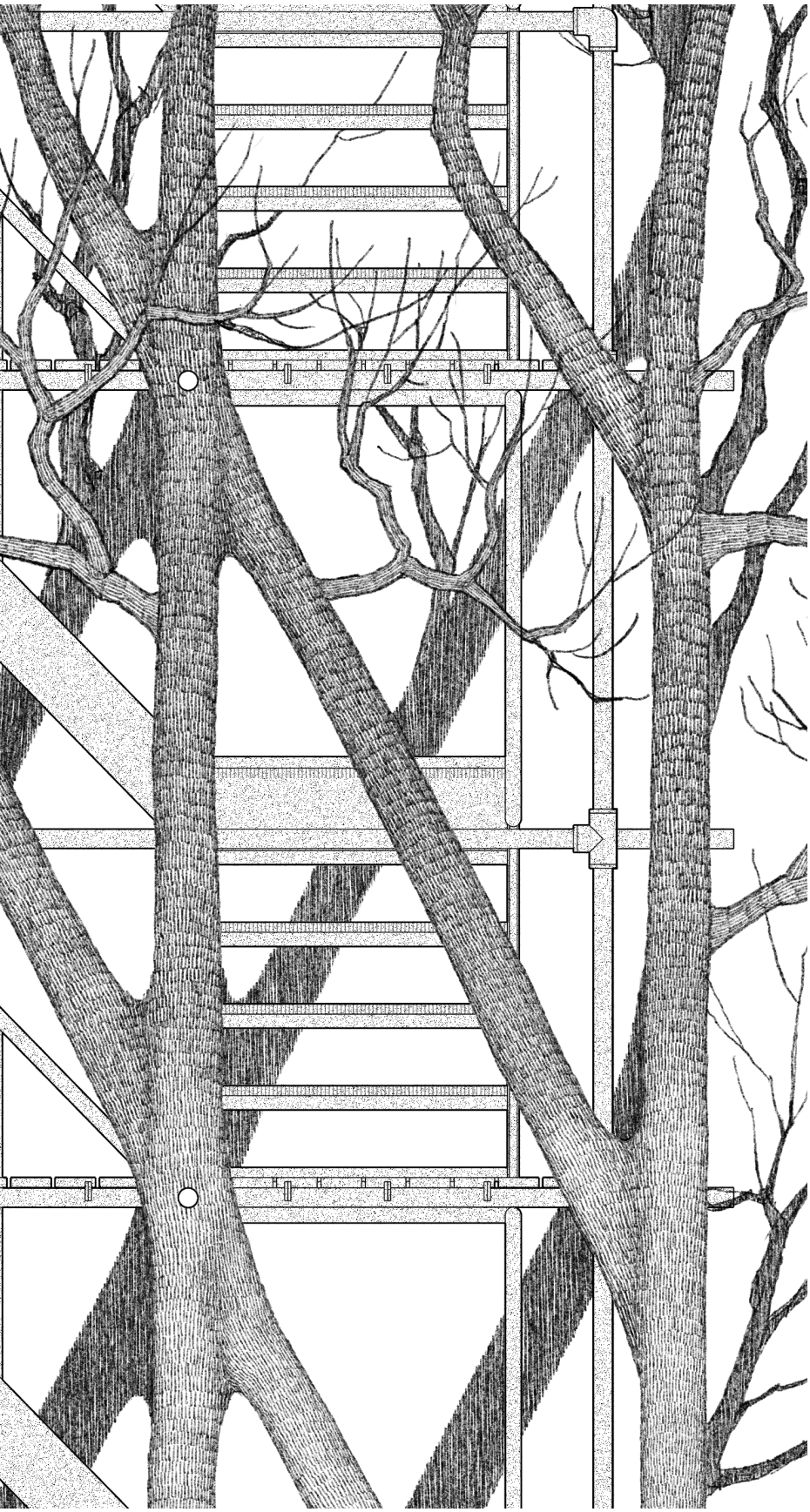


Fig. 5.8. Drawing 2 Elevation zoom-in

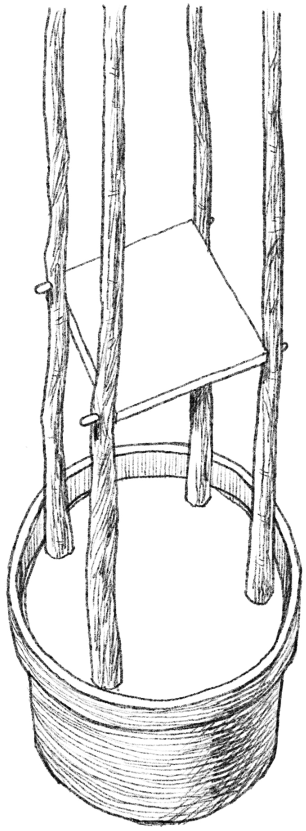
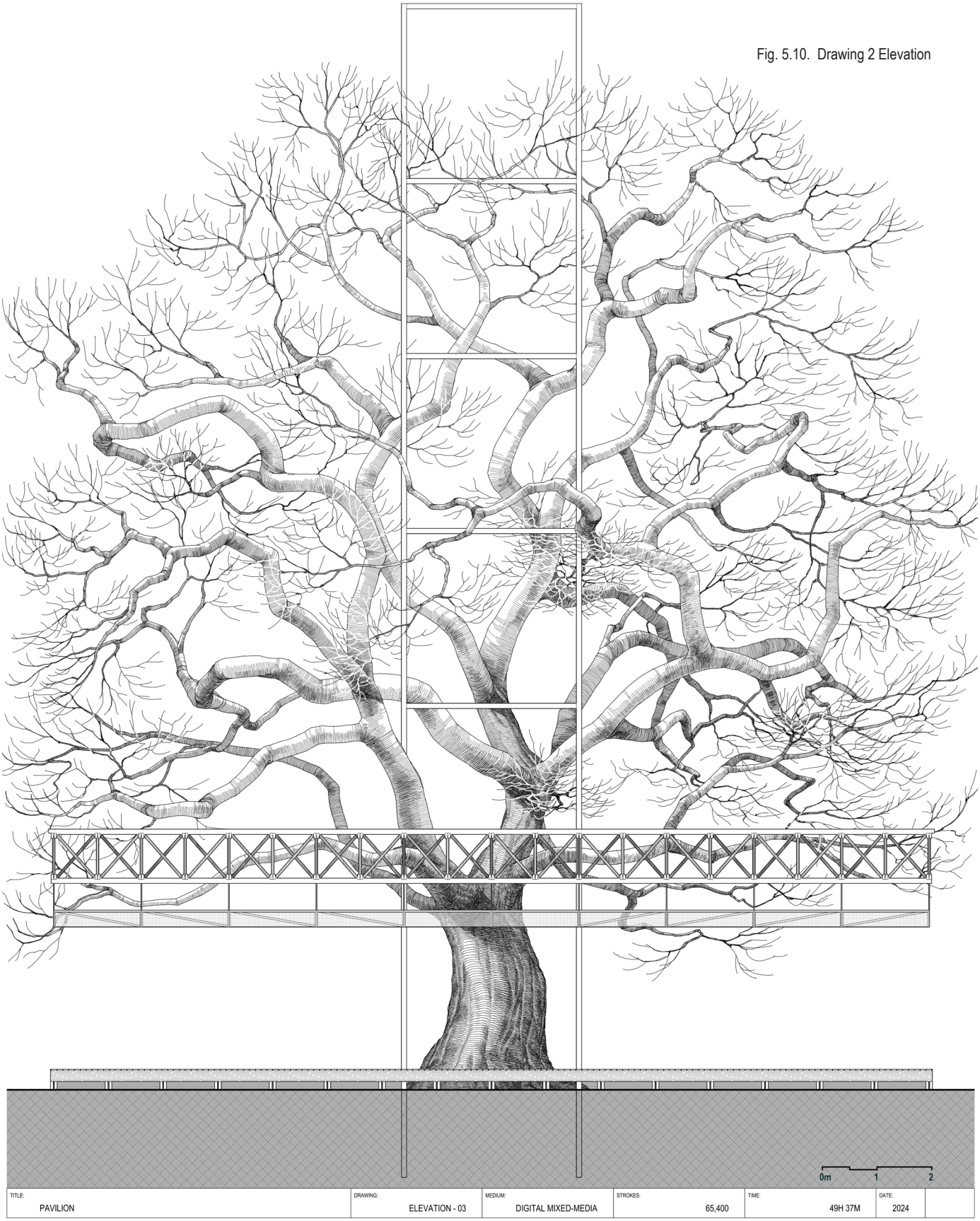
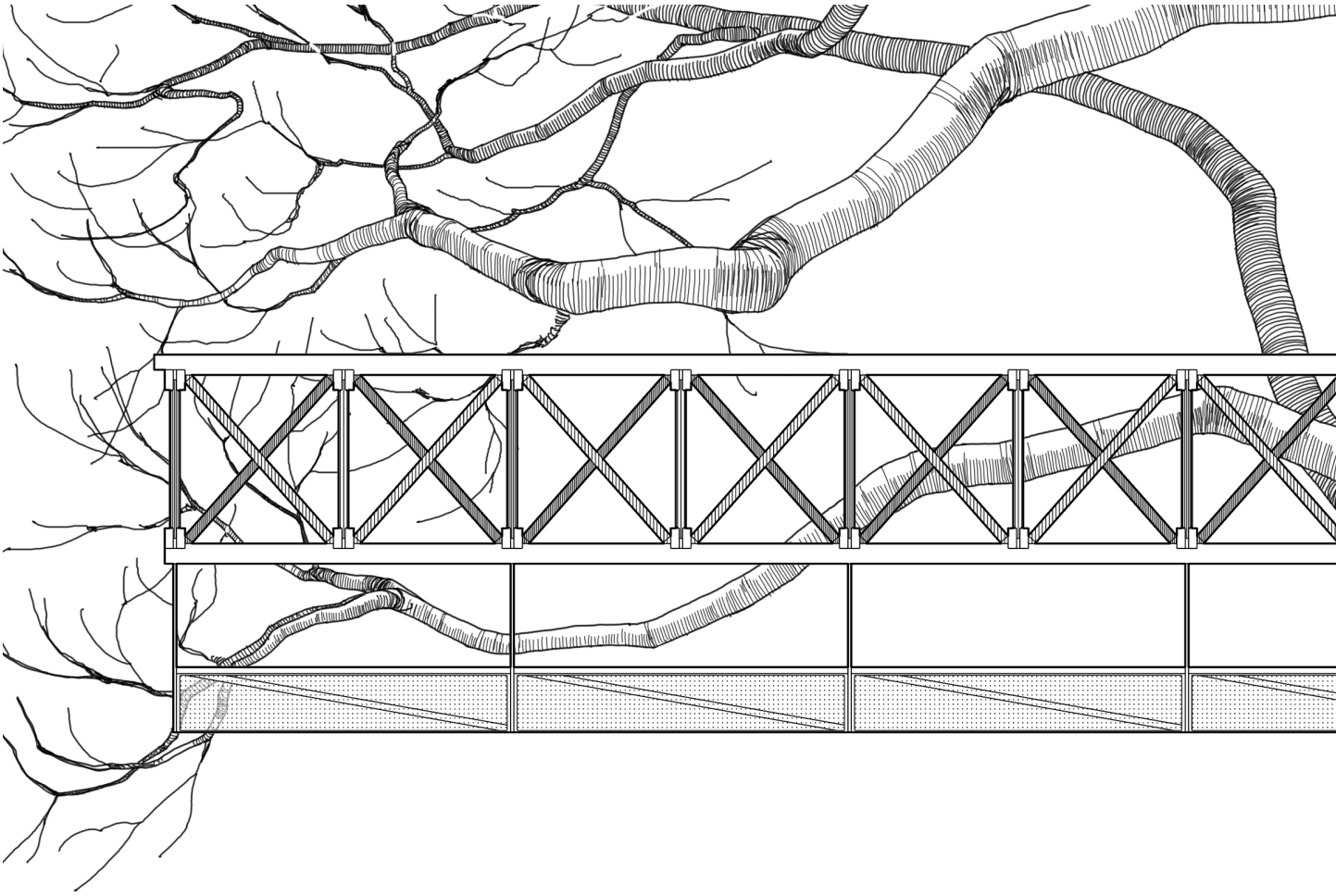
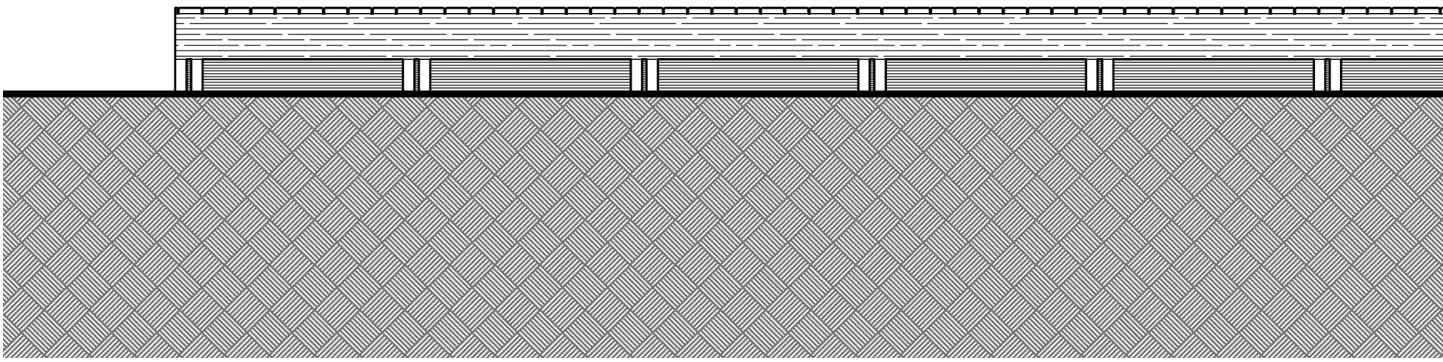


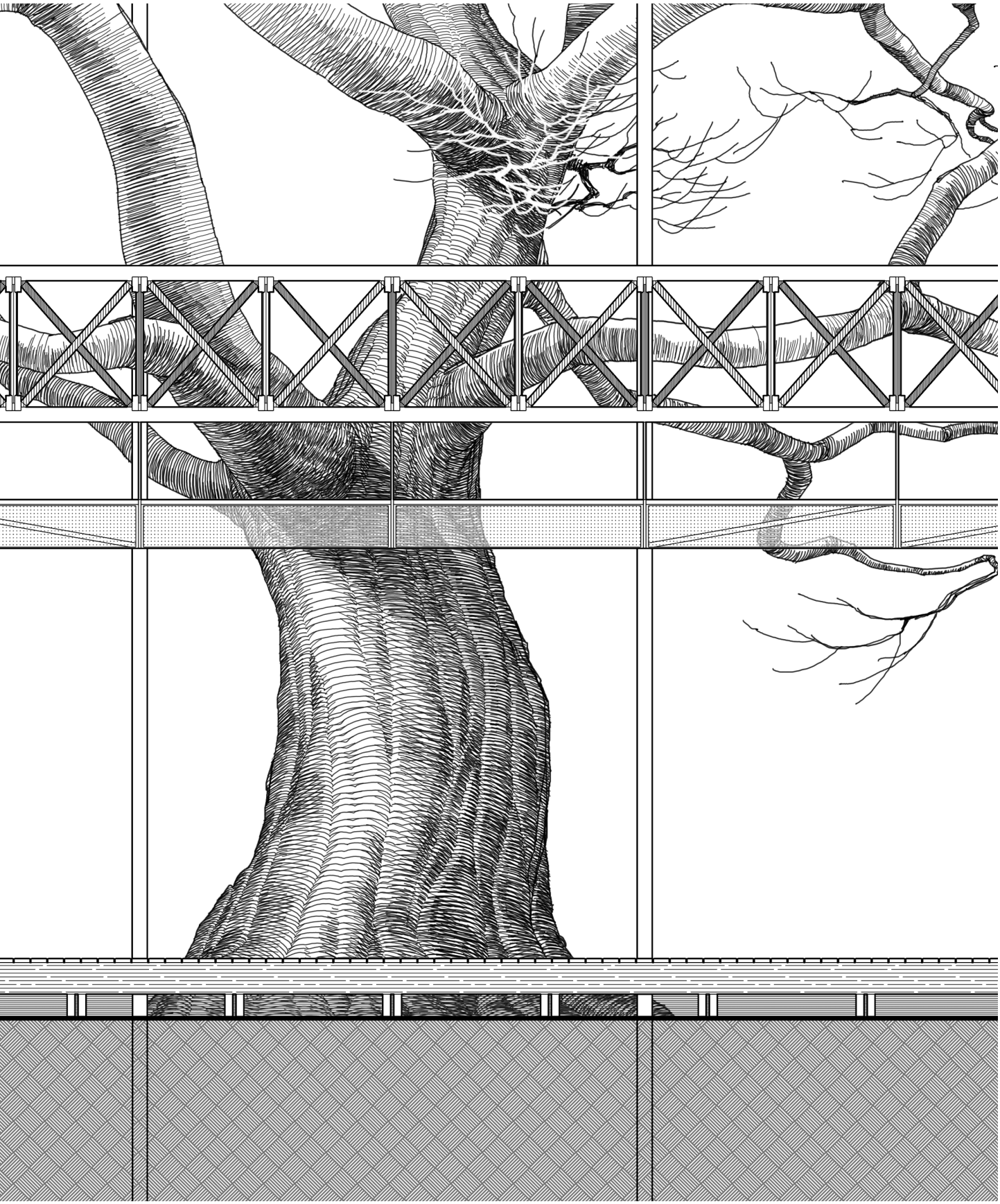
Fig. 5.9. Sketch of 2A

Fig. 5.10. Drawing 2 Elevation









5.3 Conclusion

This thesis investigated practices of tree shaping as a potential alternative construction method. Its many benefits in creating hybrid greenspaces, sustainable qualities, and visual pleasantry are worth continuing research, conducting studies, and spotlighting as a viable niche in architecture. Fundamentally, the benefits of trees in urban spaces are undisputed, but not always implemented or available. Arbortecture, including baubotanik architecture, is an opportunity to combine buildings with trees, a hybrid in material and function.

Through this document, existing research around tree shaping as building was reviewed from ancient historical examples to its conception from a desire for environmental sustainability and the fascination with land art. Investigations of techniques in gardening, agriculture, and bonsai gave context for the craft of tree shaping and its mutually aligned skills from these various disciplines. It takes all these influences and inferences to better understand tree shaping's role in the practice of arbortecture. With the introduction of the modern study of baubotanik architecture, the thesis gives insight to the realistic potential of arbortecture and its real-world practice as an academic study. By learning from the works of pioneer artists in tree shaping and case studies of many structures created over time by visionaries, more informed views of arbortecture's abilities and limitations are established.

Alongside theory and history, this thesis also conducts experiments in attempt to put into practice skills defined in baubotanik, arbortecture, arborsculpture, horticulture, and bonsai. Multiple simple connection designs are sketched and proposed as small-scale experiments using plants to demonstrate the practical techniques in disciplines around tree shaping. Two sets of experiments with many iterations were proposed and documented. While series 1 followed the progress of repotting and conducting on mass-produced decorative willow plants, series 2 used native black willow cuttings as experiment material. The goals of these studies were to document samples of real-world practice and learn from their successes and failures to inform potential full-scale projects.

The experiments act as an exercise of horticultural design, where the process is heavier than the final product. Through these sets of experiments, a better understanding of botany, bonsai, and trees are appreciated.

Informed from the experiments, three conceptual drawings are produced as designs for theoretical structures. They aim to show spatiality, and the important aspects of change found in arbortecture. Combining digital drafting and hand rendering, these drawings are hybrid in nature and further engage with the idea of living tree architecture as buildings that can truly exist in our urban spaces.

In this research, Arbortecture and baubotanik are positioned as a reasonable reaction to the growing need for better infrastructure, green spaces, and sustainable construction, though it is not a primary resolution to the crises faced in cities. While this thesis reviews a lot of benefits to tree shaping in architecture, it is not a perfect construction method. Like almost any alternative solution, it is inherently attached to its own obstacles.

Learning from past research and being informed by the experiments conducted, many obstacles stand in the way of arbortecture as a common practice. Time being a main barrier as the method of construction is primarily reliant on a process that cannot be expedited. For example, many of Konstantin Kirsch's structures from the 1990's at *Waldgartendorf* are still in progress even three

decades after the start of their construction[2]. In many large infrastructural and critical applications, construction simply cannot take multiple decades to become functional. This directly limits the use of arbortecture and baubotanik methods to novelty buildings, public structures, or secondary architectural elements which do not impede the function of the building. Another obstacle lies in the material's inherent reliability. A living plant requires many conditions to be met to maintain good health and to grow expectedly, diligent upkeep is not always possible, and growth failures will occur with limited degrees of oversight. Plants often die for reasons beyond control, and sometimes it takes many years. Even in the Baubotanik Footbridge by Office for Living Architecture (OLA), many plants from the willow bundles were replaced 12 years after construction as many original willows had started to fail from overcrowding and structural overload[3]. Learning from examples like this, the most reliable application of living plants are components designed with replaceability. A further problem for arbortecture is precision. Structural precision is critical for the safety and construction of buildings. When integrating living trees, the construction must account for large amounts of error and built-in adaptability for the physical growth of trees. Even with accurate estimations of tree size and diameter through botany, external factors especially applied in hybrid construction will affect expected plant growth. This makes the use of arbortecture in highly precise environments and absolute alignments difficult. Finally, both a benefit and drawback of living tree architecture is its localization. Different tree species are geographically confined to certain regions. For example, the Baubotanik Tower by OLA had its original willow trees replaced with a better adapted species of swamp birch after eight years as the willows did not grow as rigorously in that environment[4]. Not all species will be successful in different locations, while some may be invasive causing more environmental harm. It is difficult to create one generalized arbortecture handbook for global construction reference. Nonetheless, because of the regional nature of trees, arbortecture projects can be highly characteristic and unique to its settings. The same base structure built with different species of trees can be iconic and distinct, developing regional identity through architecture.

2 "Waldgartendorf," accessed November 1, 2024, https://www.naturbauten.org/waldgartendorf.html.

3 "Baubotanik Footbridge · OLA Office for Living Architecture," accessed November 1, 2024, https://www.o-l-a.eu/project/baubotanischer-steg/.

4 "Baubotanik Tower · OLA Office for Living Architecture," accessed April 17, 2023, https://www.o-l-a.eu/project/baubotanischer-turm/.

Despite its drawbacks, there are niche applications that arbortecture could thrive in. In the current state of the discipline, it is useful in public spaces such as pavillions, bus shelters, footpaths, canopies, greenhouses, lookouts, tunnels, and installations. As OLA suggests, it has high potential as living walls, skins, facades, and envelopes in residential, institutional, and public architectural applications[5]. This is also ongoing research that OLA and University of Stuttgart is continually conducting[6].

Many of Ferdinand Ludwig's work with the Baubotanik Group and OLA took upwards of 10 years to reach completion, while many more are still ongoing. Comparatively, pieces of architecture at similar scales could be completed within months. In the end, baubotanik and arbortecture are a timely, imprecise, and somewhat unreliable processes to redesign simple connections that logistically make more sense being fulfilled with materials already manufactured. However, by reframing design strategy, these factors can be harnessed and effectively used as features of design emphasizing patience, adaptability, and naturalistic beauty. The study of arbortecture should be seen as a theory of architecture, capable of reframing the element of time. In modernity, architecture has become an object to be presented, its beauty found in austere completion. From design magazines to developer renders in marketing material, to the high-rise condos and vacation homes themselves, it has become a surface level view of the built environment. Arbortecture is presented as an idea on how beauty and purpose in architecture is related to how we recognize beauty in the natural landscapes changing with seasons, the patina of copper and leather, and even the wilted sunflower paintings by Vincent van Gogh. They capture fleeting moments defined by their process, slowing down the need for quick and instant results. Perhaps the central goal of living tree construction is to abolish the idea of architecture as a consumable capital product. Instead, this thesis proposes a reframing of architecture as a highly involved, endearing, and meaningful process to both the designer and the occupant, while being intrinsically connected with time. Buildings could be akin to gardens capable of flourish, change, and death.

5 Ferdinand Ludwig, Daniel Schönle, and Sonja Duempelmann, Growing Architecture: How to Design and Build with Trees (Basel: Birkhäuser, 2023), 198–208.

6 Ludwig, Schönle, and Duempelmann, 198–208.

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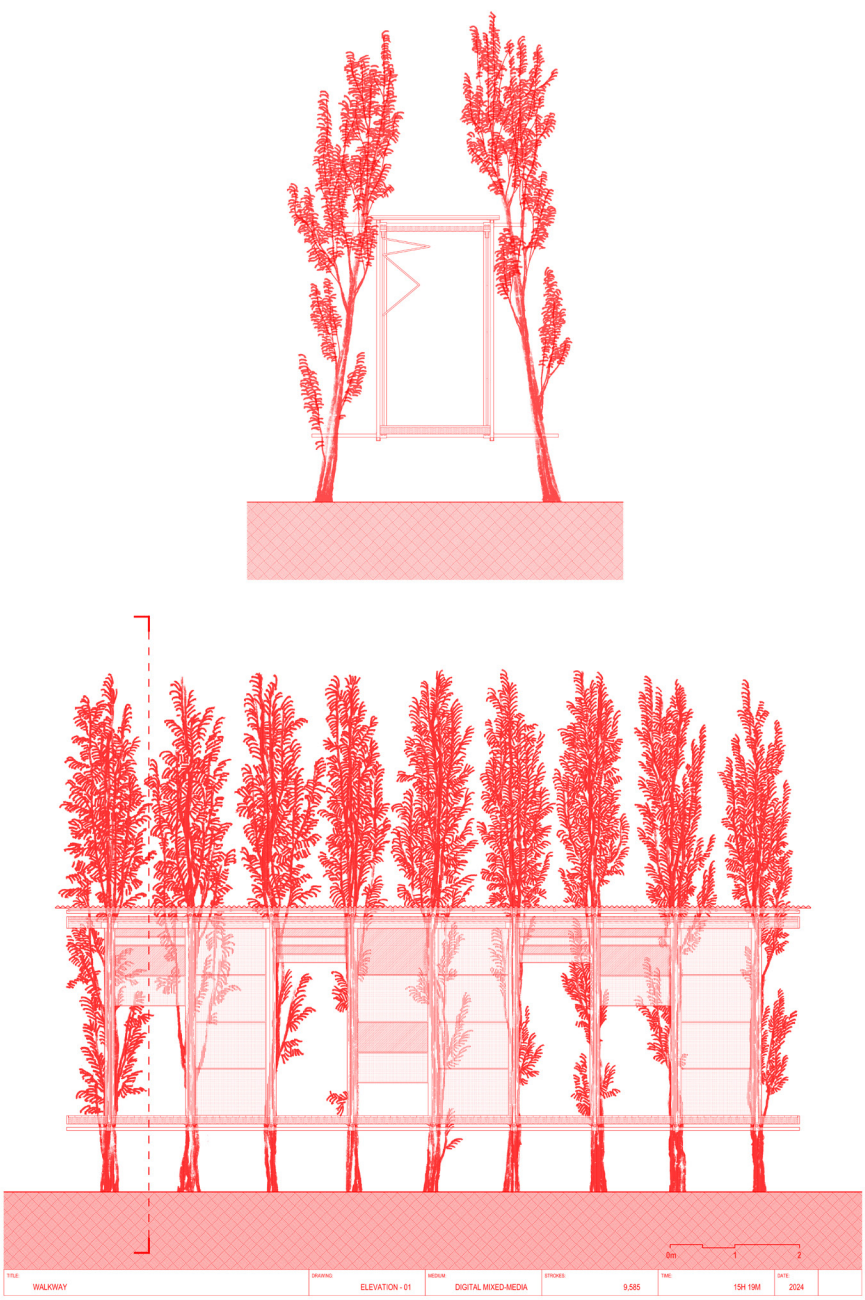
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Appendix


0m
1
2
TITLE
WALKWAY
DRAWING
ELEVATION - 01
MEDIUM
DIGITAL MIXED-MEDIA
STROKES
9,585
TIME
15H 19M
DATE
2024

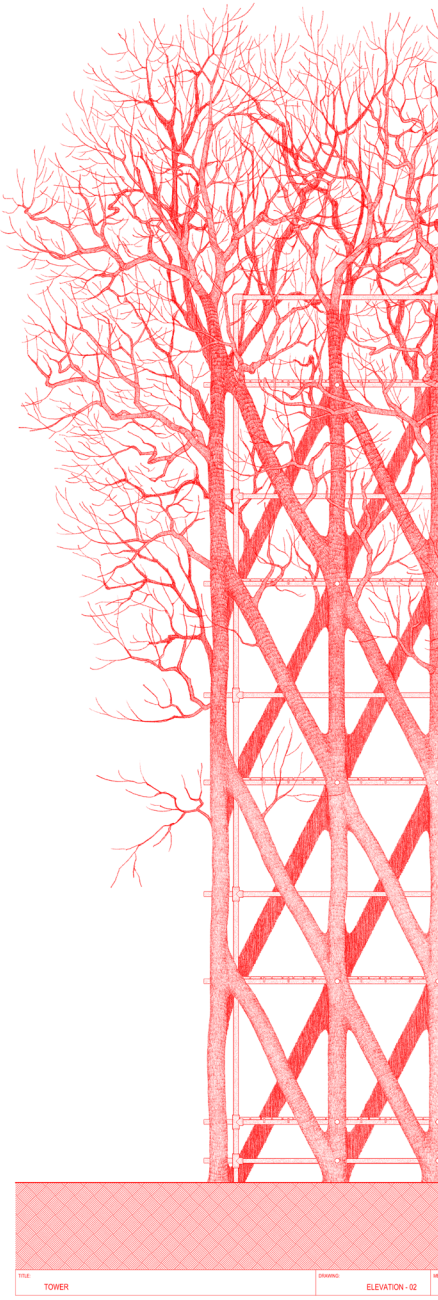
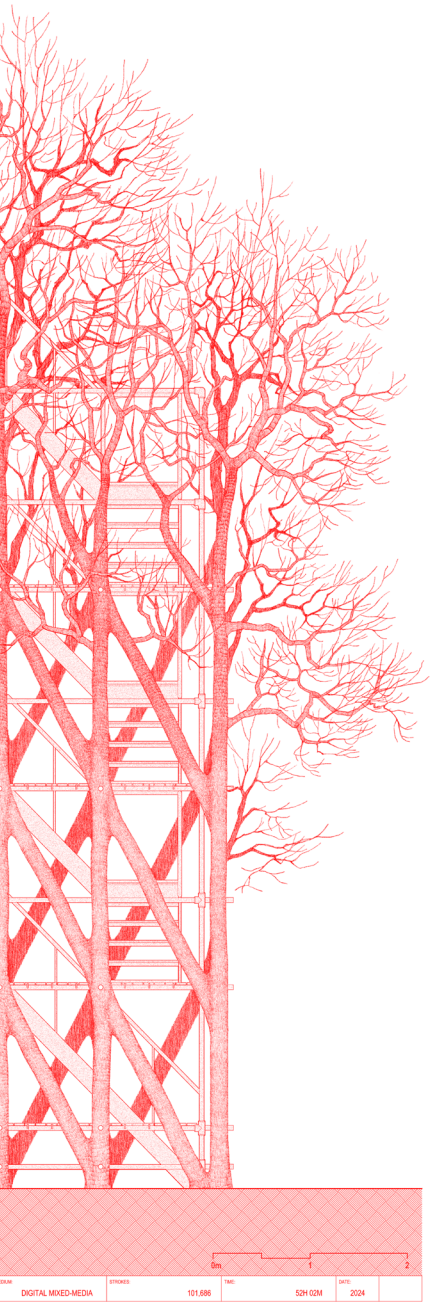

TITLE
TOWER
DRAWING
ELEVATION - 02

Fig. 6.1. Set of three final aspirational drawings printed for thesis defence







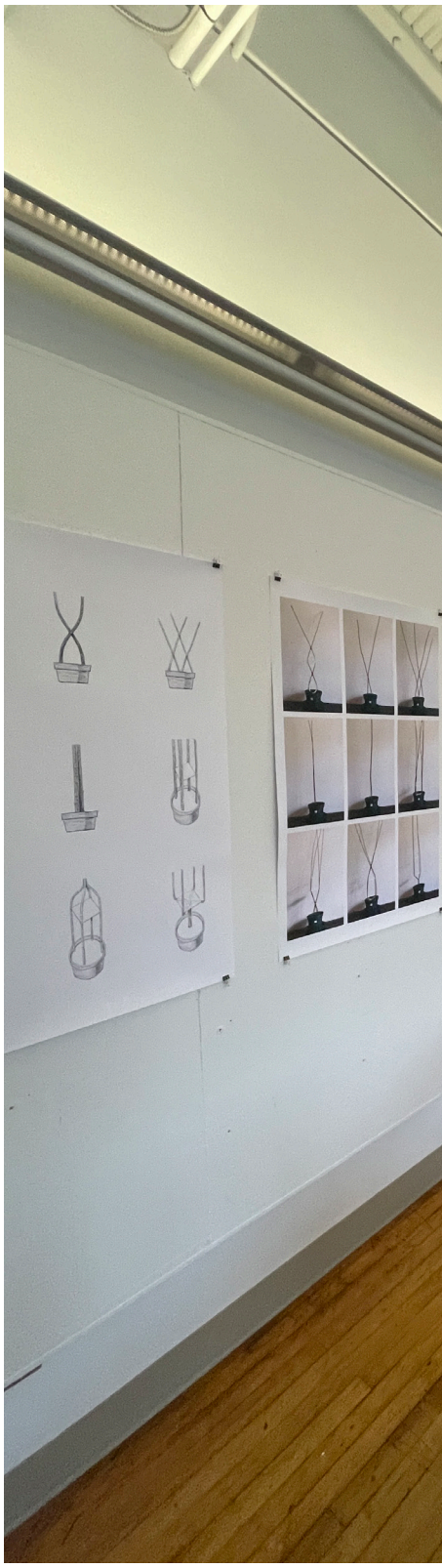






Fig. 6.2. Photographs documenting some work displayed at thesis defence



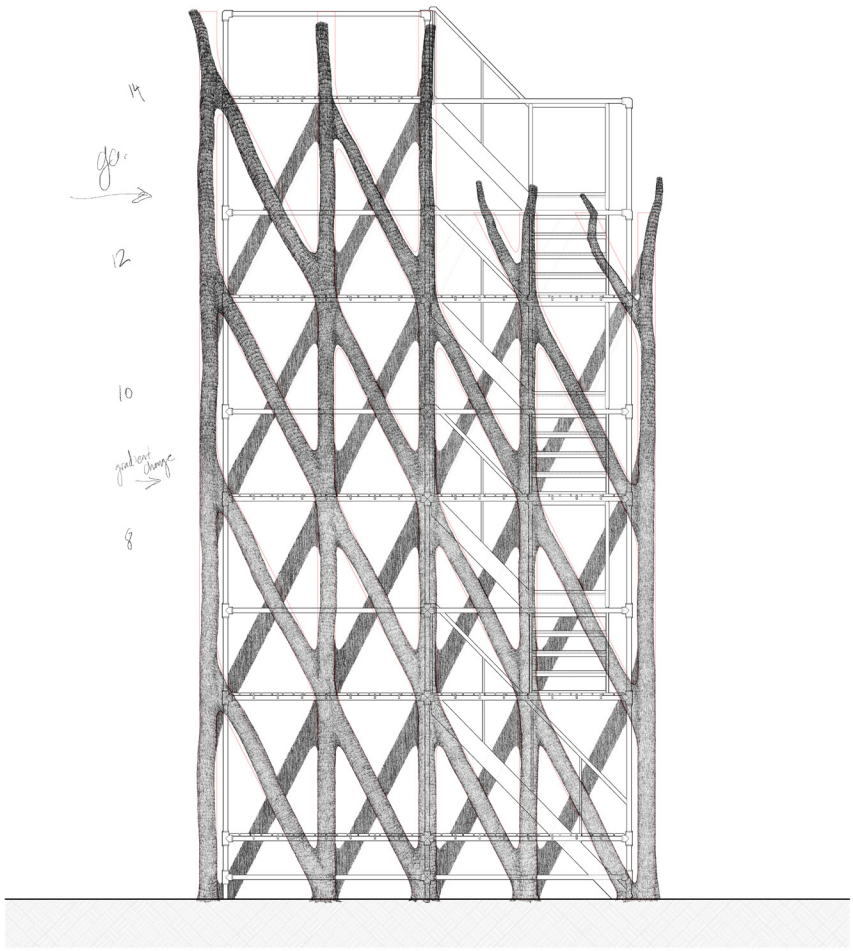


Fig. 6.3. Photographs of process work fixing broken walnut frames to display drawings



Fig. 6.4. Photograph of some artifacts displayed at thesis defence




14
12
10
gradient change
8

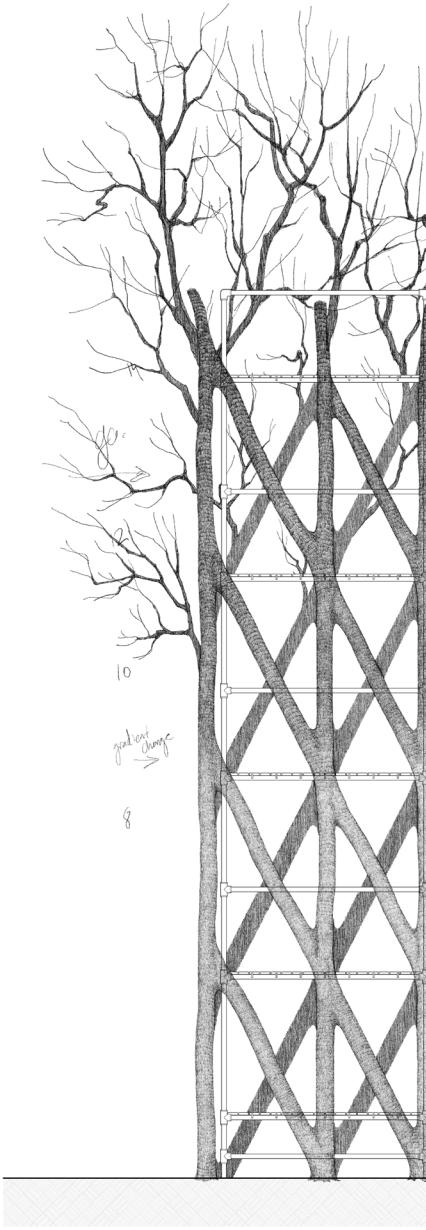
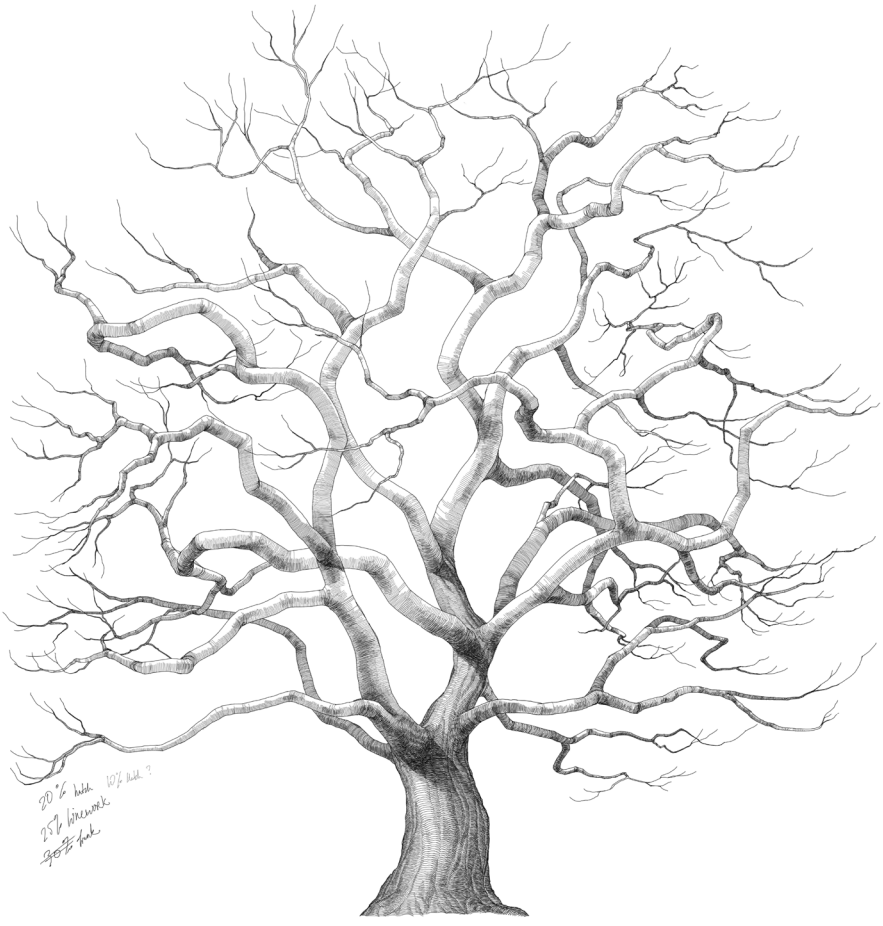
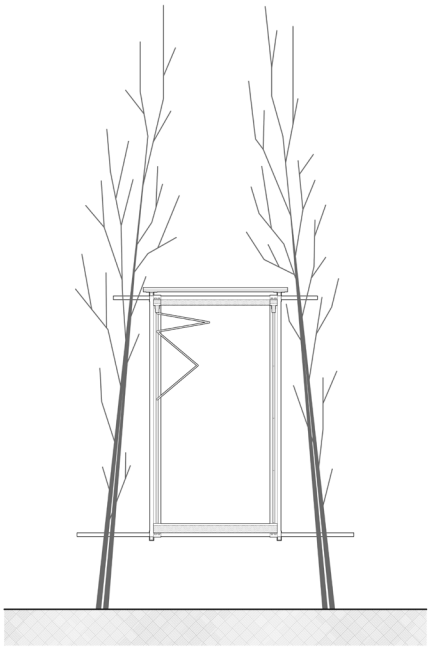
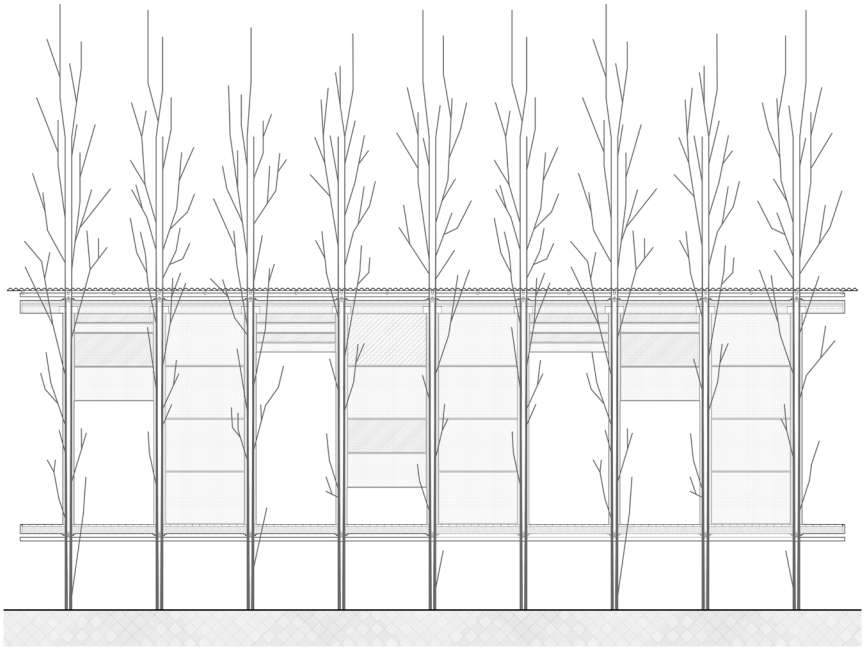

14
12
10
gradient change
8

Fig. 6.5. Work in progress stages of two final drawings









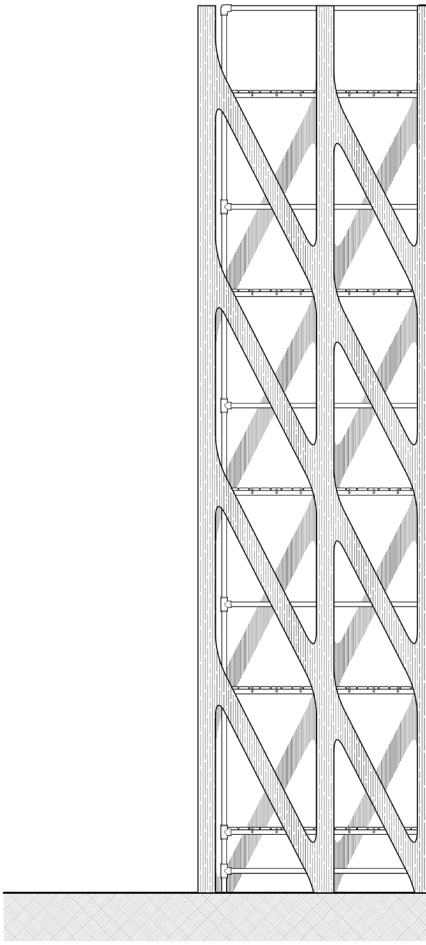
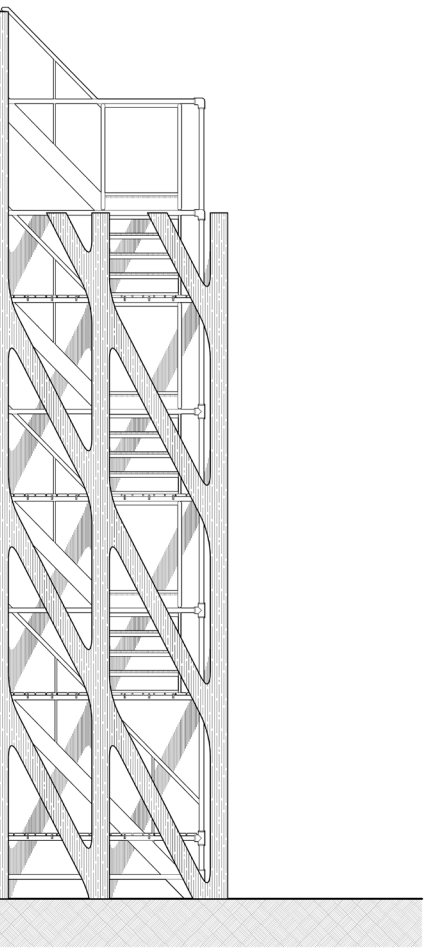
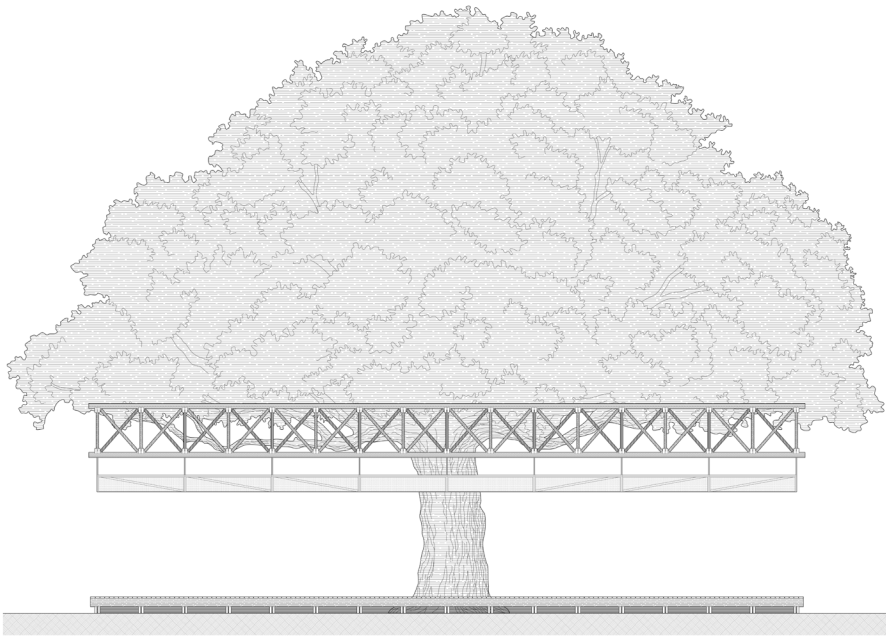


Fig. 6.6. Early drafts of the three final drawings as exported from CAD software





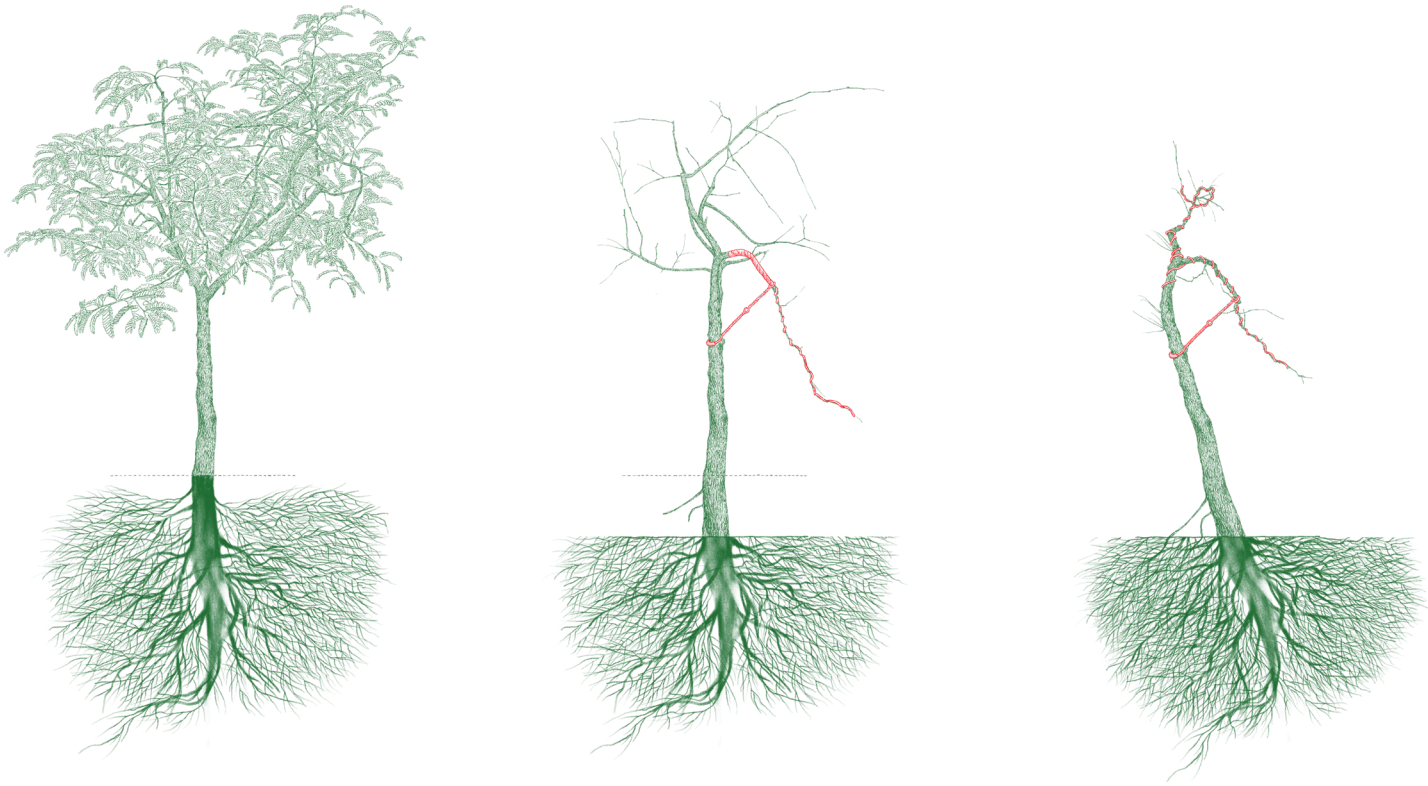
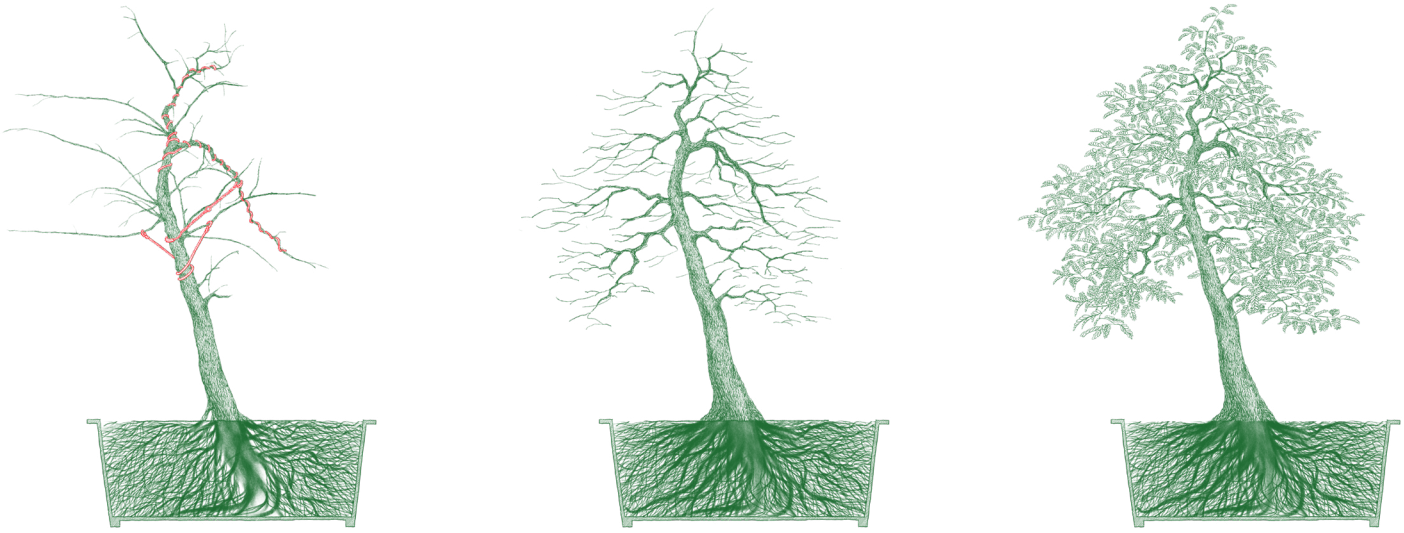


Fig. 6.7. Series of tamarind bonsai progress illustrations including the root system



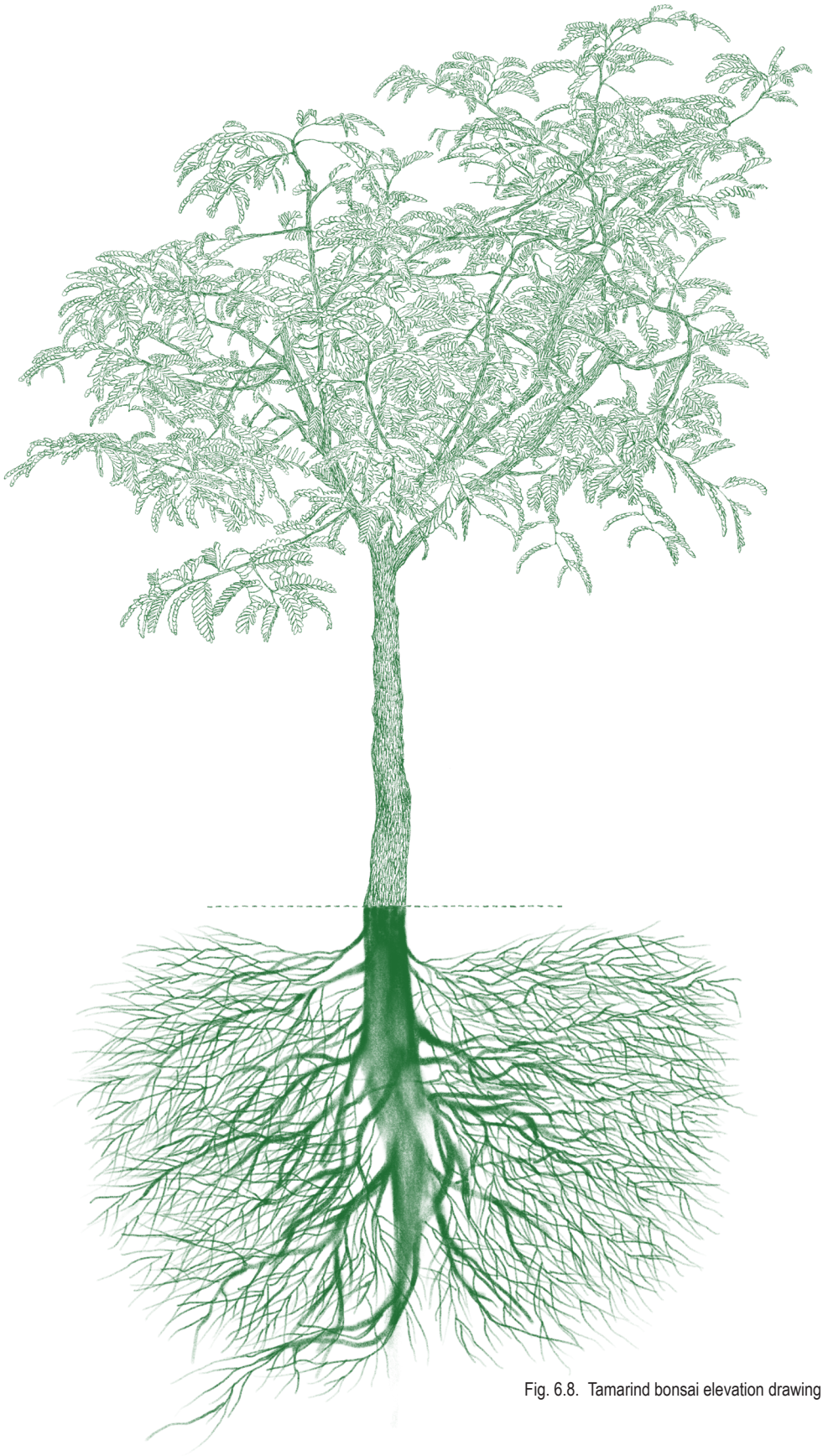


Fig. 6.8. Tamarind bonsai elevation drawing initial stage

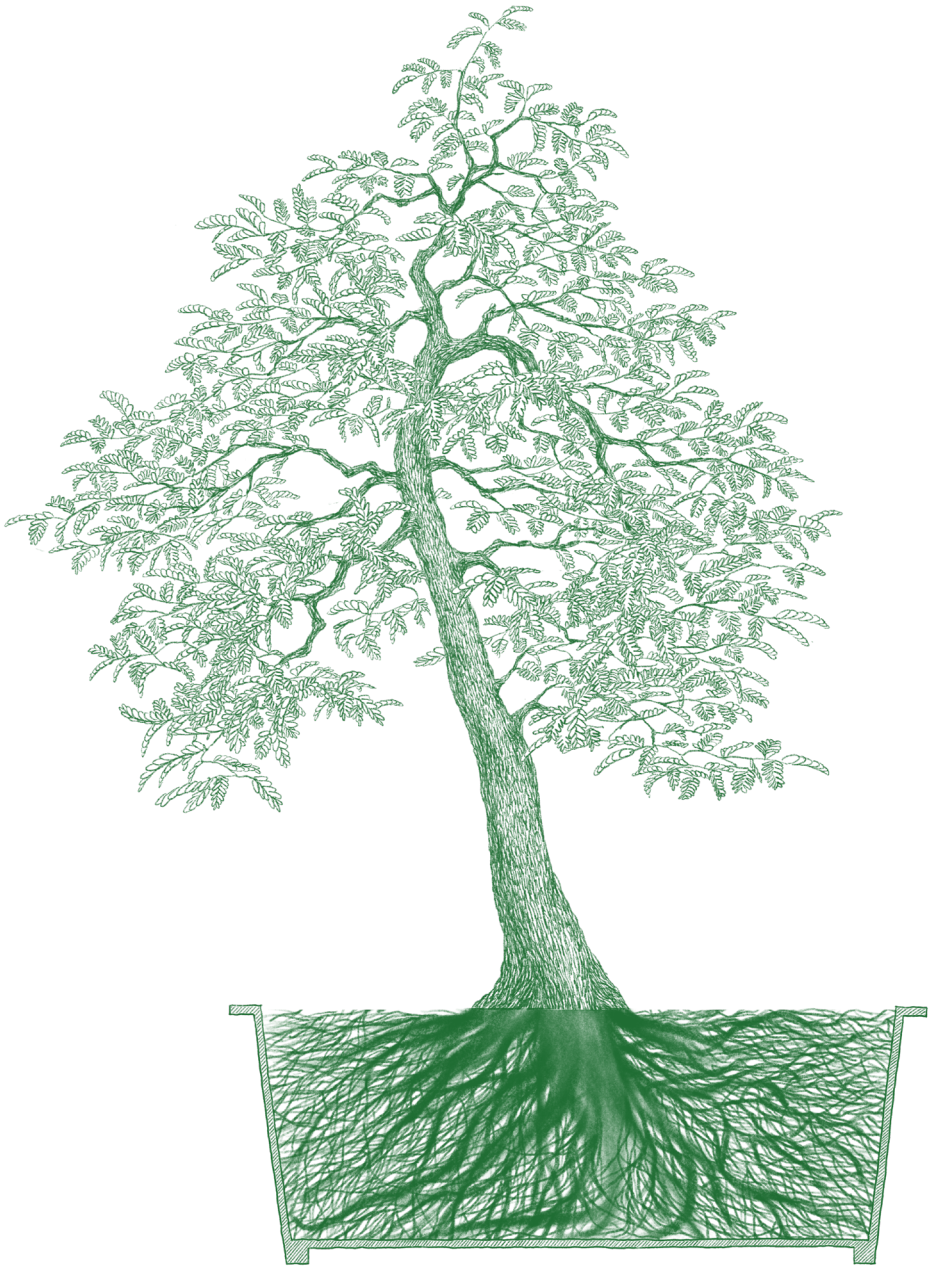


Fig. 6.9. Tamarind bonsai elevation drawing imagined end stage