Cultivation, Computation, and the Morphological Intelligence of Plants: Deepening the Human-Botanical Relationship in the Landscape

James Barnes[1], Audrey Barnes[2]

[1]The University of Virginia, Charlottesville/USA · jb2nf@virginia.edu
[2]James Madison University, Harrisonburg/USA

Abstract: Plants demonstrate intelligence, albeit a non-zoological form. Advances in digital and physical computing technologies provide new avenues for developing a deeper engagement with this intelligence – an ideal space for the digital landscape architect. Morphology is both a fundamental expression of plant behavior and an important element of landscape architecture practice, providing a unique dialogistic medium. Cultivation, a practice historically associated within the discipline, could theoretically be renewed to this end: a Computational Cultivation. This paper seeks to frame this poorly defined area and identifies challenges and opportunities for research and application. A series of case studies that intersect digital technologies, traditional cultivation practices, and morphological behavior are explored. From these, a synthesis of possibilities, both applied and philosophical are constructed.

Keywords: Plant intelligence, morphology, planting design, landscape maintenance, computational cultivation

1 Introduction

In 2003, plant scientist Anthony Trewavas proposed that plants are intelligent beings capable of learning, complex behaviors, and communication (TREWAVAS 2003). A controversial statement at the time, yet our understanding of plant biology has evolved since then, and a growing body of research supports the notion that they are more than stationary, lower lifeforms unaware of their environmental context. For example, trees have been shown to communicate between each other via mycelia networks (SIMARD 2018) and some plants modify their physical behavior based on prior experience (GAGLIANO et al. 2014). Intelligence, for this paper, is broadly defined as the ability to change behavior based on experience and it considers morphology an expression of intelligence. It is important to note that these perceived breakthroughs by modern science affirm what many indigenous cultures with animistic worldviews already believe about the plant world (HALL 2011). While still a matter of debate (TAIZ et al. 2019, CALVO et al. 2020) – plants do demonstrate their own metaphorical wisdom as they interact with the world. Perhaps thinking of plants as intelligent beings is the more rational, spiritual, and sustainable perspective.

What is the significance to the field of landscape architecture? Foremost, the discipline provides unique perspectives and toolsets for bridging the communication divide between humans and the botanical world. Landscape architecture as a practice originated from cultivation – the designing and tending of plants (GIROT 2016). Typically embedded in cultivation is a close attunement to plant behavior. Today, digital-physical approaches now provide new pathways for plant cultivation and associated "attunement" by 1) modeling behavior, 2) compressing time, and 3) scaling intervention. The potential of this research space is examined through morphological case studies that collectively represent a hybridity of computation

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advances and cultivation techniques – a *Computational Cultivation.* Collectively, these case studies explore the question: how can digital landscape architecture intersect with plant growth and morphology, and what could the role of human/plant intelligence interaction be?

In other words, plant intelligence and plant utilitarianism are considered on equal footing. This dual approach should theoretically provide more significant practical and philosophical implications. First, by situating the inquiry in inherent plant intelligence it provides a more even ontological terrain for dialogue. What could plants teach us about their sense of time, entropy, and uncertainty, among other things? Secondly, the intelligence of plants provides a theoretical grounding (or perhaps counterpoint) for the exploration and application of artificial intelligence to landscape architecture, which Cantrell and Zhang propose is itself not fully realized theoretically (CANTRELL & ZHANG 2018). Finally, from an application perspective, thickening the relationship between designer and plant intelligence should ultimately produce new creative possibilities and efficiencies in planting design and stewardship. Julian Raxworthy proposed that reconnecting the discipline with cultivation could creatively invigorate the field (RAXWORTHY 2019), as novelty may emerge from the maintenance of planting designs. How this might manifest with digital-physical hybridity is an open question, but Internet of Things (IOT)-infused responsive technologies (CANTRELL & HOLZMAN 2015) that sense, actuate, and model plant behavior at landscape scales is one possibility. Versions of this future already exist in "smart farming" production landscapes via drones, robotic fruit pickers, etc., albeit in a highly utilitarianism context (CHRISTIAENSEN et al. 2021). These systems, while technically informative, do not typically privilege plant ontology and are not the focus of this paper.

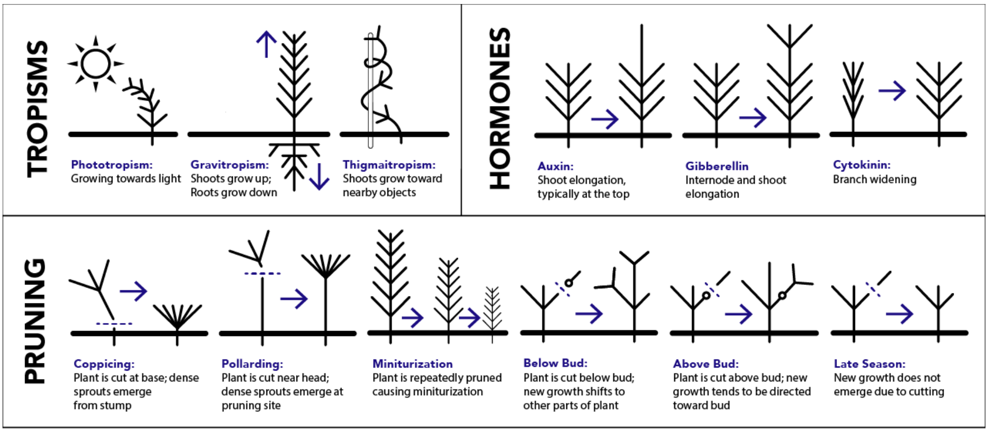

Fig. 1: Typology of Plant Growth Interaction Factors

Plant have developed a suite of unique behaviors to grow towards resources, avoid predation, and reproduce (Fig. 1). Plant forms speak to the responsive, pattern-generating, problem-solving behavior in plants, in other words, morphology an expression intelligence. Human intelligence has long taken advantage of these behaviors for cultivation purposes. In particular, the shaping of plant growth into desired forms has evolved in multiple unique contexts across the globe (Fig. 2) and provides a strong starting position. Traditional techniques in pruning and training woody plants such as espalier and bonsai demonstrate one of the highest aesthetics of this type of plant-human relationship; a technical and interactive relationship develops between humans and plants – one that might span multiple human generations. These authors argue that this morphological interaction of human-plant intelligences represents a conversation, if an unhurried one.

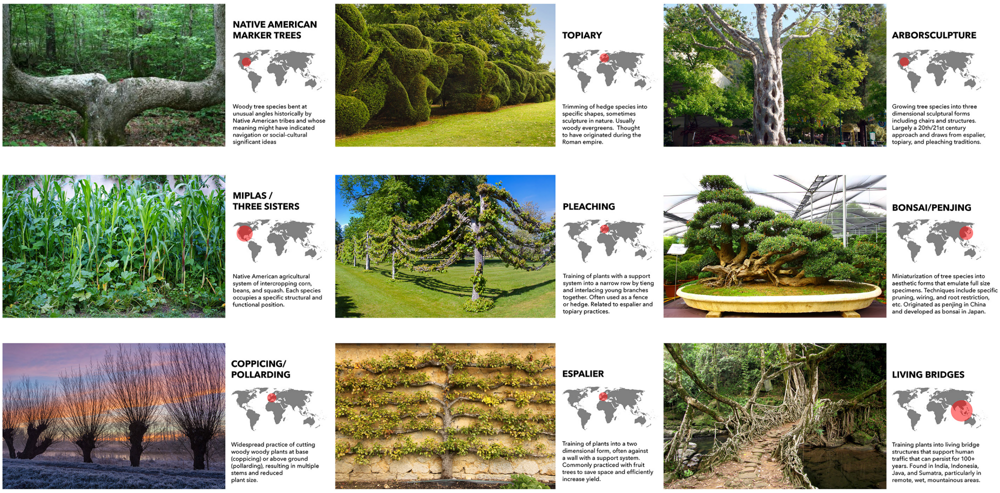

Fig. 2: Global Morphological Cultivation Precedents (All sub-images public domain)

Extending this conversation with plant morphology through novel ways is a logical entry point for the digital landscape architect. Just as some in architecture have engaged digital materiality and fabrication in ever greater technical depths (BEORKREM 2017), landscape architecture could chart a similar course, with an emphasis on the field's own dynamic, living medium. Procedural models including Lindenmeyer's L-Systems are perhaps the most familiar and developed tool for designers in this space (PRUSINKIEWICZ et al. 1990) and are useful in representing models of plant form and growth through recursive rules but represent only one approach. Parallel developments in the plant sciences including Functional-Structural Plant Models (FSPM), but focus on production landscape contexts (VOS et al. 2010). Sophisticated digital-physical investigations of plant behavior, situated in design and explored among a range of species is needed for more meaningful application.

2 Methods

Recognizing that the nexus of plant morphology, cultivation, and computation in the design realm is poorly defined, the authors conducted an extensive literature review of related research papers as a starting point of inquiry. This included the fields of landscape architecture, architecture, agricultural and horticultural sciences, robotics, engineering, and industrial design. Research that did not explicitly consider morphology were excluded. Among the few qualifying papers found, peer-reviewed case studies were selected. An effort was made to select papers with divergent approaches, focal species, and spatial scales, and that considered plant-human intelligence engagement explicitly or implicitly. (Table 1). All projects are situated in a speculative frame. From these case studies, common ideas and directions are synthesized and presented in the discussion section.

Table 1: Selected Case Studies in Computational Cultivation of Plant Morphology

Project	Goal	Species Focus	Plant Behavior/ Human Interaction	Computational Component
Flora robotica	Self-repairing and organizing trellis	Vines	Phototropism	Sensors, LEDs, AI
Baubotanik	Structural living architecture	Trees	Grafting/inosculation	Simulation and modeling
TrimBot 2020	Automated hedge trimming	Hedges	Pruning	AI, sensors, robotics, photo-grammetry

3 Case Studies

3.1 Flora Robotica

Flora robotica was a consortium initiative to "develop and investigate closely linked symbiotic relationships between robots and natural plants and to explore the potentials of a plant-robot society able to produce architectural artifacts and living spaces" (Hamann et al. 2017). A series of experiments and installations in this space were produced spanning a range of approaches. Most notable for this paper is their robotic node trellis system (Fig 3), which focuses on phototropism as a manipulatable design element (Wahby et al. 2018). Tropisms – plants growing to or away from an environmental cue – are the most dominate growth behaviors that plant exhibit. Among these, phototropism and gravitropism are fundamental as they direct plant orientation to the light and ground.

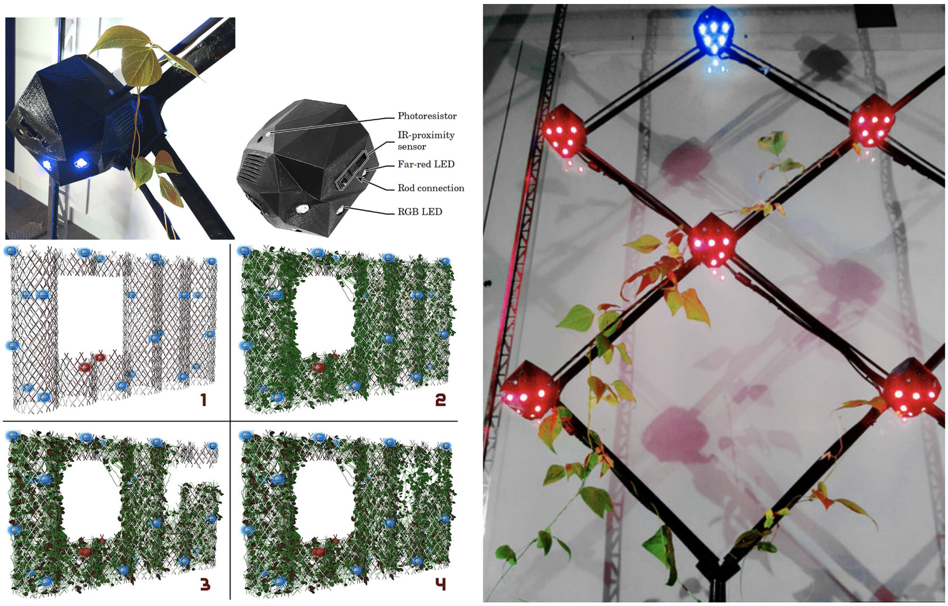

Fig. 3: (Clockwise L-R): Robotic node components; Plant trellis guidance; Self-repairing trellis concept (images: Wahby et al. 2018)

The robotic node project investigated how a vining plant (common bean; *Phaseolous vulgaris)* responded to variable light as a growing stimulus. A series of light emitting IoT devices were attached to a trellis at junction points. Red wavelength light is shown at baseline, while blue wavelength is used as an attractor (plants tropisms prefer blue light). IR Proximity sensors in the nodes detect plant growth tips within 5 cm. Experiments "demonstrate the ability of the nodes to shape climbing bean plants, steering the plants' binary decisions about growth directions as they navigate".

While experimental at this stage, the application goal would be trellis systems that self-organize and self-repair based on different environmental and plant conditions, as well as algorithmic control of the nodes. Vining plants provide a fast-growing case study, but conceptually the model could work for woody species. An eventual system might significantly reduce plant maintenance labor compared to traditional techniques. HAMANN et al. (2017) state that this system provides a one-way system of interaction between robot and plant, and thus is not a true biohybrid. To achieve this would require plants signaling to the robot node when to change wavelengths, etc. The researchers are exploring electro-physiological means for plant communication in future work. However, when considering growth response as a type of morphological communication, the interaction could be considered two-way; plants "signal" to the human/system by changes in their growth.

3.2 Baubotanik

Baubotanik, German for "Building Botany" is a living architecture system developed by Ferdinand Ludwig (LUDWIG 2016). The initiative's goal is to develop a system of living structures in cities using trees as load bearing components (Fig 4). This approach draws inspiration from the living bridges of Southeast Asia where *Ficus elastica* plants are grown together across ravines into the form of foot bridges, capable of withstanding repeated human traffic. These bridges take decades to form and persists for potentially centuries, becoming stronger as the plants continue to merge (LUDWIG et al. 2019). Fundamental to Baubotanik and these other examples is grafting (or inosculation) – joining living plants with other plants, or human-made components (Fig. 4). Detailed analysis of grafting, including species comparisons, angles of graft, growth rates, load-strength, etc. were conducted via plant simulation and growth experiments (LUDWIG 2012). A series of 1:1 scale installations have been built/grown over several years including footbridges, towers, and building facades. To accelerate the development of these structures, multiple levels of plants are grown and subsequently grafted from top to bottom, effectively creating a taller system of plants more rapidly.

From this research, numerous insights have been assembled about the architectural potential and limits of trees. For example, the first installation, a footbridge, contained diagonal trees for supports. These did not survive over time, perhaps due to graviomorphic deflection – when plant growth is forced from its naturally direction (typically upwards), growth tends to slow, and senescence may occur. Ludwig states: "if living trees are the subject matter of architectural design and construction, then the basic patterns and conditions of plant growth have to be recognized as essential design parameters." Another realization is that self-thinning (i. e., death) will occur, particularly as plants grow and some are outcompeted for resources. Embedded within this observation is emergence and uncertainty, driven in part by the unpredictable interactions of plants and their environments.

Fig. 4: (Clockwise L-R): Metal/plant grafting over time; "Plane Tree Cube" Building and future; Tower growth overtime, Modeling of tower growth

3.3 TrimBot2020

TrimBot2020 is an experimental project to develop an autonomous hedge trimming robot and associated metrics of performance (VAN MARREWIJK et al. 2022). Vegetation maintenance is a labor-intensive process and as a response, automated systems such as robotic mowers are becoming more common. The regular pruning maintenance of topiaries and hedges into desired forms represents an undeveloped area in this space. Compared to mowing contexts, topiaries are significantly more spatially complex forms. TrimBot2020 developed and tested a robotic trimmer in a real garden setting that could create spherical, cylindrical, and cuboid shaped topiaries (Fig 5). A Robot Operating System (ROS) FlexBE state machine was mounted on a Bosch Indego robotic lawnmower with RGB cameras providing machine vision input of topiaries that were matched to spatial form databases. Trimbot efficacy was measure via point cloud photogrammetry analysis and human examination. The system was able to achieve up to 60% efficiency. While not high enough performance for application, the project demonstrates the first known attempt at robotic hedge trimming. Among the three case studies, the TrimBot represents the most artificial intelligence-centric interaction; humans set the conditions and observe performance but are not active participants in the process. This interaction is largely one-way, driven by the robot's form database.

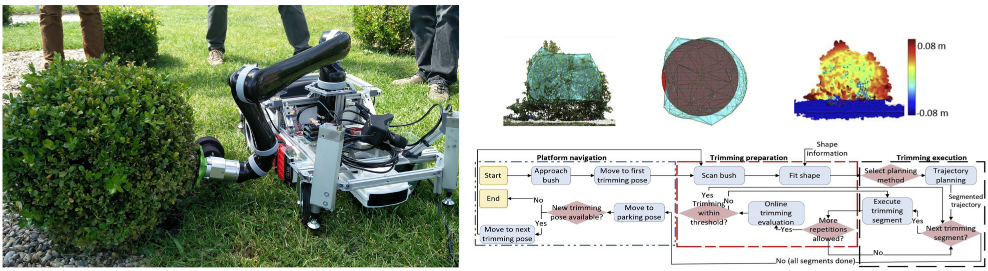

Fig. 5: TrimBot 2020; Spatial analysis of topiary form; AI decision tree

4 Discussion

These case studies provide three distinct examples of human-plant-digital interaction, steps towards a computational cultivation perspective. Collectively, the following insights are gleaned. Foremost, plant intelligence as a construct is not clearly articulated in any of the selected papers, although it forms an undercurrent theme: the dialogistic process of morphological engagement between human and plant. For all papers, who controls this dialogue, including its parameters and outcomes, was largely defined by humans. This one directional control may preclude a deeper consideration of intelligence. Future research where desired outcomes are not solely anthropocentric should produce more substantial insight. How this could play out in the real world where aesthetic and performance goals matter is unclear.

Secondly, intelligence is closely tied to the ability to communicate. Developing new processes of conversing with plants beyond morphological response is a space for further development. *Flora robotica*'s suggestion of electro-physiological communication provides one speculative possibility. Mechanisms to compress growth and time are also likely need to expedite communication, such as Baubotanik's multi-story grafting technique. Other technical ways could be pursued from a landscape frame. The role of artificial intelligence in developing means of communication remains an area for deeper elucidation. Moreover, as AI continues to influence discourse, positioning plants as intelligent agents provides a non-humanistic, non-digital frame. A triple hybridity between human, artificial, and botanical intelligence in the landscape, with the latter forming the lodestar of this relationship, seems a prudent theoretical and applied research direction.

Finally, it must be noted that few relevant research papers were found that fit the literature review goals, and all were from Northern Europe. This presents a significant knowledge gap in geography, species types, cultivation practice, and broader technological and cultural perspectives. For example, cultivation practices from Asia like bonsai and the Americas like the Three Sisters are fertile grounds for exploration. Embedded in then are different ontological worldviews on human relationships with plants and landscapes – critical cross-cultural knowledge to broaden perspective. Additionally, all case studies were single species. Multi-species investigations that capture the essence of landscape complexity would enrich the knowledge base.

5 Conclusion

The shared human-plant journey of cultivation, which began eons ago along with the origin of civilization, may be entering a new technological phase of evolution, captured by terms such as "precision agriculture", "smart farming", and "agriculture 4.0". In landscape architecture, it might possibly be entering a more dialectic phase. Plant morphology provides a logical shared space for extended conversation. Arguably, humans (including designers) have much to learn from the only complex organisms capable of photosynthesis on the planet. *Computational Cultivation* provides a means for interrogating this knowledge gap – and an ideal space for further research by the digital landscape architect.

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