Botanical design: exploring the application of parametric plants in furniture

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Abstract

Although far away, the pandemic of 2019 has given rise to many thoughts towards people's lifestyles and attitudes. More and more people are getting used to working and studying at home, which has given rise to many inspirations for the development of technology related to the lifestyle. Studies have previously demonstrated that incorporating botanical decorations into living scenes can benefit people's mental and physical health. There are also many artists and scientists on this basis to explore the integration of plants and machinery development, trying to use the characteristics of plants to achieve the purpose of convenient people's life. "Biophilia" advocates the human instinct to be close to the natural world and defines the innate emotional connection between humans and other living things as 'pro-life'.

By parametrically controlling the growth of plants to create furniture forms for people to use, this article tries to push the boundaries between living and non-living, natural and artificial, and computational and biological intelligence. The experimental method is adopted to precisely control the exposure of experimental plants to indoor environmental qualities such as water, sunlight, air movement, gravity, touch and media to produce tolerant porous shapes in their growth forms and then shape into furniture form. This has also been verified by previous studies that show the effectiveness and possibility of creating self-standing 3D structures by integrating computational design tools in designing with plant roots.

In addition, this case also combines knowledge from disciplines such as biology and materials science to parametrically predict trends in the survival of plants as intelligent organisms and to explore the use of plant ecosystems in the construction of man-made landscapes by presenting the possibility of plant roots as sustainable materials and transport carriers. Products created so far include chairs and tables using plant roots. The paper details the process of designing parametric plant furniture and the product's effect pictures. The second half of the paper highlights the potential implications of this design technique. At the end of the article, the research explores the future direction of parametric plant design, i.e. the use as furniture while preserving the natural properties of plant growth, thus creating a new ecological cycle in future use. Overall, this study has been carried out with important implications for biological, sustainable, and environmental design. In addition to the current research, which is mainly concerned with the simple planting of space, this study goes further and explores the plasticity of plants themselves as controllable biomorphs. With the current trend of sustainable design, it is also worth looking at how ecologically sustainable and circular living spaces can be constructed. Finally, this research will also enrich the diversity of human living spaces with tactile sensory and interactive properties that can be further developed and applied to the health and education sectors in the future, aiming to improve the well-being of the inhabitants.

Author keywords

Plant arts; biophilic design; parametrical design; sustainability; furniture design.

Introduction

Design practice is affected by a growing understanding of the ecological footprints caused by humans. In design practice, there is a growing understanding of the ecological footprint caused by humans (Sahoo & Sethi, 2021). With the increasing awareness of environmental pollution, searching for new materials and solutions has become a major trend in recent years. As a result, eco-design, or "sustainable product development", has come to the fore. Wimmer et al. (2010) define eco-design as an approach that takes into consideration the environmental impacts of products during their whole lifecycle. Design practices also vary in terms of their CO2 emission (Kim et al., 2013), energy efficiency (Favi et al., 2012), recycling (Gallagher et al., 2019) etc. In addition to the aspects listed above, other studies explore design from the perspective of the whole, with great attention now focusing on the "cradle to cradle" design framework, initially proposed in 2002 by architect William McDonough and chemist Michael Braungart. Representing a continuation of a sustainable approach that takes into consideration multiple forms of life and future generations, "cradle to cradle" design is a biomimetic way of designing products and systems that models human industry on nature's processes, where materials are viewed as nutrients circulating in healthy, safe metabolisms (McDonough & Braungart, 2017).

This research explores an awareness of sustainability that aims to push the research for new materials and solutions as a branch of botanical design. It is also an approach of "sustainable product development" (Wimmer, Lee, Kun-Mo & Po-

lak, 2010) designed to improve the environmental impacts and the quality of human life.

Even though some research exists, it is a new area and is still in its infancy. Especially research on parameterisation in plant design (Song et al., 2019). Thus, this research takes the approach—Growing Design (Camere & Karana, 2017; Ciuffi, 2013; Montalti, 2010) as the main concept, trying to take the growing materials from living organisms (plant roots) to achieve unique material functions, expressions and sustainable design solutions. In Growing Design, designers collaborate with biological organisms, guiding their growth and forging the conditions in which a material/product is created. Such a creative process may generate novel materials, exploring the range of properties by controlling the growth of the organism or by experimenting with different shape possibilities by directly growing materials into a desired product idea (Camere & Karana, 2017).

In early 2020, during the COVID pandemic lockdowns in many countries, the idea for this practice arose. Limited access to outdoor activities prompted a reevaluation of the relationship between humans and nature, and the potential for incorporating plants in furniture design. Given that plants have existed on Earth much longer than humans, this research explores the intersection of the two. Despite the pandemic's waning impact, mobility issues still prevent some, such as the elderly and disabled, from experiencing nature still common. Thus, this research results in the cultivation and design of furniture utilising the Bougainvillea glabra's roots as the primary focus for conducting furniture design. The current collection includes a chair and table. The research aims to contribute to a sustainable environmental design by offering unique insights into parametric design and plant growth control.

Theoretical basis

Sustainability and parametric approaches can be used together to create innovative and sustainable solutions. Inspired by the natural forms of plant roots and a desire to maintain organic shapes and patterns, this research seeks to create more intuitive and user-friendly products that feel more connected to the natural world. This offers a means of keeping the most original feel and inspiring the use of more sustainable materials and manufacturing processes, as natural systems often use minimal resources and generate little waste. Such considerations provided the initial inspiration for this research and its ultimate objectives.

Sustainable design focuses on reducing the environmental impact of products and spaces, considering the entire lifecycle of a product from its design to its disposal. This approach can include using sustainable materials, minimising waste and energy consumption during manufacturing and transportation, and designing products for disassembly and recycling. Sustainable design can also incorporate the principles of biomorphic and parametric design by optimising the use of materials and reducing the environmental impact of the design process. In this research, there are clear sustainable advantages to harnessing the environmentally friendly nature of plant roots, the low level of industrial intervention in the creation process, the natural form of the finished product, and the subsequent recycling, treatment, and reclamation.

The parametric design uses algorithms and digital tools to create complex, non-linear shapes that respond to specific design parameters, such as structural integrity, environmental conditions, or user preferences. This approach can help to create more efficient and optimised designs that use materials and resources more effectively. Parametric design can also be combined with biomorphic and sustainable design to optimise the use of materials and reduce the environmental impact of the design process. In this research, the main objectives are (1) to explore the reason of adopting parametric tech in design practice, (2) to achieve tailored plants, and (3) to explore their adoption in furniture design.

Together, these two design approaches can create sustainable, innovative, and beautiful designs that respond to the natural environment (Eren, Düzenli & Akyol, 2018; Yoo et al., 2020).

Table 1. Two primary materials horizontal comparison.

Plant types	Length of stem	Technical support/advantages	Weakness for furniture design
Bougainvillea glabra	Single stem up to 6m; Example: In the sixth lane of Liantang Village, Luohu District, Shenzhen City, bougainvillea glabra climbed along the building from the underground to the 8th floor, occupying most of the wall surface and forming a "flower waterfall" with a height of about 20 meters.	There are many research bases in China and other areas; Many cities in China regard it as the city flower, like Shenzhen, where also has a plant-research center; In Chaoshan region of China, craftsmen specializing in the cultivation of bougainvillea species for root carving; life time is long; Evergreen woody large vine, water, fertilizer, adequate sunlight; When it has enough water and fertilizer, it grows as fast as it can; Non-perishable and durable, it can still be used for sculpture after being transformed into a dead body.	Slow growth, need to optimise cultivation approaches; There are many kinds of species and more experiments need.
Fungi	After the operation of crushing, various shapes can be generated; There is no diverse manipulation of features.	There have been successful cases, and the products can be smooth, waterproof, sustainable cycle; There are related research centres in Netherlands, Germany, the United Kingdom, China etc.	Cell polarity and growth rate affect mycelium morphogenesis; As furniture material is easily affected by room temperature, humidity and other environmental factors; Different fungus need to be selected for experiments; Most experimenters still need to mix it with wood, waste or other materials.

Drawing inspiration from natural systems and using advanced digital tools, designers can create products and spaces that are both functional and aesthetic while minimising their environmental impact. Integrating these design approaches can lead to more efficient and sustainable designs, benefiting both people and the planet.

Methods

The research is based on taking advantage of computer vision and sensing improvements. The key is determining which rhizomes can be controlled by effective parameterisation. The transverse comparison was conducted on three raw materials of bougainvillea glabra and fungi as the primary analysis objects. The focus is mainly on the physical characteristics of the two materials, the advantages of application, and the weakness of furniture design. There are two reasons for the materials chosen: firstly, the accessibility of the material was a key consideration. Bougainvillea glabra is widely grown in the southern regions of China and fungi are well-researched for cultivation. Secondly, the team included sustainability and low carbon as core objectives in the initial design planning. In other words, we wanted to eliminate unnecessary industrial processes throughout the design. Ensuring the original growth of the plants was another key factor considered. Therefore, combining these two considerations led to the selection of trillium and fungi as the two alternative raw materials.

It is clear from Table 1 that the biological characteristics of bougainvillea glabra - its ability to survive for long periods, the width and length of the plant's roots, and the fact that it is grown over a large area in southern China - make it very suitable as a raw material for plant furniture. Although fungi are also extremely plastic. The use of fungi as a raw material for furniture may require the production of appropriate abrasives for the targeted cultivation of colonies and a series of tests on the load-bearing capacity of the furniture once it has been shaped. Thus, bougainvillea glabra was chosen as the main object of study. However, it is not the perfect raw material in its original form. The biggest problem is its slow growth rate. Therefore, various nutrient solutions (to promote growth) were used for testing during the design process. In the end, coconut water and tetracycline-based growth hormone were used in this study as the main nutrient solution to stimulate the growth of bougainvillea glabra.

Results

The study is currently in its experimental phase and is set in a factory located in Wuhan, China, where the root of the bougainvillea plant is being extensively researched. It should be noted that this is a conceptual investigation. The entire process can be divided into two parts: cultivating the roots to produce raw material for furniture design and using a parametric model to control the plant's secondary growth and shape it into plant furniture.

Cultivating process

The project is still in the experimental stage and should be considered an investigation on a conceptual level. Thus, a bougainvillea glabra design is taken as an example to explain in detail. First, selecting a container with a large basin mouth and mixing a large amount of river sand with culture soil is necessary to maintain bonsai. It is important to note that when planting the stump into the mixed culture soil, the bonsai stump should be raised above the mouth of the basin. River sand curing bonsai has good drainage permeability and is a better choice. Another point worth noting is that after adding a large amount of river sand, the soil's fertiliser protection performance is weakened, and water and fertiliser management should be paid attention to in the later maintenance to ensure the normal growth of plants. Let the roots sink deep into the soil. Then consider whether to transplant. The detailed steps include six, from root extraction to gravel cultivating root.

Table 3. Six steps of cultivating the root.

1 Root extraction	Coil up most of the root system and curl it into a certain shape. During transplanting, the root system of the plant should be lifted upward, preferably beyond the height of the pelvic mouth, and most of the coiled roots should be fixed with tools and wrapped in sand. In the normal maintenance process, under the influence of external factors such as wind, sun, rain, etc., most of the coiled roots will be slowly exposed, and the improved roots will be slightly shaped and processed. Expose the root system in a regular time and remove the soil from the roots of the plant, leaving some of the roots bare.
2 Developing root	Fill a deep cylinder pot with a layer of soil (nutrients added with growth hormones) at the bottom and sand at the top. Plant the prepared plants in the pot. In order for a plant to grow, its roots will keep spreading down to absorb nutrients. What we need to do is, every once in a while, remove some of the sand from the top of the pot, so that the root system will slowly come out. Finally, the roots of the plant have sunk deep into the nutrient soil at the pelvic floor. After the upper layer of sand is removed, the plants are replanted in the pot together with the nutrient soil, and the exposed roots can be artificially fixed with tools after shaping. After a period of time, it can be set, and this time can be exposed to the natural wind and sun, which can naturally promote the aging of the exposed roots.
3 Revealing the roots	Plant the plants in shallow POTS. Due to the limited height of the pot, the root system of the root part of the plant will definitely be exposed to the soil of the pot. The root system can be gradually fixed, and finally shaped.
4 Desoiling	If breeder want to create the effect of hanging roots and exposing claws, you need to expose the roots on the surface of the soil. You need to spray water, and you need to flush the soil away from the surface and expose the roots.
5 Choking	Plant into the pot, pile soil at the roots so that the base of the plant is above the pot but not completely exposed. Wait until the plants are alive in the pot, slowly from high to low remove the backsoil, after a long time of maintenance and shaping, can be replanted on the pot.
6 Gravel cultivating	Use plastic to roll up and make a cylindrical drum without a bottom, or use a wooden bucket or bamboo basket without a bottom to surround the plant and fill it with sand, a few pebbles, water and fertilizer. Once the plant is alive and the roots have penetrated into the soil beneath the sand, remove the sand from the top several times, preferably at different intervals with the help of growth hormones. Finally, remove the roll and reserve the finished product.

Parametric growth

The main branches were intentionally bundled and different environmental stimuli, including water, gravity, touch, and media, can guide plant roots. With artificial manipulation, plant roots can be shaped to grow in various directions and either stay on the surface or penetrate obstacles they encounter. In

materials science and engineering, the porous structure of parameterization allows plant roots to form a network structure with bearing capacity. By placing obstacles in the direction of growth, the roots can be shaped, and the hierarchical drive of botanical roots can be combined with parametric porous structures. After experimenting with AGAR medium and 3D porous barriers, small and large porous pla structures were 3D printed to design appropriate barriers for the roots and complete the "parameter porous bead experiment." The "bonding ability" of the roots associated with the porous structure enables them to combine into 3D blocky patterns with high compressive strength, verifying that the porous structure of the 3D printed plant can produce a certain tolerance in root formation.

The process of parameterizing plants can be divided into eight steps. Firstly, record the growth of the plant roots, including growth rate and time. Next, an algorithm is generated, which may be integrated within the GH modelling software. Thirdly, the initial furniture design model is set to roam freely. Fourthly, record the user's body data in detail. Fifth, determine the rhizome (starting point), which involves combining personal data with the user's usage habits, distribution of force points, and common postures. Sixthly, using this data, deepen the model and set the "obstacles" and "collisions" in the GH parametric modelling software. Seventh, use a Boolean Toggle to control the reset operator. Eighth, the rootstock grows gradually according to the obstacle position, creating a stable path network. Extract the trajectory lines and use the Weaverbird plug-in to smooth the surface (which can be set to subdivide the structure). Finally, a furniture model with a support structure is created.

There are several recommendations for this whole process. The main branches should be kept bundled and guided. Plant roots can be shaped gradually in different environments by water, gravity, touch, and other media. Plant roots can be artificially guided to grow in all directions and can stay on the surface of obstacles or penetrate them when encountered. In the porous structure of parameterisation, the plant roots can form a network structure and develop bearing capacity, because the porous structure allows the plant roots to grow into a denser network structure with a higher degree of fit that ensures a stronger network structure.

Figure 1. The grinding picture of the production process.

Figure 2. Effect pictures of the two items.

The project initially planned to include a wide range of furniture products, such as tables, baskets, chairs, lamps, etc..However, there was a shortage of funds during the project. The final products therefore consisted of a chair and a table (see Figures 1&2).

Conclusion

Sustainable design is the global challenge and goal of humankind. Sustainable product design and production driven by technology can reconstruct human and environmental relationships. As the embodiment of this concept, plant furniture design is important. Taking the tree house as an example, it can effectively withstand nature's storms. After an earthquake or tsunami, the only structure that can guarantee human survival is a treehouse. This design is also significant for improving the urban environment and solving the housing problems of low-income and homeless people.

In addition, plant furniture is of great significance for establishing a biological regenerative life support system. Bioregenerative life support system is the core technology of long-term manned space activities in the future. It has the advantage of continuously regenerating oxygen, water and food, the necessities of life for human beings, in a closed system. Plant is an important part of the biological regenerative life support system. Plant furniture can complete its metabolism and regulate indoor and outdoor temperature and air quality, significantly benefiting disease patients, medical places, urban planning, etc.

There are drawbacks to such studies. The first is the high cost of input. Suppose the related techniques are to be promoted on a large scale. In that case, further experimental studies on the rhizosphere growth of Bougainvillea are needed, such as experiments on guided growth in different environments. Later user testing, as well as the cost of promotion, are significant expenses. Secondly, the maintenance of the product also needs a series of experiments to test its usability, such as whether it will grow mouldy in the supermarket environment, how to maintain it and so on.

Creating a meaningful product application concept, i.e., designing for material experiences, takes much work. It requires a critical understanding of what the material offers in terms of function/utility and overall experience: *how it gratifies or disturbs our senses, what meanings, associations, and emotions it evokes, and what it makes us do* (Giaccardi & Karana, While a material with endless combinations of its ingredients, would excite and inspire designers in exploring its possibilities for design, this may also give a sense of uncertainty (Daalhuizen, Badke-Schaub, & Batill, 2009; Krishnan & Bhattacharya, 2002), as the *boundaries of the material* would not be known in an early stage of a material-driven design project (Barati, Karana, & Hekkert, 2015).

In a word, this research uses this case to analyse the characteristics of the growing design process, which aligns with the notion of WHO 2022 sustainable development goals. The creative thinking and design of material and product concurrently expand the boundaries of design toward new territories asking for new tools and methods, which also is one of our future research endeavours.

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