TEACHING COMPUTATIONAL APPROACHES IN BAUBOTANIK

Developing a design-and-build workflow for a living architecture pavilion

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ABSTRACT

Living architecture is characterized by dynamic and complex processes, thus requiring a non-static design approach with precise measurement and representation. The next generation of designers are data native and today's circumstances, such as international collaboration and pandemic restrictions, necessitate greater exploration of computational tools. This provides a good opportunity to teach landscape- and architecture students computational tools for living architecture design. This study establishes, through a taught studio, a workflow for designing and constructing with living trees. It involves photogrammetric surveying, tree representation, parametric design, prefabrication, final installation, and concepts for future growth management. A Baubotanik pavilion, around 12m by 4m, is designed and built. Its roof is supported by 32 London Plane trees around 3m above ground. In following decades, the trees are expected to grow into and through the structure as well as above the pavilion roof. The installed pavilion is scanned for deviation assessment.
The workflow proves the feasibility of design and build of complex geometry that fits existing trees. In this process, students are equipped with the iterative design thinking to work with trees in complex architectural settings, integrating dynamic plant growth into future city planning.

1. INTRODUCTION

In comparison to industrialized building materials, living tree structures are dynamic and heterogeneous. They have complex and diverse topologies and functions, and for this reason, can provide benefits throughout growth, human use, and decay. When these characteristics of living architecture are considered (Baubotanik, see Ludwig, 2016), they contradict the contemporary static design process, where complexity in design and construction is minimized. To address this, a feedback-loop strategy for living architecture is applied to Baubotanik projects using a research-by-design approach (Zimmerman, 2007): design decisions are not made once, but multiple times through the life cycle of the tree structure according to its actual growth; in the meantime, knowledge for manipulating trees is acquired during the repeated process of observation, decision-making and maintenance. This dynamic design process focuses on uncertainty (Cf. Ludwig, 2021), for which digital methods (such as capturing tree status and simulating growth) can be useful.

In this context, the integration of digital tools in a dynamic design workflow and the reactions of humans (both designer and user) and trees to that workflow must be explored. The next generation of landscape- and architecture designers are data natives. The role of computational thinking in science, technology, engineering, and mathematics education was widely discussed in recent years (Li, 2020). An education model specifically for living architecture design is therefore in urgent demand, where the future-oriented design approach with multiple dynamic uncertainties is taught. All in all, this study is motivated by two interconnected aims: to explore the workflow of computational living architecture design; and to teach Master students design with trees in a dynamic process. (see Figure 1)

The subject of the course described here is a Baubotanik pavilion located at Neue Kunst am Ried (Baden-Württemberg, Germany), a space for artists to exhibit work that engages with nature. At the site, a grove of 32 London Plane (Platanus hispanica) trees was planted in 2012. The trees surround stone tables and an oven for visitors to gather, eat, cook, and discuss. In Baubotanik projects, the feedback-loop strategy for designing living architecture is a ping-pong game between designers and trees. In previous Baubotanik projects, designers have always served the first shot – the initial settings are usually completely planned by humans. In the project presented here, the trees serve the ball. A team of 11 students, 3 instructors and 6 prefabricating helpers from diverse disciplines returns the ball by designing and building a roof structure (12m by 4m) supported by the trees. In coming years, these trees are expected to return the ball again by growing onto and through the technical structure. The ping-pong game will continue in this way until the end of trees' life cycle.

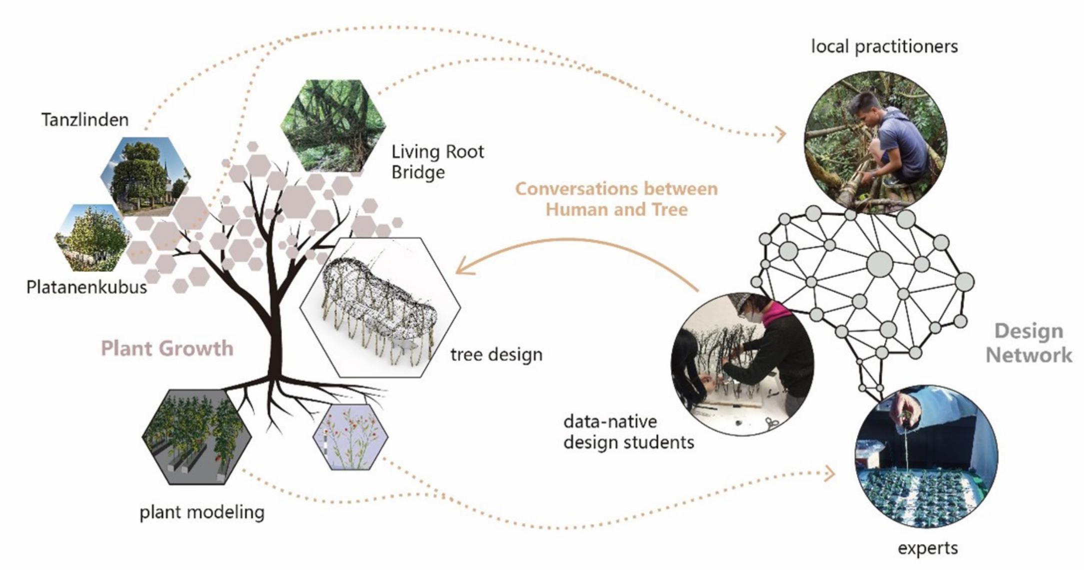


Figure 1:
(top)
Teaching concept of the feedback-loop strategy for design of living architecture: on the left, knowledge derived from living architecture traditions and plant modeling in botany; on the right, the design network consisting of local practitioners, researchers and designers who learn from plant growth to design living architecture, which allows further understanding of plant growth.

2. METHODOLOGY

2.1 COMPUTATIONAL DESIGN

The computational design approach begins with a data workflow, including data acquisition, interpretation, and geometric design. To acquire the initial data, the trees were surveyed using photogrammetry (Middleton, 2019). About 1500 photos were taken at various positions and angles to generate 3D point cloud models of the site. Especially during the covid-19 lockdown in Germany, the point cloud replaced on-site excursions. The model consists of 70 million discrete points. To interpret the data, woody trunks and branches of the relevant trees are manually extracted from the scene. Wu B. (2020) provides an automated alternative. Then, a skeleton (Huang, 2013) is extracted for each tree. The average distance between surface points and the nearest trunk point is calculated as the radius of the trunk at various points along its length and cylinders fit accordingly to represent trunk and branches. The geometric design of the technical roof structure is generated in Rhinoceros and Grasshopper (McNeel, 2021). Inspired by Wang's (2002) study, a truss structure can follow complex Bezier surfaces, meeting both the geometric form and mechanical requirements. Moreover, a truss allows for thin rebar elements, which tree branches can easily overgrow and encase. For the Baubotanik pavilion, six pairs of approximately coplanar branches are selected. On each of the 6 planes, a curved truss is drawn to fit closely the shape formed by the branches. These 6 trusses provide the basic roof form. At regular intervals along the length of each truss, perpendicular trusses are added to connect the 6 original ones, forming a space frame (see Figure 2 upper left). In this way, the geometry of the roof is formed close to the natural shapes and positions of selected branches.

2.2 FABRICATION

The roof's fabrication relied on a combination of handwork experience and building tests using different materials. It was proved through 1 to 1 testing that pre-bent rebar (mostly in 8mm diameter) in slight tension would not deform significantly after additive welding into trusses. The 6 plane trusses were firstly fabricated on mounting plates that configured with digital drawings. Afterwards, the space frames were directly bent and welded on the plane trusses that positioned tightly on tailor-made wooden scaffolding. Then, the whole roof structure was divided into 14 pieces for lacquering and transporting. Finally, the 14 pieces were assembled into 3 larger components on the ground next to the site and lifted to the treetops (see Figure 2 right). At appropriate points of contact, the space frame was fixed to the trees with screws (see Figure 3). Every step in the fabrication apart from lacquering refers directly to the digital model.

Figure 3:
Detailed connection techniques. Left: truss pieces were connected by M8 screws, reinforced with rebar stick and metal rings. Right: the space frame was fixed to trees with screw hooks.

2.3 EDUCATIONAL MODEL

In terms of the educational model, students began with a lecture series on computational tools and progressively explored deeper into their application in living architecture. The 11 students are skilled in (landscape) architecture design. Two have worked in the field of carpentry; Three have experiences with parametric design in Rhino and Grasshopper; but all are new to living architecture design and digital representations of trees (Godin, 2000). Through the lecture series, they learnt about spatial data, skeletonization, tree mechanics, and growth modelling. To explore the diverse applications for dynamic growth design, students worked in three groups, developing three concepts, which narrowed down to two for deeper analysis. These condensed into one design and the team members specialized on individual tasks for translating the digital model to a buildable structure (see Figure 2 bottom left). Merging the groups pushed communications and exchanges among students, forming an atmosphere of one team. This teamwork also motivated student to learn the novel methods despite difficulties in the process. At the end of the studio, an anonymous survey is sent to individual students. They are asked for feedback on the teaching method and their learning outcomes.

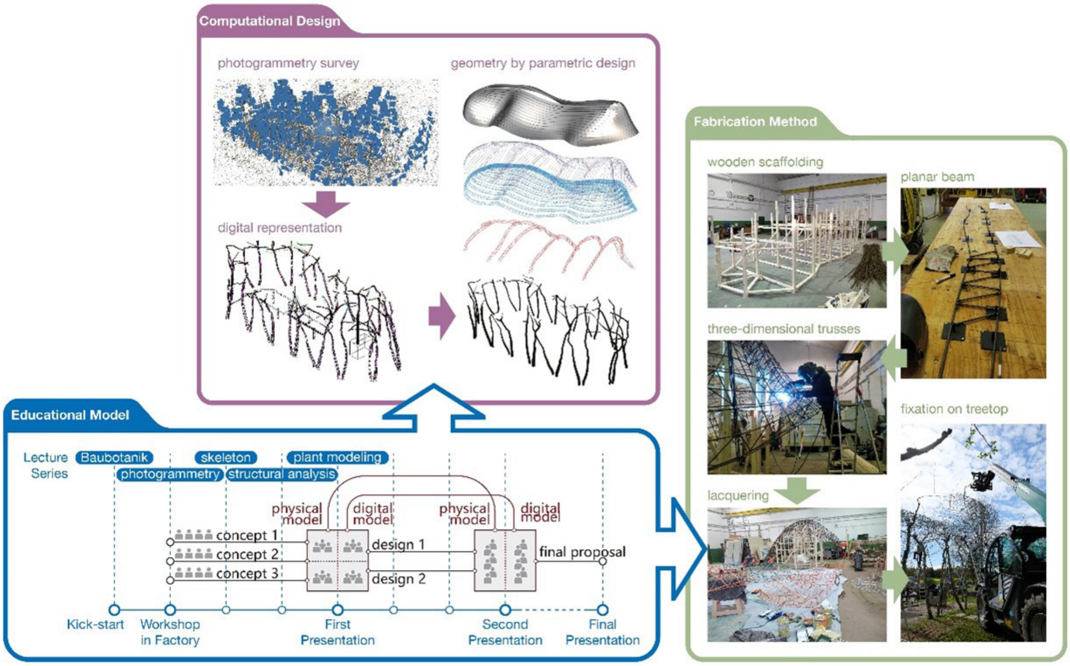


Figure 2:
(top)
Overview of the teaching, design, and fabrication workflow. Bottom left: concepts and general application of digital methods were taught to students prior to design; three design groups competed to develop concepts, narrowing down to 2 groups at the design and modeling phase, converging on one proposal for fabrication. Top: digital methods learning was applied to develop the computational workflow including data acquisition, interpretation, and geometric design. Right: the group's diverse skills are needed to continuously refer the fabrication to the digital model.

3. RESULTS

3.1 BUILT PAVILION

This study results in a reliable workflow to teach, design, and build living architecture on existing tree structures. Unlike building a structure on a solid foundation, young trees are not fully stabilized for structural load. The Platanus trees on site have diameters at breast height (DBH) ranging from 0.05m to 0.1m – one person can push and pull the tree to make the top of the trunk (at ca. 3m above ground) move up to 0.2m. So, the challenge lies also in dealing with the inconsistent deformation of the trees under the load. Considering this, the truss structure enables a tolerance for inaccuracies because the trunk can be fixed at multiple points to the space frame. Flexibility in spatial positioning is part of the proposed solution. Therefore, precise measuring equipment (i.e., total station) is not necessary during the prefabrication and installation on site. Instead, plumb lines are used to give a visual coordinate reference in space. By overlaying the LiDAR scan of the pavilion with the original digital plan (see Figure 4), the deviation is assessed precisely. In general, the geometry, position, and rotation of the pavilion in the digital plan match well with the reality on site. Most of the space frame does not deviate more than 0.2m, commonly around 0.1m. These deviations are likely caused by unstandardized handwork in bending the rebar and inexact estimation of trunk deflection under loading. The largest deviation is 0.4m. It occurs when one plane truss is incorrectly positioned 10.9 degrees higher on the wooden scaffolding than in the digital plan. This deviation did not affect the match of the overall fit of the truss to the trees. So, this workflow results in building structures with good tolerance to fit existing living trees. Besides the trunk, branches at the higher end of the trees have been intentionally pressed down by the truss structure from their original positions to fit the roof geometry. They will begin growth to carry the load. All these adaptions are documented by the point cloud models scanned before and after the implementation (figure 4).

One feature of Baubotanik projects is the ongoing growth of trees. In the summer of 2021, all the 32 London Plane trees grew prosperously (see Figure 5 right). Screw hooks through the centre of each tree trunk to connect the trees with the steel structure did not affect the vitality of the trees recognizably (compare Ludwig, 2012 a and b). A truss structure without closed roofing allows adequate sunlight to reach the leaves. As the branches grow, they are pruned and manipulated to grow through the truss. Hook-and-loop fasteners are used to pull soft branches closer to the truss elements so that they encase the roof at many points with their girth growth. In this way, the structure grows stronger. In the next step, shingles will be progressively added to the roof as these connections strengthen, eventually covering the whole area, apart from a reserved hole at the top through which the branches can continue to grow (see Figure 6). As it is a ping-pong-like iterative design process (described in section 1), this scenario should not be a "final result". Due to competition for space and light (Boeck, 2014) some mortality among these trees is expected. Such variables are factored into future design stages.

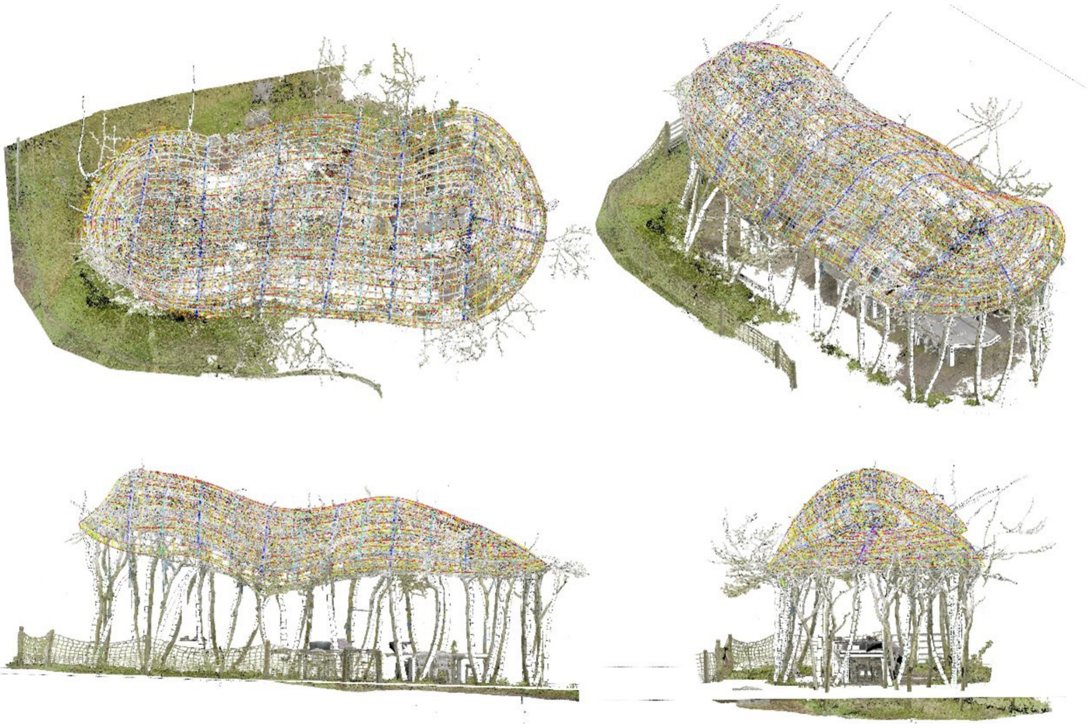
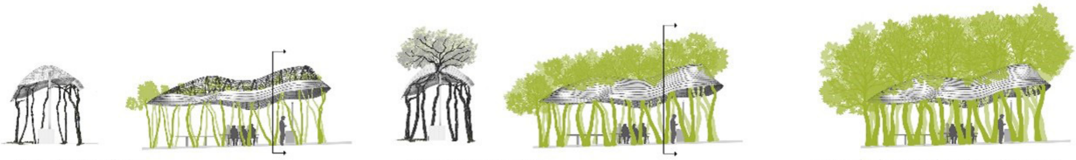


Figure 4:
Overlay of the computational model and the accomplished pavilion: trees in the digital model are drawn with white pipelines; designed truss system is represented with slim colored tubes; actual positions of trees and the structure after implementation are presented by the point cloud.



2021 - first installation

2030 - tree connection

2060 - further growth under maintenance

Figure 5:
(top)
Photos of Baubotanik Pavilion. Left: the situation immediately after the installation in April 2021. Right: 3 months after the installation, new leaves grow out. The project has a dynamic appearance through seasons with different shades, light and color.

Figure 6:
(bottom)
Scenarios for Baubotanik Pavilion: The branches grow under the roof and provide stronger support; shingles will be added.

3.2 TEACHING EVALUATION

The education model allows students to explore the broad horizons of a digital-first workflow, including dynamic growth prediction, precise tree mechanics, and environmental modelling. Nevertheless, they do not lose sight of the transition to a built structure, as the digital model runs continuously in parallel with the fabrication. From the 11 sent questionnaires, we received 6 feedbacks. 33.3% of the students “fully agreed” and 66.7% “agreed” that the teaching contents were well coordinated; 83.3% of the students fully agreed that the course structure motivate them to learn the contents better. 66.7% of the students found the difficulty level fit their ability while 33.3% said the course was a bit difficult. Half of students “fully agreed”, and the other half “agreed” that they can transfer key skills from this design studio to elsewhere. The perspective this engenders in students is applicable in future urban design, in which precise data feeds complex dynamic models for living architecture design.

4. CONCLUSION AND VISION

This study aims at two questions: how to integrate computational approaches in a workflow of living architecture design; how to teach data-native student both new design methods with digital tools and dynamic design thinking for developing living architecture. To address these two questions, a Master-level studio was organized to design and build a Baubotanik pavilion. The design phase explored a computational workflow including photogrammetry survey, abstracting tree representation, and producing parametric geometry. The fabrication phase relied on the digital model from the design phase for tailor-making the complex truss system. The built pavilion was installed on the trunks of 32 London Plane trees on site. The deviation analysis using LiDAR scanning data proves the feasibility in this novel design workflow; the teaching evaluation from students proves the effect in the explored educational model.

This study extends the current scope of Baubotanik by achieving a design-and-build structure fitting existing trees. It is like returning the ping-pong ball served by the trees. However, it remains to be answered how to continue this game with an affordable solution to constantly make design decisions and perform periodic maintenance accordingly (i.e., pruning and bending). This involves deeper research in simulating tree's reaction to manipulations, setting goal parameters and a decision-making mechanism (Shu, 2021). Precise documentation is essential to the next phases of building, beginning with the design and construction of the roof shingles. Iterative LiDAR surveys will capture the density, extent and direction of new branch growth, and the degree of overgrowth of the truss – these conditions will inform the material, size, and attachment method of the shingles. The ping-pong between tree and human is multifaceted. Diverse environmental features such as light and air flow can be designed using the whole range of tools at the architect's disposal. Only then, Baubotanik, in other words living architecture design, can eventually become a common game played between humans and trees around the world.

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