3D Printing Heritage Trees

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Abstract: We have developed a method for 3D printing of heritage trees from laser scanned point clouds. Heritage trees are ancient trees of significant historical, cultural, and ecological importance. Louisiana has many large, old, and culturally significant specimens of southern live oak, i.e. Quercus virginiana, and bald cypress, i.e. Taxodium distichum. These trees are charismatic megaflora – specimens that capture the imagination of the public and encourage broader support for biodiversity conservation. To preserve a record of the most significant heritage trees in Louisiana, we have developed a process of terrestrial laser scanning, volumetric modeling, and powder-based 3D printing.

Keywords: Heritage trees, terrestrial laser scanning, point clouds, volumetric modeling, 3D printing

1 Introduction

Heritage trees are trees of significant historical and cultural value, which are often large, very old, and of great ecological importance (BLICHARSKA & MIKUSIŃSKI 2014, LINDENMAYER 2017, LINDENMAYER & LAURANCE 2016). Louisiana has many large, old, and culturally significant specimens of southern live oak, i.e. Quercus virginiana, and bald cypress, i.e. Taxodium distichum, which are threatened by coastal change. To preserve a record of these irreplaceable cultural icons, we are laser scanning the most significant heritage trees in Louisiana. To share the stories of these ancient trees, we are 3D printing models of these specimens. By exhibiting these 3D prints, we hope to build awareness of natural heritage, coastal change, and biodiversity loss.

Large, old trees are keystone structures in ecosystems (LINDENMAYER & LAURANCE 2016); they host a multitude of species, have vast root networks hosting fungal symbionts (BEILER et al. 2015), serve as banks of ecological memory and genomic biodiversity (PIOVESAN et al. 2022), and sequester great quantities of carbon (GILHEN-BAKER et al. 2022, LUYSSAERT et al. 2008). With old age, trees develop morphological attributes including massive stocks of biomass, extensive crowns, large lateral roots and branches, fissured bark, deadwood, cavities, and buttresses (LINDENMAYER & LAURANCE 2016). Their increasingly complex morphology creates diverse microhabitats. Their cavities, for example, are hotspots of saproxylic biodiversity (ZAPPONI et al. 2017) that support species – including many types of insects, fungi, bryophytes, lichens, and microorganisms – that rely on dead or decaying wood (GROVE 2002, HAELER et al. 2021).

Ancient and monumental trees can be culturally significant for their age and history, for their symbolism and aesthetics, and as sacred entities (BLICHARSKA & MIKUSIŃSKI 2014, HABERMAN 2013). The natural and cultural heritage of ancient trees often spans generations, with communities passing down their values and tending to the trees from one generation to the next (JIM 2005). Such large, old trees are often given unique names – such as the Big Cypress, the Monarch of the Swamp, and the Duelling Oaks – that serve as toponyms, as place names. The Dueling Oaks, for example, was a notorious 19th century dueling site in New Orleans where duelists would meet to fight between a pair of southern live oaks

Journal of Digital Landscape Architecture, 9-2024, pp. 605-613. © Wichmann Verlag, VDE VERLAG GMBH · Berlin · Offenbach. ISBN 978-3-87907-752-6, ISSN 2367-4253, e-ISSN 2511-624X, doi:10.14627/537752055.

(LOUISIANA WRITERS' PROJECT 1941). While one of the trees was lost to a hurricane, the other still stands in New Orleans' City Park and is estimated to be 300 years old.

As trees grow to extreme old age, they develop unique aesthetics. The Big Cypress, an ancient 1500-year-old bald cypress in the Cat Island National Wildlife Refuge (STERN 2022), has a trunk with a massive girth, a vast cavity, extensive buttressing, and many knees (Fig. 1 & 8). Its form is complex and convoluted, but majestic. The natural heritage of such ancient and monumental trees are recognized in many countries by designations such as champion, legacy, or heritage trees (BLICHARSKA & MIKUSIŃSKI 2014). The Big Cypress, for example, is the largest recorded specimen of Taxodium distichum and is registered as the current national champion (AMERICAN FORESTS 2017). These ancient, monumental trees are charismatic megaflora – specimens that capture the imagination of the public and encourage broader support for biodiversity conservation (HALL et al. 2011).

Fig. 1:
3D Print of the Big Cypress,
Cat Island, Louisiana,
Age: 1500 years, Height: 28 m, Girth: 16 m,
Model Scale: 1:200

Fig. 2:
3D Print of the Monarch of the Swamp,
Barataria Preserve, Louisiana,
Age: 600 years, Height: 21 m, Girth: 6 m,
Model Scale: 1:200

Large, old tree populations, however, are in decline around the world (LINDENMAYER et al. 2012). While Louisiana has many large, old, and culturally significant bald cypresses and southern live oaks, these trees are at risk due to a lack of legal protection, coastal change, and senescence. Risks include saltwater intrusion due to coastal land loss, blowdown from intensifying storms, and intentional removal for infrastructural construction. Since industrial logging from the 1890s to 1920s decimated old growth cypress forests in Louisiana (MANCIL 1972), the recruitment of large, old cypresses is limited.

To preserve a record of these rare, iconic, and irreplaceable specimens, we have developed a method for 3D printing heritage trees from laser scanned point clouds (Fig. 1 & 2). Trees are challenging to 3D print because of their complex, fractal geometry. Their branches subdivide into smaller and smaller parts until they terminate in a myriad of leaves. With common technologies like fused deposition modeling and stereolithography, printing this multitude of overhanging parts may require an impractical amount of support structure. Depending on the 3D printing system, these tiny parts may even be too thin to print at a given scale. Large, old trees are even more challenging to print because they may have cavities, hollows, fissures, buttressing, vines, and epiphytes. We use a process of laser scanning, point cloud processing, voxelization, volumetric modeling, and powder-based printing to 3D print heritage trees with enough detail to represent their aesthetic character and unique, ecologically important features. Our process can also be used to calculate the volume of large, old trees with extensive cavities for biomass and carbon estimation.

2 Methods

To 3D print heritage trees we have developed a process of terrestrial laser scanning, point cloud processing, volumetric modeling, and powder-based printing. To implement this process, we used Faro Scene to register the scans, CloudCompare to process the point clouds (GIRARDEAU-MONTAUT 2023, GIRARDEAU-MONTAUT et al. 2005), VoxelTools for voxelization (WAART 2023), Dendro for volumetric modeling (OENNING 2022), and Potree to render the point clouds (SCHÜTZ 2016, 2022). Dendro is a volumetric modeling plugin for Grasshopper which is built on the OpenVDB library (ACADEMY SOFTWARE FOUNDATION 2023, MUSETH 2013). The specimens are published on our server xyz.cct.lsu.edu as interactive point cloud visualizations powered by Potree, a render engine for massive point clouds.

2.1 Scanning

First the specimen is captured as a point cloud using terrestrial laser scanning. To rapidly record scans at different heights around the tree with high overlap, we use a phase-shift terrestrial laser scanner on a pneumatic telescoping mast. While long-range time-of-flight sensors are currently considered the standard for applications in forest ecology (CALDERS et al. 2020), we use a phase-shift sensor because it is lighter, less expensive, faster, and still provides the resolution required, albeit with substantial noise. Scans are taken in concentric rings around the tree at multiple heights to capture the complexity of the tree's branching structure and canopy. It can be challenging to record the crown of very tall, isolated specimens with dense foliage using phase-shift terrestrial laser scanning as the top of the canopy can be occluded and multiple beam interceptions with leaves will generate noise. For some specimens, we use lidar on an unmanned aerial system to capture the crown of the tree in more detail. Another approach for capturing tall specimens is to construct scaffolding for scanning as shown in a scan of the Centenary Fig Tree in Brazil by researchers at Ghent University (CALDERS et al. 2023).

2.2 Point Cloud Processing

Once a specimen has been scanned, the point clouds are colorized, registered, segmented, and cleaned. To account for uneven illumination, points are assigned laser illuminated high-dynamic range color based on return intensity and panoramic photos. After the individual point clouds captured at multiple scanning positions are co-registered as a single global point cloud, the specimen needs to be isolated. While some heritage trees are isolated specimens that are easy to manually segment out of their surroundings, others are surrounded by so much dense vegetation that they can be challenging to isolate. In such cases, algorithms for automatic semantic segmentation and instance segmentation can be used to isolate specimens (WILKES et al. 2023). Once the specimen has been isolated, it should be cleaned by removing artifacts, noise, and stray points. Noise and stray points can be cleaned automatically using statistical outlier removal and a low-pass filter. Artifacts and any remaining noise can then be removed with manual segmentation. If airborne lidar from an unmanned aerial system is co-registered with terrestrial laser scans, it should be subsampled or homogenized to mitigate artifacts – such as banding, swath overlap, Moiré patterns, and corduroy patterns – caused by variations in point density (PETRAS et al. 2023).

2.3 Volumetric Modeling

Point clouds can be modeled volumetrically as voxels, i. e. 3D cells in a regular 3D grid, in preparation for 3D printing. Point clouds are voxelized based on presence or absence in a 3D grid with the detail of the resulting volume depending on the resolution of the grid. Volumetric modeling is useful for 3D printing point clouds because the resolution of the grid can be adjusted to fill gaps and thicken thin parts. While a fine resolution grid of voxels may generate gaps and parts that are too thin to print, a coarser resolution grid will fill gaps and thicken these parts. While a coarse resolution voxel model is blocky (Fig. 3), the marching cubes algorithm (LORENSEN & CLINE 1987) can be used to generate an angular, faceted, but less blocky volumetric representation from a voxel grid (Fig. 4). An even smoother representation can be generated by modeling points as spheres composed of supersampled voxels (Fig. 5).

A smooth volumetric model of the tree can be created by generating an empty voxel grid, modeling a sphere of voxels around each point in the point cloud, and then smoothing the resulting volume. The radius of the spheres should be set, based on the density of the point cloud, so that most of the resulting spherical volumes merge together into a single, printable volume. With a Boolean union a base can be added to the volumetric model of the tree so that the 3D print will be able to stand freely. This volume can then be exported as a mesh for selective laser sintering or binder jet 3D printing. These technologies are suitable for 3D printing trees since they build models in beds of powder without support structures. Boolean operations can also be used to cut transects through the volume to explore the internal structure of the specimen (Fig. 7).

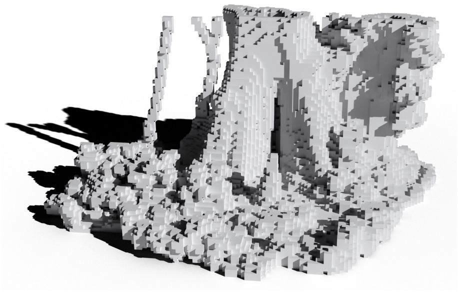

Fig 3: Voxels

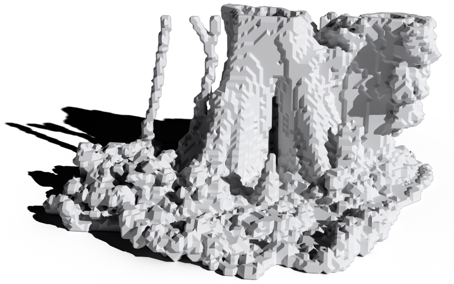

Fig. 4: Marching cubes

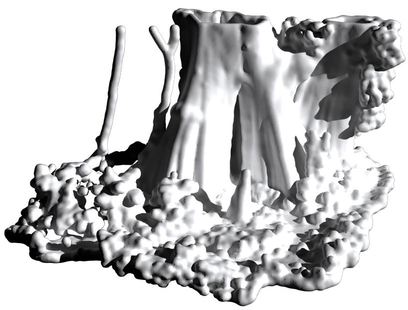

Fig. 5: Volume

Fig. 6: Point Cloud

Fig. 7: Transects showing the cavities within an ancient bald cypress

Fig. 8: Point cloud rendering of the Big Cypress, Cat Island, Louisiana

Fig. 9: Point cloud rendering of the Monarch of the Swamp, Barataria Preserve, Louisiana

Fig. 10: Point cloud rendering of the Dueling Oak in City Park, New Orleans, Louisiana

2.4 Visualization

A collection of heritage trees has been published on our server xyz.cct.lsu.edu as interactive point cloud visualizations powered by Potree, a render engine for massive point clouds. The meshes for 3D printing can also be downloaded from our server or from Zenodo, an open repository for research artifacts. The Potree render engine supports point cloud rendering techniques including high quality splatting and eye dome lighting (SCHÜTZ 2016). While we publish true color point clouds to better represent the aesthetic character of these ancient specimens (Fig. 8-10), point clouds can also be colored more abstractly by values such as return intensity or illumination.

3 Conclusion

With terrestrial laser scanning, heritage trees can be recorded in immersive detail. These irreplaceable specimens can be archived as point clouds in open data formats that record their morphology and aesthetic character. 3D prints of laser scanned heritage trees can serve as physical artifacts for archiving, exhibition, and education. 3D printing is an accessible medium for building awareness of the grandeur, mystery, and plight of these charismatic megaflora. Our method for 3D printing trees could be adapted for printing landscapes designed using point cloud modeling (URECH et al. 2020).

Dataset

The Atlas of Heritage Trees – our growing collection of ancient, monumental trees – is published on our server at https://xyz.cct.lsu.edu/atlas-of-heritage-trees and is archived on Zenodo at https://doi.org/10.5281/zenodo.8353292 under the Creative Commons Zero public domain dedication (HARMON & NAM 2023). The data and scripts to reproduce the work presented in this paper are available from https://doi.org/10.5281/zenodo.10477059 under the Creative Commons Zero public domain dedication (HARMON & NAM 2024).

Acknowledgements

This project was funded by the LSU Arts & Humanities Support Fund and supported by the LSU Center for Computational Technology, the LSU Center for GeoInformatics, and the LSU Coastal Ecosystem Design Studio.

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