Characterizing Interwoven:

A guide for designing the properties of root-textiles

Israel Carrete | July 2021 | Delft University of Technology

Characterizing Interwoven:
A guide for designing the properties of root-based structures

Publication date: 08-07-2021

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This document is part of a graduation project conducted for the master Integrated Product Design at the Faculty of Industrial Design Engineering at Delft University of Technology called:

Characterizing Interwoven: Testing and Modeling Root-Based Textiles

Introduction

This document aims to serve as an aid to designers who are looking to start designing with Interwoven. Interwoven is a material structure created from plant roots whose growth is shaped into a designed structure. Diana Scherer, an Amsterdam-based artist, created these structures as part of her "Exercises in Root Domestication" work in 2016. This work showcased plant-root intelligence and was meant to begin a dialogue around the relationship between humans and nature.

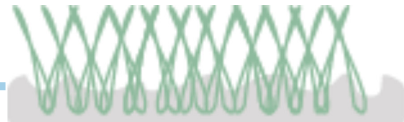
Though originally used as a textile, Interwoven structures have the potential of disrupting other industries, such as natural fiber composites, which is why Scherer began a collaboration with TU Delft in 2016 to map out the design space of Interwoven and turn it into a feasible commercial product.

The design of these structures is composed of the following three stages:
(1) Molding stage,
(2) Planting stage
(3) Processing Stage.

Each stage has parameters related to it which affect the final structure and properties of the design. The master thesis that this work originated from tested some of these parameters extensively. The correlations between a selection of these parameters and the corresponding mechanical and structural consequences is detailed further in the following pages. The list of parameters is not exhaustive. The intention is to create a foundation with relevant parameters from which new studies can continue.

Molding Stage

The molding stage refers to the processes that occur before planting the seeds. This includes the plant selection, mold design, and any other relevant parameters.



Planting Stage

As the name implies, this stage concerns the preparation of the plant for growing. Any parameters that affect plant growth and health are included here

Processing Stage

This stage includes any post-processing that occurs with sample preparation. From cutting and deforming the Interwoven structure to the desired size and shape to using it for making composites.

How to use this guide

Process Stage

Since this guide is an accompaniment for the master thesis from which it was extracted, the sources of information include both experimental results, as well as a literature publications.

Each identified parameter is presented along with its effects on the properties of the resulting structure. The corresponding test or literature source describing the impact of the parameter are then referenced on the right.

An example of the format is shown below.

+ Positively affected qualities of the structure

− Negatively affected qualities of the structure

Image or illustration of the parameter in question

Source of Information

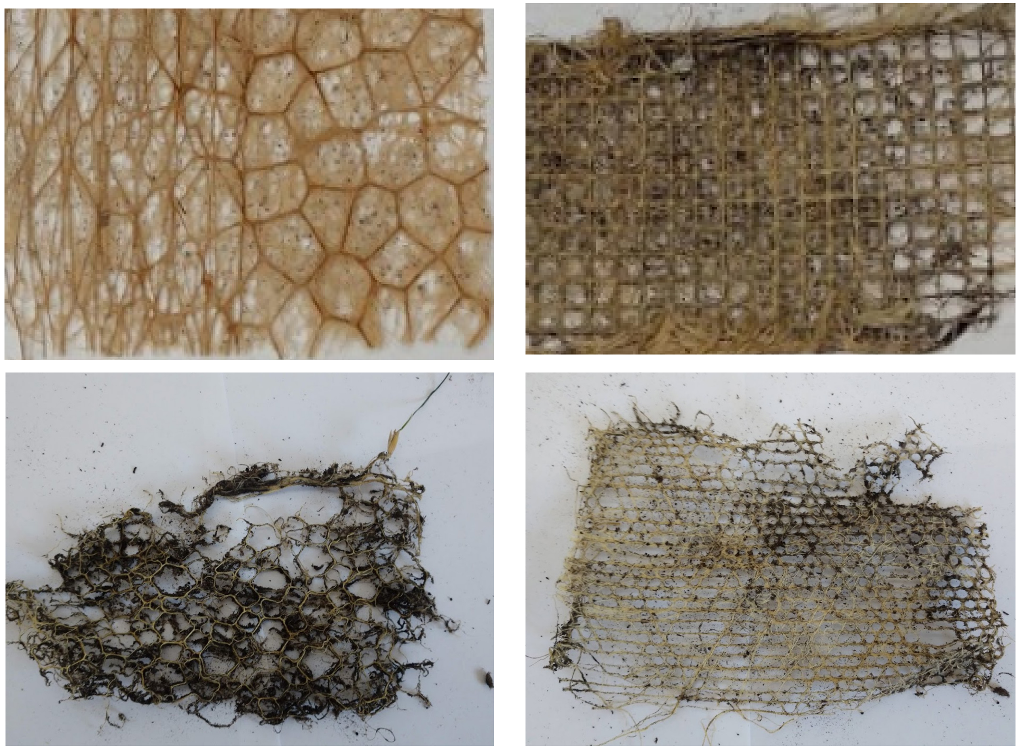
1. Chapter X - Title ... Subsection... heading (this refers to a section of the accompanying master thesis report.

2. Author, (Date), Title... -> this is a regular citation to literature

Molding

Pattern

One of the most unique aspects of the Interwoven process is how roots can be molded into seemingly any pattern. Though the pattern affects the material experience of the user, it also impacts mechanical properties by introducing anisotropy. This means that the mechanical properties differ depending on the direction they are tested in. Certain patterns lead to more heterogeneous properties than others.



+ Material experience and sense of wonder increases with the complexity of the pattern because it is not something that is expected from plant roots.

− Anisotropy increases, meaning that the root alignment with a loading direction impacts mechanical properties immensely.

Source of Information

1. Chapter 4: Characterization ...Root Orientation Tests
2. Chapter 4: Characterization ...Experiential Characterization

Thickness

Molding

The thickness of the template (mold used for growing samples) affects the structural formation. If the mold is too thick, the sample is no longer a planar “sheet” of roots, it becomes a three-dimensional object, and the strengthening benefits of fine roots formed in thinner samples is lost. Though the tests in the thesis did not test this quantitatively, the thicker samples had an elasticity in the direction of the thickness that will dampen impacts, which the thinner samples did not have.

Examples of a grid made from a 1cm template thickness (top) and a 3mm template thickness (bottom)

\+ Thicker samples can be compressed in a way that is likely to dampen impacts.

− Part of the strength of Interwoven structures comes from the network of fine roots that connect the coarse roots that make up the designed pattern. Thicker samples lose the root density of these networks.

Source of Information

1. Appendix B-1: Dimensional Calibration Tests
2. Chapter 4: Characterization… Experiential Characterization

Molding

Pattern Size

Pattern size refers to the dimensions within the repeating unit of a pattern. In the case of the square grid used in the thesis, this refers to the length of each square (denominated as the cell size). All else being equal, an increase in cell size increases stiffness while a decrease leads to more elasticity.

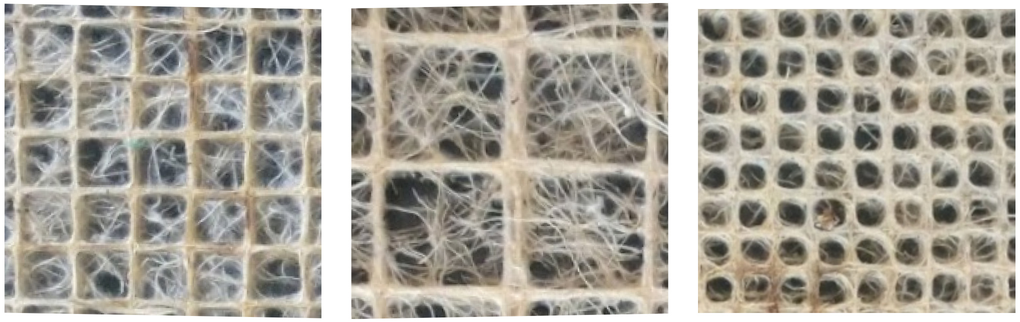
A draft angle (needed for separating roots from templates) also affects the rounding of the pattern. This is most evident with the smallest cell size.

+

A larger pattern size correlates to a stronger response (in tension) and a stiffer material. A decrease in pattern size yields a structure that can deform more and bends more easily.

−

Larger patterns correlate to materials that are less elastic, and are thus more brittle. Smaller patterns have lower strengths than their counterparts.



Examples of different pattern sizes for a square grid pattern: (1) 1cm cell, (2) 2cm cell, (3) 0.5cm cell

Source of Information

1. Chapter 4: Characterization ... Grid Cell Size Tests

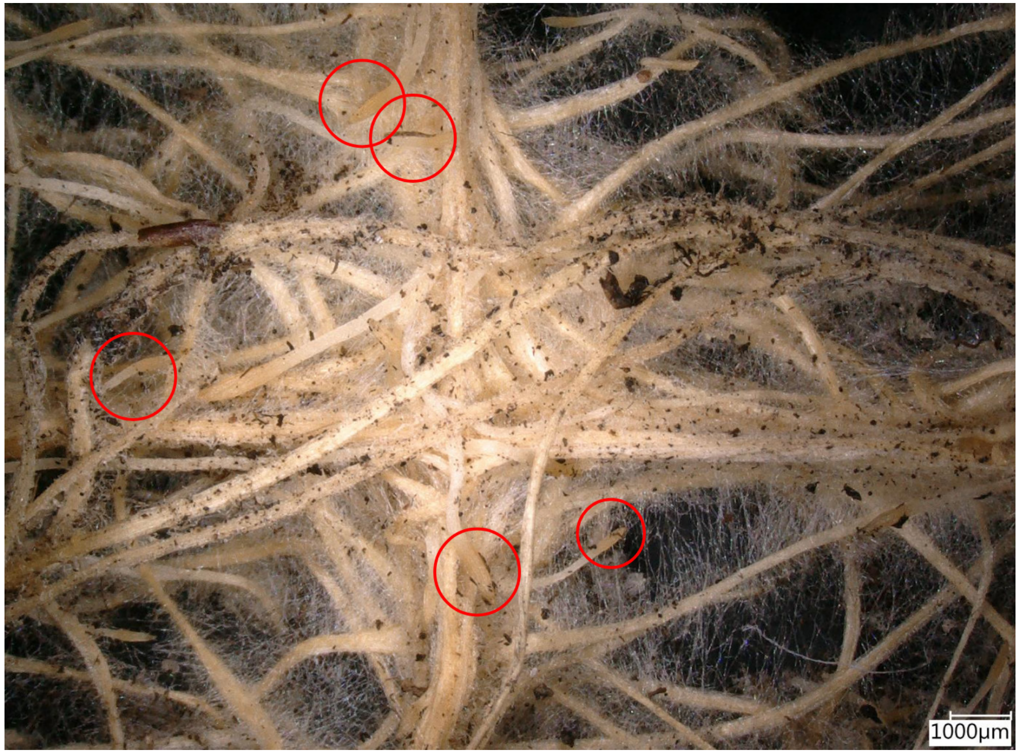
Vertex Root Tip Density

Planting

A microscopic analysis conducted on the tested Interwoven samples revealed that there is a correlation between the number of root tips at a junction of squares and the strength of the material. The parameter for adjusting this density is as of yet unknown, but it is likely controlled in the plant stage. It could be related to cell size or an accumulation of nutrients at the nodes of a pattern, but these are merely speculations at this point.

More root tips at a pattern node lead to stronger tensile properties.

Less root tips correlate to a weaker material and is likely a result of roots avoiding the intersection when growing.



Example of what is meant by root tip density on a cell vertex. The circled areas are the tip of the root.

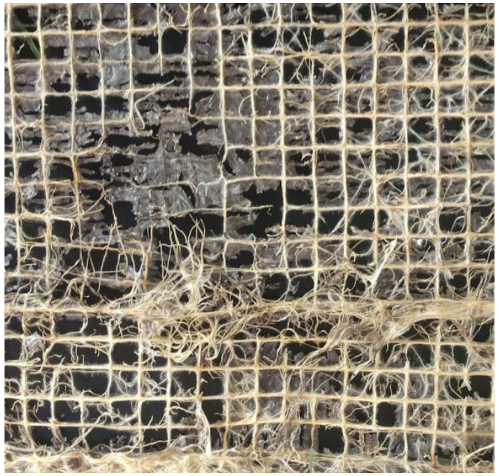
Source of Information

1. Chapter 4: Characterization ... Grid Cell Size Tests
    - Microscopic Analysis
2. Mancuso, S., & Viola, A. (2015). *Brilliant Green: The Surprising History and Science of Plant Intelligence*. Island Press.

Planting

Growing Substrate

The medium in which the plant is grown affects root health since each substrate provides different nutrients. The direct effects on mechanical properties have not been tested, but agar as a substrate leaves behind a thin film that connects some of the roots, which would increase the effectiveness of load distribution among roots.



Roots grown in agar display residual agar as a film (right) or as discoloration (left)

Roots grown in soil have residual soil and more fine root development.

+ Growing roots in agar results in “cleaner” roots with a residual film that improves load distribution. Soil samples have more fine roots developed between the grid cells.

− Residual agar discoloration could increase the speed of decomposition in roots.

Source of Information

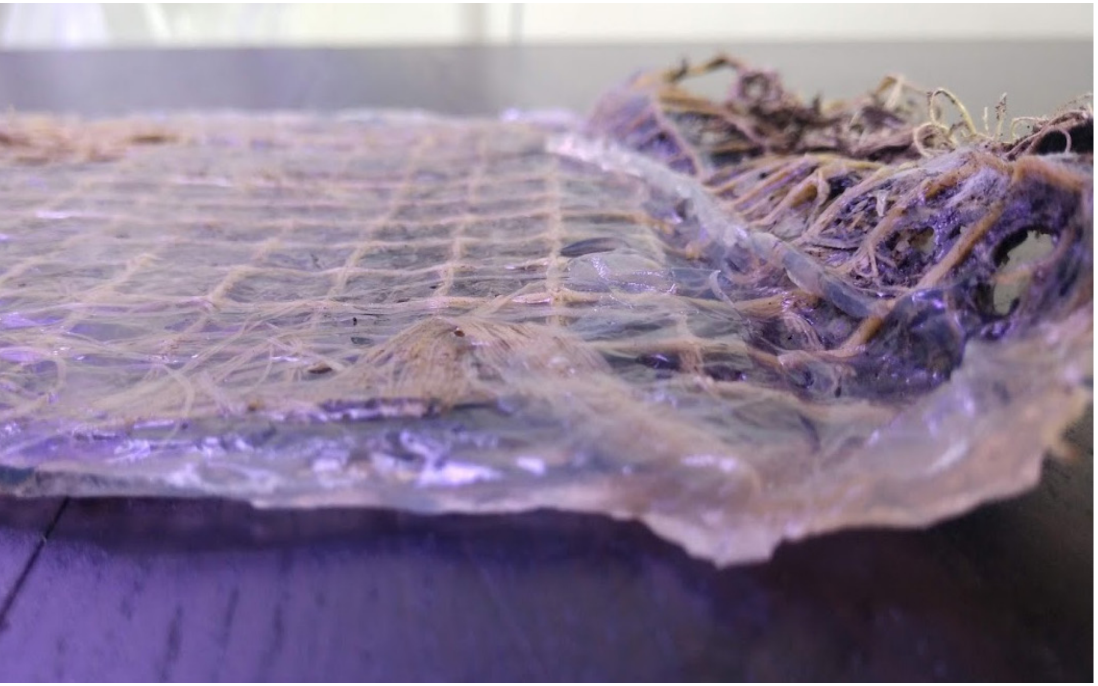
1. Chapter 3: Tinkering ... Fabrication parameters - Composite Design

2. Zhou, J. (2019). *Interwoven: Designing Biodigital Objects with Plant Roots: Exploring Material Structure and Experience* (E. Karana & J. Wu (Eds.)) [Design for Interaction, TU Delft]. https://repository.tudelft.nl/islandora/object/uuid%3Affdcf947-06df-4941-a587-bdf008f87783

Composite Matrix

Processing

Interwoven structures alone are not efficient in transferring a mechanical load amongst the roots, which leads to weak materials. Introducing the use of a compatible polymer matrix improves the transfer of a load and makes the material stronger and easier to handle. However, the matrix that is used has its own properties that impact the strength that the resulting composite might have, so it must be chosen wisely.



Agar gel used as a matrix for natrual fiber reinforced composites (NFRCs)

\+ The use of polymer matrices improves load distribution between the roots in an Interwoven structure. Strength goes up, and the material feels less fragile (in the case of the agar matrix).

− The matrix must be chosen carefully. There are some resins and polymers that are processed at temperatures that could be detrimental to the roots, or they may not adhere to the roots easily, becoming a detriment instead of a benefit.

Source of Information

1. Chapter 3: Tinkering ... Fabrication parameters - Composite Design
2. Ford, D. (2019). *Interwoven: Growing a Durable yet Delicate Composite Textile* (E. Karana & M. Sonnevel (eds.)) [Design f or Interaction, TU Delft]. https://repository.tudelft.nl/islandora/object/uuid%3Af8efc51a-db33-4db9-a74b-10a5d9135b37
3. AL-Oqla, F. M., & Sapuan, S. M. (2014). Natural fiber reinforced polymer composites in industrial applications: feasibility of date palm fibers for sustainable automotive industry. *Journal of Cleaner Production*, 66, 347–354.

Composite Fiber/Root Clamps

Processing

The use of biopolymers for matrices allows for shrinkage and warping when the fibers are embedded into the matrix. To prevent shrinkage, a mold or set of clamps should be used. To prevent any unwanted deformations caused by internal stresses, the mold should be as close to the final dimensions of the piece as possible.

Clamping down the composite while the fibers are embedded into the matrix prevents shrinkage and increases strength.

Cutting the completed composite causes some distortion. The clamp should also act as a mold from which little post-processing is needed.

Example of warping without clamped during preparation (left) and individual clamps for tensile testing (right).

Source of Information

1. Chapter 3: Tinkering ... Fabrication parameters - Composite Design
2. Chapter 4: Characterization ... Composite Tests... Individual