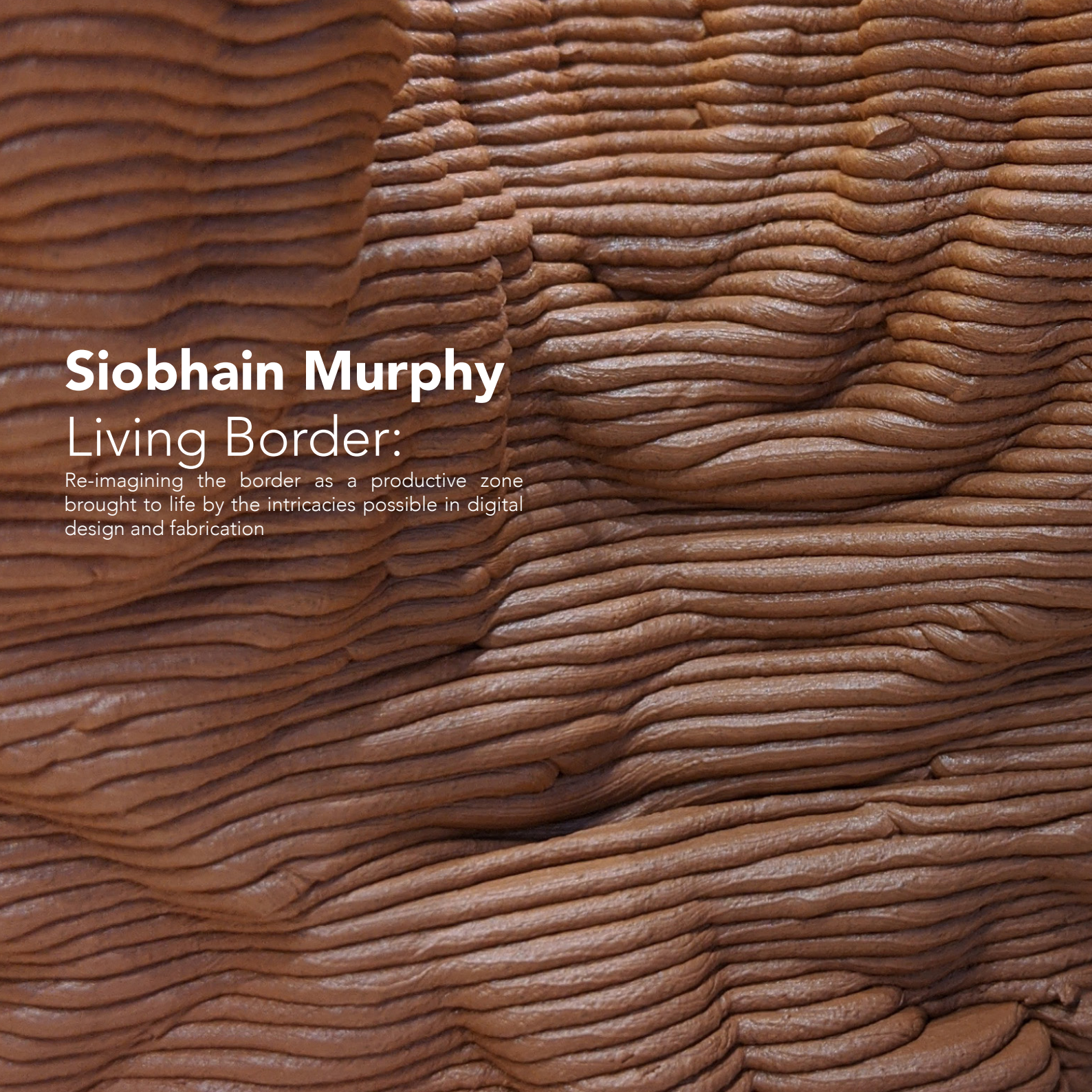

Siobhain Murphy

Living Border:

Re-imagining the border as a productive zone brought to life by the intricacies possible in digital design and fabrication

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Lund University

LTH School of Architecture
Spatial Experiments

AAHM10: Degree Project in Architecture

May 2020

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Contents

Abstract

This project aims to open a dialogue on the role of the border in todays society. Computational design and emerging 3d fabrication technology will be implemented as a tool to create a border typology modeled after the abundant, productive hedgerows found in nature. Experimentation will delve into the possibilities of digital design and how to manipulate and control algorithmic processes to grow a library of forms and systems which can be deployed to create a spatial experience that encourages cross border collaboration, while simultaneously creating an environment for plant life to thrive. 3d printed clay will be used to animate these forms and its inherent qualities will be exploited to increase the performance of this grown space. The surface qualities and tactility of the unusual brick forms can act as an attractor, drawing people to this threshold rather than repelling communities as many border interventions do.

Can we use technology in design and fabrication to re-imagine a border as a place of production and cultural richness rather than a place of separation & reduction?

Introduction

This work aims to understand borders, challenge our need for them and re-imagine their implementation. We have an opportunity to re-learn what a border can be and whom it can serve using digital design and fabrication to create complexity that closer resonates with the complexities of borders.

The first part of this thesis will focus on the injustices and inadequacies of borders by studying anecdotes and the complexity of border region communities. It will study the Northern Irish/Irish border as a rich context where the border can be re-understood and manifested physically through 3d printed clay brick forms. This section will set the scene for the project by understanding the history and difficulties of this border.

The second section will experiment with growing forms with algorithmic processes that capture qualities found in one of natures greatest borders: the hedgerow. Digital form creation and control over the outputs will be tested alongside the development of system to respond to the needs of growing plant matter. Creating a bountiful living border is central to this intervention. Digital design and 3d printing will bring intricacy, performance and visual/tactile interest to this border. This part will include precedents and small studies into growing plants in non traditional ways.

The final section will propose a border structure built from the library of forms generated in the experimental stage.

The Border Context

Part 1: Borders & Their Failures

Part 2: The Irish Border & Its Complexity

1.1: Borders & Their Failures

Introduction to the Inadequacies of Borders

Across the world we dwell between borders. At times these borders are invisible, diminished and passable. In other times the invisible lines become strings of tension, and they manifest physically into walls, fences and fortifications. We work everyday toward global openness, international cooperation and easier movement for the citizens of this world. In many cases our efforts do more to pretend that a border does not exist rather than face the more difficult task of dismantling the physical or imagined boundary. The current pandemic has shown us that the lines we have been smoothing for decades can become tangible, impassable overnight.

Wherever you have borders, defining who lives where and assigning what quality of life you can access, there is the risk that some people become stranded on the 'wrong side' of the border. In many ways the thing that maintains the need for borders is inequality between sides. If both sides were equal we would meet a world without borders.

Borders can be the location to dwell on the inequalities in our society, or they can be a place of cooperation and productivity if we design them to act so.

The 'Wrong' Side of the Border

Wherever the lines are drawn, invariably some people end up displaced. Separate from those peoples and cultures they identify with. Often that which has always been your home becomes a hostile land. Your home has become someone else's. Somehow you have become other, an outsider at home. Our desire to wall things in and out separates and severs people and communities. Is there another way?

(WAÁNATAN, 2018)

Border Failures and Inadequacy Study 1: The Tohono O' Odham

The Tohono O' Odham Nation are native people of the Sonoran desert whose ancestors have occupied the desert for 1000 years, cultivating a lifestyle and rituals in the unforgiving desert climate. Their practices have given them a unique understanding of the life of the desert. In homage to their home they transverse the desert on sacred pilgrimages to ancient holy sites.

The homelands of the Tohono O' Odham have been bisected, first by an imaginary line and later a wall agreed on by others. Their rituals and lifestyle has been severed in two, divided by a wall whose purpose it is to divide the peoples of the United States and Mexico. The wall is not intended to separate different groups of Tohono, yet they are a casualty of this fortification. If we believed in the equality and rights of all people maybe this line would have been drawn around their territory. Maybe we could have left the Tohono whole as we divided ourselves. Maybe a line is not the right shape to divide us. (WAÁNATAN, 2018) ,(Tohono O'odham Nation. 2020)

Border Failures and Inadequacy Study 2: Automatic Citizenship

Emma de Souza, lives in Derry/Londonderry in Northern Ireland. She is fighting a legal battle with the British Government for her right to be Irish and not British. In the eyes of the British Government she has automatic British citizenship since birth as she was born within the United Kingdom, to at least one British parent.

The Good Friday Agreement which brokered peace in Northern Ireland referred to the right of the inhabitants of the North to self determination in terms of Nationality. The agreement recognizes the right of Northern Ireland inhabitants to be Irish, British or both. De Souza has only ever held an Irish passport. Irish is the identity she has always held.

This is a political grey area, as the 1998 Good Friday Agreement (GFA) is contradictory to the laws set out in the 1981 British Nationality Act. In the decades since the GFA this political inconsistency has been left unchallenged until Ms. de Souza. Irish and British citizens have the right to live in each others countries and be treated as the natives of that country. Legally it does not matter what nationality you hold between Britain and Ireland as you will have the same rights and access to the same social structures. There is, however more than legal status to nationality and identity. This uncertainty in Northern Ireland of who you have the right to be is a failure of the Good Friday Agreement. It is a reminder of the complexity of people and their nationalities and identities in Northern Ireland.

Emma de Souza lost her case against the British Home Office. She was informed she must renounce her automatic British citizenship in order to identify as Irish in Northern Ireland. Her appeal against the judgment is underway. (Moriarty, 2019)

These cases show us the failures of people left behind when borders have been drawn. When we reduce borders to nothing more than a sterile line of inside and out. Belonging and alien. If we create more intricate thresholds we can allow life to filter through, like the Tohono O' Odham, or we can create more graduated thresholds which recognize the duality of people occupying the same land such as in the case of Emma de Souza.

"It is the wall that always crosses us."
- R Rael

Across the world wherever there are borders there are people who the line of the border left behind. People who without moving have arrived in a foreign land. Many people have always been in the lands they still occupy, but by the general population they are treated as 'other.' They have become outsiders at home. It's fascinating and devastating how people and cultures can be severed by ideals of power. By the desire to categorize someone else as 'other.' As undeserving. As dangerous. As not worth your empathy. How do we dare to draw these lines?

Our ideas and beliefs in the current social structures keep borders alive. Borders are stark lines, whereas changes in peoples and cultures do not happen at any single imaginary line. People and cultures fit more to a gradient. Slowly changing customs, beliefs and languages over distance. Fitting lines to the gradient of culture will always come up short. Borders might always be unsatisfactory at best and devastating at worst.

Borders have historically been about power and resources and the idea that beyond the border are people who are different or undeserving of the resources within your border. What is the purpose of modern borders? Do we still need them? Are our border conditions like walls, fences and checkpoints still fit for the purpose?

Borders are kept alive today by economic inequalities between sides. Inevitably this devalues the worth we place on the humans, on the less powerful side of the economic divide. The closer we come toward equality the further we erode the need for borders. The emphasis is placed on economic equality rather than demographic equality. A world where human equality trumped economic differences might be a world entirely devoid of borders.

[Typical] Borders are Subtractive

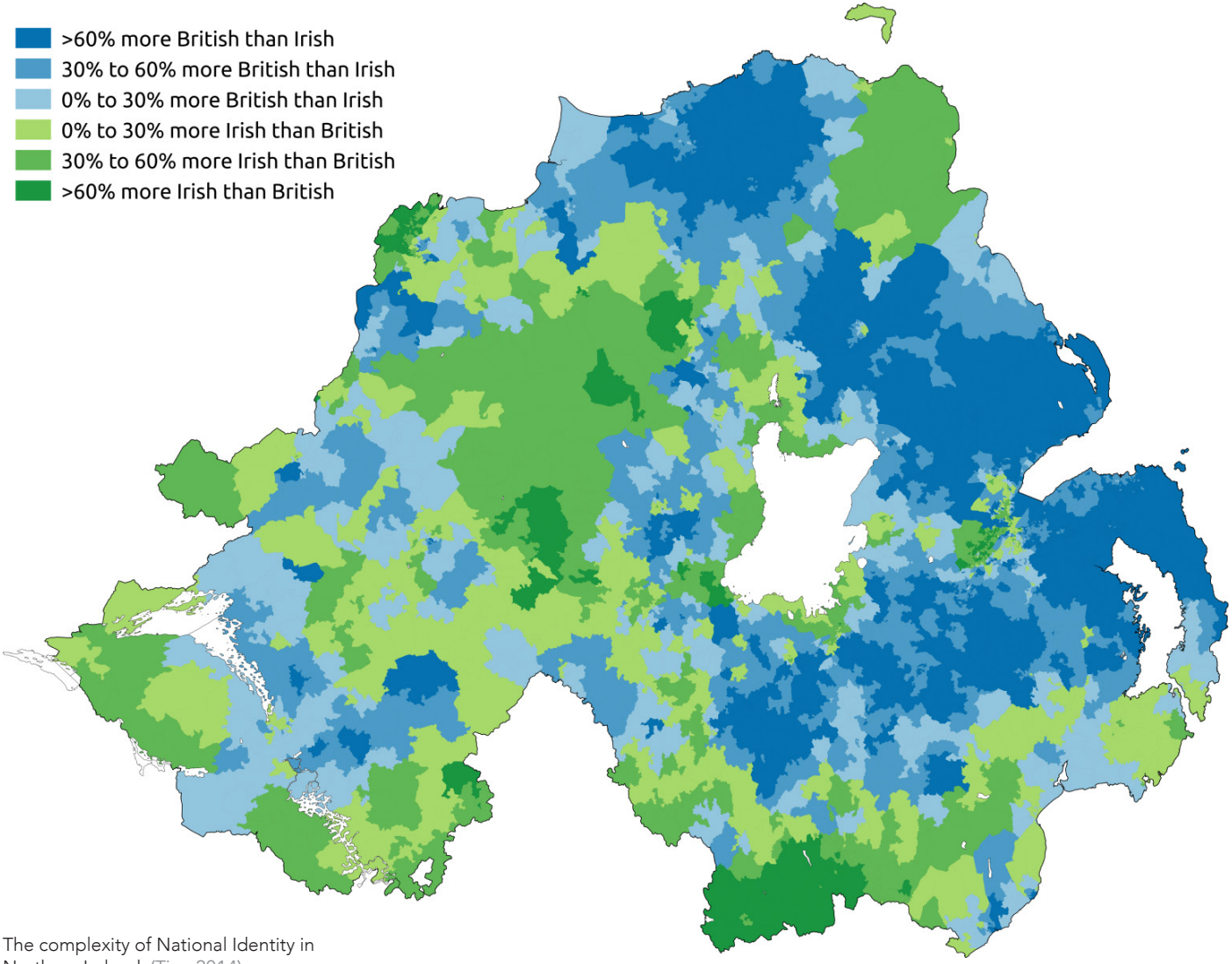
Borders take away so much from us:

Our families and neighbors.
Our access to resources and opportunities beyond the border.
Our complexity, they confine us to generalized groups.

Is there a better way understand a border? A richer way to make boundary conditions? This project aims to re-understand the border as a productive boundary, a human made hedgerow where life thrives off the interdependence of species or peoples.

It is difficult to satisfy every border, everywhere with a single solution. Here we will examine the complexities of the Northern Ireland/Ireland border condition and propose a solution that is inspired by the possibilities of creating a complex boundary condition using 3d printing and biomimicry. This boundary can be a magnetic attractor to the community it serves. A place to celebrate the overlap of peoples.

1.2: The Irish Border & Its Complexity



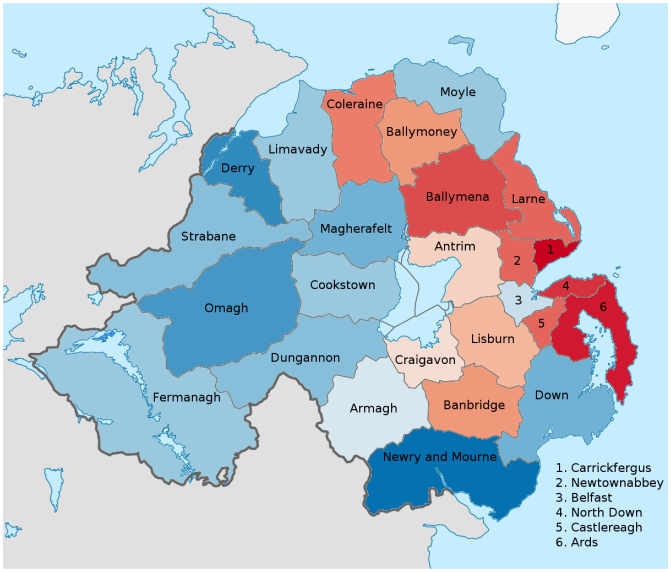
The complexity of National Identity in Northern Ireland. (Tier, 2014)

Making The Irish Border

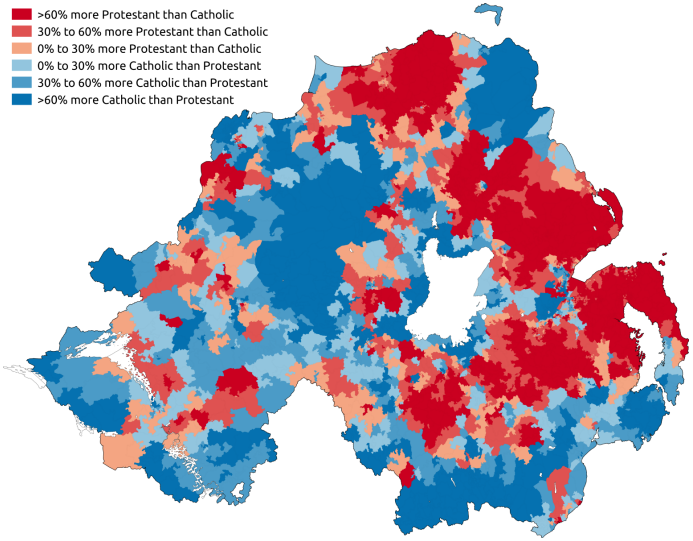
The Irish border had an entire life cycle in the 20th century, it was contrived, existed and (mostly) disintegrated between the 1920s and 1998. Brexit has caused the border to raise it's ugly head and make us aware that the Border never really left us, even if we forgot about it.

During negotiations of Ireland's departure from the United Kingdom a commission was set up to investigate where to place the border by interviewing those in the borderlands. The hope was that the border could be drawn to criss cross back and forth and accommodate the most people possible, allowing them in to live in Britain or Ireland in line with their culture and identity. After two years of efforts to redraw the border culminated in outrage from all sides when the proposed border was leaked prematurely, the project was dropped entirely and thus the border was born without rhyme or reason. The default border adhered to the county borders, much of which had been outlined in the 1300s.

The effect of this was, on both sides of this new partition people were stranded, isolated or abandoned by those they considered their fellow countrymen and women. For the nationalists (those favoring union with Ireland) in the North it was at times a bitter betrayal. They occupied the same land they and their ancestors had always occupied, now they were a minority underrepresented in Parliament and segregated from their native language, culture and identity in the south. Meanwhile, in the South, the violent war of Independence had stirred up anti British sentiment. Unionists (those favoring union with Britain) living there felt their welfare and property was now at risk. The following years saw many abandon their homes and businesses and make their way back into the British Empire due to the hostile atmosphere demarcation had caused. The making of a line gave a physical location to where you ceased to belong in a country that had never before seen a border. (Ferriter, 2019)



(Tier, 2014)



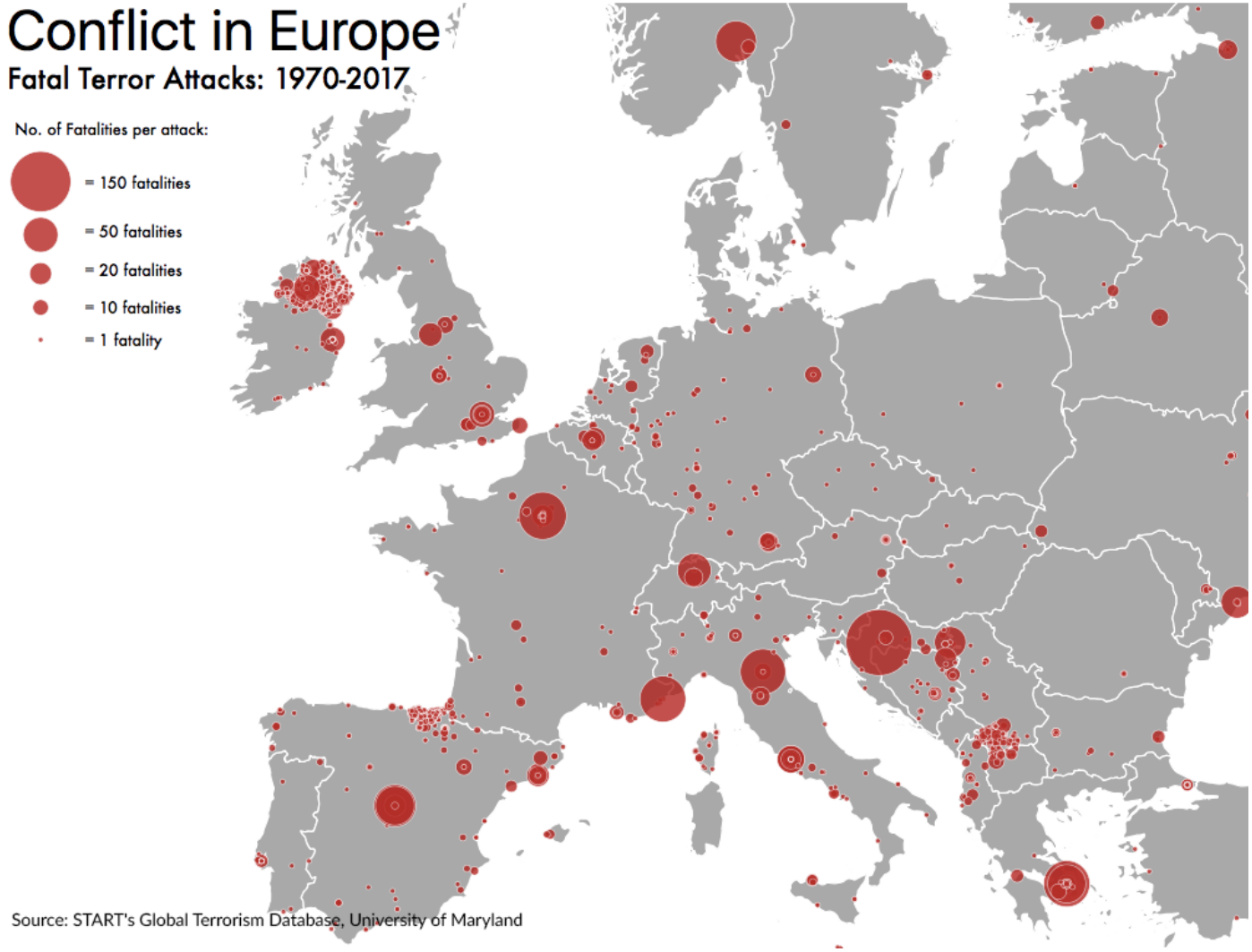
(Tier, 2014)

Resolution of Division

These two maps have the same data source and the show the same information at different resolutions. Both show the predominant religious affiliations in Northern Ireland which strongly correlates to, but is not the same national identity distribution. It clearly shows that as you decrease the resolution, you gloss over many people. The division of Northern Ireland is often reduced to catholic vs protestants, though the reality is much more complex.

The reduction of complexity was one of the drivers of the unrest in Northern Ireland. When so many were blurred over through political gerrymandering, their voices were unheard. Without a forum to enact political dialogue select groups resorted to violence to prompt change.

One of the saddest things that borders do is reduce us to the lowest possibly complexity: us and them. Those within and those outside the boundary. We must learn from this failure of the typical border.


Conflict in Europe
Fatal Terror Attacks: 1970-2017
No. of Fatalities per attack:
= 150 fatalities
= 50 fatalities
= 20 fatalities
= 10 fatalities
= 1 fatality
Source: START's Global Terrorism Database, University of Maryland

The Troubles & The Peace Process

The Troubles, which began in the 1960s and lasted until the Good Friday Agreement, was a time of profound aggravation and distrust between groups with different identities in Northern Ireland and border communities in the South. More than 3500 people lost their lives in bombings, abductions, police killings, retaliation killings and assassinations. Innocent bystanders were often caught in the indiscriminate bombings. The 1998 Good Friday Agreement brokered Peace which has largely prevailed. The Good Friday Agreement recognized bi-nationality and the possibilities of bi-governance where the Government of Ireland could become a consultant in the running of Northern Ireland.

An important part of the Good Friday Agreement was the devolution of power to Stormont, the Northern Irish Assembly, so more governing could take place in Northern Ireland, rather than London. The Northern Irish Assembly has been suspended or dissolved five times since 1998 caused by a breakdown in the Peace Process and cooperation between political parties. Power reverts back to London. The peace and cooperation is still tentative.

Suspensions:
11 February – 30 May 2000
10 August 2001 (24-hour suspension)
22 September 2001 (24-hour suspension)
14 October 2002 – 7 May 2007
9 January 2017 – 11 January 2020

Apathy

Eavan Boland described the Troubles in her poem the War Horse, where neighbors use the 'Subterfuge of Curtains,' to hide from the realities of the destruction in this Western corner of the British Empire. The Irish and British governments and many of their citizens turned a blind eye to the Troubles. They hid behind the borders or distance between them. Northern Irish, Irish were abandoned by those in Ireland and Northern Irish, British were forgotten by their fellows in Mainland Britain. The Border was a convenient line beyond which was not your concern.

Irish Times

Border Porosity

A commission set up post Brexit to survey the border found 208 official road crossing between Ireland and Northern Ireland. In comparison the entire eastern front of the EU has only 120 Border Crossings. The porosity of this border is one of it's greatest challenges to lawmakers but one of its more powerful attributes in the campaign for cross border relationships and peace.

Internal/External Border Overlap

The current rules of the Border are unclear due to the delay in Brexit negotiations.

This is no longer a single border, but an overlaying of multiple borders with conflicting filtration criteria. This is an **internal** border within the Common Travel Area (CTA), an agreement similar to the Schengen Agreement but concerning only Britain and Ireland and allowing the free movement of people within the CTA. This is an **external** border for the EU. Irish and British citizens can cross the border unhampered if they travel without taxable goods. What about third country citizens who legally travel to Ireland but illegally transverse the border to Northern Ireland? All parties at the Brexit negotiations table want no return to the Hard Border with physical checkpoints and immigration control but no one knows how to achieve this while satisfying the paradoxical natures of the Internal/External Border Overlap.

Current proposals suggest that Northern Ireland remain inside the customs zone of the EEA, though outside the EU. This means that Northern Ireland will have a customs border with Britain. This proposal has yet to be ratified in Northern Ireland. Even in the event that the law passes, it will be up for review every four years. Northern Ireland is stuck in cycle of economic uncertainty and identity uncertainty. Maintaining connections to Britain, Ireland and the EU, but with obstacles that prevent total participation in any of theses unions or relationships.

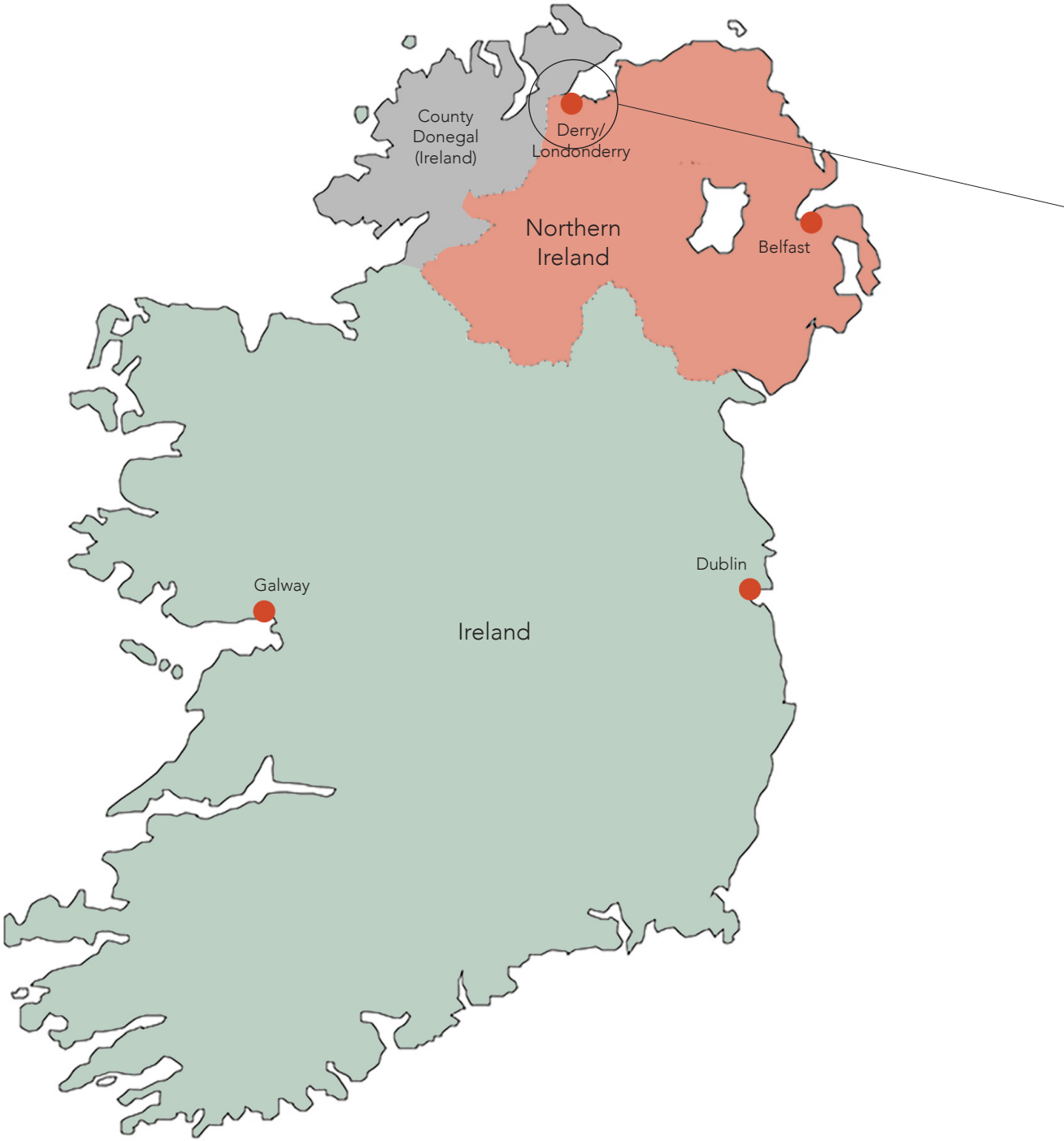
Re-Imagining the Border

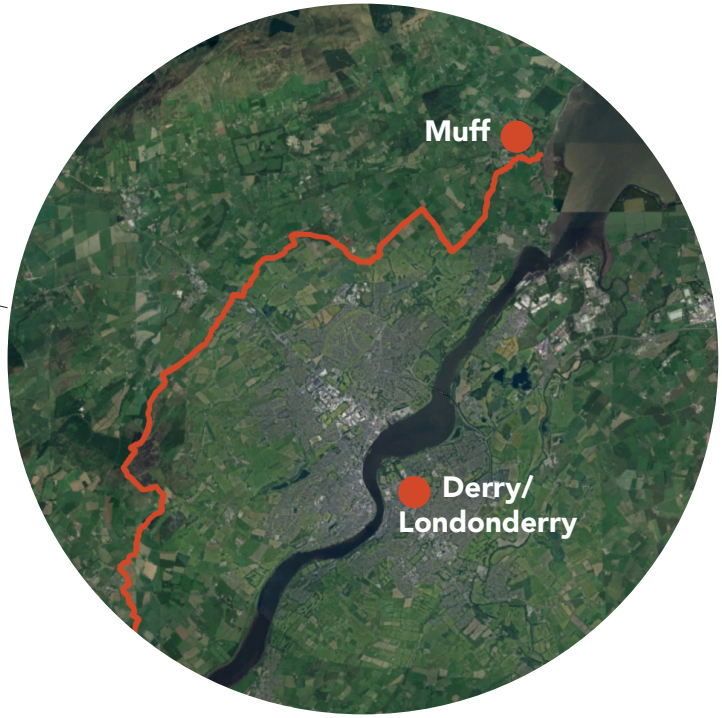
This project aims to re-imagine what a border can be, how a threshold can provide for the communities it surrounds. Can a border be the place to heal the scars that very same line brought about? Can the growth and nurture of plant life create a living border where both sides come together to care for their divisor. In building a living border we may dismantle the prejudices, grievances and animosities that have prevailed in some border communities.

What role can digital design tools play in building a new human-made hedgerow where the fertility and efficiency of growth break down some of the futilities of this border. Communities from either side can walk this line and pick fruit and vegetables from the only thing that equally belongs to both of them, the border that divides them.

If we rediscover a border with new purpose, new tools and unfamiliar forms we can rewrite what that border means to the communities that are divided by it.

The border line


County
Donegal
(Ireland)
Derry/
Londonderry
Northern
Ireland
Belfast
Dublin
Galway
Ireland

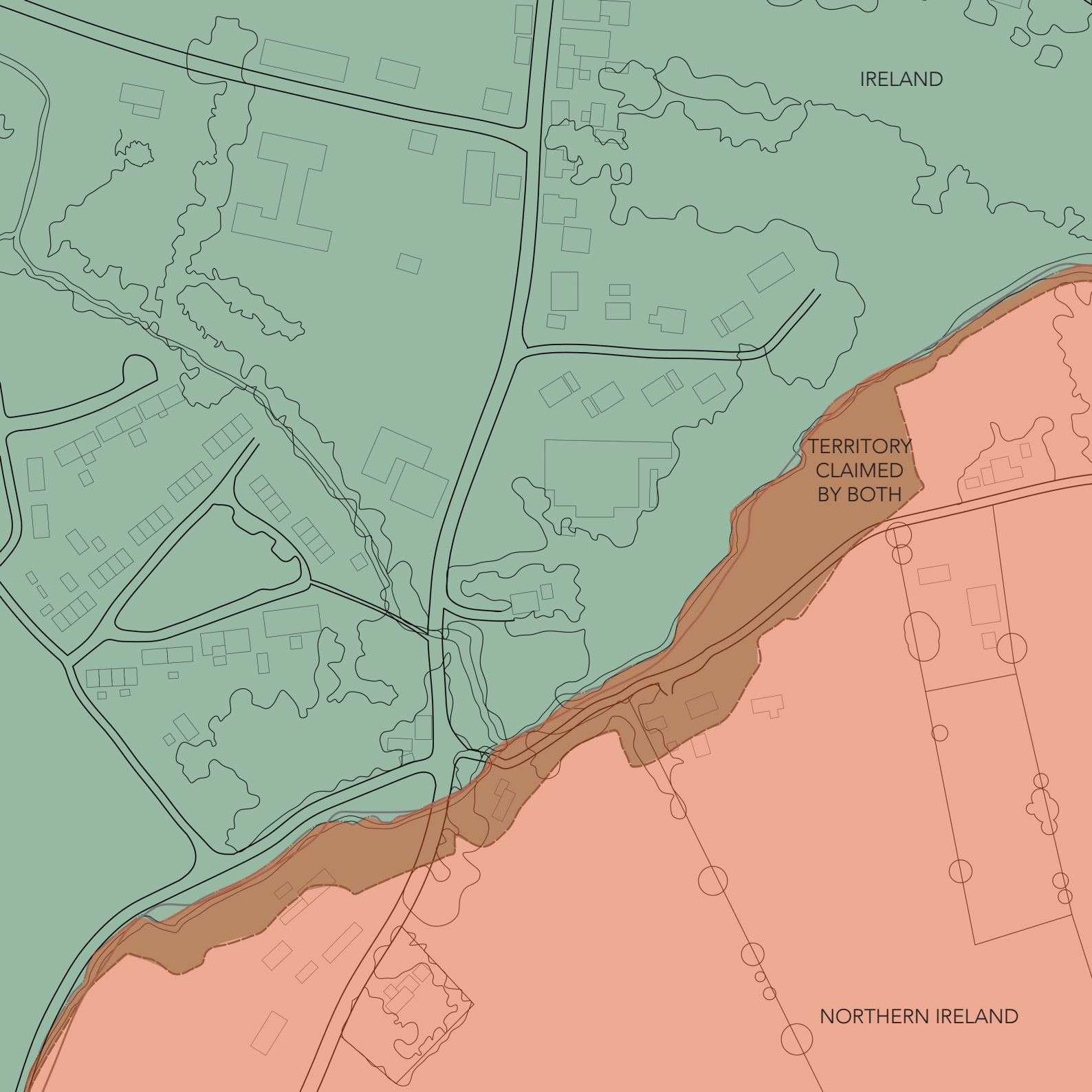


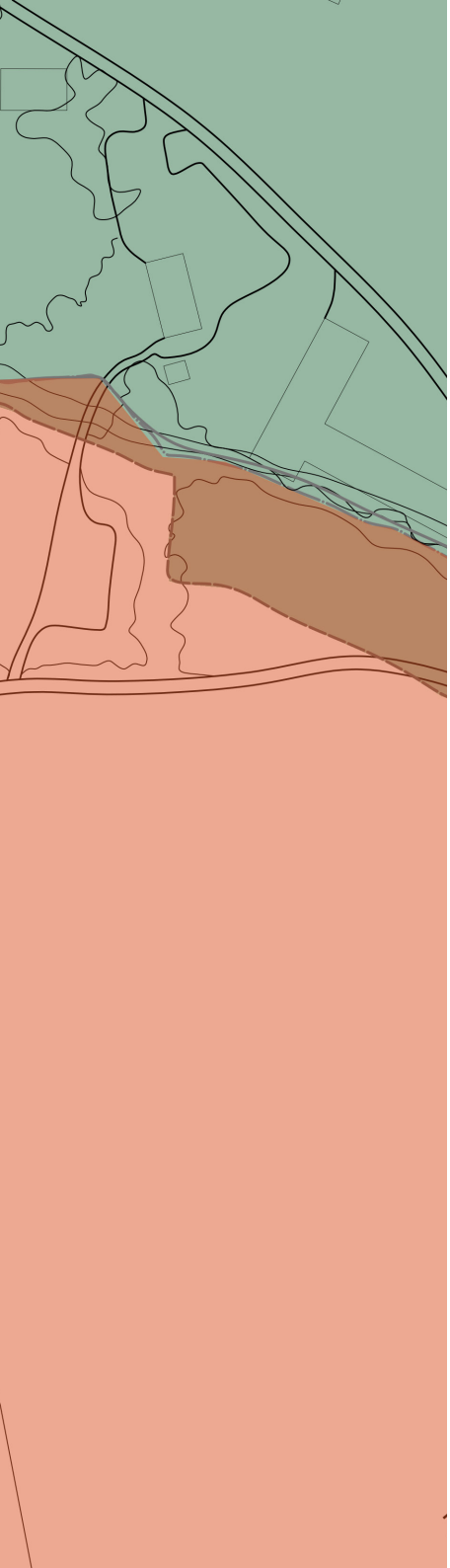
The Location

This project takes place on the Donegal/Derry threshold at the Northwest end of the border furthest from the Dublin/Belfast corridor where the crossing between both capital cities is smoothest and least contentious. In more rural areas animosity has lingered. Donegal, in Ireland has perhaps suffered more than any other place in the Republic of Ireland since partition. Donegal is almost cut off from the rest of the South, with only two roads passing through the town of Ballyshannon connecting them to the rest of the country.

Donegal relies much more closely on cross border ties. After the separation of the state, the people of Donegal lost their railway connection. Their main hospitals have been downsized with a push to send patients to Dublin some 3 hours away (through the North) and Galway some 3.5 hours away. In times of a hard border Donegal is very isolated. In times where the border recedes Donegal is very reliant on nearby economic center of Derry/Londonderry. Where access to higher education, shopping, train stations, airports, ports, freight communications and hospitals are 30 minutes away rather than 3 hours to the closest Irish cities.

While Donegal has been under-served since the border came into being, Northern Ireland had been underrepresented politically. Difficulties between political parties have lead to impasses, which has resulted in Northern Ireland being governed from London rather than their own parliament in Stormont. Without its own government it, Northern Ireland has suffered. Both Northern Ireland and Donegal are often left out and left behind in the progress made in London and Dublin.


IRELAND
TERRITORY
CLAIMED
BY BOTH
NORTHERN IRELAND



The Inaccuracy of the Border

'People talk and act as if the border were something as impenetrable and controllable as the Berlin Wall,' but as he pointed out, the border is not actually visible...
D, Ferriter quoting J, Peck in 1973

One of the long standing issues of the border has been its inaccuracy and intangibility. At many border crossings there is not even a sign to alert you that you have transversed an international line. You may notice that speed limits have changed between mph and km/h or you might not. Many sections of road straddle the border so that one lane is in Northern Ireland and the other is in Ireland. While it benefits everyone to reduce to physical imposition of the border, simply ignoring it might allow the power of it to simmer on undetected. If we face the border and recognize it head on, we can do more to dismantle the prejudices it fostered and generate a new productive border type.

The border lines on the left are taken from the websites of Ordinance Survey Ireland and Ordinance Survey Northern Ireland. The borders do not align. This mistake could germinate an idea that becomes a positive attribute of the border. Those who live within a certain distance of the border could hold cross border nationality, and passports. We could move towards borders that are more than a line, that better serve the communities who dwell on and around them.

The following scheme takes place on the north edge of this territory further smoothing and diluting the border.

Design & Fabrication

2.1: Ideation and Precedent

2.2: Digital Design and Fabrication

2.1: Ideation and Precedent

Hedgerows

Hedgerows have become a source of inspiration in this border. They are a naturally occurring divisor that is permeable and porous to wildlife and growth. Hedges are green highways across our mono-cultural agricultural fields, connecting habitats and allowing for the survival and nurturing of small animals and interdependent plant life. Hedges are boundary conditions to strive for, where the border is more fertile, productive and teaming with life than the places between the borders.

Mono-cultures prevail between borders, but borders themselves can be places of richer culture and better interdependence and multiculturalism, if we design them to perform for us.

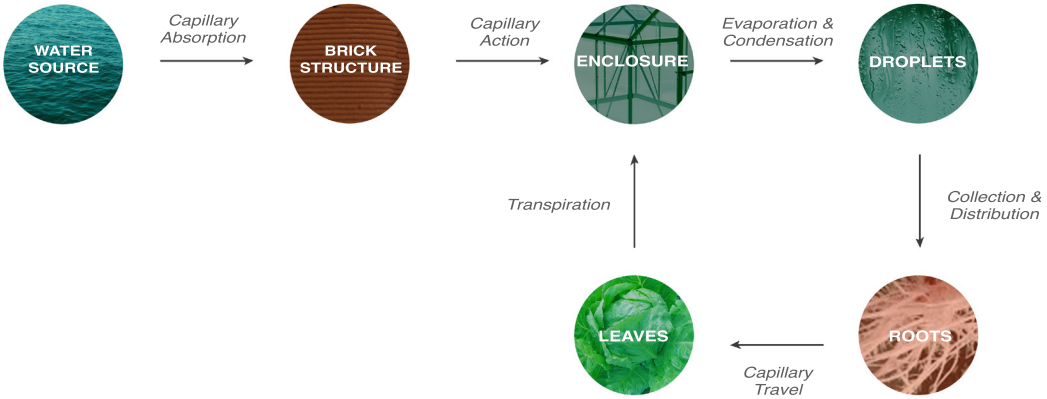
Biomimicry

Biomimicry in architecture gives us the opportunity to take inspiration from solutions in the natural world and apply them to architectural problems. Qualities of a hedgerow to mimic:

1. Porosity: allowing certain scales such a pedestrians and wildlife to filter through.

2. Growth: Hedgerows promote growth and create fertile environments for many scales of life to thrive.

3. Interdependence: The overlaying of species and varieties of plant and animal life make a stronger ecosystem than a mono-culture.



Proposed water cycle.

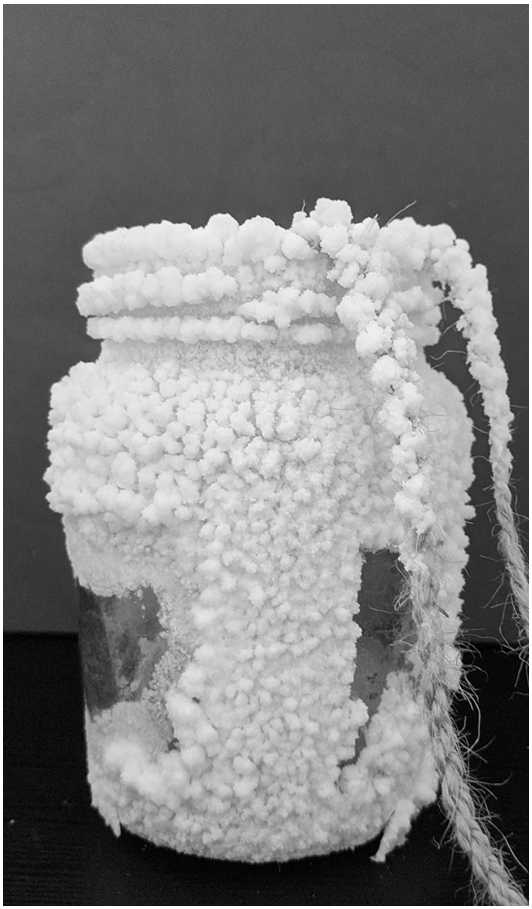
A Strategy for the Irish Border

To bring life to this boundary an ecosystem will be developed on the border line. At this site the border line predominantly follows the stream allowing us to feed off the water source and transport water to growing systems above.

Growth algorithms will be used to develop a brick structure that emerges from the ground and creates a greenspace above providing a climate to support plant life. Water will be passively transported through strategic elements of the structure using capillary action.

Capillary (CA) is a means of passively transporting water from its source to the growth environment. CA is caused by water particles having more attraction to a medium (adhesive forces) than to its neighboring water particles (cohesive forces). CA is observed in many building materials including wood, concrete and brick. CA is most effective at transporting water in materials with the smallest porosity. For example water will travel further in brick than concrete due the pore size.

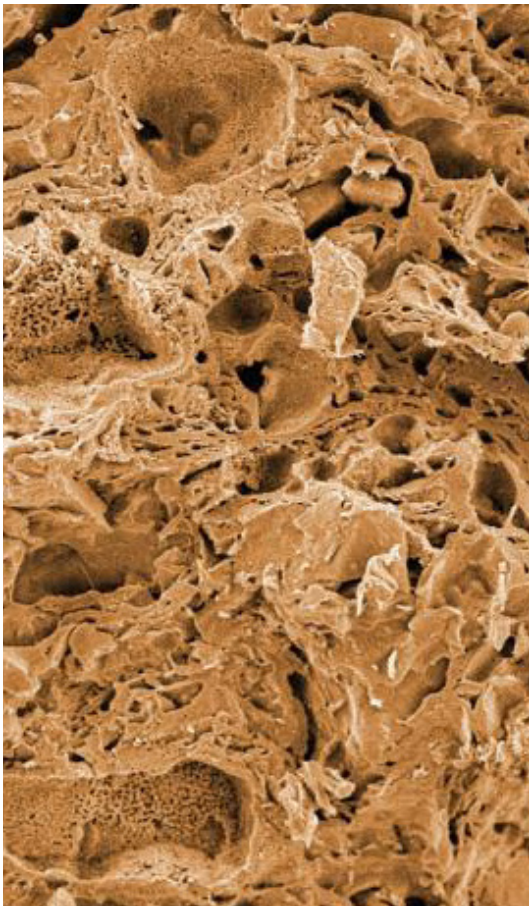
This project uses capillary action in 3d printed brick to passively transport water from the boundary stream to a growing environment above. In the enclosed growing room, the temperature difference will cause the carried water to evaporate and condense on the interior of the glass. This water has been filtered by the brick and purified in the evaporation process. This water can then be redistributed to unique growing environments.



Testing the ability of capillary action in twine to cause salt water to climb up the twine and out of the container. Instead of following the twine, once the water reached the lip of the jar, it ran down the face of the glass, taking the path of least resistance. If the twine was not in contact with the glass, the water would have followed the twine.

Capillary action evident in fired clay, using salt water, which leaves evidence of the path taken after the water is evaporated. This image shows that the action is not only vertical, but is space filling. The salt residue can be seen in the overhang, which is not part of any vertical path.

Capillarity



(Zarhi, Burko and Burko, 2020)

The micro-structure of fired brick pulls water from the stream to the growing environment above.

(Zarhi, Burko and Burko, 2020)

This capillarity of brick gives rise to the possibility of using this material as a container for a hydroponic growing system.



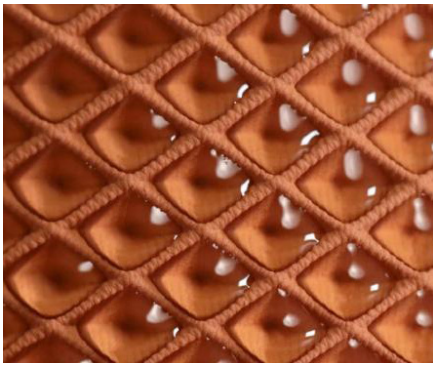
(Ocean Reef Group, 2020)

Growth Precedent 1: Nemo's Garden

Nemo's garden is an underwater growth experiment where a hemispherical air bubble is secured to the seabed. The air bubble is open to the water below and due to a temperature difference between the air inside the biosphere and that of the water surrounding it, the surface of water inside the biosphere evaporates and condenses on the interior lining of the sphere. This water has been passively desalinated and is used to feed the plants within the system.

General agricultural accounts for 70% usage of the worlds fresh water supplies, this project rethinks our usage of water supplies. Growth in this environment also negates the need of pesticides.

Basil grown in this environment was more fragrant than that grown in a standard environment due to increased pressure in the underwater biosphere causing an increase in the aromatic oils. (Ocean Reef Group, 2020)



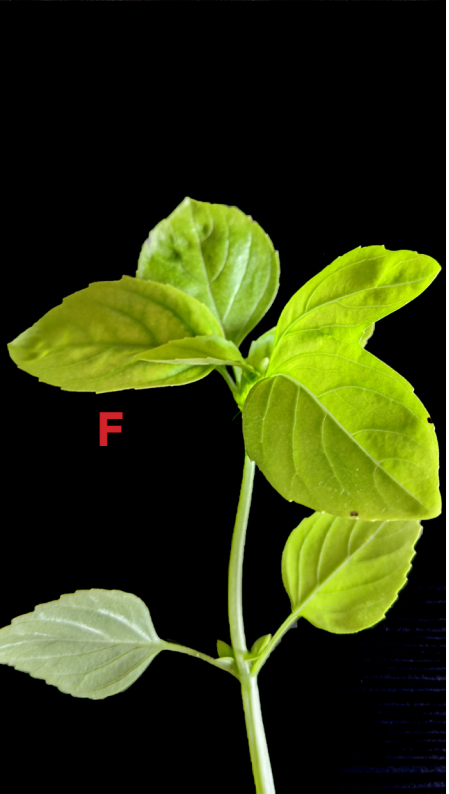
(Zarhi, Burko and Burko, 2020)

Growth Precedent 2: Terraplanter

Terraplanter is a hydroponic growing vessel made of cast ceramic. The hollow vessel is filled with water which is slowly absorbed by the micro-pores of the ceramic structure and travels to the outside of the vessel. Specially designed pockets hold the water allowing the plant to drink. The surface is carefully textured to encourage plant roots to grip. The roots have access to a constant supply of water and oxygen, and the medium of soil is dispensed with.

This project displays the unique characteristics of clay and its suitability as an environment for growth. (Zarhi, Burko and Burko, 2020)


A
B
C
D



Hydroponics Growth Test

This hydroponics test was carried out on a specimen of basil originally planted in soil. Two cuttings were taken from the mother plant and submerged in water for propagation. This study began in winter and for the first eight weeks both the parent plant and the cuttings were mostly dormant and slow growing.

The submerged cuttings were started in a glass vessel. To ensure success you must keep the water level above the roots and change the water once a week, as the roots are absorbing the oxygen from the water source, and to prevent water stagnation from promoting unhealthy bacteria. This is especially important in the early phase.

As spring approached and growth accelerated, the plants were moved to a terracotta vessel, where 5-6cm of water were added every three days. The water was no longer changed in its entirely, merely topped up. As the water is absorbed and evaporated through the clay walls stagnation is avoided due to the slowly moving absorption and evaporation cycle.

The clay material is near the perfect intersection of solid and porous, to allow for only a gradual need for refilling.

A & B show the leaves and roots of the hydroponically grown basil specimens. C & D are taken from the parent plant in soil. The roots were much darker and more frail than those of A & B. They were so weak that some were lost when they were removed from the soil. The diameter of the individual hydroponically grown roots was larger than that of the roots submerged in soil.

E shows the terracotta plant vessel filled with water.

F shows the leaf shape of the hydroponically grown specimens. The leaf shape was much broader than the specimens grown in soil which were comparatively long and narrow.

2.2: Digital Design and Fabrication

The Role of Digital Tools in Design and Fabrication

Digital design tools in the form of generative and growth algorithms aid in form finding, space generation, visual interest and adding performative intricacy to this border proposal. Grasshopper for Rhino is used as a parametric design tool to generate individualized forms in the landscape. Forms, inspired by growth seen in nature make a porous boundary that locally responds to criteria for structure, capillarity, evaporation or space making.

Using algorithmic design in conjunction with 3d printing allows us to add complexity to our border proposal. Complexity that elevates this border above a mere line, creating a gradual, porous threshold. Complexity that adds performance to the structure and facilitates it to support the growth of plant life. Complexity which creates undulating, unexpected forms and tactile experiences which act to draw the community in and allow this border to attract rather than repel.

Glossary of Terms in this Section

Cura:
3d models can be imported in to this software and sliced into layers. Cura then creates Gcode for the 3d Printer to read. See Gcode.

Deliminator:
A tool that works within Silkworm, to customize the printer movements at the beginning and end of extrusions. These include move up/down, retract filament. These movements and retractions are described by vectors and magnitude.

Differential Growth:
This growth can be observed in flower and coral, where localized growth occurs at a faster rate than elsewhere in the organism.

Gcode:
File type describing movements and extrusion to the 3d printer. Can be auto-generated with a slicing program like Cura, customized with the silkworm program. Or written in plain text code.

Grasshopper:
Plug-in for the modeling software Rhino. Allows parametric control and scripting in Architecture and design.

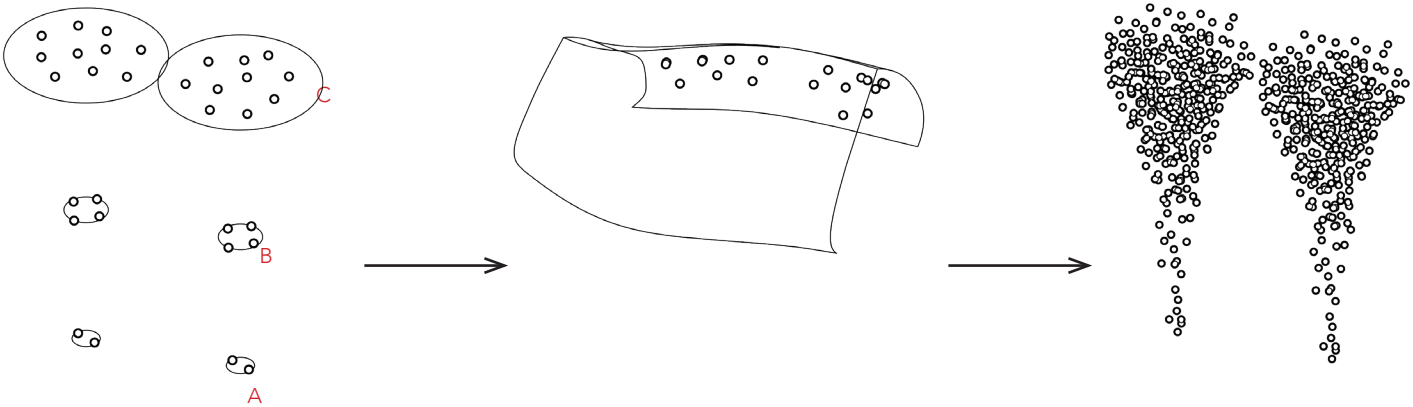
Kangaroo:
Physics simulator component within Grasshopper.

Meshmachine:
Re-meshing component in Grasshopper.

Rhino:
3d modeling software

Shortest Walk:
Component within Grasshopper that generates path. Used here to simulate branching.

Silkworm:
Component within Grasshopper. Generates customized gcode allow greater control over print settings.

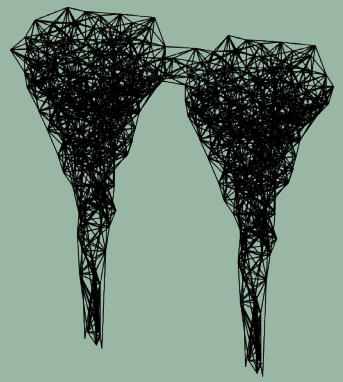


1. Source points (A) and target points (B & C) are input.

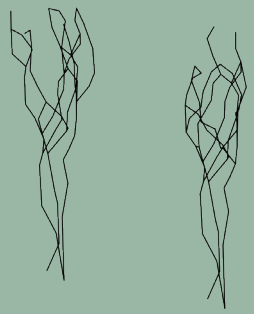
2. Target points (C) are pulled to the roof so that the column grows to fill the available space. An offset is allowed to prevent intersection

3. A cloud of points is generated surrounding the target and source points.

Simulating Branching with Shortest Walk

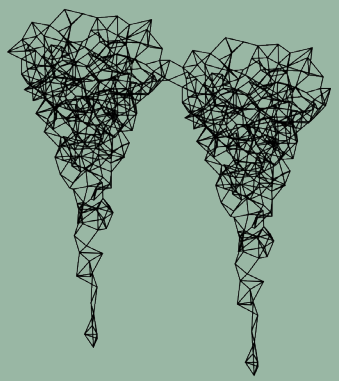


4a. Search for 3d proximity in the point cloud. This example searched for 9 nearest neighbors and creates links between.

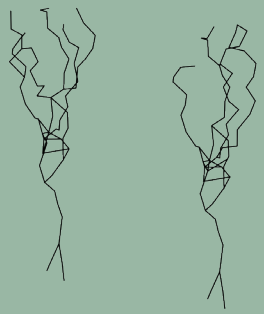


5a. Shortest walk between source and target points. Path is more direct when links are created to more neighbors. This increases verticality which is important for success in clay printing.

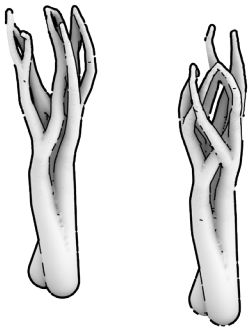
OR



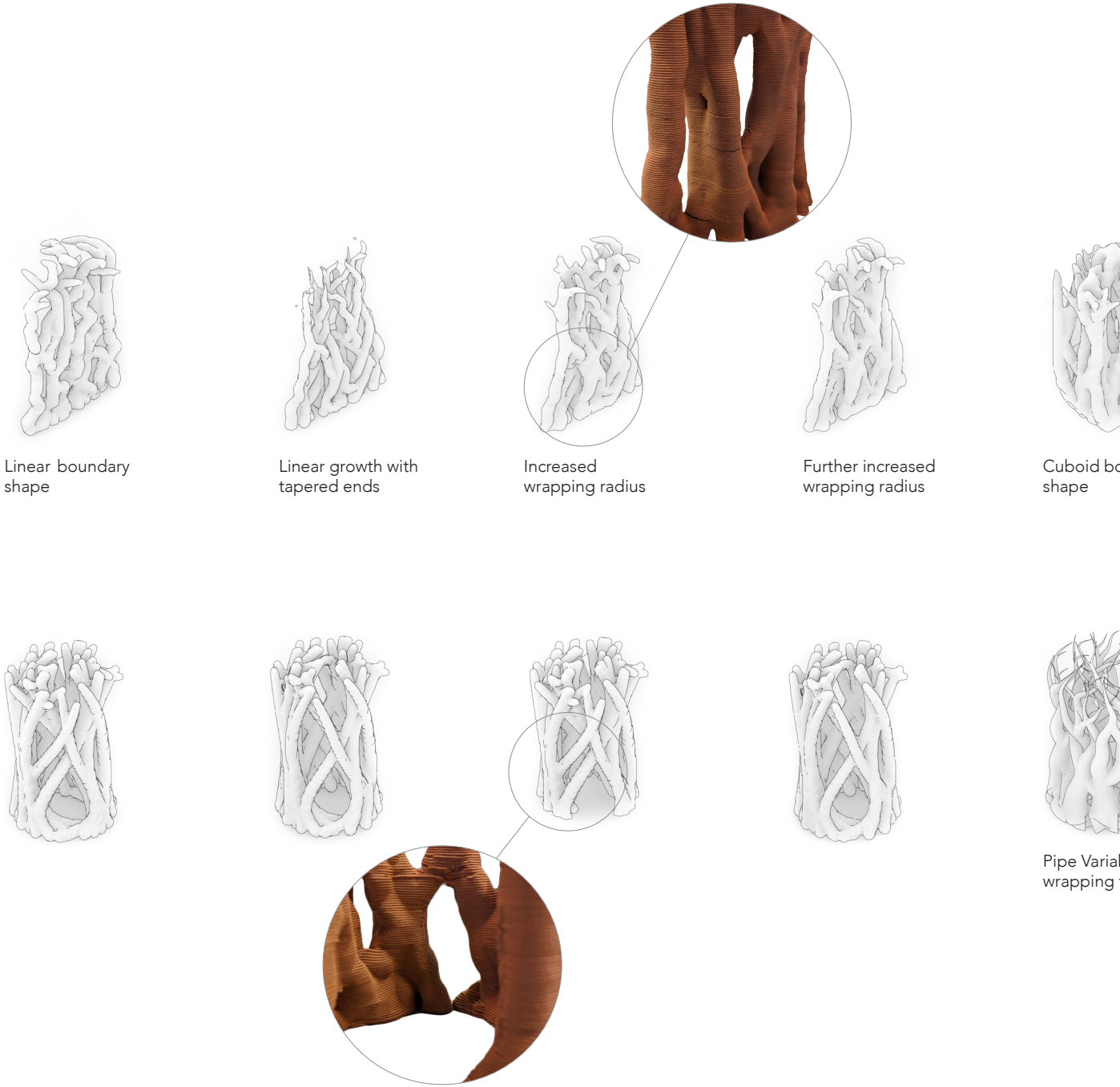
4b. This example searched for 5 nearest neighbors and creates links between.



5b. Shortest walk generated path with more horizontal travel than 5a

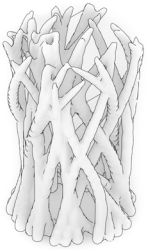


6. Curves generated from shortest walk are divided in a list of points which are then wrapped in spheres with a range of radii. These spheres are then unified into a single mesh.


Linear boundary shape
Linear growth with tapered ends
Increased wrapping radius
Further increased wrapping radius
Cuboid bo shape
Pipe Varial wrapping

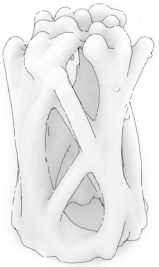
oundary

Cylindrical boundary shape

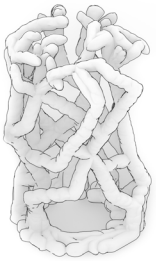


Decrease wrapping radius

ble
tool



Smooth polyline input and mesh output



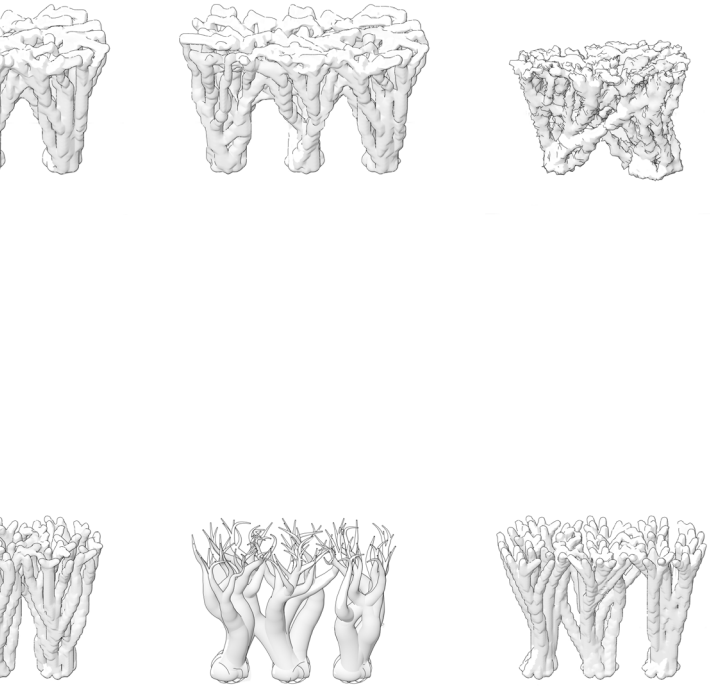
No smoothing

Form Finding

Tests using shortest walk component to simulate branching in Grasshopper. Parameters being modified:

Input boundary geometry
Polyline smoothing
Geometry wrapping with Cocoon
Geometry wrapping with pipe variable
Cocoon wrapping parameters
Output mesh smoothing

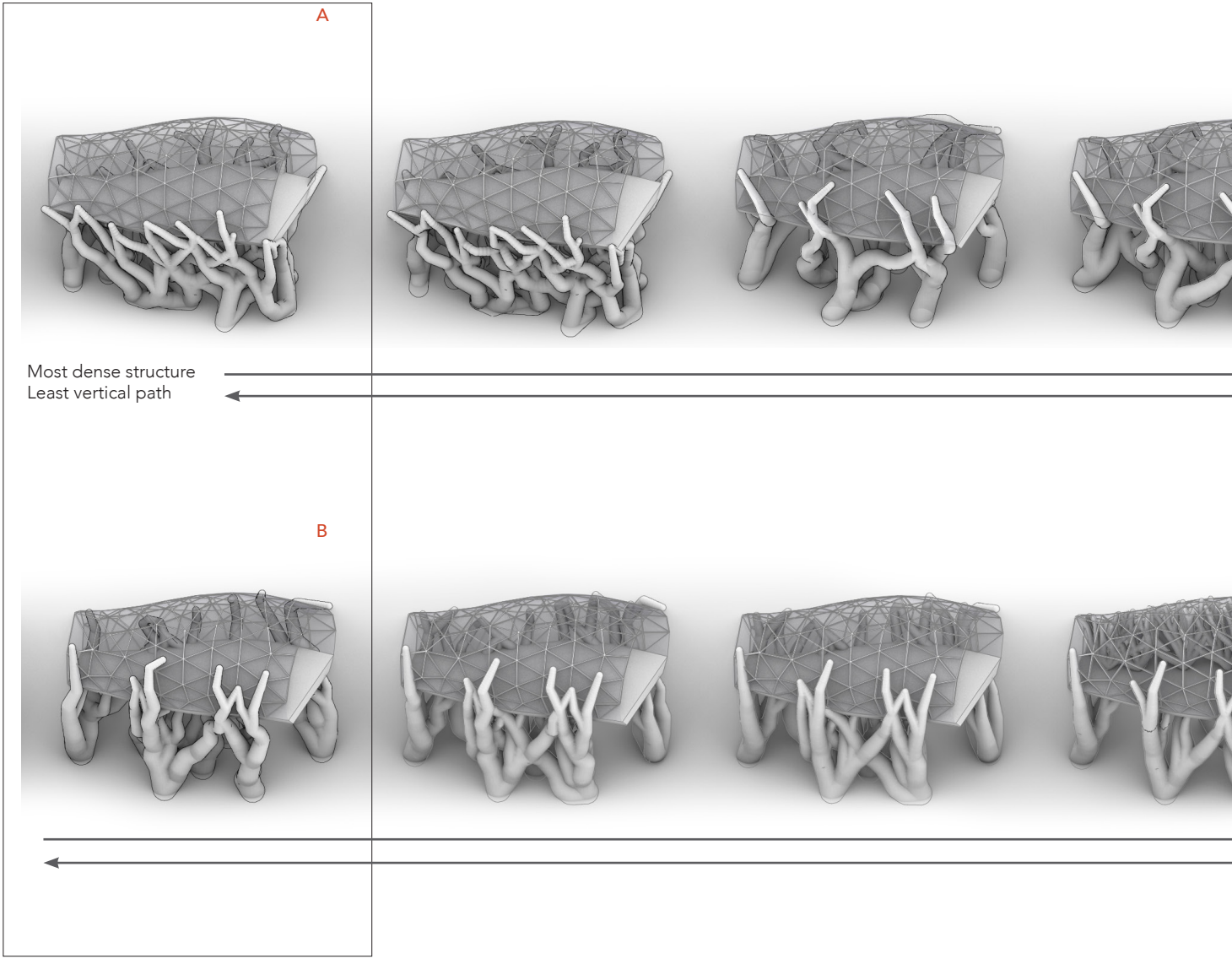
This stage investigated how to control the tools and generate porous brick structures. Early test prints confirmed the printability of the forms and overhangs. A clearer picture of the desired outcome was needed to continue.

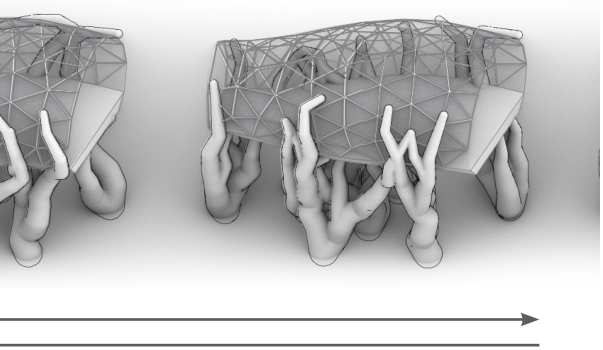


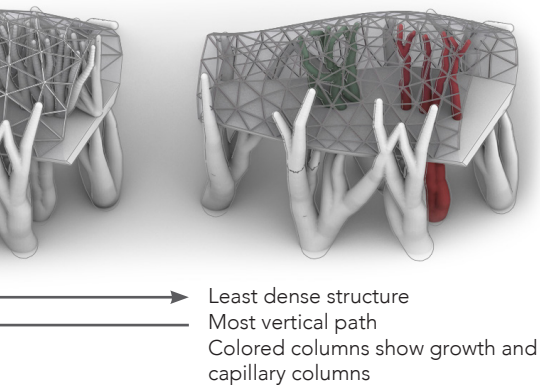
Form Finding 2

Testing distinct elements growing from individual source points to common target points allows for branches not to be cantilevered as in a standard tree branching. Growing from different sources to similar target points allows for branches to be mutually supporting structures like arches. Keeping these forms in the realm of what is possible to be 3d printed in clay was a constant undercurrent in this process.

The prints were continually successful in printing and supporting their own weight. Further structural test would be necessary but from this point it was assumed that successful self supporting prints were feasible.


A
Most dense structure
Least vertical path
B





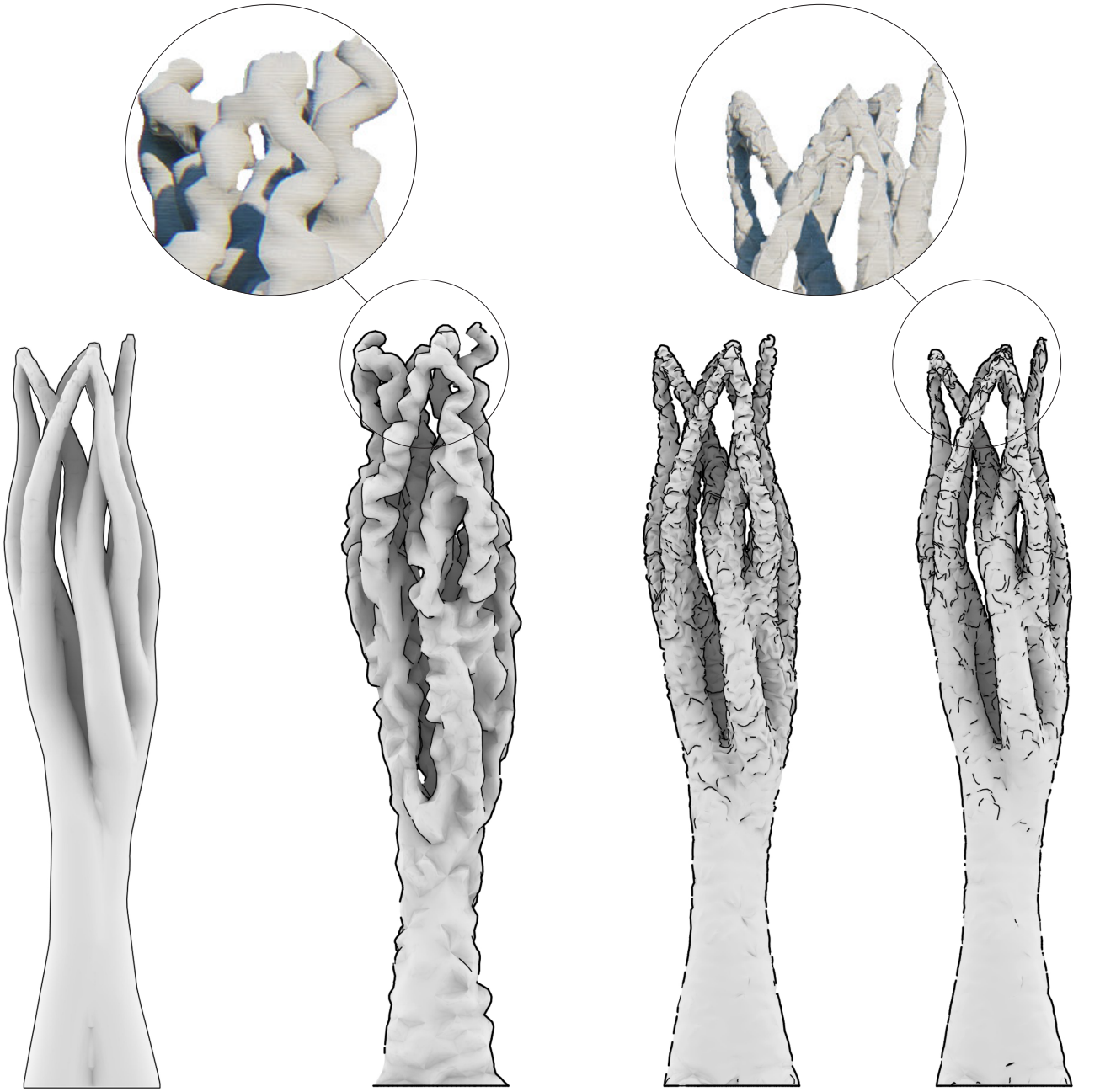
Application and Distribution

Test showing the logic of a border hedgerow with open porosity below and contained greenhouse above.

These tests vary the density of the structure and the verticality of the pathways. The dense structures were visually interesting but very much a barrier, at this scale a human could not pass the threshold. The closer to vertical the pathway, the easier the print and the greater the structural performance. However the most vertical structures were too reduced and lacked the expression and tactility of the more organic paths.

These experiments facilitated finding a balance between performance (structural, capillary etc) and aesthetic and interest.

Strategy A & B were carried forward. A to be used in the growing chambers were the load carried by the structure is greatest, and B in the walkways between where the load is lighter. This created a continually changing boundary, which at some points you can easy walkthrough and others where you must walk around.

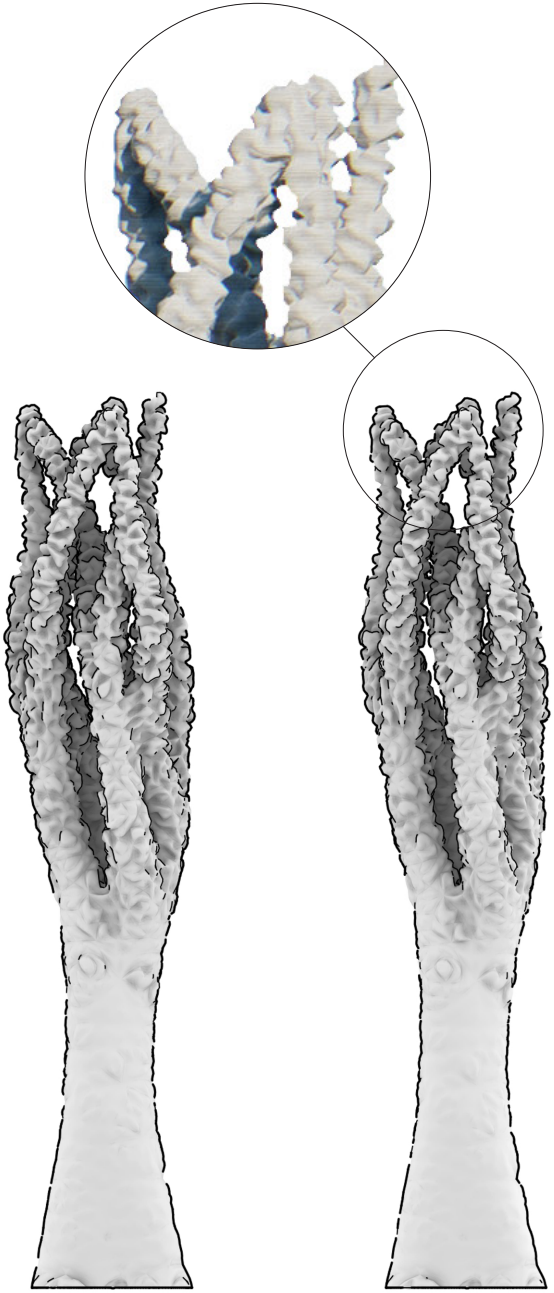


Original Mesh

Mesh resolution too large, subdivide further

Sphere collide prevents self intersections during growth. Radius too small.

Self intersections are also caused by growth happening too fast, if sphere collide cannot keep up



Improved sphere collide prevents self intersections.

Final output smoothed.

Simulating Differential Growth

After using shortest walk to generate a branching shape the resulting mesh was ran through meshmachine which allows a gradient of mesh faces to be created. Larger faces at the bottom of the structure and smaller mesh faces on the upper half of the structure.

Kangaroo can then be used to increase the mesh edge lengths, while pulling the resulting mesh to the original input mesh to keep the general shape.

This allows the overall form to remain while local folding increases the surface area to improve evaporation.

3d Printing Brick

3d printing brick allows us to add complexity to the existing qualities of fired clay like its compressive strength, its tactile character, and its capillarity. Earthenware clay is readily available in Donegal.

The first complexity that was tested in 3d printing was creating drips above an extrusion designed to catch the dripping water. The idea was to test if you could extend the range of the capillarity, if you cause the water to rise up one wall and drip into the catcher, from where it would rise again, reseting the max capillary rise. Repeated as necessary.

This idea was inspired by the way in which plants take in water from the ground and pull it upward to the surface of the leaves where it evaporates. The 3d printed columns would absorb, transport and allow evaporation of water similar to the water cycle in xylem and phloem tubes.

Testing printing of overhanging 'basins' to catch drips. Pathways modified using silkworm, to allow for greater control of the print path, in contrast to a slicing software which auto-generates layers.

Testing drips and basins on an increased scale. Very small print nozzle, (1.2mm diameter) made the print very frail, in addition to the geometry. Deformation in the drying process meant that the drips and basins no longer aligned.

Testing weaving walls to reduce deformation during drying. Also testings partial infill to increase stability and reduce deformation.

Strategy Reflection

Test to print capillary tubes within a column.

While progress was made with the 3d printer and manipulating geometries for overhangs, a test was simultaneously carried out on an already fired piece of earthenware to see if drips would form at a low point. In the image to the right water did not fall from the low point although it accumulated there. Due to the tiny size of the pores in brick, only very small accumulations of water would gather. A small drop of water can defy gravity and remain suspended from a low point due to the cohesive forces between the water and the surface of the brick, and aided by the surface tension of the water.

Another flaw with this strategy was that in order to create interlocking geometries to drip and catch, a lot of mass was sacrificed in the cross section. All this void would not transport water. A solid volume of the same external proportions would transport more water. Having voids also increases the surface area, from which evaporation can occur. Evaporation needed to be controlled and minimized until the water reached the growing chamber. From this point on solid masses of clay were taken to be the most efficient.

Though water was evident at the overhang, it never formed a drip.

3d Printing Continued

Moving to solid bricks allowed a focus on the surface geometry which can benefit from the intricacies of 3d printing. These columns have areas where evaporation is minimized, to promote capillarity and areas where the surface is increased to maximize evaporation within the growing zone.

Strategies to minimize evaporation, include:

1. Minimize surface area by using a single cylindrical shape. A circle has the shortest perimeter relative to cross sectional area.

2. Glaze the exterior of the bricks in the minimal surface area zone, to create a waterproof layer to keep the water in.

Once the column passes into the growing zone, surface area increases to allow for more evaporation at once. Strategies to increase evaporation:

1. Using branching to increase the surface area while maintaining the same cross sectional area.

2. Using differential growth simulation on the surface of the branches, which increases the surface while pulling the shape to the original geometry.

Testing infill patterns in Cura. Concentric infill pattern. Line spacing too far apart.

Concentric infill at outer edge with parallel lines at interior. Flow rate too high causing a buildup of material around the nozzle.

Under extruding at first layer, but over extruding at second layer causing material to drag. This could be caused by imperfect first layer height. Cura also has first layer setting to allow for differences.

Solid Bricks - Printed Infill

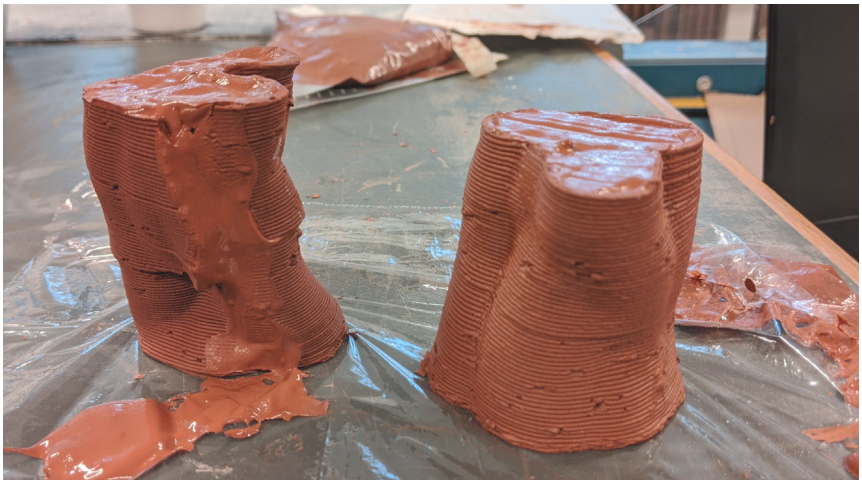
As the layers increased, the drag increased, even though the flow was static after the first layer.

In order to have continual capillarity, the bricks needed to be filled. Printing infill is a difficult balance between having the print lines close enough to adhere but not overlapping so much that it causes a build up of material at the nozzle, which degrades the print quality. These tests use the automatically generated infill settings in Cura. The results were poor and the amount of variables in Cura made it very time consuming to isolate exactly which variable or combinations would give the perfect infill. Another solution would have been to design a custom infill and use silkworm to slice the geometry and create the Gcode for the printer. Silkworm would have given more control of the infill line spacing, and individualized flow rates for initial and subsequent layers. This avenue was not pursued as it required the implementation of deliminaters, which had not been mastered. Deliminaters are movements at the start and end of extrusions, for instance retracting filament and moving the printhead upwards so as it travels it does not crash into existing printed parts.

Filling the bricks.

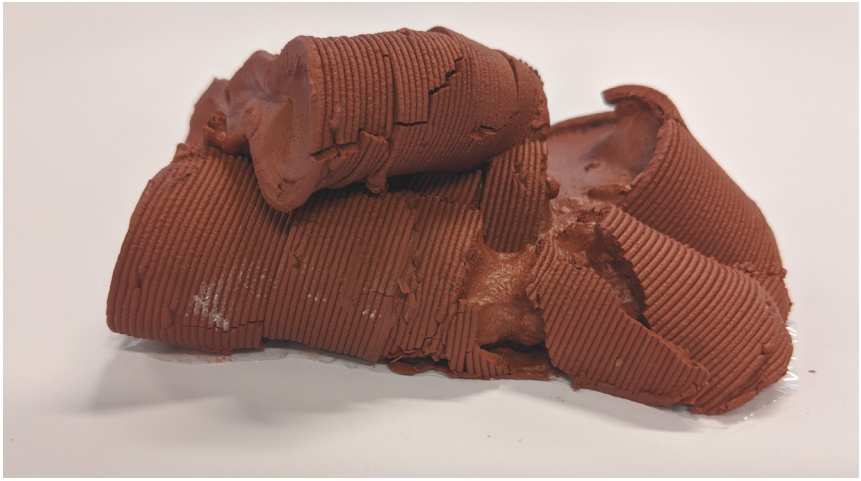
The infill was very soft but did not flow. It needed to be wet enough to manipulate into all the spaces. Too wet would cause instant deformation as the weight of the wet infill overcame the strength of the shell. This shell was printed with a 1mm nozzle.

Solid Bricks - Slip Infill



The dried shell on the left split immediately, whereas the semi wet shell deformed slowly, at least at first...

These tests show manually filling the bricks, treating the printed shell as a formwork. Using the same clay as the printed clay, water was added until the mixture was almost pour-able. Using a piping bag the shells were filled. The material did not quite flow so it had to be coaxed to space fill the shape. The dried print quickly absorbed the water from the infill and started to deform. The process was repeated to fill a freshly printed piece that was still damp.

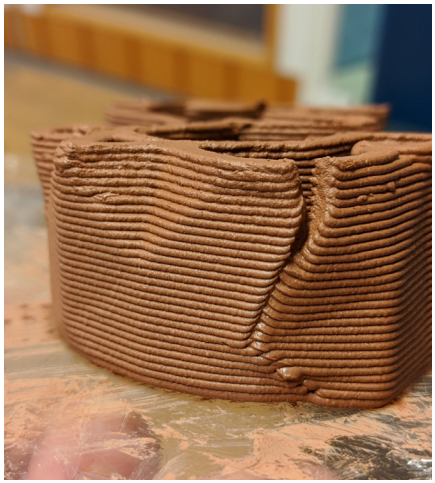


Eventually both tests crumbled.

The wetter shell held its shape better than the dried shell.

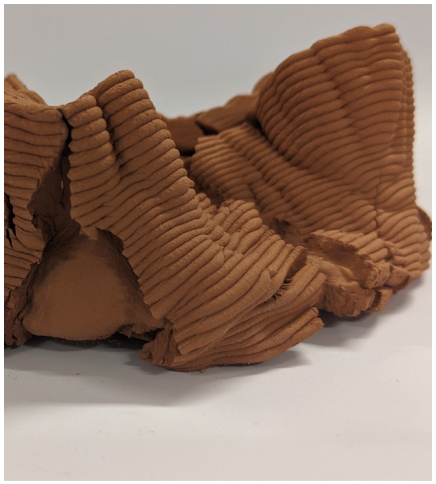
Test to show surrounding the area around the printed shell with a desiccant while the bricks were filled. This provided opposite forces in am attempt to slow or stop the deformation and give the water somewhere to go.

In conjunction to using the desiccant, the print surface was updated from plastic to cotton. The cotton would help draw the water out of the infill and could be placed on a desiccant bed. Cotton was a nice material to print on as the printed material adhered well to it. It performed best when it was pre-dampened and had a light coating of clay.

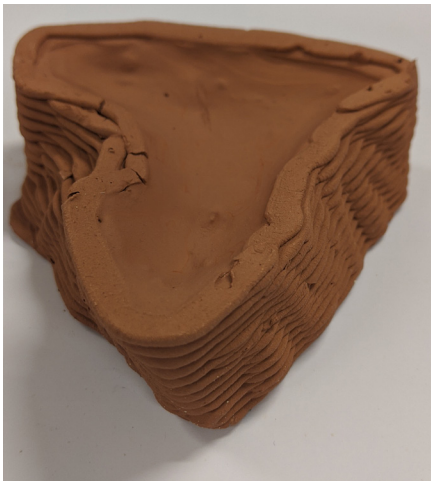


Once the use of delimiters succeeded, Cura was dropped in favor of silkworm which allows more control in generating Gcode, there are also less variables when using silkworm so it is quicker to isolate issues. Seams were a weak area. This was overcome by randomizing the start and end point of the print lines.

The surface complexity was increased for evaporation purposes but has the dual benefit of producing a sturdier printed shell.



Fail.



Eventually a successfully filled brick. The shell had layers from two different models: 1 the original shape, and 2 the same shape which had undergone differential growth on the surface. Every second layer alternated between the two models.

The resulting shape was very strong but the surface resolution caused by the intersecting models had lost some of its character.

Using a larger nozzle (4mm) and a lower height bricks were successfully filled without the knitted texture. Shrinkage of the infill caused a dip at the top of each piece but this could be filled with mortar during assembly.

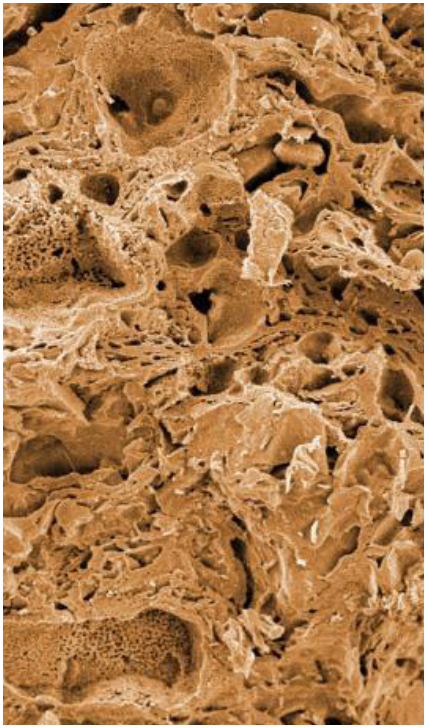
Brick Filling Reflections

Alternatives to creating these shapes could be using a mold to slip cast the elements. A huge draw back of this is the waste create the molds for so many individual pieces.

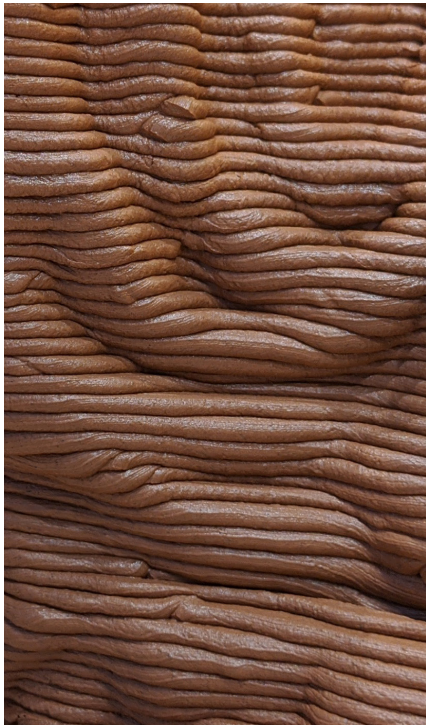
A different style of printing such as binder jetting, where a bed of clay powder is locally dampened might be possible. Deformation would no longer be an issue as the print remains embedded in the dry material around it until it has set. This technology is very expensive any not readily available.

Scaling this project up to 1:1, and printing with a larger nozzle ca 50mm would help ease the process. Filling the model as you print and adding a fibrous reinforcer would help protect against deformation and fails.

(Zarhi, Burko and Burko, 2020)



Micro Scale



Meso Scale

Macro Scale

Scales of Performance:

Micro:
The micro-structure of the material facilitates the movement of water via capillary action.

Meso:
The surface texture is designed to facilitate the evaporation of water by increasing its surface area in strategic locations. The surface texturing also adds to the visual interest and tactility of the forms which make up this border intervention.

Macro:
The large scale mimics branching growth. Creating unrecognizable forms is part of re-imagining a border as something with complexity, value and interest.

Assumptions Carried Forth

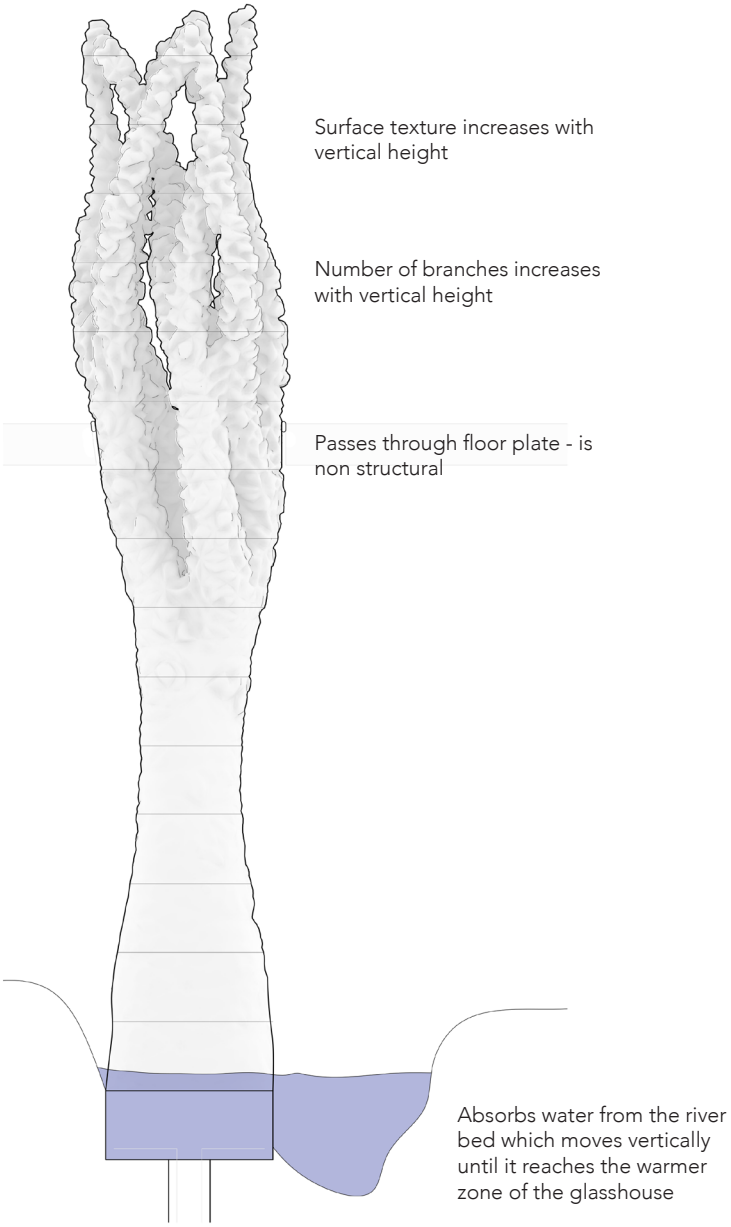
1. Capillarity & Evaporation
When developing the scale of the project it was assumed that under ideal conditions, such as porosity of brick between 5% and 8%, that capillarity could move water to a height greater than 6000mm above the source. Very little reference material studies increasing this phenomenon. In traditional architecture capillary action is minimized in masonry. According to The Building Science Corporation, "The theoretical limit of capillary rise in concrete is about 10 kilometers." (Lstiburek, 2014) In brick the travel is even further. 10 km would never be reached in application due to external environmental factors like evaporation, which is minimized in this project. Tests at 1:1 scale would be needed to perfect and prove that water could climb the 4500mm from the source to the underside of the growth chamber, but for this project it is assumed that capillary action in externally glazed brick could reach the growing chamber.

2. Craftibility, Printability and Stability
This element of the project was tested small scale. It is assumed that printed at 1:1 scale, with the input of structural engineers this would be a viable structural system.

3. Hydroponics System
Many elements have been individually tested here such as capillary action, 3d printing, filling shell prints and hydroponic growth. Each element that works as a discrete process is assumed to function similarly as part of a larger system.

Project Implementation

Column Typology 1
Column Typology 2
Column Typology 3
Column Frequency Plan
Interior Plan
Roof Plan
Section
Visualizations
Fabrication


Surface texture increases with vertical height
Number of branches increases with vertical height
Passes through floor plate - is non structural
Absorbs water from the river bed which moves vertically until it reaches the warmer zone of the glasshouse

Column Typology - Type A

Purpose
The purpose of this column is to absorb water from the stream and allow it to travel vertically from outside to inside the growing chamber. This column needs to maintain a continuous path to allow water flow. For this reason it is self supporting only.

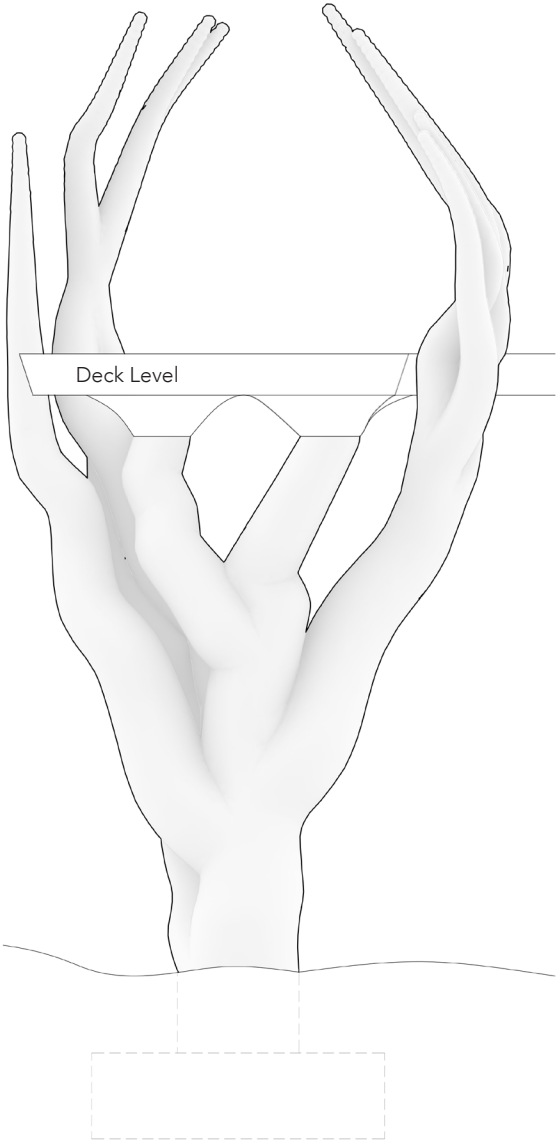
Material
The column in made from fired red earthenware achieving a porosity of approximately 8%. Outside the growing chamber, the exterior of the bricks is glazed to reduce unwanted evaporation. As the column passes into the interior zone it is left unglazed, to aid evaporation in the interior environment.

Texture
The texture varies across a gradient, starting with a relatively smooth surface and culminating in a heavily folded texture, designed to improve evaporation.

Height
Column type A is approximately 6m tall.

Structure does not pass through deck level. Some branches reach to support the deck level and other branches wrap up and around the structure of the roof to aid in its support.

Column has a undulating surface throughout. Column location is outside the river bed.



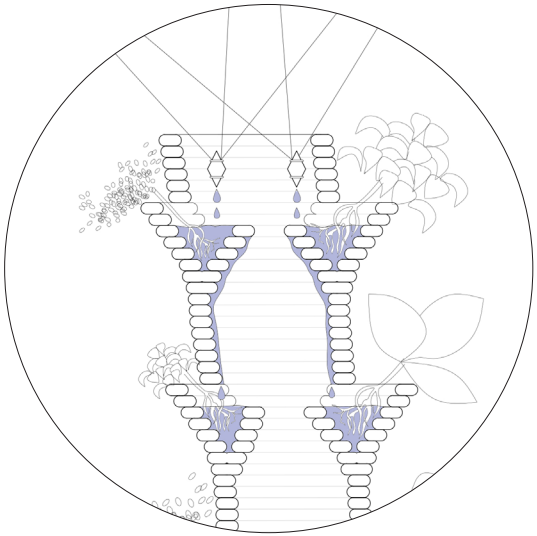
Column Typology - Type B

Purpose
Column type B gives support to the deck level of the interior space and wraps up and around the deck to hold the roof in place. Only one instance (from one source point to multiple target points) is shown for clarity. In side by side application, target points have multiple source points, this allows overlapping and coming together of the structure to form shapes similar to arches and reducing cantilevering. This column is reinforced (see assembly and fabrication).

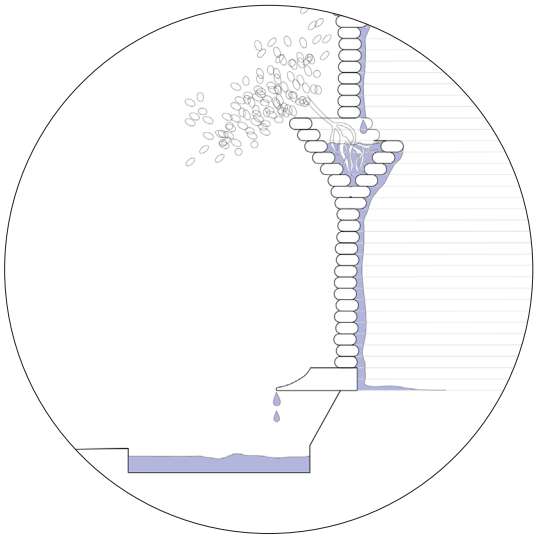
Material
The column is made from fired red earthenware. This support structure is not glazed.

Texture
The texture remains constant throughout.

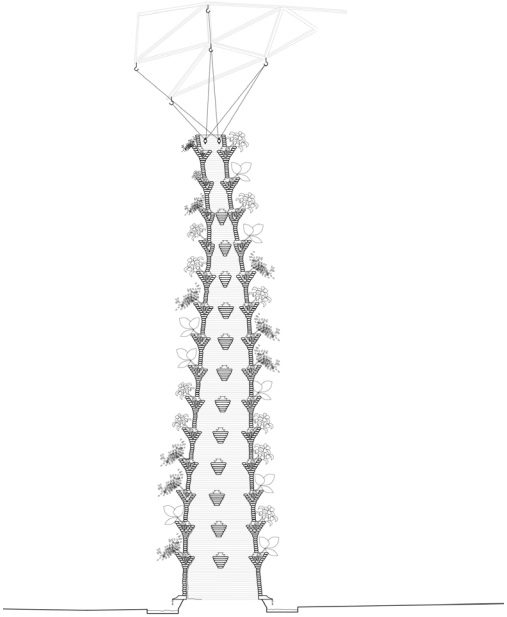
Height
Column type B is approx 4m tall at the deck level and 6m tall at its zenith.



Top of grow column where water enters the system.

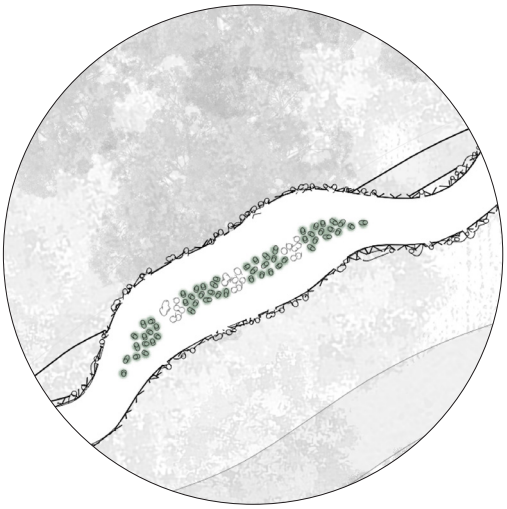


Floor junction of water coloum. Overflow water is collected and redirected back into the water cycle



Section through growning column type C.

Column Typology - Type C



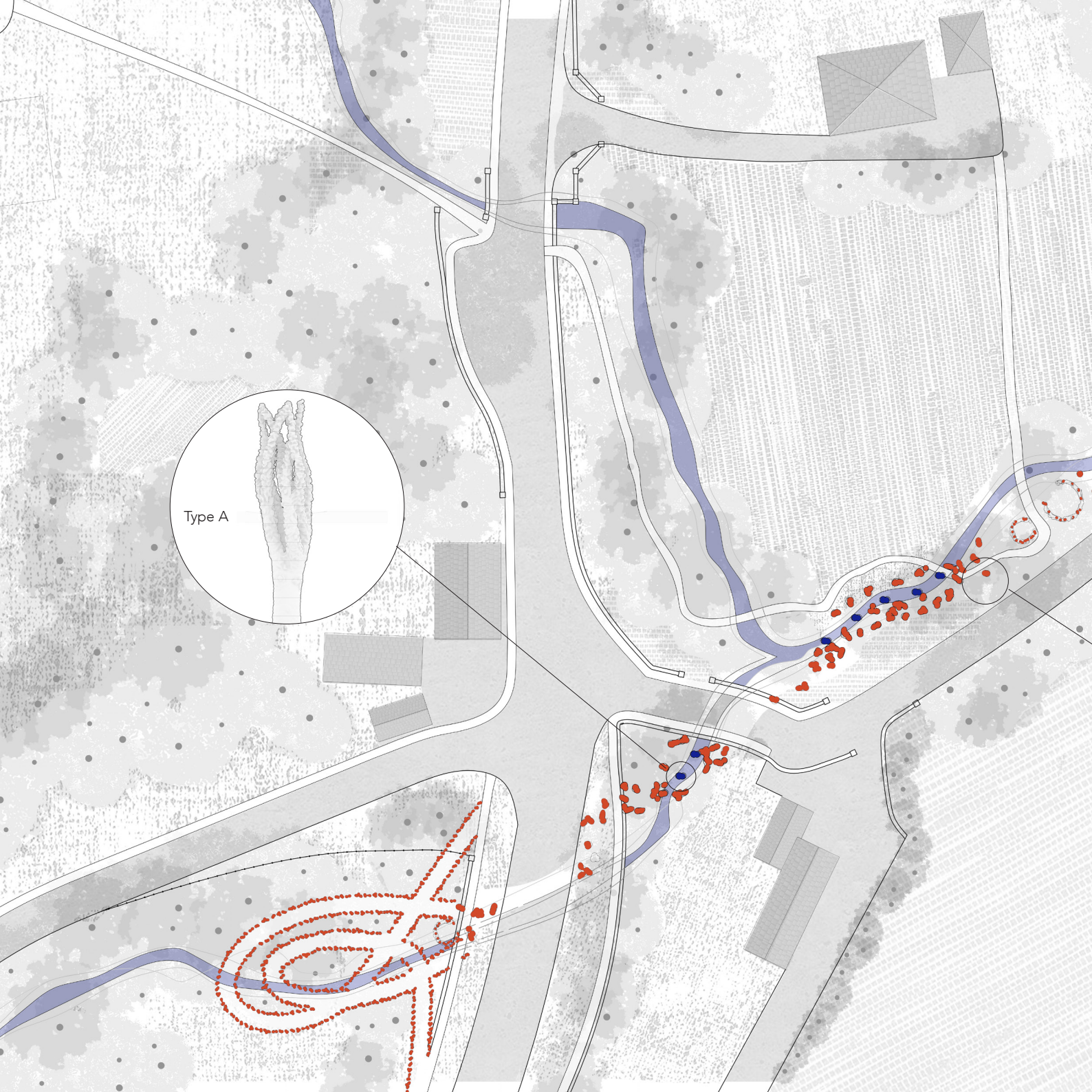
Purpose
This 'column' is a growth column that is found in the interior of the growth spaces. The interior is hollow with pockets printed into the walls of the shell. These pockets create an ideal habit for hydroponic growth. Water which has traveled through column type A, evaporated and condensed on the interior surface of the roof is guided into these grow columns by steel cables weighted at the end. Water can then drip passively into the grow column creating a slow but constant replenishing of water. The pockets are positioned so that once one pocket has filled it overflows and trickles down to the pocket below, constantly exchanging water. Some water will be lost to evaporation and recycled back into the system.

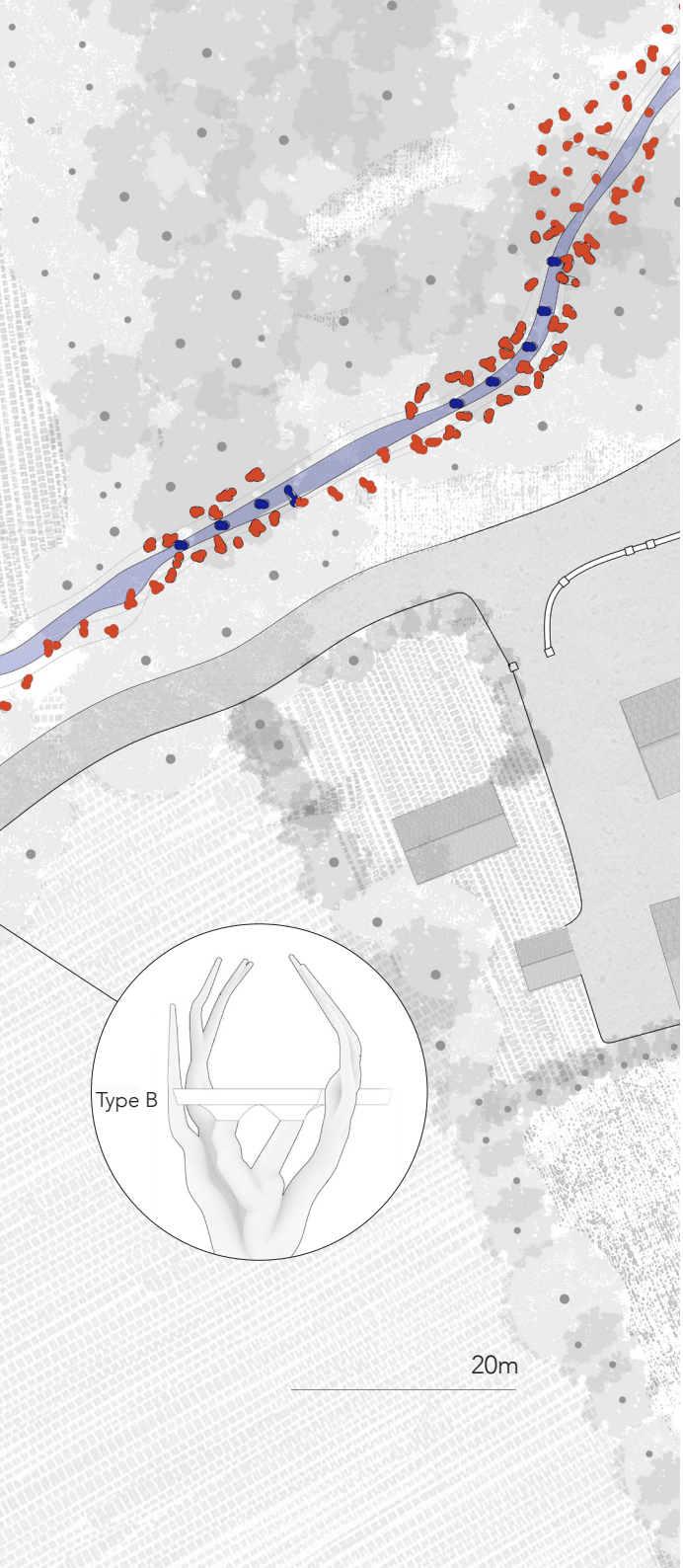
These columns sit directly above select support columns (Type B).

Material
The column in made from fired red earthenware. Unglazed.

Texture
The texture remains constant throughout. The pockets can be created similarly to the basins experimented with in the original prints.

Height
Column type C is between 2.5 and 3m tall.


Type A



Column Frequency

This map shows the distribution of columns taken at a height of 1m above ground. A change in density of column placement is caused by changes in program across the interior zones. Where column density is sparse, these are pass through zones and where columns are most dense signifies growth chambers where the load carried by the columns is greatest.

The exact border (if such a thing exists) is deliberately omitted from this map. A new blurred border can start to be discerned from the from the scattered column trajectory.

The columns start to echo the tree trunks of the surrounding hedges and forested areas, connecting to these green highways.

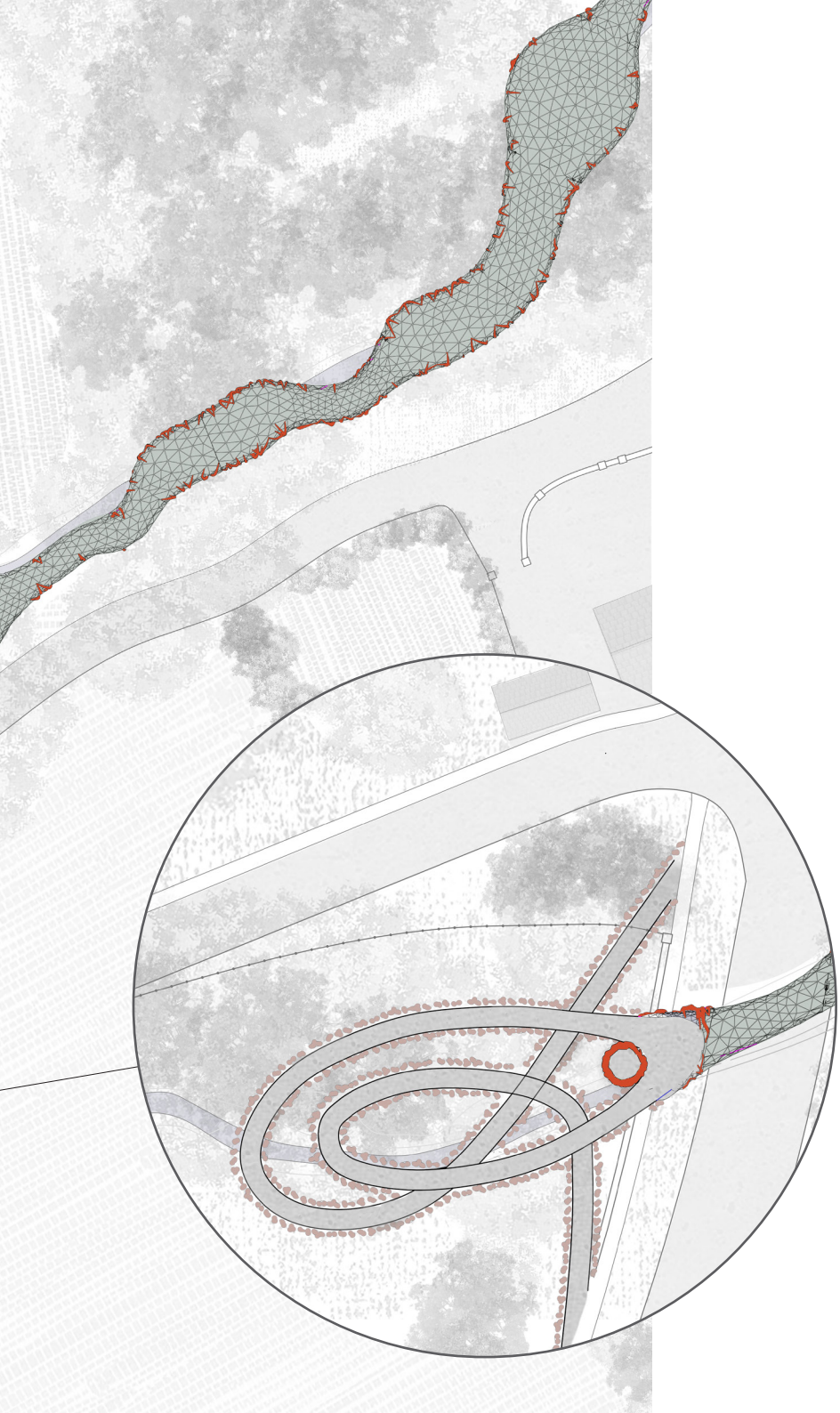
This version of a border is a producer for the local communities, a community garden. It is porous and permeable. It is a border infrastructure that provides more than it takes away.

This is a celebration of the place where two communities come together rather than an obstacle between them.

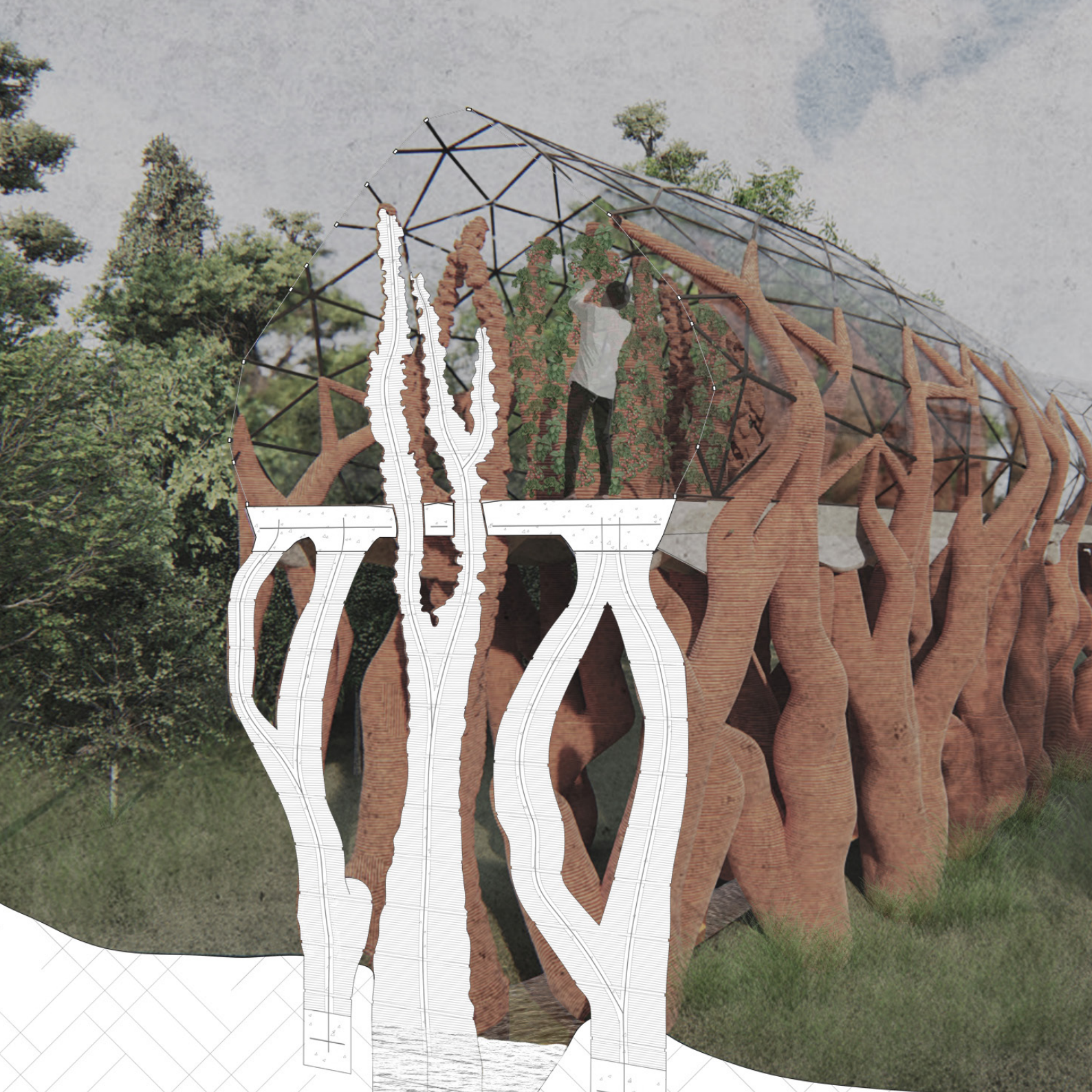

Circulation Spaces

Interior Plan

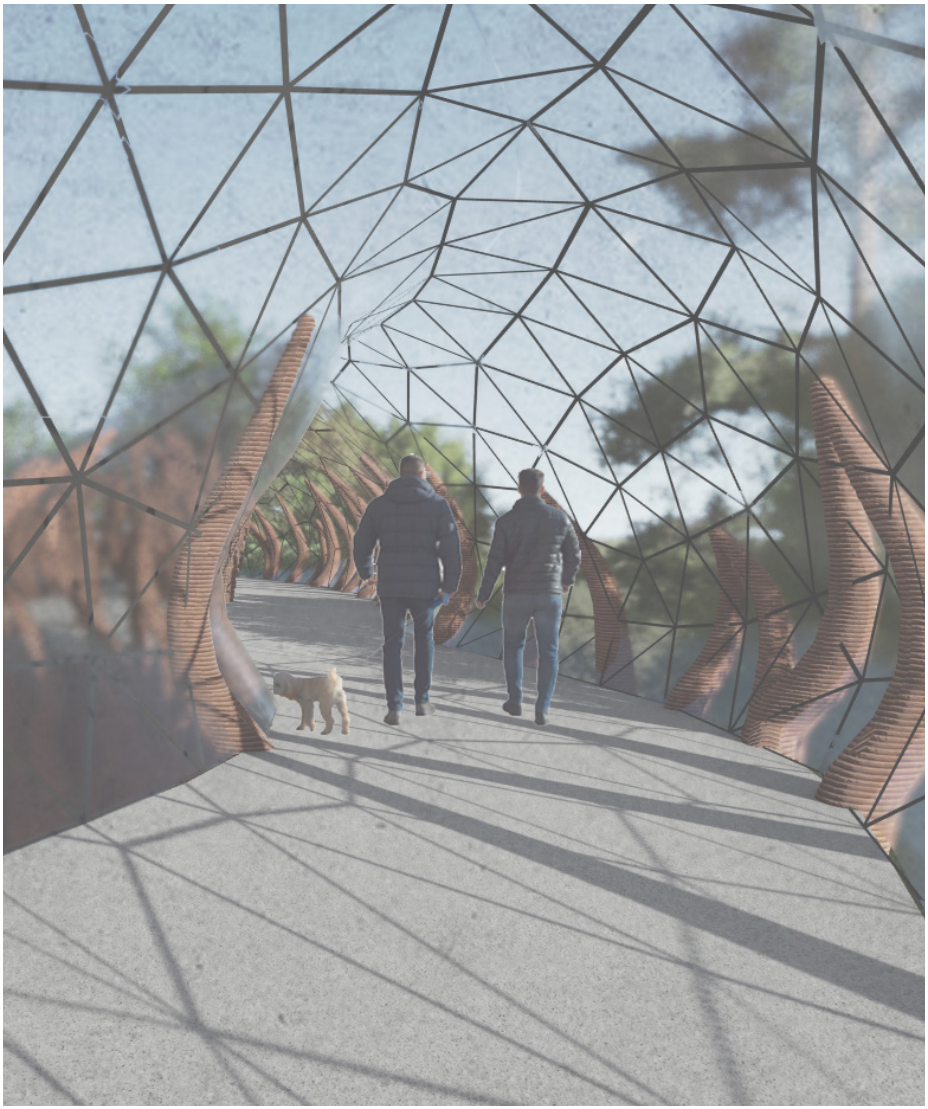
Roof Plan



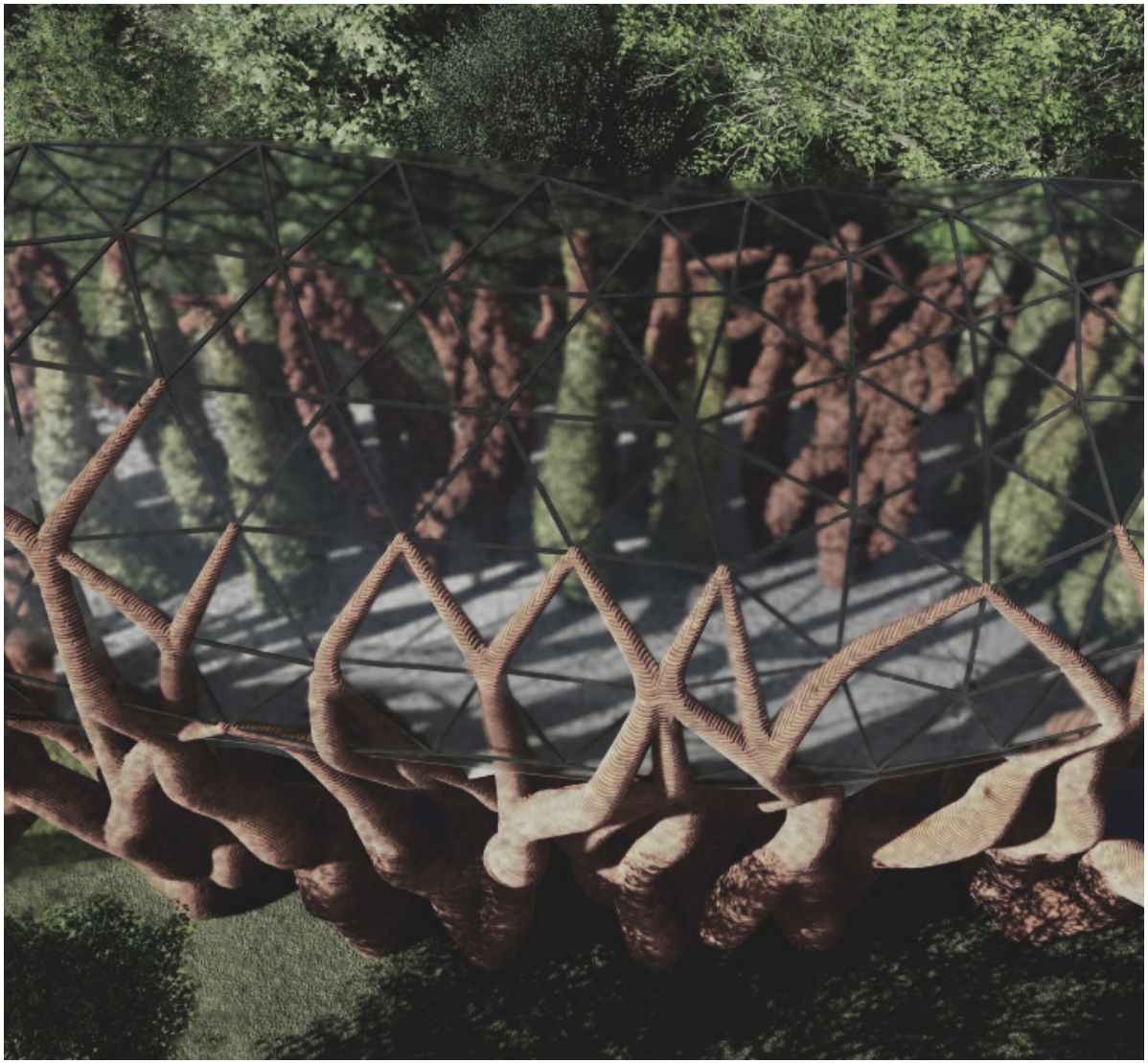
This ramp is the ceremonial entrance to the project with entrances from both countries. Two intertwining ramps which take you from the street level on a curving journey to the level of the growing chamber. On this journey you cross the border twice before arriving at a third crossing above. This entrance takes time to transverse, allowing reflections on what it means to cross the border. Does it mean anything at all?



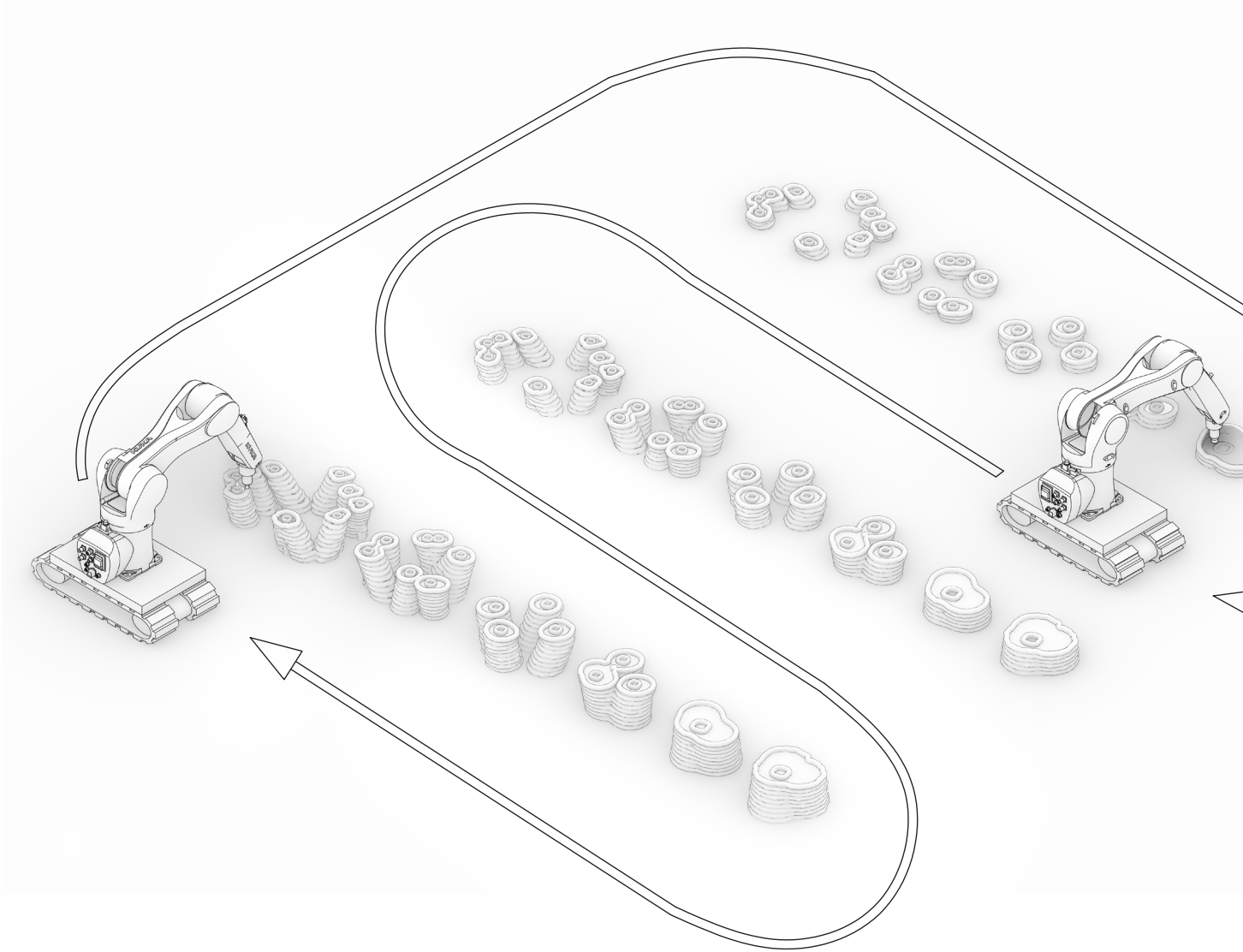
3D Section



Internal Circulation

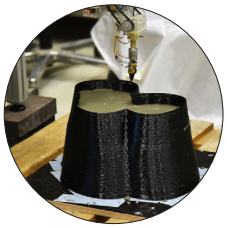


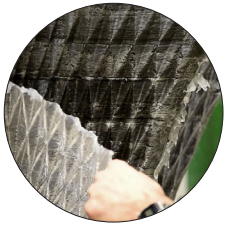
External Roof View



Print → Fill → Dry → Fire in Kiln → Selective Glaze → Fire in Kiln → Asse

Fabrication & Assembly





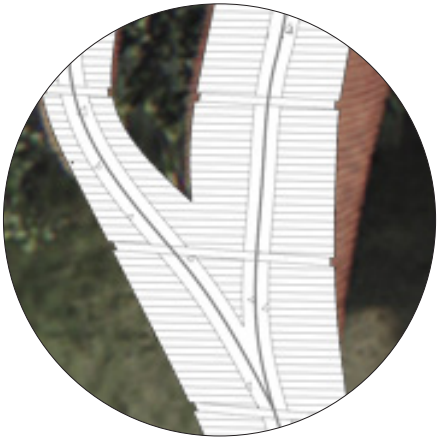
Gramazio Kohler Research

This proposed fabrication process builds on the research undertaken in the 3d printing stage. In order to overcome the printing difficulties outlined before, this proposal suggest two robotic arms could work simultaneously. One prints the accurate outer shell. An inner shell is added to allow reinforcement to feed through during assembly. The second robot arm can fill interior spaces with a fluid mixture.

This system would benefit from printing 3-5 layers at a time before moving to the adjacent brick. This greatly increases the travel time of the robotic print arms but allows the clay to set in between each new pour. Sacrificing the travel time lowers the risk of deformation and greatly aids the drying process.

A similar system with different materials is employed by Gramazio Kohler at ETH. They use a plastic formwork to cast layers of concrete. Alternating printing and filling to allow the concrete to cure and some stability to be achieved before continuing.

mbly



Reflections

Reflections

This journey has uncovered so many interesting threads that revolve around borders. The anecdotes and stories are filled with loss and tragedy juxtaposed with adventure and tales of overcoming.

There came a point in the journey when it became clear that this would not be an overarching response to all borders. A perfect solution to a border is probably not having a border at all. In the future we might reach this world, where small city states govern local issues but central governments imposing far flung boundaries may disappear. Until then, we can try to improve what we have got.

An interesting and difficult part of this project at times was the fact that this border is imagined. No wall exists. People have for now, the luxury to cross the line uncontested. Is building a structure on this boundary contrary to the ideals of breaking down borders? Or, can we strip the border of it's negative lingerings by indeed meeting it face on? This project takes nothing away from this community. It adds value, by becoming a producer of plant-based food, by allowing spaces for contemplation. Contemplation of the idea of a border and how we allow it to divide us.

Using computational design and 3d printing allowed for the successful manifestation of spaces and structures that are out of the ordinary. Growing this in a contentious context can act as a magnet to draw the communities together. This technology affords us the ability to create excitement and wonder through the built environment, in ways that are unattainable in traditional building and design. There is balance to be learned in this field. Designing the algorithm to perform for the Architect, rather than as an uncontrolled identity.

There is so much more thought to be invested in borders and their inherent issues on a global scale. In this context at least we can re-imagine the border as a productive place, a place for contemplation and a place for healing. By building a border structure we may help to heal the scars of the borders in our minds.

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