19W 4984100000 Architectural Biomimetics

Static Structure

A Study on Coral Behavior as Architectural Inspiration

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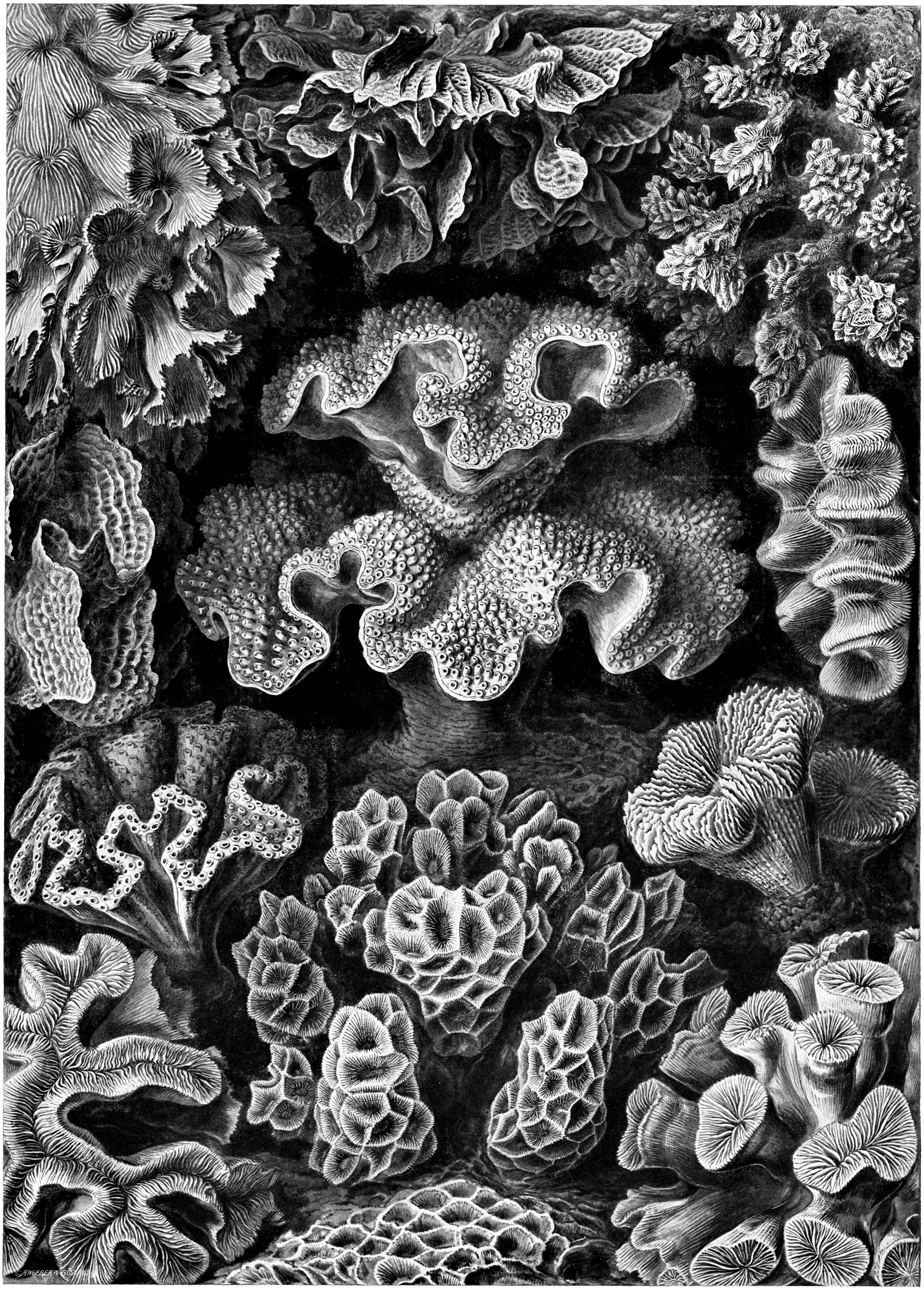


Hexacoralla. — Sechsstrahlige Sternkorallen.

BIOLOGY

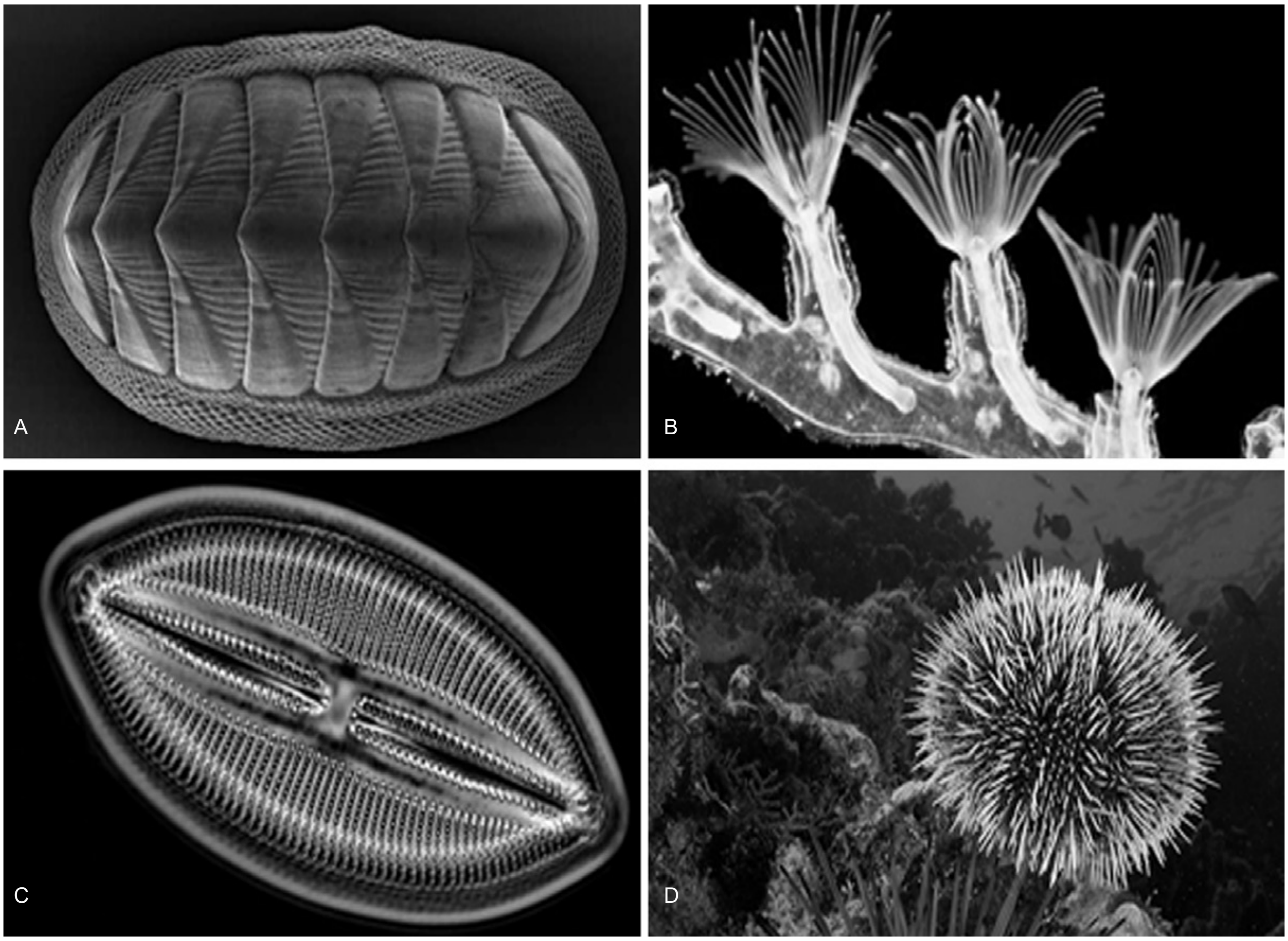


FIGURE 01: A) Chiton B) Lophophorata C) Diatom D) Urchin (Veron, 2000)

BIOLOGICAL CONCEPT GENERATOR

Each animal has its own unique morphology, anatomy and behavior. Most of these characteristics are highly evolved and fulfill functions with almost perfection. Using an animal as a concept generator does not mean simply copying the part of interest one-to-one, but rather investigate the animal in order to attain insights into its morphology, anatomy and behavior. Connecting these parameters to each other and thinking about their function helps us to determine key principles. Finally, the investigation's results can be used for abstraction and new concepts, contributing to solutions of architectural problems.

Our criteria for sought after animals is static structures. Basically, this includes any kind of skeletons, shells, and other softer yet static structures. The process started with some broader research on several invertebrates. Pre-selected groups included chitons, sea urchins, corals, diatoms and Lophophorata. This pre-selection was done to give some examples of pretty different invertebrates and even protists (diatoms), representing quite a diversity in static structures. Early during research, our group became most fascinated by the corals.

Further research dealt with general principals found in stony corals, and never was limited to just one species of corals. Issue for further investigation was the modularly structure of coral colonies. This modularity might be used for an architectural biomimetic application.

FIGURE 02: Acropora Polyp (Veron, 2000)

STONY CORALS

Stony corals (Scleractinia) are small animals belonging to the phylum of Cnidaria, even if their appearance is floral. Cnidarians' common characteristics are the possession of nematocysts (stinging cells), radial symmetry and a comparatively simple physique with only one body opening which serves as anus and mouth (Veron et al. 2016). In the following, we mainly present descriptions of stony corals that live in shallow tropical oceans. They mostly live in colonies and build up the tropical reefs.

Phylum: Cnidaria
Class: Anthozoa
Subclass: Hexacorallia
Order: Scleractinia (true stony corals)

Polyps are the individual coral animals. In contrast to many other cnidarians, corals just live as sessile polyps and do not have a jellyfish (medusa) generation. There is one noteworthy aspect concerning nutrition. Especially in tissues of reef building corals Zooxanthellae (small, endosymbiotic dinoflagellate algae) are found. This symbiosis creates a safe habitat for the algae and provides the algae with CO_2, whereas the polyp receives photosynthetic products for nutrition and additionally has access to more calcium carbonate for faster skeletal growth (van Treeck, 2017).
Their body is made of two layers of cells, ectodermis and gastrodermis, separated by the mesoglea (jelly-like layer). Retractable tentacles and nematocysts are used to catch food.

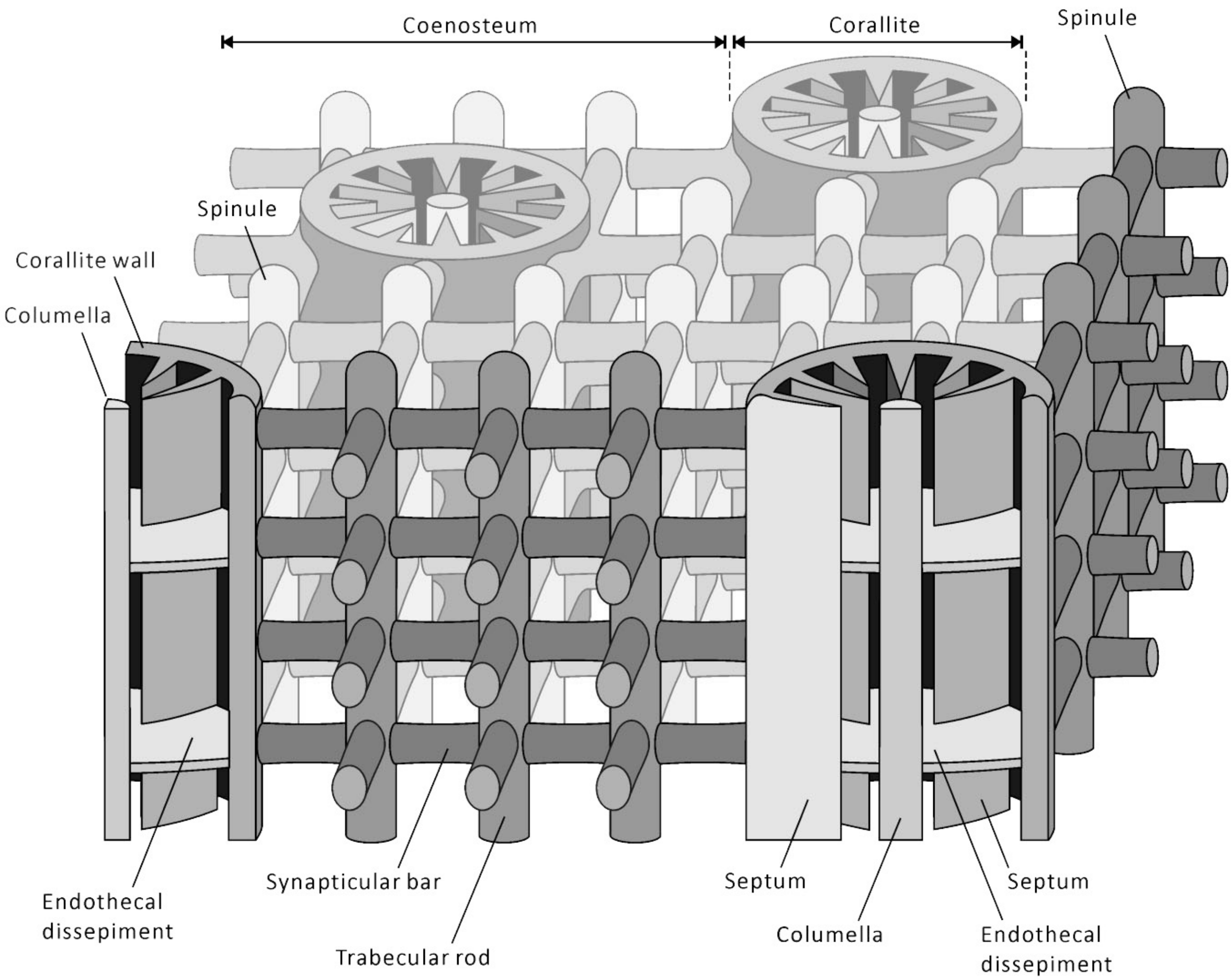


FIGURE 03: An idealized schematic figure of a coral skeleton (Veron, 2000).

The polyp's ectodermis secretes calcium carbonate and thereby creates the polyps' exoskeleton called \`corallite´. Primarily there is found a tube (corallite wall) with vertical plates (septo-costae). The coenosarc is another thin tissue between adjacent polyps which deposits calcium carbonate as well. Polyps are able to retract themselves into the corallites in order to be protected (Sheppard et al. 2018).

Following a definition by Veron et al. (2016), there exist five skeletal elements forming the corallites walls which vary in proportion in different coral families and/ or genera.

These elements are:

a) **septo-costae** [inside of the tube = septa, outside of the tube = costae] which become thickened within the wall,
b) **coenosteum** [is a general term for porous (not solid) skeletal material situated between the costae of corallites or between one corallite and the next] and which forms a sponge-like structure,
c) **synapticulae** which are horizontal rods forming a lattice between the septo-costae,
d) **sterome** which forms a non-porous layer within the wall and [is a solid sheet which forms the inner lining of (or all of) the corallite wall and gives the skeleton a porcelain-like finish]
e) **epitheca** which forms a thin non-porous layer on the outside of the wall.
The wall is very prominent in some corals but is inconspicuous in others where individual polyps may be indistinct" (Veron et al., 2016).

Beside these structures, there occur some additional skeletal elements in some species, but all elements

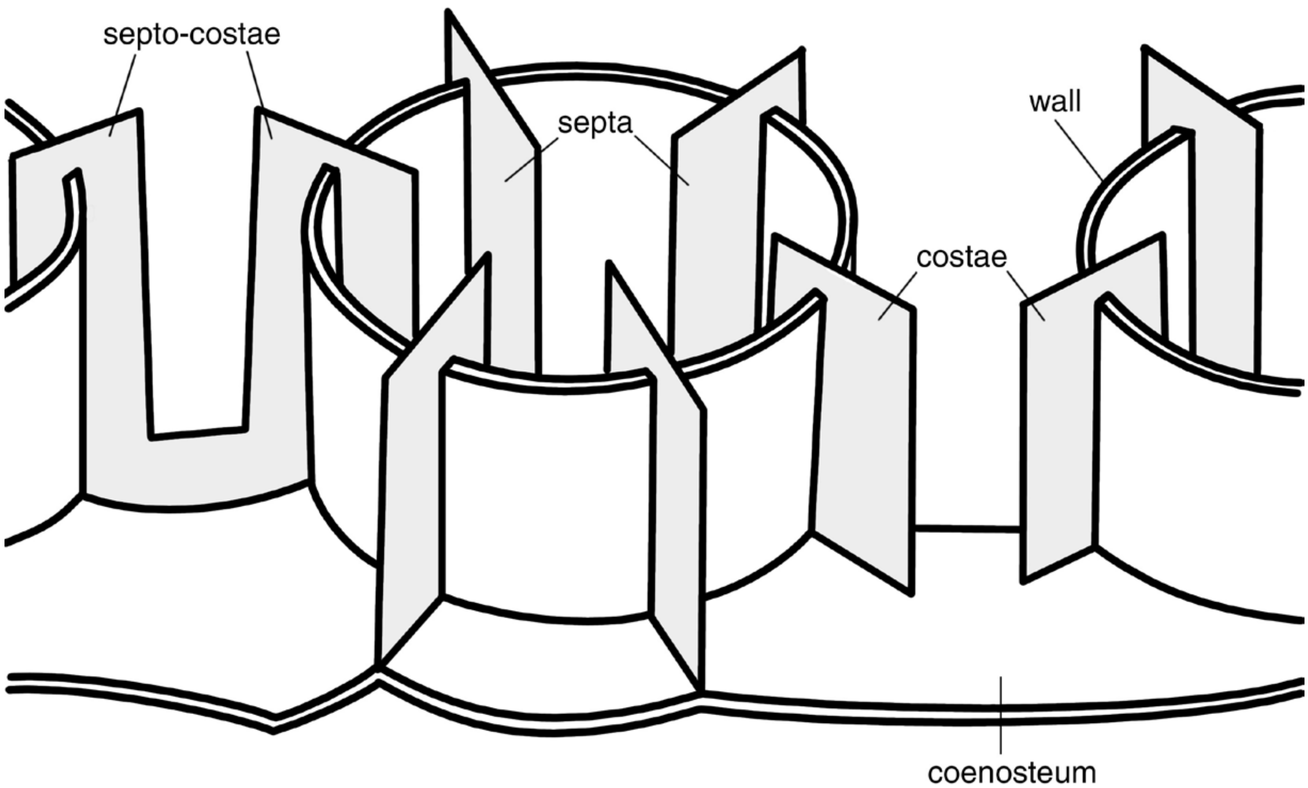


FIGURE 04: Diagrammatic representation of the basic skeleteal elements of corals (Veron, 2000)

used for abstraction are covered by the list. Scleractina belong to the subclass of Hexacorallia thus sixfold symmetry is often found in the polyps of stony corals. Hence, they have six septa or a multiple thereof. Furthermore, corals often have a columella and paliform lobes. The columella is formed by intertwined teeth-like structures on the inner margins of septa. Paliform lobes are pillar-like projections on the inner margin on some or all of their septa. Arranged in a circle around the columella this structure is referred to as paliform crown (Veron et al., 2016).

Septa provides support to the mesenteries. Primary septa are full plates and separate two sets of mesenterial pairs. Secondary septa are partial plates that separate mesenteries within a mesenterial pair. Mesenteries are infoldings of the mesoglea and its lining gastrodermis. Thereby increased surface serves digestion among other things (NOAA).

Corals often reproduce by asexual budding. While budding the parent polyp divides in two or more daughter polyps. The budding process determines the way polyps (respectively corallites) are connected and consequently the type of colony that results. Distinguished budding styles are on the one hand and extratentacular budding (outside the tentacle ring; daughter corallites forming on the side of the parent corallite) and intratentacular budding (occurs within the tentacle ring; corallites of daughter polyps have shared walls).
Sometimes both budding styles occur within one colony which has been observed for genera Astrea and Acanthastrea. In the valleys of meandroid colonies (e.g. Platygyra) the individuals have no or just an incomplete wall between adjacent polyps.

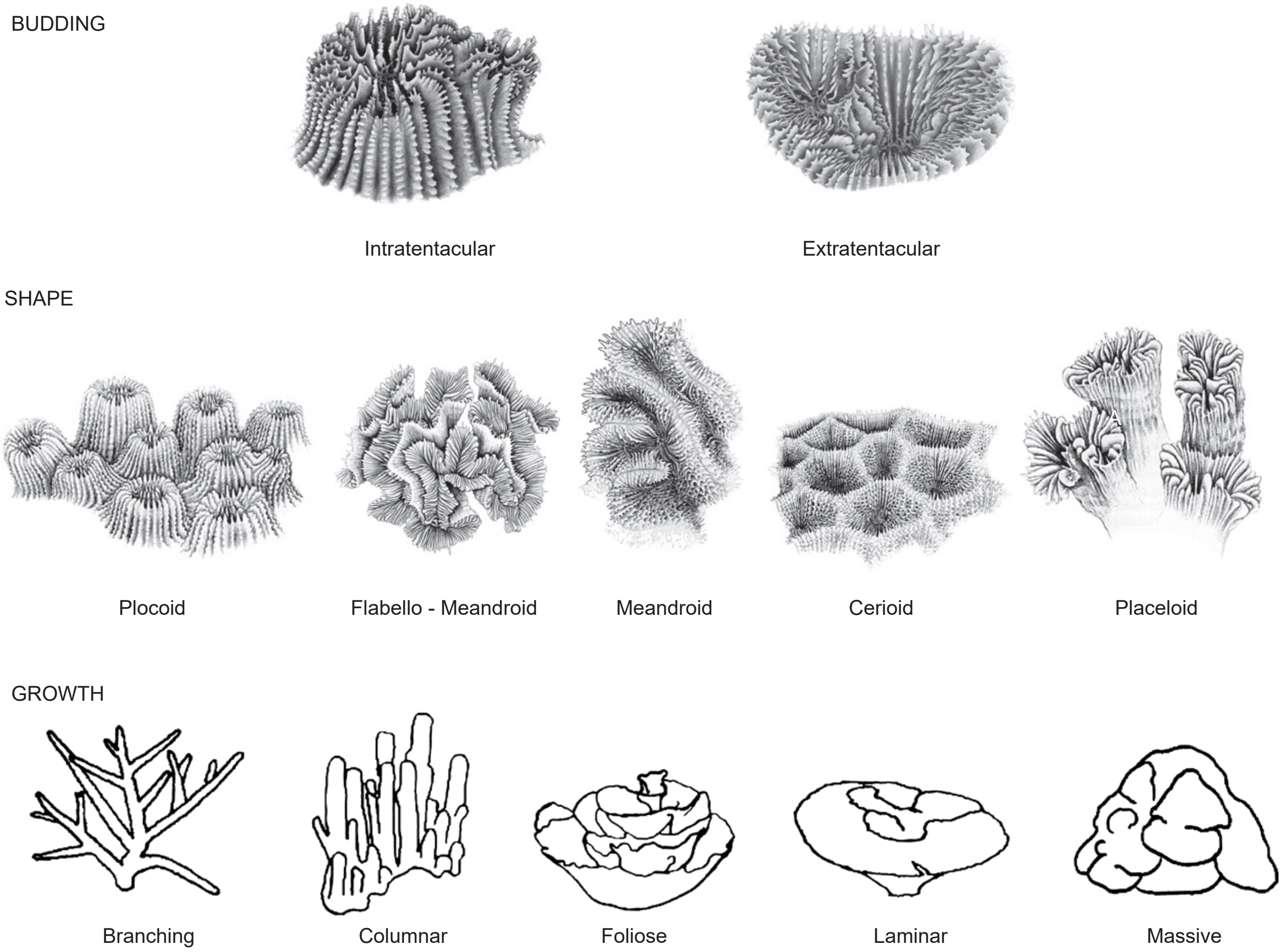


FIGURE 05: Meso and macro architecture in corals. Geoff Kelly.

Following terms are used for colony types: plocoid, phaceloid, meandroid, cerioid (share common walls but don't form valleys) and flabello-meandroid (for further descriptions see figures)(Veron et al., 2016).

The range of shapes is both genetically and environmentally determined, the degree of variation differing among species. The most common terms used to describe growth-form are ordinary descriptive words:

Encrusting: thin layers enveloping the substrate
Branching: forming branches
Arborescent: tree-like appearance
Columnar: forming columns
Laminar: (plate-like - sometimes forming tiers).

In summary, it can be stated that the single skeletons directly protect the polyps; then the polyps grow in colonies and finally these colonies are needed to build large wave resistant reefs.

The growth pattern of the coral colony is directly influenced by environmental conditions. In shallower waters, the corals tend to grow in denser solid formations, and in deep waters , spindly branching formations. This is due to the availability of nutrients and sunlight at the different depths. Another key factor that influences the growth is the presence of waves. Corals will grow in direct response to the prevailing current or wave direction.

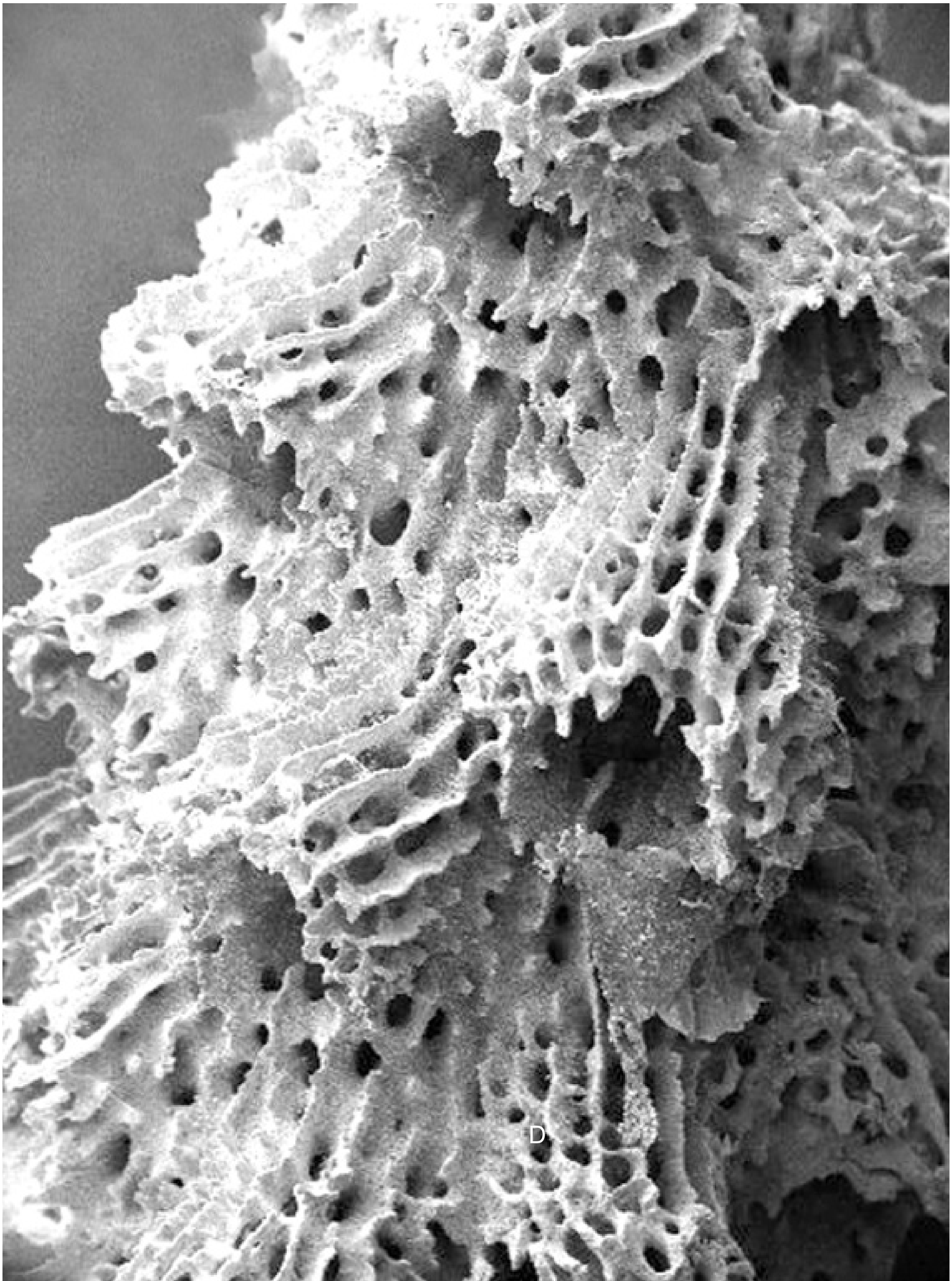
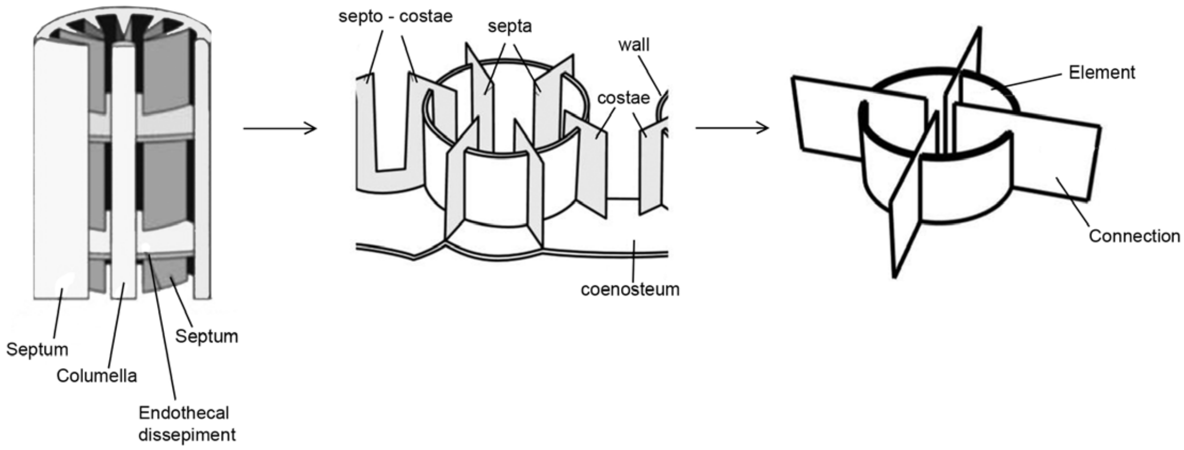


FIGURE 06: Acropora sample - University of Tubingen

FIGURE 07: Photographer David den Ouden

ABSTRACTION



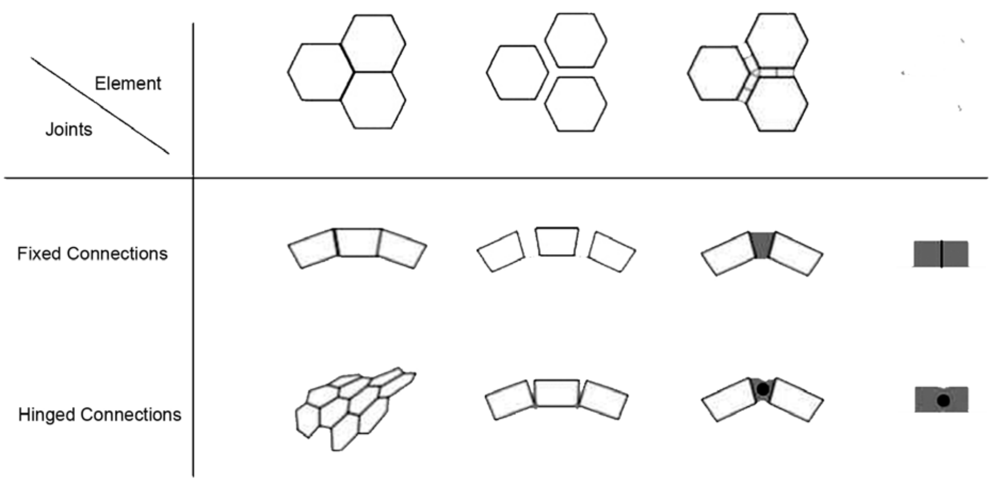


FIGURE 08: a. Biological Abstraction process b. Module types

Abstraction:

In order to abstract architectural concepts from the coral biology, the coral was studied in a bottom up manner.

The corals achieve varied morphologies with small variations to the same unit structure. Our biomimetic research was driven by the curiosity to figure out ways to abstract those principals and bring them into the architectural realm.

After thorough investigations in to the global morphology of the coral the research was streamlined to its unit structure – the Coralite. They have 5 components which are Septum, Columella, Endothecal and the Epitheca. The Coralite was conceptually simplified into 2 major components: the Septa and Epitheca. The Epitheca is a calcium wall which provides structural rigidity to the whole global form, whereas the septa are the non-structural ribs which are predominantly used as a nutrient channel.

The architectural abstraction reimagines the two basic biological components as two basic architectural elements: a module and a connection system. These two components can be reiterated with small variations to proudce a myriad of morphologies.

We decided to focus on generating permutations of the connection system. There are 6 basic variants of connections: wall-wall fixed, wall-rib fixed, rib-rib fixed and wall-wall hinged, wall-rib hinged and rib-rib hinged modules.

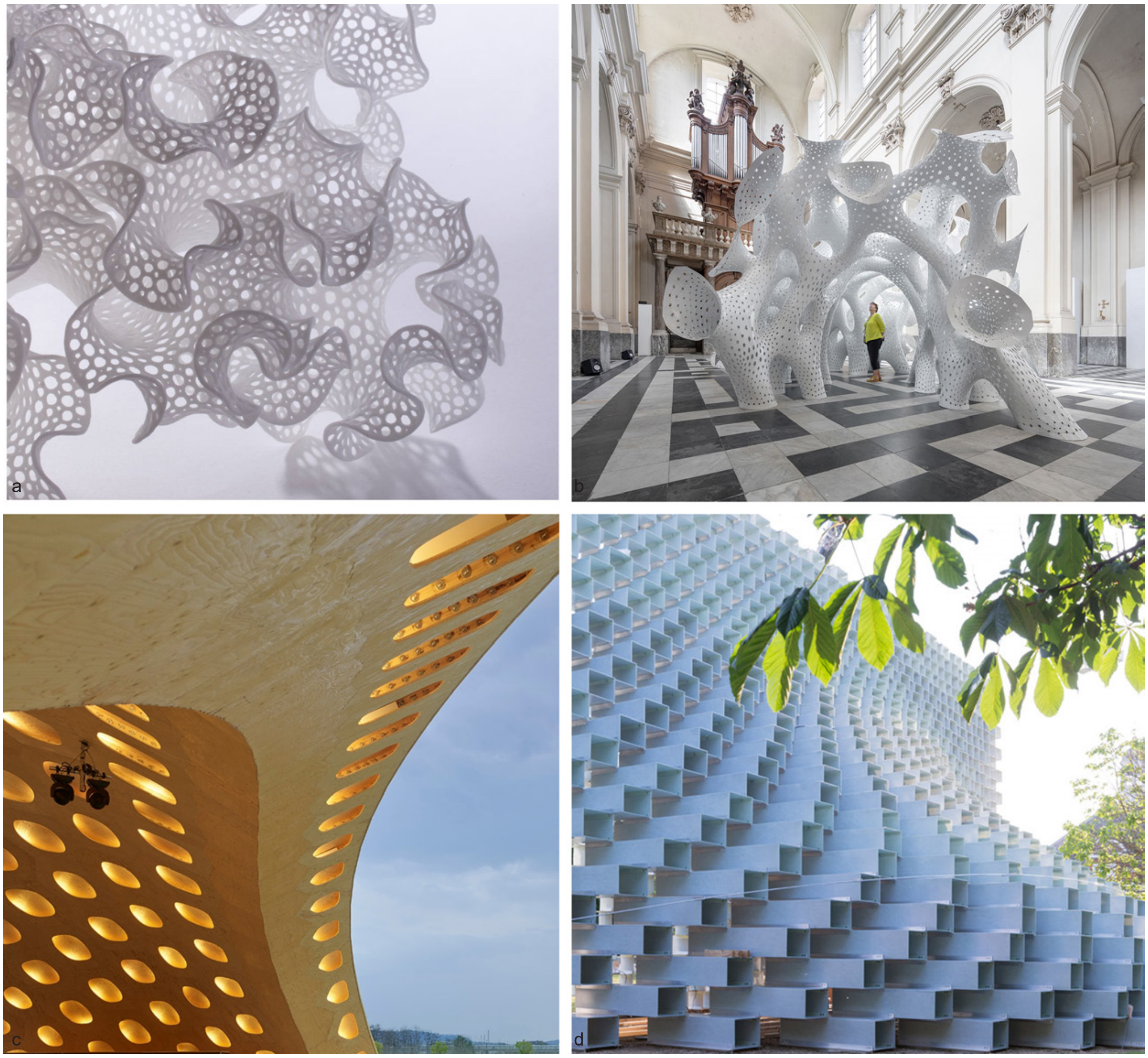


FIGURE 09: a. Floraform - Nervous System b. Marc Fornes - the Everymany c. The Buga Wood Pavillion - ICD/ITKE d. BIG Serpentine Gallery pavillion 2016.

State of the Art:

Various precedents were investigated to further understand the process of development and further our project's detailing.

Floraform Sculptures by Project Nervous System:
the project produced 3D-printed forms, where the surface curvature reflects the growth pattern, as well as a zoetrope that acts as a physical animation of the growth process.

Bruges Triennial by the Everymany:
The installation has a triangular plan, which has an intricate form inspired from corals. The pattern creates several openings and curves which try to freely flow and provide an enchanting experience to the visitor

Buga Wood Pavilion 2019, ICD and ITKE:
The project is inspired from sea urchins and buils upo the idea of more form with less materials. The project follows the principals of biomimetics and modular components to get a stable global form.

Serpentine Gallery, Bjarke Ingels Group, 2016:
The installation focuses on generating an abstract global form using same repetitive modular elements. The modular elements which are hollow block in these cases are shifted forwards and backwards to create undulating surfaces.

FIGURE 10: Photographer David den Ouden

Development

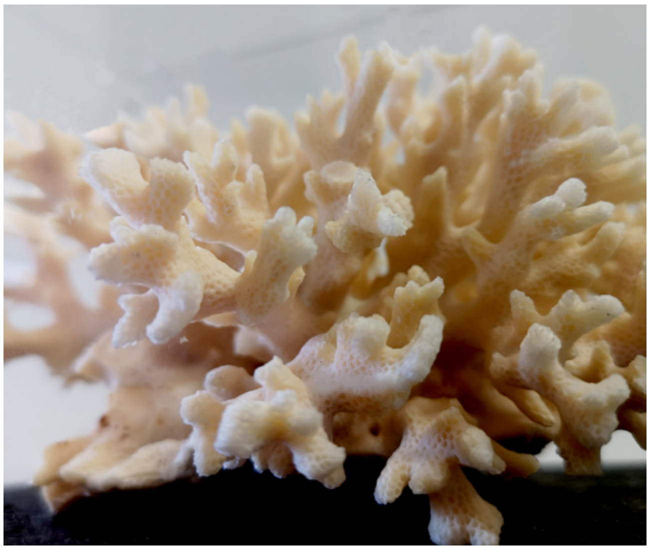


FIGURE 11: Stony Coral Skeleton

FIGURE 12: Favia Coral Skeleton

FIGURE 13: With Shared Walls

FIGURE 14: Individual Walls

FIGURE 15: Individual Walls with Bridges

Theory

The corals are structurally performative at both the global scale and the individual cell level. At all scales, coral biological principles can be extracted to be used in both structural engineering and manufacturing logics.

Modular nature:
Starting from the scale of a polyp, we identified that different polyp geometries will change the global structural typology. For instance, while stony corals generally possess a spiky morphology, favia corals form a sphere structure using the typical module, but built up by a bounding wall and radial ribs. Just altering the shape of the individual polyp results in very different outcomes.

Joinery:
Similarly, different joinery types between polyps will change the global geometry. Even if the polyps have the same geometry, a differing joinery type will greatly alter the global morphology. We classified the joining patterns into the following three catalogs: cells that share walls, cells that share radial ribs, and cells that also don't share walls or ribs. These joinery logics have a great impact on coral density and overall geometry.

In the case of corals, there is only one joinery type used in a particular species. They don't use different joints for different conditions, but will instead adapt the same joint.

In architecture, it would be economic to produce a great quantity of the same module, and yet, be able to produce different shapes. The manufacturer could have a standardized production line, and the standard modules joined in a variety of ways.

FIGURE 16: Flat Assembled Hinged-Joint Shell

FIGURE 17: Singly Curved Hinged-Joint Shell

FIGURE 18: Singly Curved assembled Fixed-Joint Shell

FIGURE 19: Singly Curved assembled Fixed-Joint Shell

Implementation

The coral logics were extracted and implemented with different combinations. Figure 19 is looking into cell with shared ribs and fixed joints, whereas figure 17 explores the possibility to bridge the modules with hinged connections.

In this case, we surmised that the coral system of attaching to neighbors could be used for a shell structure. The coralites form rigid connections with eachother that allow them to behave as a cohesive unit.

Further, this concept can generate a myriad of shell morphologies with minor alterations to the connection. In the case of the hinged connection, the global structure can be manipulated into different shapes. With the rigid connections, the angle of attachment can be parametric to generate different global shapes. In this way, a simple manufacturing logic could be modified to make a grerat variety of forms.

However, this shell typology is actually behaving very different from a coral, and is perhaps too abstract. Every individual cell does not perform so much as a shell element, but as a bunch of stacked up columns. Further, this design is insufficient due to in-plane instability.

Moving forward, we decided to extract the coral stacking feature as part of our next design, which would also solve the problem of in-plane instability.

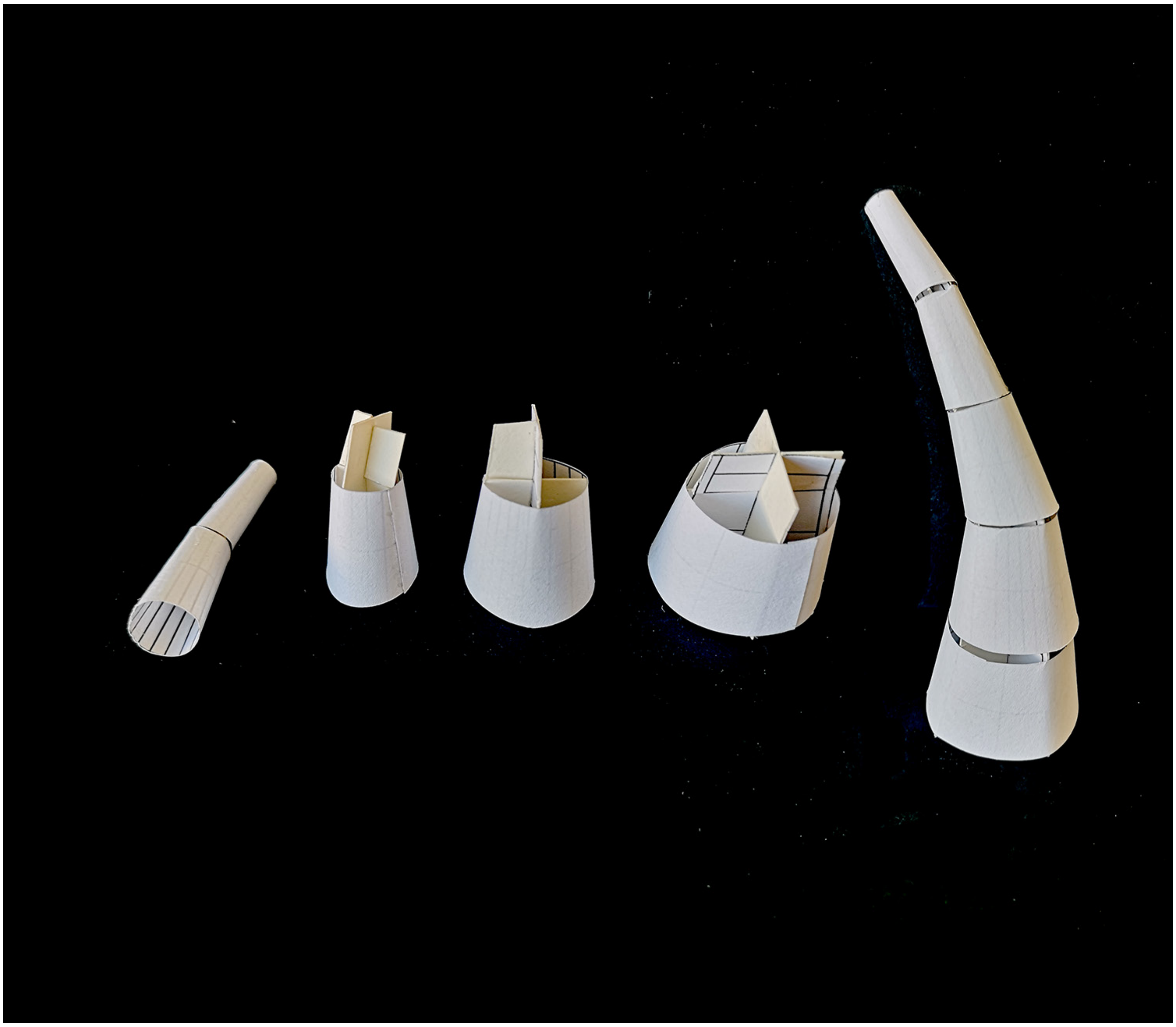


FIGURE 20: Model with plug type connecions

Stacking Logic

The corals attain their height by stacking on eachother end to end. This logic is extracted for architectural modules to attach to one another.

In the case of the corals, the calcium carbonate is simply accumulated on top of the previous layer. This makes for one continuous wall that is shared among neighboring coralites. It behaves in a similar manner to a 3d printer, using the old layers as the foundation for the new.

This architectural abstraction is using more traditional building materials in lieu of 3d printing methods. The modules will be materialized out of some sort of sheet material like wood or steel, and so the growth logic needs to be reimagined.

The coral's ribs are purposed as an attachment for the modules to join end-to-end. The ribs are a protrusion that plugs into the relief in the next module. This forms a rigid male-female connection that can resist bending forces. This type of coupling is not how the corals build, but it does use all of the existing elements without having to use fasteners.

This type of exploration exemplifies how the biological role model can inspire abstract solutions to architectural problems.

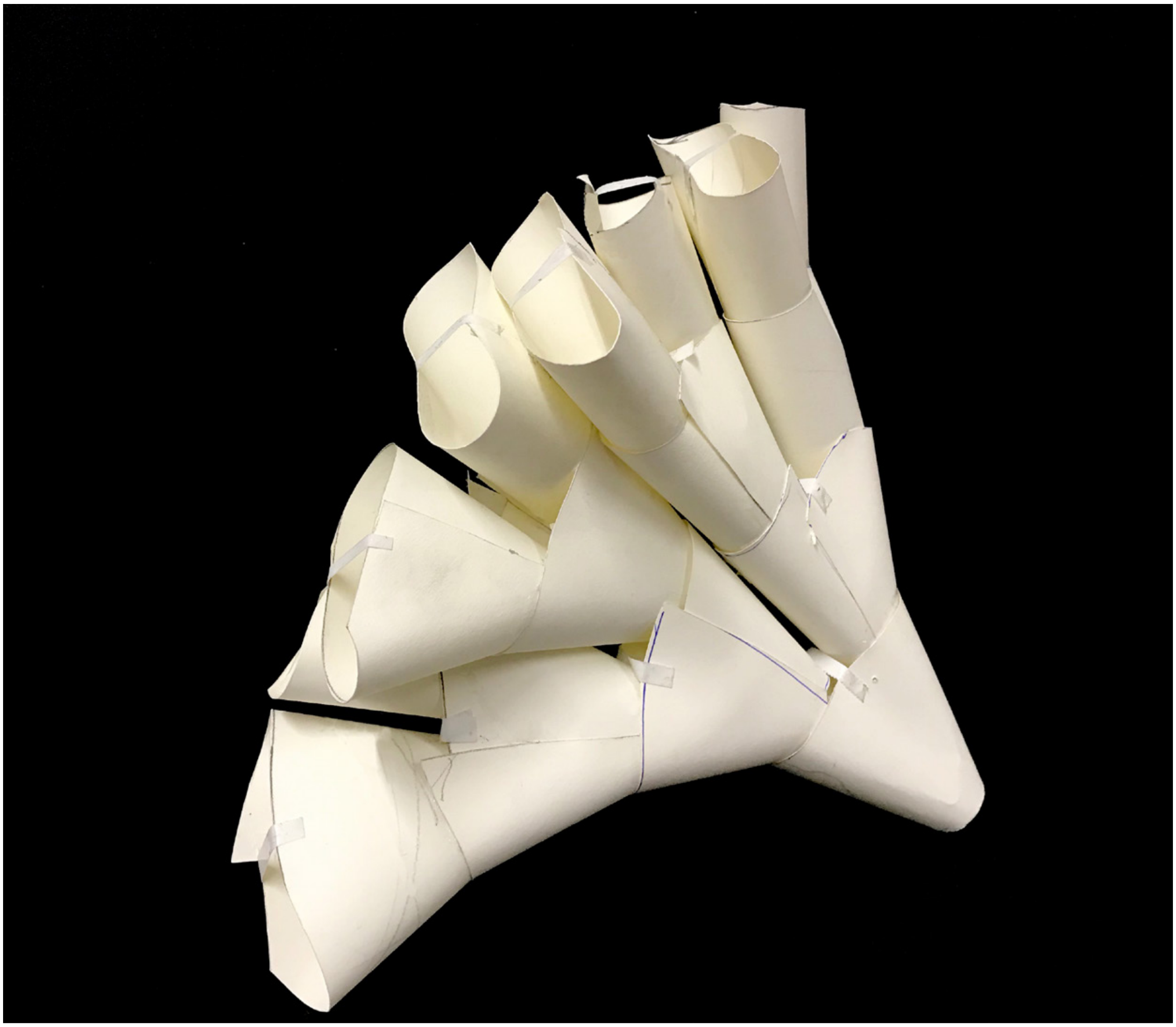


FIGURE 21: Model with bending actived kerfed modules

Branching Logic

The coral grows in a type of branching logic where each coralite splits into two. It is visually similar to a cellular mitosis (figure 22).

The architectural abstraction creates a module by isolating the splitting coralite. The geometry is derived from lofting one circle to two circles. The module takes on the geometry of a flattened cone, which functions as both the primary structure, and the coupling unit for growth.

As the structure grows, and becomes more dense, the modules have a tendency to twist. This adds depth to the structure as it attains height. However, a more seemless service is desired

FIGURE 22: Coral Reproduction

FIGURE 23: Tri-mesh shell with interconnected radial ribs and walls.

FIRST DIGITAL EXPLORATIONS

The development of these first algorithms considered the septo-costae and the wall of corals as stiffeners that could be applied to shell structures.

The idea that corals grow differently according to its environment was also one of the principles abstracted here. The algorithm could be applied to an initial surface, whcih would form an optimal pattern depending on that initial surface shape.

The first approach uses the natural quad pattern generated by the mesh (figure 24). The second uses the Meshmachine component from Kangaroo to remesh the surface, producing triangular faces (figure 23). The third is a dual from the previous mesh, which generates a pattern coposed of heptagon, heaxagons and pentagons. Those patterns were then used as a base to generate mass customized modules. They all have radial ribs interconnected, creating a network system that interlock them in place.

These algorithms were the first attempt to analyse how corals structure themselves. However, the final result that we produced are shells, and do not represent the way corals actually develop. Biological corals grow continuously, stacking material on top of each other, like a living 3d printer.

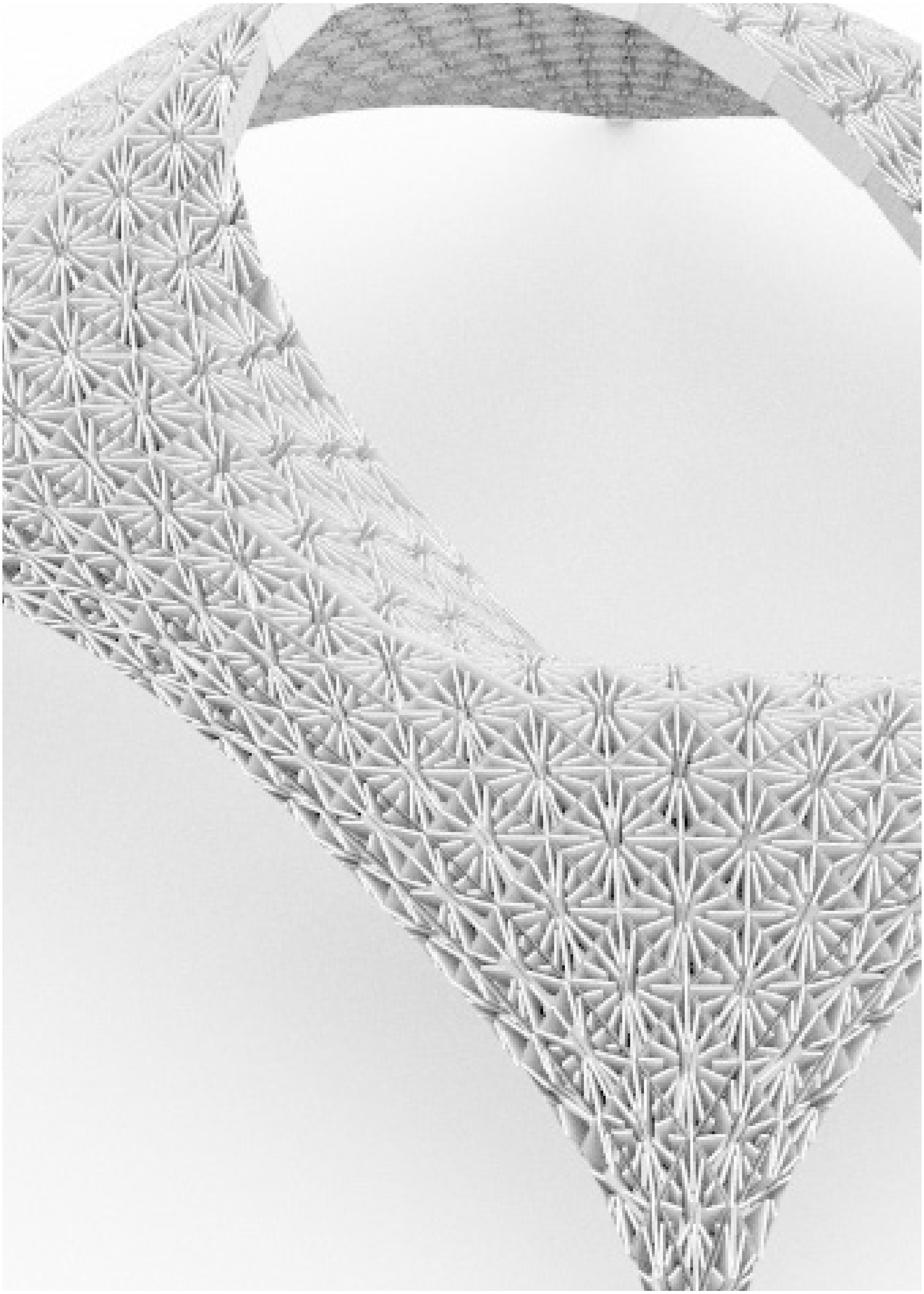


FIGURE 24: Quad-mesh shell with interconnected radial ribs and walls.

FIGURE 25: Phyllotaxis mesh.

Second Digital Explorations

On our first explorations, the development went too far from how corals actually structure themselves. We decided to steer the development to be more closely related to how corals really grow.

To do so, we explored some natural growing patterns. First, we looked at drawings found on the Paléontologie française. There we found interesting patterns that closely resemble the phyllotaxis pattern (figure 25), which is the way plants grow their stems. It is a pattern that has in its logic the golden angle and the Fibonacci sequence.

The patterns are also found in some corals like the Hexacoralla, (represented on plate 69 of Ernst Haeckel's book, Art Forms in Nature) which have some simple rule logics that could be used to generate some explorations. This logic is called differential growth and it is found in many different living beings.

Differential growth logic makes the surface grow while pushing the new part of the surface outwards, thus, avoiding collision with the old consolidated surface.

These studies served as material to discuss the efficiency of the coral shape for structure in the construction industry. The group met with the tutors from ITKE to discuss these shapes, however, we concluded that they were only optimal for underwater conditions.

Also, these shapes started to look too literal, mimicking the corals too closely and not actually inspiring a solution that could be translated into a construction system. We decided to move forward to another approach.

FIGURE 26: Vertical growing mesh.

FIGURE 27: Photographer David den Ouden

ARCHITECTURE

FIGURE 28: Final Table Coral Morphology

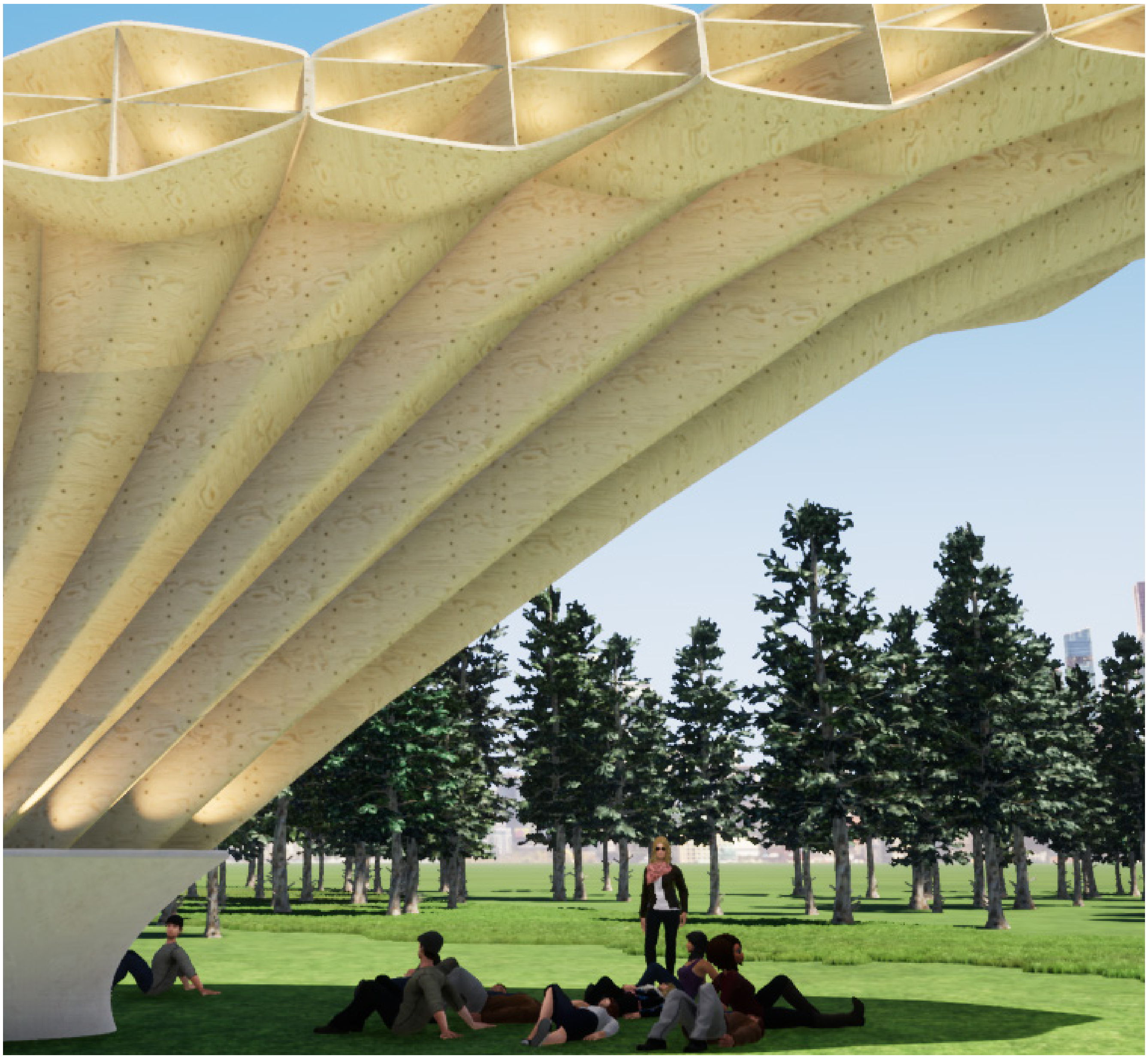


FIGURE 29: Example of pavilion being occupied

The Design

The final design is a wooden modular construction that emulates the growth logic of the coral. It reaches out in all directions to form a canopy for human occupants.

The global form emultes a table coral, growing out from one central foundation into a canopy structure. The table coral form is then modeled into a relaxed geometry using Kangaroo. This new geometry is designed as a catenary shape that follows the flow of forces.

The individual module is designed much like the coral inspiration. It is a hexagonal prism with central ribs for stiffening. The hexagonal shape allows for tight packing with neighbors, but it also means the vertices have 3 edges connecting them for structural stability.

By using the ribs, the entire module is triangulated. With this type of structure, there are tensile hoop stresses at the top of the structure . This requires the corals at the top to be fastened together tightly to form a type of tension ring. This is achieved by bolting the flush surfaces together.

FIGURE 30: The Coral Pavilion

FIGURE 31: The Coral Pavilion

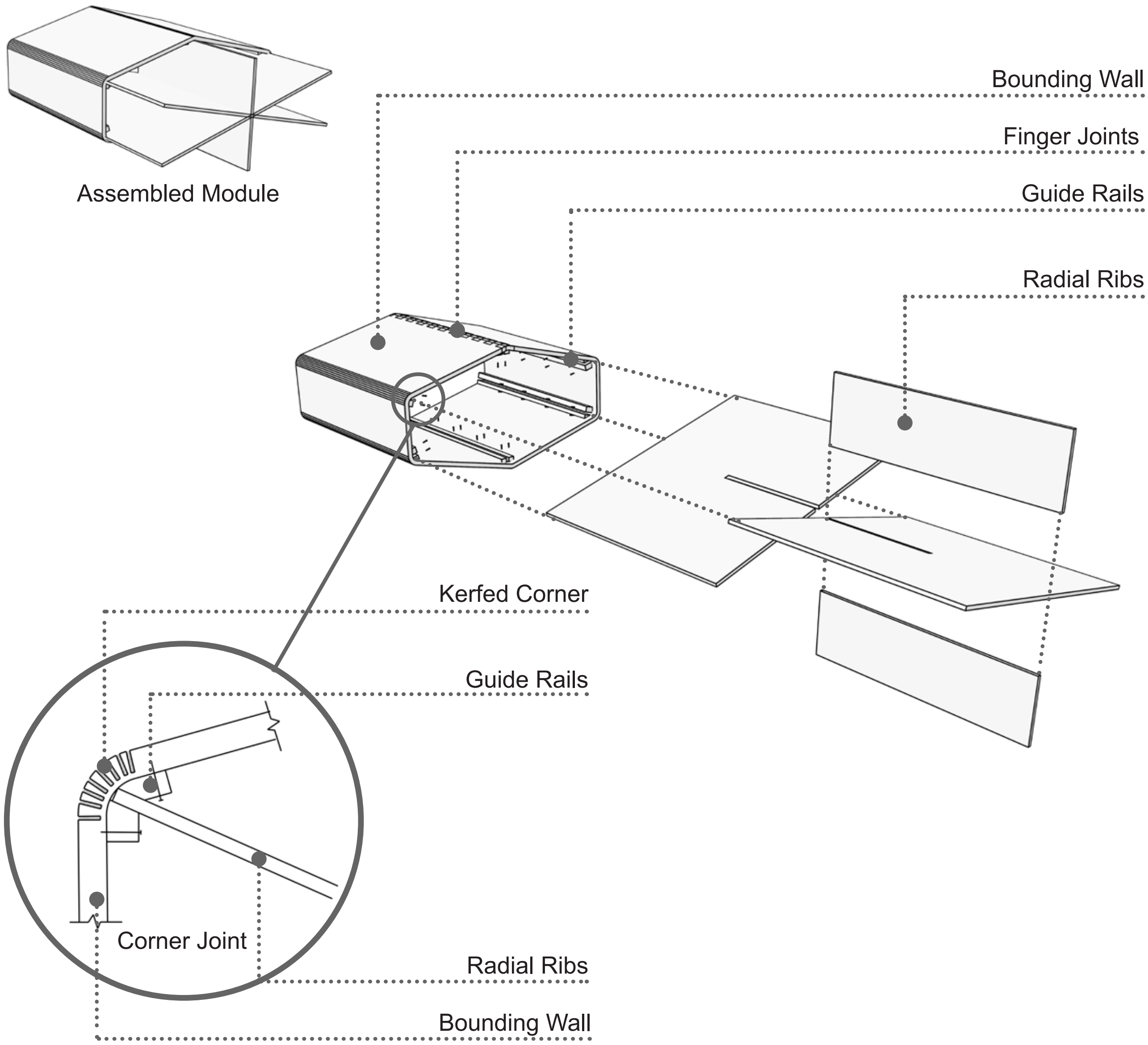


FIGURE 32: Module Details

Construction

The structure grows through the logic of modules stacking on top of one another. In this architectural abstraction, the central ribs protrude beyond the walls to form a male plug. The plug can then interface with the Guide Rails of the next module.

The structure grows in size through the modules increasing in diameter as the height increases. This logic is different in the biological corals, which increase in size through a type of branching logic. However, this branching logic did not make sense for the creation of a stiff shelll structure. This encouraged us to simplify the growth logic to a simple stacking of elements.

The manufacturing process is flexible and easily adapted to different designs. We wanted to design a construction technique to be used on a myriad of possible forms. When a form is procided, our algorithm generates a coral construction for that particular shape.

Every element is constructed from the same type of flat plywood sheets. This limits the amount of machines needed for fabrication, and it also allows the fabricator to order a large quantity of the same material. Also, the structure can optimize its stiffness by changing the amount of central ribs. This variable cross section allows us to use the same material to generate different structural capactities.

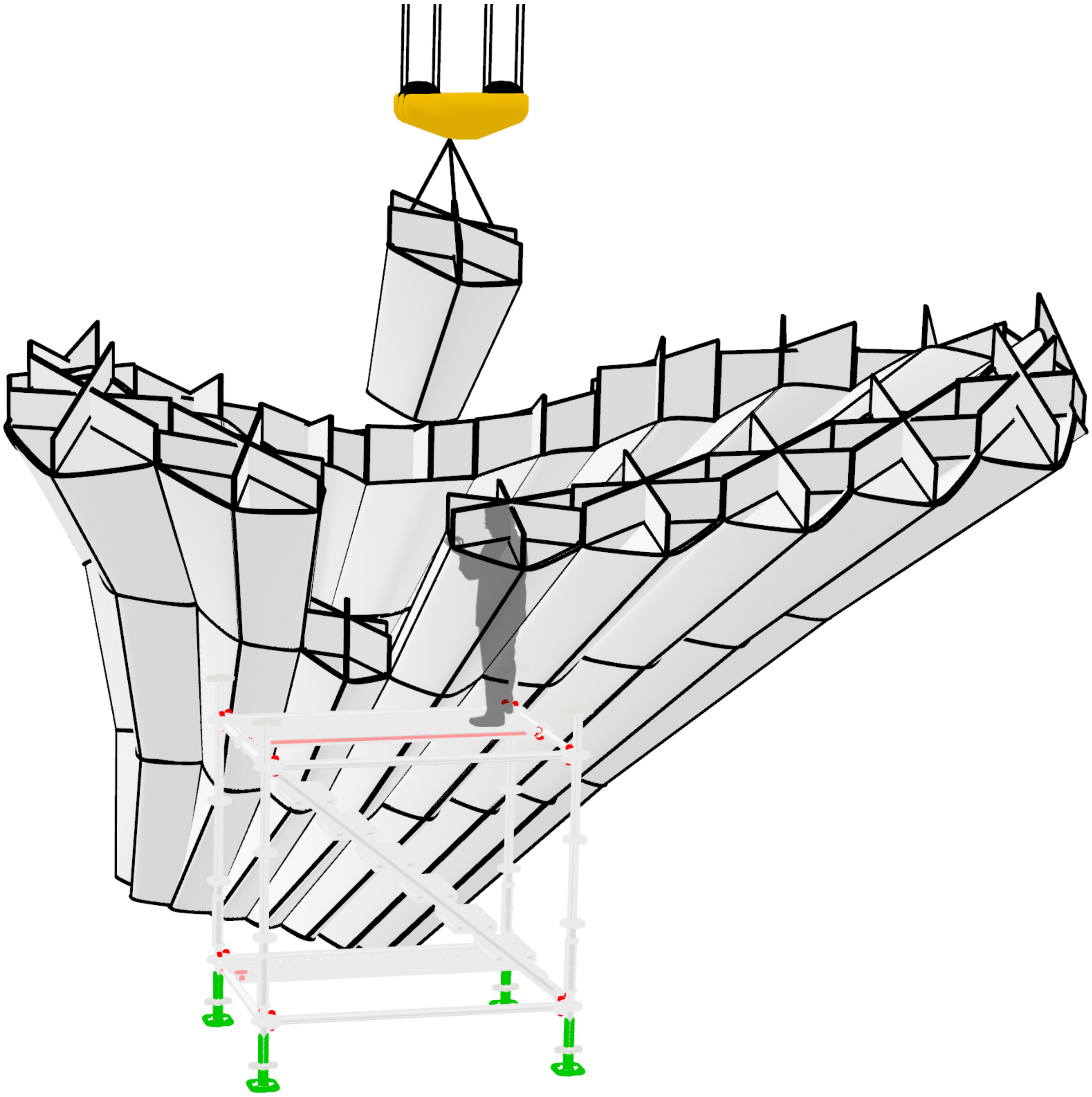


FIGURE 33: Construction Procedure

All of the pieces are CNC'd from plywood. The central ribs can all be fabricated from discrete pieces. The module walls however, are fabricated from one large sheet of plywood. The wood is kerfed to allow the wood to bend at the corners. In this way, the entire hexagonal prism is formed from bending one continuous sheet of plywood. At the ends, finger joints are milled to allow the plywood to close the shape.

Before bending the wood into the hexagonal shape, the wood guide rails must be fastened to the surface. This process can be executed with a 6-axis anthropmorphic robot. The robot uses one end effector to precisely place the wooden rails, and another end effector to fasten them into place.

The fabrication is highly automated and requires very little human intervention. In this case, humans are mostly needed to facilitate moving pieces in between machines and monitoring machine operations. However, humans are needed for the construction of these discrete pieces into cohesive modules. A human is necessary to bend the module walls into the hexagon shape. A human would also slide the central ribs into the guide rails.

The on-site construction also requires human intervention. As a crane lowers the modules into place, a human would guide the machine. Then, would bolt the pieces to their neighbors. This whole operation is completed with 3 people.

FIGURE 34: 1:100 Scale prototype: Polygonal modules with plug-type joints

Physical Model

The pavilion is designed as developable surfaces such that it can be manufactured from flat sheets of plywood. This is a simple manufacturing process. It doesn't require any bending of wood or doubly curved surfaces.

When this design translates to a physical model, it likewise makes for an easy model building. All the pieces can be digitally fabricated using a laser cutter. First, the model is discretized into modules. Then, they are easily unrolled into a 2d file because they are developable surfaces. Finally, the pieces are cut out of a single sheet of thick paper using the laser cutter. The pieces are also kerfed at the folding lines.

The assembly of the model was likewise an easy linear process. The discrete paper pieces were folded at the kerfs to form the completed modules. Then, the modules were stacked end-to-end using the protuding ribs.

The hypothesis was that it would be easiest to fully stack the modules into full columns, then assemble the completed columns. However, it proved easier to assemble the module as concentric rings, moving upward in a floor-by-floor fashion.

There was a certain degree of error in the model, which we surmise is from the flexibility of the paper. With a more rigid wood material, error should be minimized. In addition, the small scale magnifies any small errors that occur. At full scale, we suspect this will be a valid assembly method.

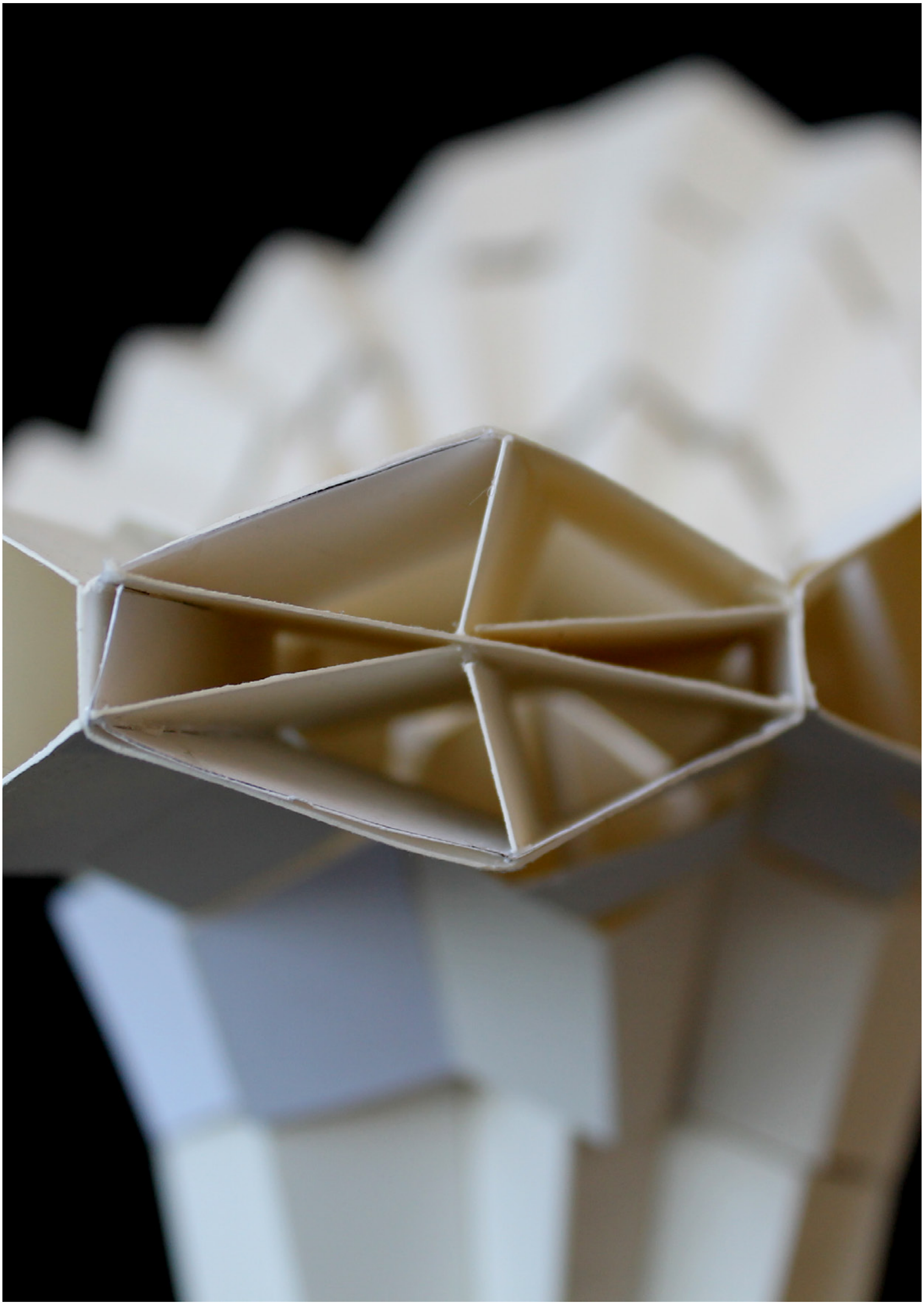


FIGURE 35: 1: 100 Scale prototype: Plug type joint.

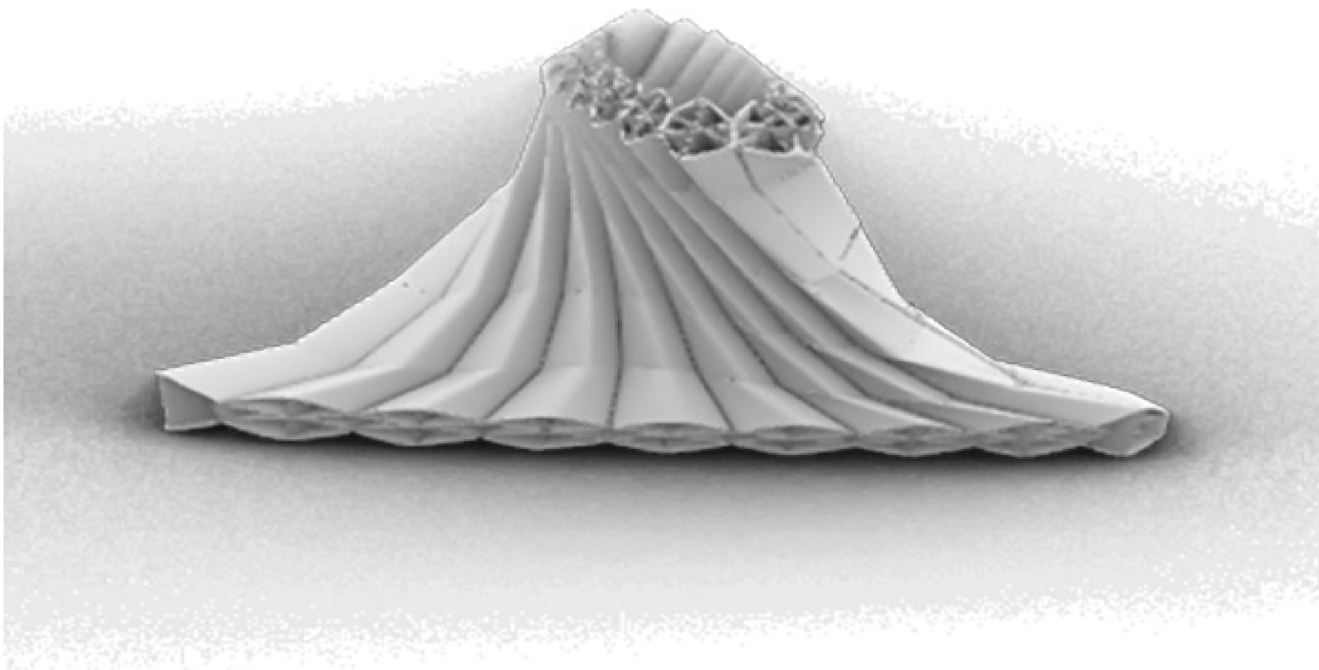


FIGURE 36: Shape Permutation

The Code

The logic of the biological coral growth allows the walls to be joined flushly to one another. In the case of the architectural abstraction, this is a challenge because the modules grow in size as they approach the top.

This code achieves flush joining by constructing the shape with concentric rings. Isocurves along the surface are divided into points. These isocurves are then offset to form 3 concentric curves. Points along these concentric curves can be indexed methodically such that polylines can be drawn in the shape of planar hexagons. In this way, the hexagons always share an edge with a neighboring hexagon.

These hexagons function as cross sections for the surface of the final shape. The hexagonal cross sections are straight lofted together. This straight loft generates a developable surface that can be fabricated using 2d methods.

The inner stiffening ribs are generated using the same set of points. A different index pattern is used, then the ribs are built with the same loft logic.

This code can be applied parametrically to any given shape. This allows us to quickly iterate a myriad of coral possibilities such as the permutation shown in figure 36.

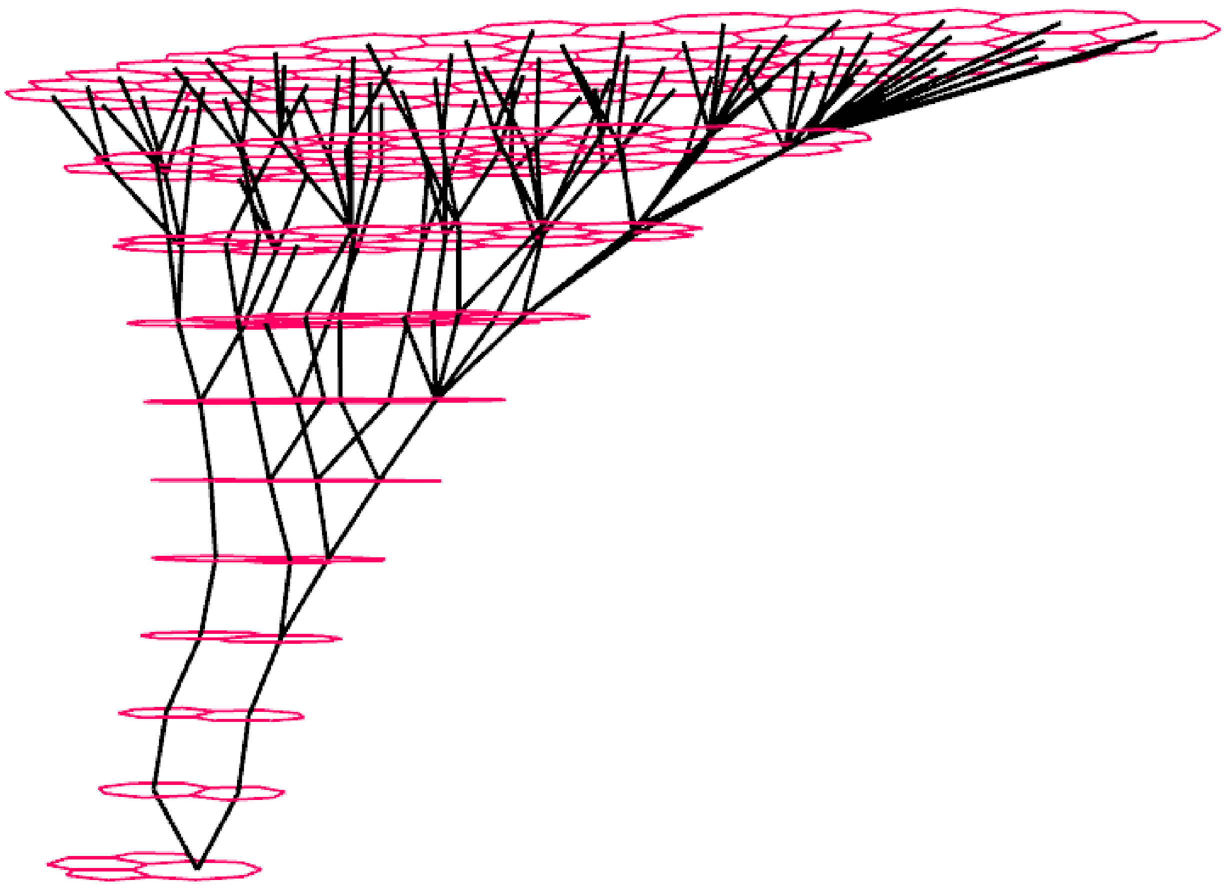


FIGURE 37: Speculative branching for future studies.

Future Development

There are several aspects which should be addressed in the future in order to develope the system.

1. The modular system could be used for various other morphologies in terms of adaptivity and versatility.
2. Currently the geometry is generated using ruled and rotational geometries. Other architectural surfaces could be further investigated for the same modular configuration.
3. The system could be analyzed and optimized for stability related loads and geometrical equilibrium.
4. A huge potential is seen for this system in terms of branching type structures. Further studies are required to implement the module configuration in these kind of structures (see figure 37).
4. Significant research is required for construction feasibility. It is suggested to carry out further investigation on relevant construction related issues and check their validity by constructing a 1:1 scaled prototype.

References

1. Humblet, M., Hongo, C. and Sugihara, K., 2015. An identification guide to some major Q uaternary fossil reef building coral genera (A cropora, I sopora, M ontipora, and P orites). Island Arc, 24(1), pp.16-30.
2. Miller, K.J., 1994. Morphological variation in the coral genus Platygyra: environmental influences and taxonomic implications. Marine Ecology-Progress Series, 110, pp.19-19.
3.Helmuth, B.S., Sebens, K.P. and Daniel, T.L., 1997. Morphological variation in coral aggregations: branch spacing and mass flux to coral tissues. Journal of Experimental Marine Biology and Ecology, 209(1-2), pp.233-259.
4. Zawada, K.J., Dornelas, M. and Madin, J.S., 2019. Quantifying coral morphology. Coral Reefs, 38(6), pp.1281-1292.
5. Knippers, J. and Speck, T., 2012. Design and construction principles in nature and architecture. Bioinspiration & biomimetics, 7(1), p.015002.
6. Nothdurft, L.D. and Webb, G.E., 2007. Microstructure of common reef-building coral genera Acropora, Pocillopora, Goniastrea and Porites: constraints on spatial resolution in geochemical sampling. Facies, 53(1), pp.1-26.
7. Burgess, S.N., McCulloch, M.T., Mortimer, G.E. and Ward, T.M., 2009. Structure and growth rates of the high-latitude coral: Plesiastrea versipora. Coral Reefs, 28(4), p.1005.
8. Knippers, J., Nickel, K.G. and Speck, T., 2016. Biomimetic Research for Architecture and Building Construction. Switzerland: Springer International Publishing.
9. Gruber, P., 2011. Biomimetics in architecture. Springer Verlag Wien.
10. Dana, J.D., 1899. Corals and coral islands.
11. Sheppard, C., Davy, S., Pilling, G. and Graham, N., 2017. The biology of coral reefs. Oxford University Press.
12. Kaandorp, J.A. and Kübler, J.E., 2001. The algorithmic beauty of seaweeds, sponges and corals. Springer Science & Business Media.
13. Chen, D.A., Ross, B.E. and Klotz, L.E., 2015. Lessons from a coral reef: Biomimicry for structural engineers. Journal of Structural Engineering, 141(4), p.02514002.
14. Sonntag, D., Aldinger, L., Bechert, S., Alvarez, M., Groenewolt, A., Krieg, O.D., Wagner, H.J., Knippers, J. and Menges, A., 2019, October. Lightweight segmented timber shell for the Bundesgartenschau 2019 in Heilbronn. In Proceedings of IASS Annual Symposia (Vol. 2019, No. 26, pp. 1-8). International Association for Shell and Spatial Structures (IASS).
15. J. Messersmith. Patterns of the Sea [online]. Available at : http://www.messersmith.name/wordpress/2009/05/31/patterns-of-the-sea/
16. D.D. Ouden. 2017, Delicate Underwater Architecture [online]. Available at: https://daviddenouden.nl/2017/02/22/delicate-underwater-architecture/
17. C.Crist.2017, 9 Images Show Vibrant Great Barrier Reef Coral [online]. Available at:https://www.pastemagazine.com/articles/2017/01/9-images-show-vibrant-great-barrier-reef.html
18. How corals reproduce [online]. Available at: https://forthereef.com/blogs/news/coral-reproduction
19. Nervous System, Flora form Sculptures, 2014 [online]. Available at: https://n-e-r-v-o-u-s.com/projects/albums/floraform-sculptures/
20. Marc Fornes, 2018, the Everymany [online]. Available at: https://theverymany.com/brugge
21. Projects 2019, Institute of Computational Design, Buga Wood pavilion [online]. Available at: https://www.icd.uni-stuttgart.de/projects/buga-wood-pavilion-2019/
22. Amy Frearson, 2016, Bjarke Ingels completes Serpentine Gallery Pavilion that is „both solid box and blob“ [online]. Available at: https://www.dezeen.com/2016/06/07/bjarke-ingels-big-serpentine-gallery-pavilion-london-translucent-blocks-unzipped-wall/

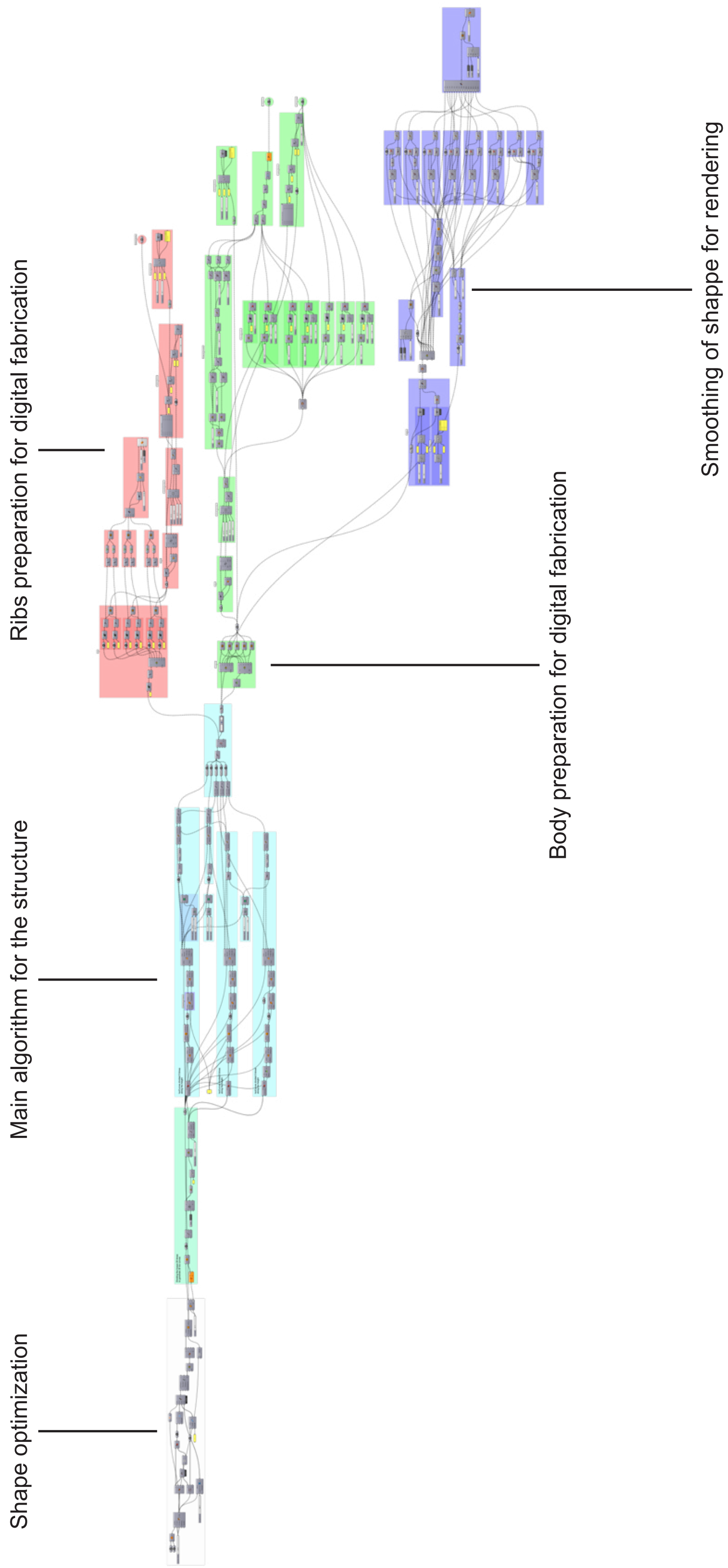


FIGURE 38: Grasshopper definition. (*Source:* Authors)

The project aims to abstract biomimetic principles of static structures and apply it to the Architectural realm. An in-depth study on the biological principals of Corals is carried out post which architectural and structural design principals are extracted. The abstraction focuses on the global coral morphology and modular behavior. During the project an architectural module inspired by the polyp structure is developed. The module can be varied based upon set of rules in order to generate different global morphologies.

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