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Design in Nature

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Final Biomimicry Proposal

Throughout this semester, I aimed to explore ways in which biological strategies in nature can influence and enhance material application in automotive vehicles. The natural examples I focused on were oyster reefs, nacre, turtle carapace, and pine cones. Utilizing the adhesive qualities, layers, sutures, and hydration respondent bending of the explored nature example, I narrowed down to focusing on turtle carapace and pine cones for application to the finalized design. My design addresses the statement ‘How might we create a climate respondent, structurally integral material inspired by nature, enabling tires to adapt to extreme weather conditions?’ This addresses the need for snow specific tire adaptations in colder climates, incorporating the hydration induced bending of pine cones as well as the sutures within turtle carapace to allow for climate adaptive tires that create grip and traction as the state of the road changes.

Oysters create a natural reef structure which shields the larvae from external forces such as tides. These reefs are built with the help of the ‘oyster cement,’ a source of natural glue. This oyster cement is unique due to its composition which contains higher levels of calcium carbonate as opposed to protein, which is commonly the composition of many marine animal glues (NSF, 2010). The addition of calcium carbonate allows for the bond and structural rigidity that is required for the reefs: “oyster cement uses two kinds of calcium carbonate, chemically equivalent but made from

crystals having different shapes and orientations. Other results indicate that the adhesive may incorporate material from its aquatic environment and may even involve symbiosis with bacteria that add sugars to the organic portion" (Carstens, 2020).

The material composition of proteins and calcium carbonate which allows for both flexibility and rigidity can be an important take away and potential area of development for future bio-inspired or bio-based materials. From the research in oyster reefs and cement, branching out into the next nature-based example to see a micro, smaller scale application of non-composition based, but more physical-structure based materials felt natural.

Nacre or Mother-of-Pearl is a biomaterial found in the shells of mollusks. This material can often be found applied as ornamentation and for aesthetic purposes on artifacts that date back thousands of years. Sought after for its iridescent and lustrous qualities, nacre is commonly used as the finishing material of higher-end objects or decorations. Outside of its visually appealing appearance, nacre has many materialistic characteristics to explore and apply in the world of biodesign.

A promising component of nacre is its ability to withstand impact, even with its thin and delicate nature. The nacre holds nanoscale deformation mechanisms which allow for it to have high resilience to damage at both small and large scales. With a phenomenon called tablet locking, where small tablets interlock throughout the nacre's structure, the energy of an impact can be absorbed and dampened: "large forces can drive nacre into locked states that allow the material to distribute strain across tablets and recoverably absorb energy through inorganic and organic compression, nanograin reorientation, and the deformation of organic inclusions" (Gim et al.). With the

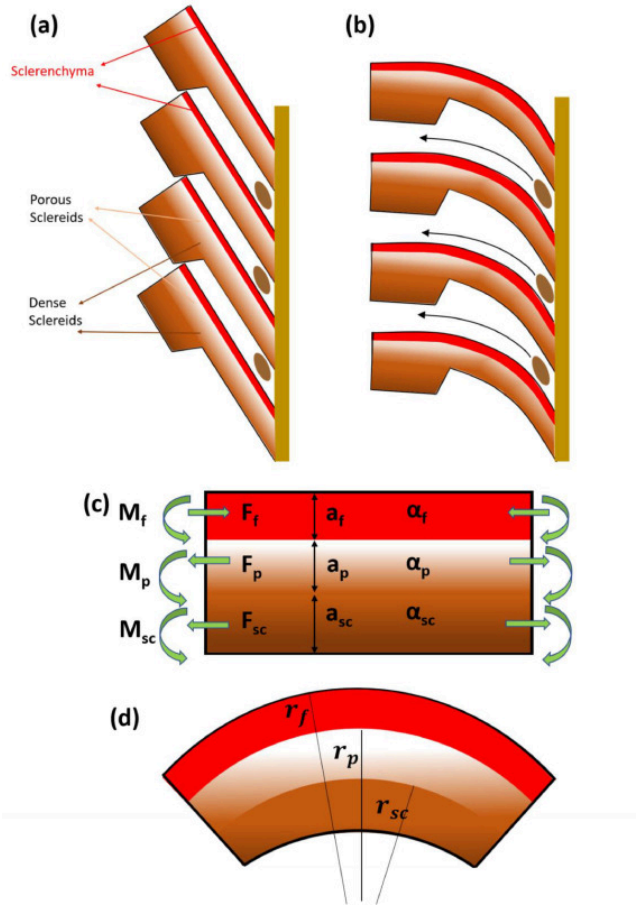
understanding of nacre's inherent properties of crack resistance and pressure distribution due to its tablet structure, we can find ways to derive the successful elements of the tablet composition and apply them to automotive applications.

While researching nacre, there was a natural draw towards finding other natural examples or species that had elements of flexible yet rigid compositions. The carapace refers to the hard outer shell in animal groups, specifically focused on the red-eared slider turtle's shell for this context. Turtle carapace is intriguing due to its geometric shape, interlocking sutures, and multi-layered composition. The dome-like structure of the shell is formed with hexagons, pentagons, and surrounding irregular shapes known as scutes. As noted by Foy, "Hexagons are the ideal shape for packing an area tightly with a repeated shape, but they cannot form a curved surface on their own. Pentagons are needed to create a tension-free bend. The range of shapes that fit together to form a tortoise's curved shell are the result of millions of years of evolution and present a natural solution to the mathematical and physical problem of creating a dome-like structure that is both strong and lightweight" (Foy, 1983). Nature's combination of multiple geometric shapes to create a curved form can be adapted for designs in our current world and for automotive purposes in creating structurally integral curvatures.

Other components that are interesting about carapace are the zig-zag shaped locking sutures that form and hold the scutes together. While the scutes are rigid and stiff, the sutures are able to absorb energy upon impact due to its slight flexibility, creating a duo that works to prevent damage upon collision or outside impact (Achrai and Wagner, 2015). Beneath the hard keratin layer that makes up the outer shell and scutes, there are layers of fibers and sponge-like tissues which are able to absorb

energy and give room for flexibility and movement in the necessary cases (Achrai and Wagner, 2012). By understanding how rigid and flexible elements work together in nature and organisms, we are able to integrate these concepts into our design processes and executions.

An organism that demonstrates a different variation of flexibility is the pine cone. Pine cones are equipped with a bi-layer, porous system which enables water absorption and desorption, thus creating swelling and bending in the figure and allowing for seeds to release or stay enclosed (Poppinga et al., 2017). In experiments conducted by Quan et al., pine cones were tested with both a bi-layer and tri-layer structure to see how the addition of another layer would interact or interfere with the natural swelling of the figure. It was found that the incorporation of the middle porous layer “has a profound effect on the maximum stresses; and the stress in the fibrous layer, which is the highest, is reduced from the bi-layer case to approximately one fourth in the tri-layer case…With the presence of the porous component in the sclereids that connects to the sclerenchyma fibers, the stress concentration between these two actuation components is dramatically



reduced and acts as cushion layer; indeed, the porosity gradient is vital for the enhanced interfacial toughness in the whole structure, conferring an enhanced integrity and durability compared to that previously calculated for a bi-layer architecture" (Quan et al., 2021).

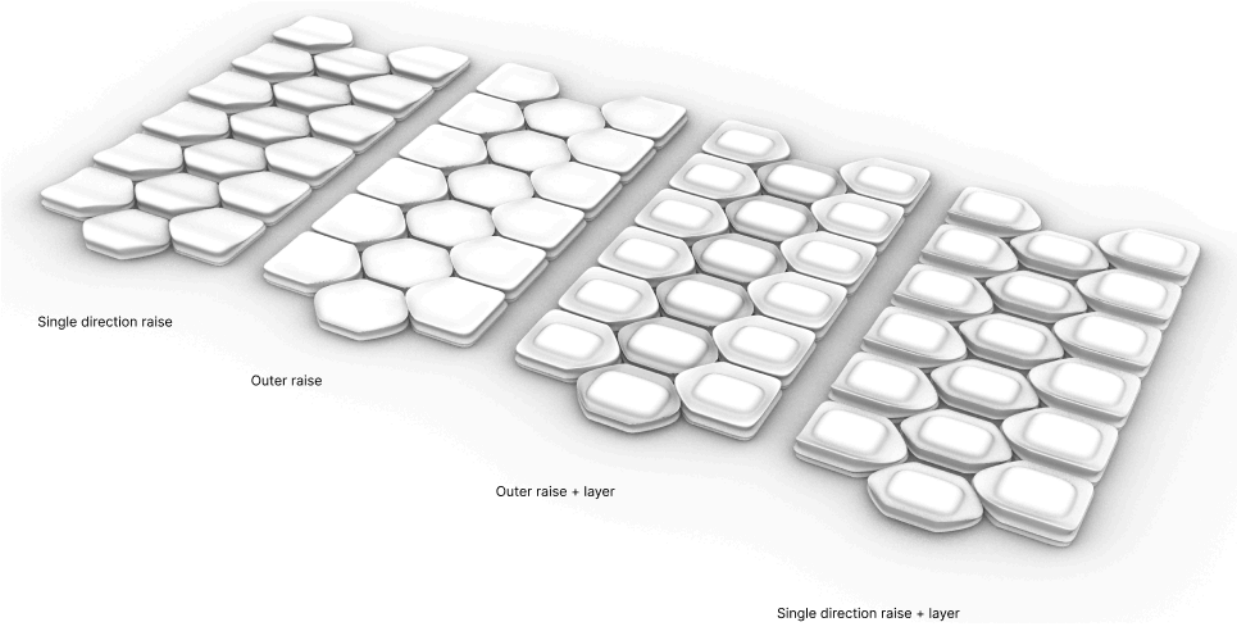
Initially the process of exploration began with material-driven design and research. While all components of layering, flexible and rigid materials, and adhesion found in the exemplified natural organisms were interesting, there were questions regarding specific use cases and directionality of the material development. With feedback that pointed towards honing in on a detailed and specific use case, personal pain points and experiences played important roles in ideating a use case scenario for a material developed utilizing the natural qualities of the prefaced nature examples.

During the midterm presentation and reviews, it was suggested to create an exposed-layer material with the rigid and flexible elements of nacre and carapace. Although this was helpful feedback, it felt too broad of a material with many spaces for application. With the addition of pine cones to the research after the midterm and feedback, it was easier to find an application that fit the mechanism and properties of both pine cones and turtle carapace, which were opted for in favor of their climate respondent and suture mechanisms. By combining the favorable qualities of these two natural examples, I arrived at designing an alternate solution for tires in extreme weather conditions, and more specifically for snow.

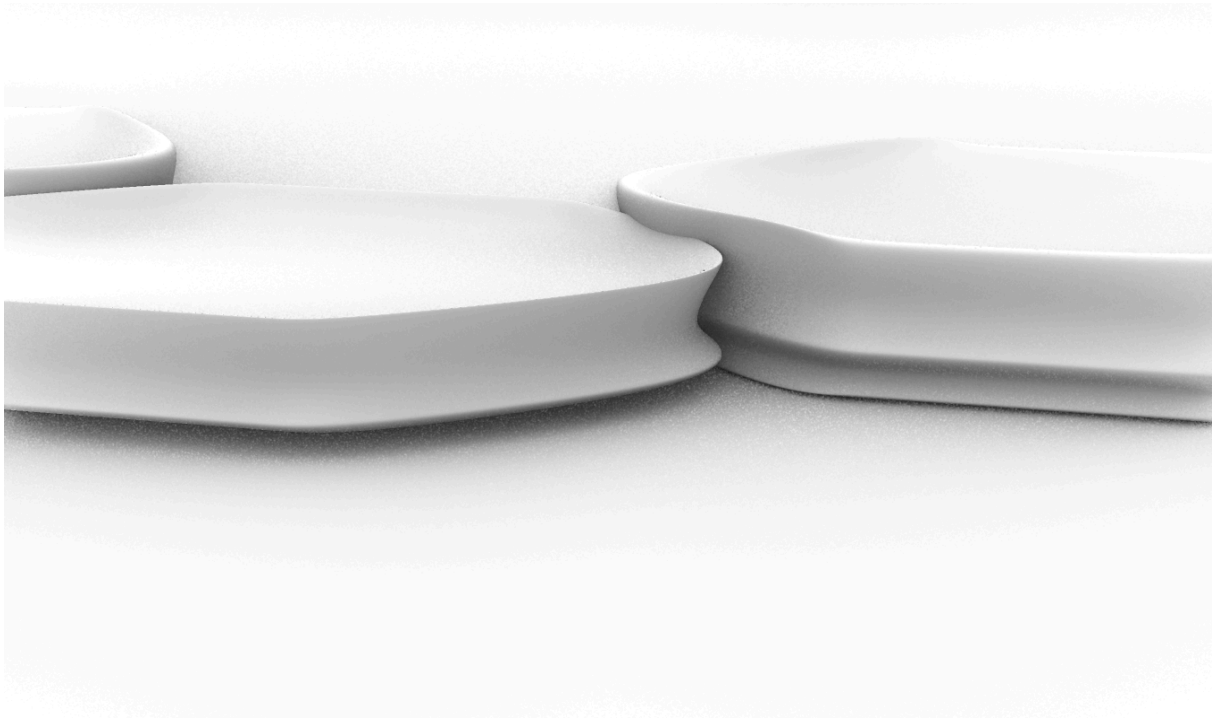
It is a common experience to have to attach and secure snow chains to the tires during the winter months in colder climates. Although it is a hassle, having snow chains is essential to the safety of the vehicle and passenger, especially in areas with lots of

snow and ice. Alternatively, drivers can opt to have snow tires, which will require a tire change every winter and spring as the weather conditions change. My proposal addresses the need for snow specific tire adaptations in colder climates, utilizing the hydration induced bending of pine cones as well as the suture structures of carapace to allow for climate adaptive tires that create grip and traction as the state of the road changes. I envision that the outermost layer of the tire would be made of a material with similar properties to a pine cone's sclerenchyma, which would allow for the layer to contract and expand in response to the surrounding climate. This is supported by research conducted on water transport systems and orders within the pine cone's inner layers, which influence the areas that open up and bend during shifts in hydration levels (Song et al., 2015).

In prototyping 3D models, I experimented with creating various methods of responses. In the ordinary state, the tire would consist of hexagon and pentagon panels with sutures that mimic the turtle carapace and hold the individual panels together. In the one rendition of the responsive state, the individual panels would rise at the corners, creating almost spike-like shapes for better traction on the road. Another response would be the edges of the panels only raising on one side, to create more grip as would be done by a snow chain in the snow. Other possible iterations and designs include adding a raised layer over each individual panel, similar to how turtles have more top volume and a dome like shape to each back panel. With individual panels connected by the sutures, damaged or punctured panels may be replaceable without having to scrap the entire tire, allowing for the tires to fulfill their whole life cycle before total replacement.



3D Modeling Iterations



Detailed shot of interlocking suture

Next steps for the spring semester consist of 3D printing the modeled components, testing, receiving feedback from experts, and material considerations and exploration. Additional considerations are furthering explorations as suggested by the project proposal feedback would also include but not be limited to researching additional nature examples which demonstrate how nature gets better traction on snow and ice, such as in polar bear paws or otters, and exploring how nature adapts and responds to changes in climate and temperature. By reevaluating and analyzing the biological strategies that best fit the responsive tire material innovation, I can better understand and inform the final form based on the newly conducted research. This step should be completed within the first few weeks of the spring semester (February to early March).

Utilizing various filaments and 3D printing methods, I would like to explore the combination of rigid materials (PLA) and flexible materials (TPU). The parts would be assembled to mimic a tire at a fraction of the scale (ex. 1:10), and tested to see how the PLA and TPU interact with one another and enable or disable strength and mobility in weight distribution. Some areas to consider for continued testing are measuring structural integrity between various designs, modularity, material responsiveness, and amount of traction gained. Experts from both scientific and automotive fields will be crucial in furthering the development and refinement of this innovation. Their help may be needed in both conducting these experiments as well as analyzing and interpreting the data that is collected. The series of prints should be available by mid to late March to allow for back and forth communication with experts and possible iterations (April to Mayl).

Another crucial aspect of the design is material exploration and consideration. With a longer time frame, material development in accordance with the composition of hydro-reactive elements present in the pine cone layers would be ideal for a full cycle inclusion of the biological inspiration. This would also apply to the turtle carapace and the sponge-like materiality of the sutures, as well as any other nature inspirations incorporated into the process down the line. Utilizing existing materials and combining them will allow me to see and gauge areas that need improvement, such as increased flexibility or elasticity, or increased rigidity, ultimately leading to a development or revision of a final series of material choices to be applied to the tires. The material can be developed simultaneously with the prints and testing for the form (April to May).

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Figures

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Lee, K. (2024, December 5). *3D Modeling on Rhino 8: Iterations*

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