This paper explores the intersectionality of design thinking, habitat restoration, and shoreline resiliency by examining contemporary practices of Artificial Reefs (AR). It asks the question if approaches for coastal city resilience can be designed to develop aquatic ecosystems.

Objectives:
to use design methodology for ecologically minded resiliency strategies.

End Products:
the end product of this research would be a 1:1 Artificial Reef deployed in the Pacific Coral region (show on next page). This reef would be made of BioMason concrete to test the versatility of an emerging construction material.

makingreefs
:Artificial Reef Structures as Ecologically Minded Resiliency

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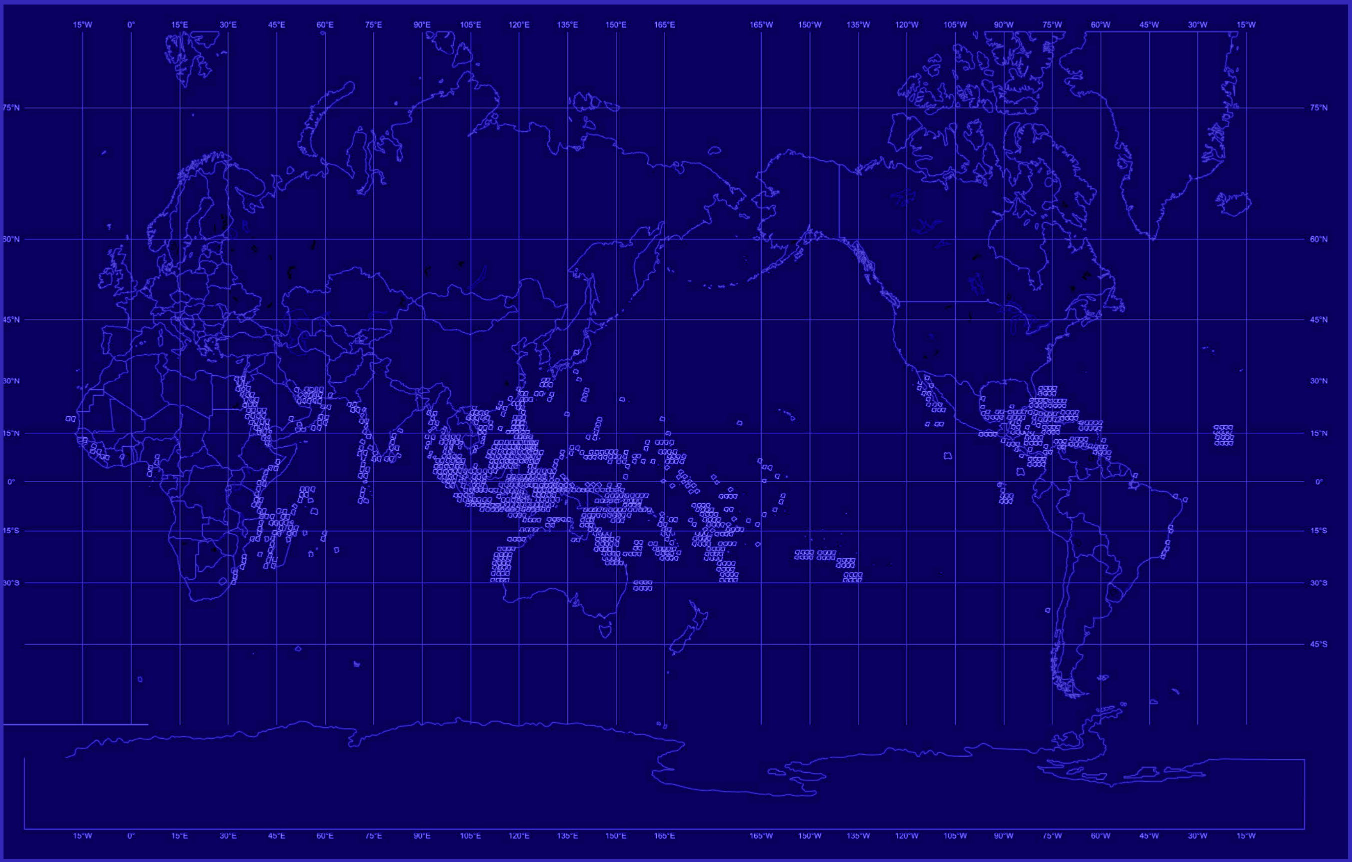


Coral Zone
[Original Content]

[Significane:]

Plastic waste generated around the global can be found in international ocean waters around the globe. Much of the micro-plastic pollutants are distributed in both pelagic and benthic zones of coastal and marine systems (Thushari and Senevirathna 2020). These zones are crucial to marine biodiversity as nodes of migrations, sites of spawning, and the intertidal area which houses coral reefs.
The convergence of the Great Pacific Garbage Patch (GPGP) and the most dense zone of coral reefs creates a serious problem. Surface water currents are the main indicator of aquatic plastic waste movement, suggesting the bulk of this waste sits atop of waters surface (Schoell 2019). This blocks vital sunlight from reaching the depth of the coral reefs, therein restricting the zooxanthellae's photosynthetic processes.

[Status Quo:]

Current research shows that submerged breakwaters can assist in shoreline stabilization via wave attenuation and wave refraction (Harris 2006). At present, there are many fabrication design groups that are making fabrication headway on assembly of AR. Recent design applications use grafted structures that are constructed to the seafloor, easily fabricated, and can be designed for specific aquaculture (Harris 2006). These firms innovate materiality to generate a symbiotic relationship between structure and ecosystem, using ceramic and calcium carbonate rich 3D printing filament. (Reef Design Lab and Objects and Ideograms). There is
much evidence providing biological networks graft better to these materials than traditional building materials (Kalam et all 2018).
A recent development includes a constructed coastal seafloor that is rich with carbon sequestering seagrasses integrated within a diverse terraform, marine framework (cite). Seagrass is a vital carbon sink (cite). There is also research suggesting that terrestrial approaches can be a useful tool in coral reef restoration and coastal resiliency.

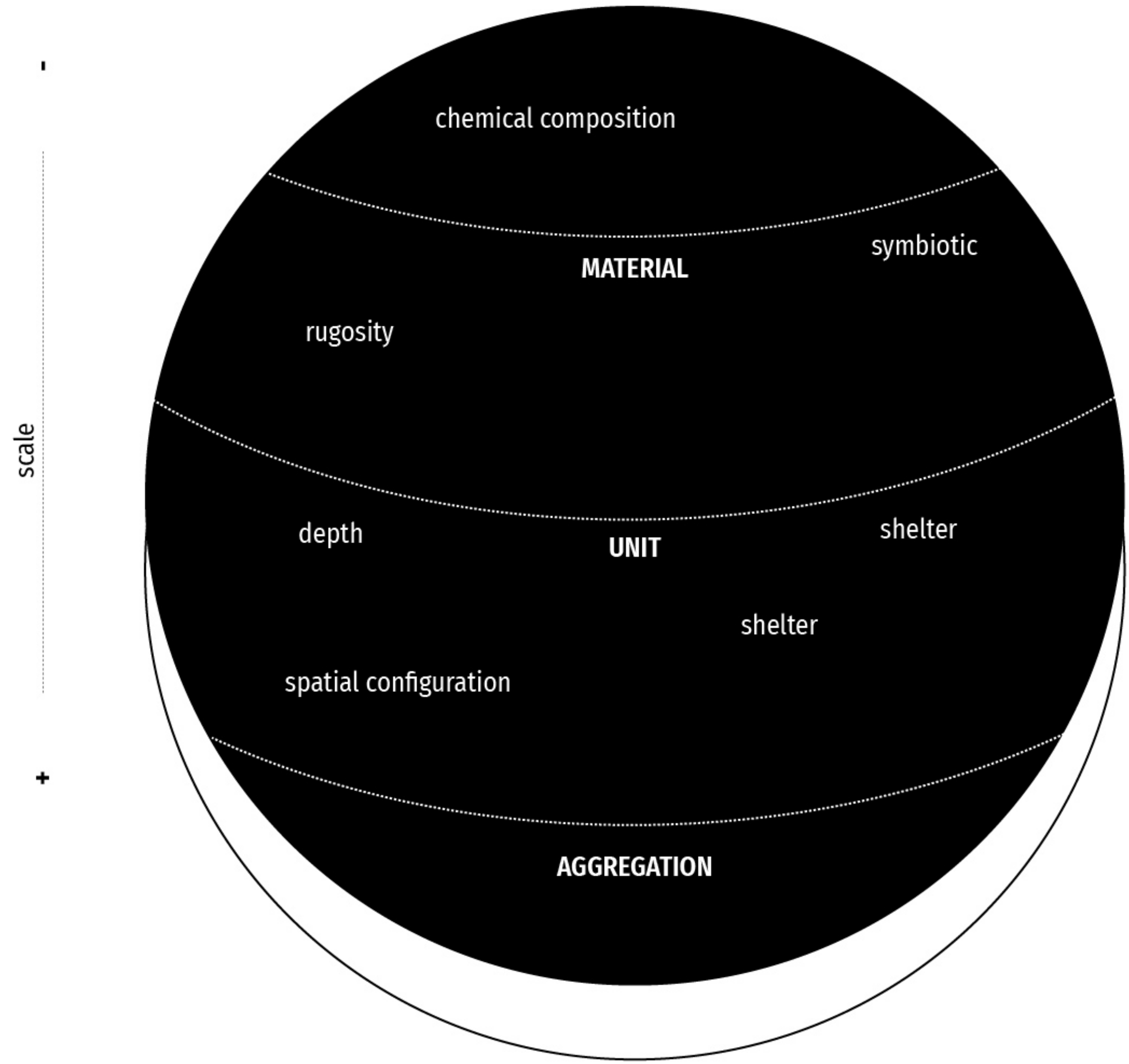
[Gap:]

Recent studies support the conclusion that reef restoration by artificial creation alone is not enough to address the present biosphere imbalances (Gong 2020). There is underdevelopment in the research surrounding coral habitats as risk reduction methods for coastal communities which generates a divide between sustainable, intersectional solutions. Municipal investments in resiliency strategies, both hard and soft, are too limited in their approaches to address the complexity of ecosystem protection. Hard strategies such as seawalls or soft strategies such as beach replenishing disrupt aquatic life and work against the natural ebb and flow of coastal cities. Hard defense strategies cause losses and alterations to shallow sedimentary habitats (Airoldi and Beck 2007). Soft strategies for shoreline stabilization are also an incomplete solution. With increasing erosion patterns happening on coastal shores, beach nourishment becomes economically infeasible (Harris 2006, Airoldi and Beck 2007). These short tem, reductive solutions that do not provide sufficient consideration to ecological complexities

There are various types of coastline habitats that work to create a buffer zone that can protect shoreline communities. Some of the habitats suchs a wetlands, marshlands, seagrass meadows, macroalgal beds, biogenic reefs, coral reefs and sedimentary habitats have a diversity of life and activity (Airoldi and Beck 2007).

The term Artificial Reef (AR) is commonly understood as a non-geologically occurring framework to develop marine communities. The intent of AR is that they emulate a naturally occurring reef through the protection, regeneration, concentration, or enhancing of living marine resources (Woo et all 2005). There are many applications and approaches to these structures but there is little research establishing a hierarchy of needs to reference when designing this multi-actor infrastructure (Ferrario et all cite). At present AR and shoreline resilience methods are mutually exclusive, where each serves a specific actor.

Right: qualitative constraints from a new AR design were pulled from various academic papers (next page) and the testing shown above.



CONSIDERATIONS	PROPOSED BY	TAKE AWAY
1. depth *+into substratum* *+below sealevel*	*harris, 2006* *konh and perry, 2019*	grip enough to withstand 157mph winds and help deter erosion. 12-21m below sea level for coral growth
2. rugosity *+ texture* *material scale : mirco*	*perksol-unkel et al, 2005* *wahl and hoppe, 2002*	essential for micro-level habitat to allow species to graft onto AR. design this scale through biomim-ickry of wrinkled skin or any organic material that is fibruous layering is saturated
3. shelter size		important to have a variety of sheltering scales within the overall aggregation to increase biodiversity
4. materiality *+composition and chemistry*	*perksol-unkel et al, 2005*	preference is given to material compositions that are encourage biological grafting, are carbon skins, generate a symbiosis between AR and ecosystem or that dissolve over time
5. spatial configuration *scale : unit tesselation*		verticle members faciliate coral growth. benefical to have variety that can aggregate to encourage cross habitat zones
6. inhabitants *+type, age, size, needs*		must allow for demersal fish, juvenille marine animals, and microbial communities
7. deployability	*harris, 2006*	should be easily depolyable under-water with most assembly happen-ing on land

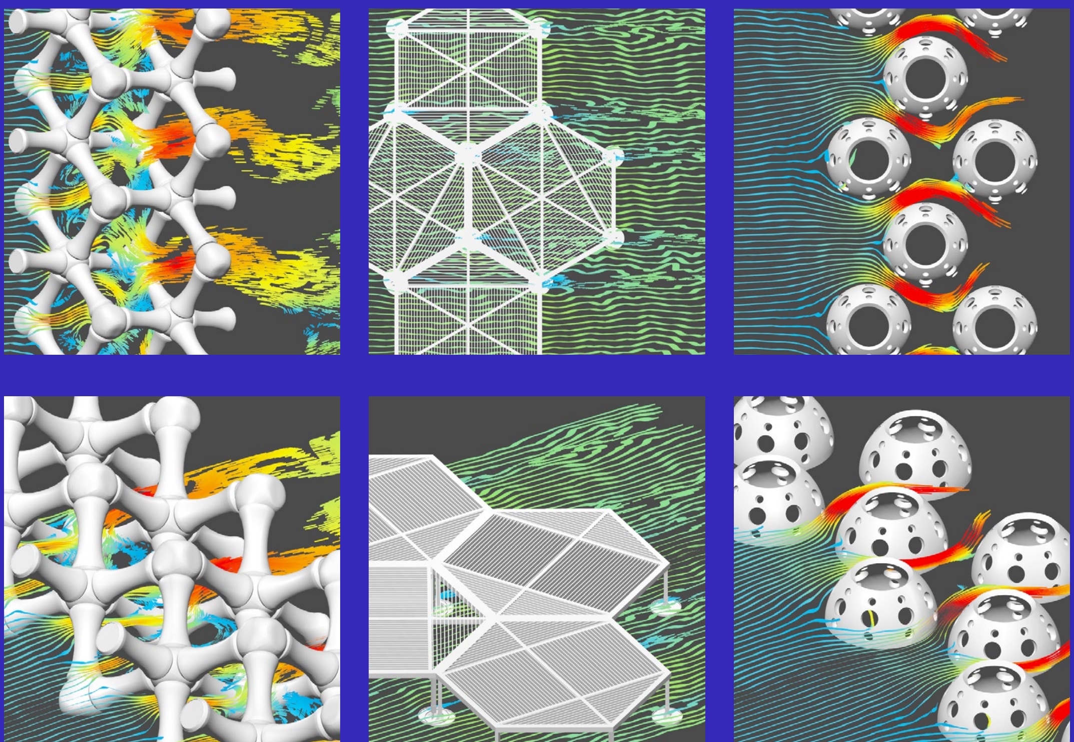
METHODOLOGY

The methodology to test this research is done in three parts. The first is digitally simulating water forces onto the existing ARs. The second step identifies successful components of the existing reefs to a novel design that is again simulated to test interactions with water forces. The final step is to create a mock of the new AR prototype.

[Digital Simulation]

This process is done with ArchoDynamics plug in for Grasshopper. ArchiDynamics allows users to test for real time wind analysis. It is noted that water engages with 3D objects differently than wind, however, this visualization opens the door to analyzing the success of energy attenuation by Artificial Reefs (AR). Rhino CFD is recommended for testing fluid bodies on static objects over ArchiDynamics. Given the time and availability of licenses, ArchiDynamics will suffice for our visualization purposes.

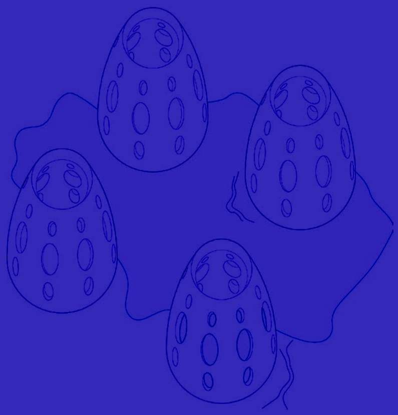
The visualizations from ArchiDynamics indicate the speed of moving energy on a gradient color scale. Blue is 0 m/s on the low end, and red is 4 m/s on the high end. The two part use of the AR as shoreline protection and habitat creation generate opposing qualifications in regards to what would indicate a successful characteristic. Successful habitats for coral have sheltered areas that protect the corals from strong wave energy that could break off pieces while also facilitating the circulation of water to ensure adequate oxygen levels (CITE). Successful shoreline protection allows for the fracturing of wave energy. Vertical components make wave energy more complex and increase wave energy transfer (Wen et. All, 2019).



Reef Design Lab Khon and Perry Reef Ball

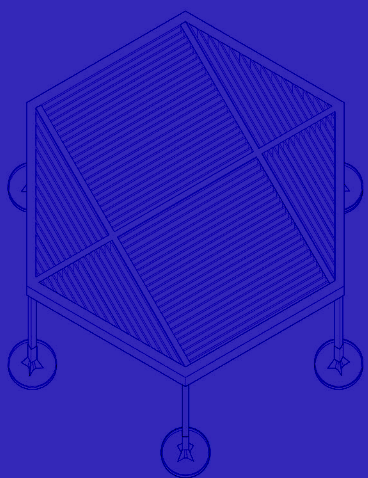
[Existing Research:] Above: velocity simulations showing increasing water speeds in red. These images help to understand if these reefs can annenuate wave energy during storm conditions. Khon and Perry has the most minimal distruption, therefore it is the least successful in the hopes for shoreline stabilization.

[Findings]



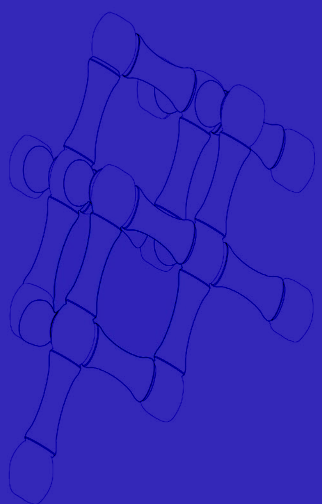
Testing the Reef Design Lab, Reef Ball, and Khon and Perry designs provide insight into considerations for the new AR.

The Khon and Perry design does little to shift the energy trajectory of the simulated forces, and therefore is not successful as a strategy for storm surge control. The flat, horizontal grate also does little to promote water circulation for coral. There is no protection for small marine life. The footings of this model are secure in the seafloor, providing additional structure to the shore stabilization. Considerations to the depth of AR structure shall be considered.



Reef Ball provides adequate protection from small marine actors in the center of the structure. This interior of the dome shape has poor water circulation, indicated through the simulated forces visualization. Around each structure force velocity increases, implying decent exterior flow. There is no indication from the simulation regarding Consideration to the spacing of individual AR components shall be here by notes.

Reef Design Labs MARS model displays the most complexity in simulated force velocity, suggesting it to be fruitful in both wave attenuation and water circulation. Mild protection for small marine life is offered between each module unit.



[Novel Design]

Iteration 1

The main takeaways from the precedent analysis are as follows:

1.Allow space of varying size animals to hide and move about as well as water to circulate.

2. Have well structured substratum connections to stabilize the shoreline.

3.Consider rugosity of all elements.

NOVEL DESIGN

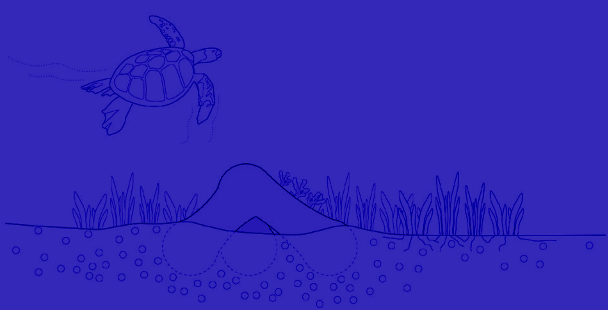
The following is to be a starting point when considering how to design an Integrated Artifical Reef. This research is to be considered a template for design and is intended to grow upon new research and fabrication proposals.

[Novel Design]
One single unit can be oriented onto any of its bounding box's six sides to allow for diversity of shelter spaces, grafting verticality, and wave attenuation. The unit full scale would be fit within a 3ft by 3ft by 3 ft volume for single user fabrication and deployability.

The substratum composition of the seafloor would impact the structure's ability to embed within the terrain. The base bulb of one unit must be fully covered by substratum to promote shoreline stability.

The aggregation of this reef would grow from a grouping of 3 or more single units and can be added to as needed.

Surrounding each aggregation and located between each of the reef components shall be seagrass meadows. These habitats, when adjacent to coral habitats, promote ecosystem diversity. As a carbon sequestration strategy, seagrass planted in close proximity to coral may help to reduce local CO_2 levels in the water, potentially lowering the chances of acidification.



[Mock Up]
The final stage of this research methodology is to create a tangible mock up of the proposed AR ecosystem, including seagrass meadows.

This process requires the casting of AR single units to aggregate. Due to limitation in material resources, this mock up is made with Rockite, a fast drying, hydraulic type of cement. Further research can be done to explore the material possibilities such as printing with ceramics or using biologically based cements such as BioMason cement. Cement and ceramics are both good options for coral reefs as the corals can feed from the calcium carbonate within the mixture.

To create the mock up a single unit of the AR was printed at ½"=1'-0" scale on a Prusa 3D Printer. This object then is used to cast a void into a 9"x9"x9" silicone mold. This mold can be made of plywood, foam core, or plexiglass and requires a pour spout to be attached to the top of one of the bulbuses through which the Rockite can be poured. Dowels or clay can be used to create the pour spout. Smooth On T20 Silicone was used to create this mold, done in a single pour. The mold could also be done in a two part mold to improve replicability. After curing, the formwork of the mold can be removed and the silicone can be cut to release the embedded 3D object. Once the object and the pour spout are removed, the mold can be taped up to be used to pour in Rockite; mixed per manufacturer's recommendation. This process is repeated for desired aggregation.

The following images show mock up AR Units within a seagrass habitat, therein generating an example of ecologically minded resiliency.

[Conclusion]

The findings of this article show that there is much research on each individual characteristic of what would be considered ecologically minded resiliency. Information about corals, seagrass, shoreline stabilization, wave attenuation, and artificial reefs are readily available but often do not overlap with one another. Architects and designers are often removed from the conversation of shoreline protection due to the necessary understanding of biological and climate processes. However, there is much that the thought and planning processes taught through architectural pedagogy can bring to the table when dealing with multifaceted issues that required nuanced solutions.

[Acknowledgements:]

The early stages of this research was largely helped by two conversations. The first with Kyle McCormick who holds a Master's in Environmental Studies from Evergreen University, which encouraged the inclusion of other marine actors, such as seagrasses, in this design consideration. Second, Liv Williamson, a Ph.D Candidate at the University of Miami in the Rosenstiel School of Marine and Atmospheric Science who provided a deeper understanding of the complexity of coral structures. The velocity studies were completed with the help of fellow GSAPP student, Timlock Li.

Intersectional design cannot be possible without the collaboration of others. Their knowledge sharing is essential to this future research of this topic of ecological design.

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