The rrreefs' Pujada Bay project, built in 2024, spans over 100m², with 820 3D-printed modules.

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One Brick at a Time

Rebuilding Coral Reefs

An Interview With rrreefs Co-Founder Dr Ulrike Pfreundt

Interview edited by G. Symes
Photos courtesy of rrreefs, Aldahir Cervantes, Geraldine Graf, Uli Kunz and Emilia Lendi

How can coral reefs be rebuilt and regenerated using 3D-printed modular clay bricks? In this interview, Dr Ulrike Pfreundt, co-founder of rrreefs AG, explains the concept, its development, how it works, the promising results and how divers and dive resorts can get involved.

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Dr Ulrike Pfreundt, Co-founder, Co-CEO and Head of Science and Development of rrreefs AG

What is your background in coral reef research, and how did it lead you to develop the rrreefs system?

I am actually a microbial oceanographer. I did a PhD in microbial oceanography, working on the plankton of the oceans and trying to understand how that contributes to larger-scale ocean dynamics in the tropical oceans. But then, in 2017, I became really, really aware of the dire situation of coral reefs and really wanted to start doing something about it more actively.

So, I decided to leave academia. I was in fundamental research at the time, and I didn't feel like I could have the impact I wanted by staying in fundamental research. I decided that I had to become active. This could be in the form of an NGO or a company. It wasn't clear at the time, but I started working on the question of how we can rebuild areas of coral reefs that are totally devastated. I looked at this question and at the solutions that were available, especially artificial reef structures, and if you have to rebuild the habitat because the area is completely destroyed. Why had this not been done in a way that actually works for coral?

Marie Griesmar, rrreefs Co-Founder and Head of Product, and Hanna Kuhfuss, rrreefs Co-Founder and Head of Field Operations and Scientific Partnerships, at work building a reef in 2024 (below). Coral recruitment is monitored on each rrreef installation (right). A 3D printer (far right) is used to produce the rrreefs' terracotta clay modules, which are then used to build reefs.

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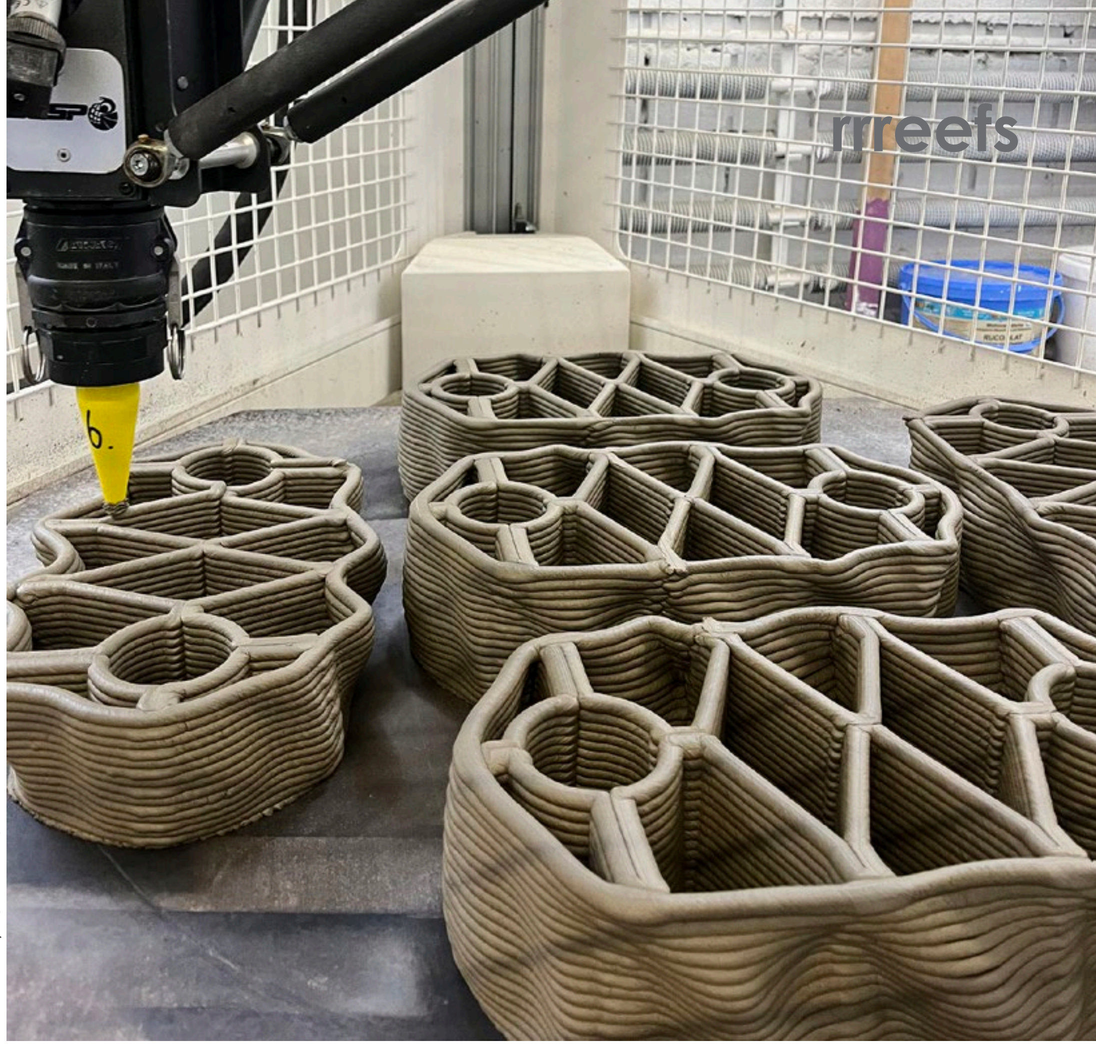

EMILIA LENDI / FOR RRREEFS

I found that most structures don't actually recruit new coral in an efficient way. And on most artificial reefs, the growth of coral isn't monitored. In fact, it seems as if new coral from larvae hardly ever grows in any relevant numbers on artificial reefs.

Shipwrecks are a bit of an exception. They can work depending on how they're oriented in the flow.

So that was kind of the basic question, and I started working on the surfaces. I started by asking myself: What if it's the way that water moves over this degraded reef that is responsible for coral larvae settling or not settling? Because coral larvae behave like passive particles in that water flow, they can't swim out of the water flow. So, they need a passive transport mechanism to a new stable surface that they can attach to.

This was my initial question: How can I generate a surface that will allow corals to attach and direct the flow towards the surface so that the corals can find the surface? And I really didn't know how to place something like this into the ocean. But then I serendipitously met my first co-founder, Marie Griesmar. She is a fine artist and a diver. Marie has been diving since she was eight years old, and she really has all the experience of how to work underwater and how to construct something underwater.

She started working with additive manufacturing of clay specifically for coral reefs, but from an artistic perspective—building sculptures in the ocean that she wanted to be overgrown with coral. We put the two ideas together, and in the end, our first reef system emerged. Marie, I would say, is the architect of the reef system, not me. I just provided some knowledge and insights on how the surfaces should be structured.

How is your reef system different from other conventional reef restoration systems?

Because of its focus on coral offspring, really. We have a very high success rate in getting coral recruits and seeing them grow and prosper after they've settled. We measure coral recruits on all of our reefs that we currently have in the ocean every six months. On all the reefs that we have measured so far, the number of settled corals has always increased from one time point to the next. The numbers are higher than a lot of measurements for coral recruitment, even on natural reefs.

What also makes our reef system unique is that it's small and modular. I mean, the system isn't small; it's the modules that are small. This makes them easy

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Reef construction at Pajuda Bay in the Philippines (left)

to handle. So, we can really work with local communities wherever we go. Most of the countries where we work to regenerate coral reefs are tropical and often have underserved communities. Having a small, modular system made from modules that can be carried by hand means we can involve a lot of people. That's probably the single most important factor for the success of any regeneration project.

The people who depend on an ecosystem, who live with that ecosystem… They have to be on board. They have to feel that it is also their project. We really integrate people on the ground into all the steps of the process, all the way to decision-making by them and not by us, such as where the reefs should be installed.

We are currently training around 10 people a year in the Philippines on how to use and install our system. We have also set up local production in the Philippines, so they can now produce their own system modules, install them and, soon, monitor them independently of us.

Why clay? What type of clay is used? What are its benefits?

It's a pure terracotta clay, and the exact composition of this clay depends on the local context. We do try to use local clay if possible. And then we have it tested to make sure it does not harm the marine environment. That's the most important test for us. Secondly, it must also have the right texture for the 3D printers. Thirdly, it has to exhibit a certain porosity after firing.

The right porosity allows water, along with everything in it, to seep all the way into the material. This helps with the growth of a biofilm and then also the growth of other organisms on the surface. Corals will attach more firmly, so they break off less easily, and coral larvae will be attracted to this type of material once they are in its vicinity.

Why is the three-dimensional structure of the rrreefs system so important for coral reef recovery and marine life?

The three-dimensional structure of our reefs is really designed purposefully, depending on the water flow patterns. If, for example, there is a strong flow at a certain site we want to regenerate, we will just make sure that the new reef is oriented (in terms of its overall structure) so that the current will not destroy it if the current becomes very, very strong during a storm, for instance.

The overall structure of our reef also leads to water being dispersed, slowed down in certain areas and sped up in others, so we have a high diversity of different flow regimes. And this again helps the overall diversity of organisms in the ecosystem.

Everything in our reef system is geared towards maximum diversity—in structure, in light, in shade, in flow—it all helps to increase the diversity of organisms in turn. This then leads to higher resilience from the get-go.

How can divers help?

Our systems are usually installed by divers. Trained divers, that is. Occasionally, we can include untrained divers in certain aspects of the build, such as the initial transport of the modules to the site and lowering them down the water column. We have also had great help from freedivers in Ecuador and the Philippines, just bringing all the modules to the right spot. That's great.

People can also sign up to become a trained reef-building diver with us, although currently only locally. For example, if someone lives in the southern Philippines, they could sign up to become one of our reef-building divers.

We are considering developing a whole course on holistic reef regeneration using the rrreefs system. But that is still a work in progress. So, there may be a PADI course on that sometime soon.

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FRONT ROW: Co-founders Marie Griesmar, Dr Ulrike Pfreundt, Josephine Graf, Hanna Kuhfuss
BACK ROW: Cassandre Wuarchoz, Tim Day, Olivia Götschi, Mauro Bischoff, Gerrit Nanninga

Life in Pajuda Bay reef (clockwise): scorpionfish, maroon anemonefish in bubble-tip anemone, juvenile yellow boxfish, lightning flatworm, pair of reeftop pipefish, *Acropora* sp. coral


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How long does it take for the embedded corals to grow enough to repopulate the reef?

After we install a reef, which takes about one to two weeks, depending on its size, nature takes over. We literally just need to install the backbone, which is designed in a way that nature can easily take over. Things will start settling on these bricks within, I would say, the first three months.

After three months, fish will visibly start returning pretty quickly. For example, in Colombia, after three to six months, we have already measured the same fish diversity and abundance as that of a nearby natural reef, meaning that it is a suitable habitat for all sorts of fish to thrive in. We also see high numbers of juveniles and fish eggs in our reefs because the insides of our modules provide a really nice habitat for them.

The first settlement of corals takes place anywhere between one and six months, depending on when their spawning occurs or when different spawning events happen. These corals then grow at different speeds.

It depends on the type of coral. Let's say a fast-growing coral, such as staghorn coral, may grow to about fist size within the first year, when it is still growing really slowly. Then growth explodes, of course. After two years, it may be football size, and then it gets larger and larger every year. After about five to seven years, I think you won't be able to see our structure anymore because it will be fully overgrown.

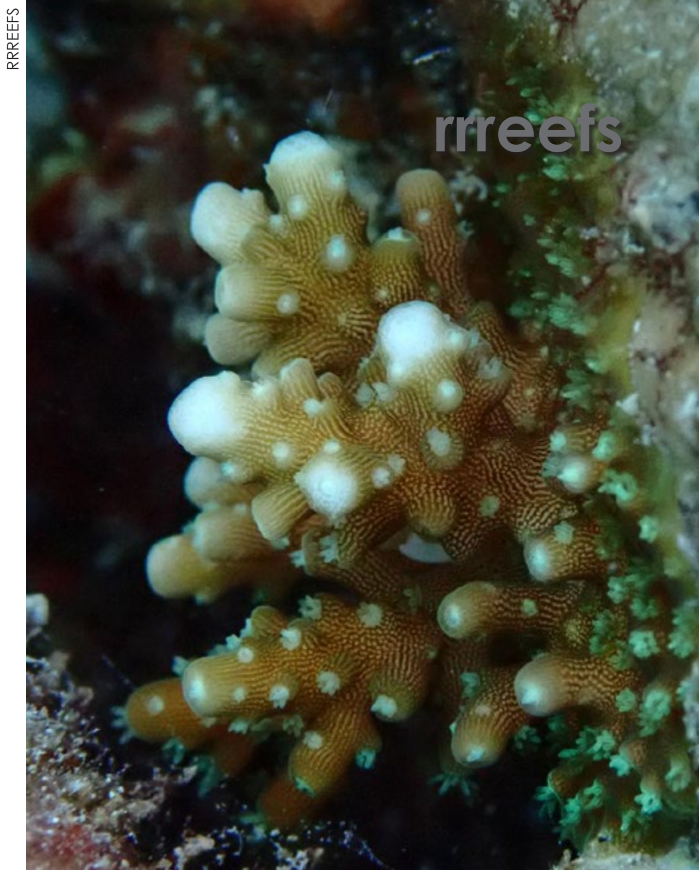
However, we don't currently have a reef that old in the water. Our oldest reefs, off San Andrés Island in Colombia, have been in the water for about three and a half years. While you cannot see the material of our structure anymore, you can still see its overall structure.

How do you measure the success of each project?

To measure whether a project works or not, we send a monitoring team into the water every six months. These are mostly local experts who are guided remotely by our teams here in Switzerland, although perhaps only the first time. After that, they are usually pretty independent.

We also monitor coral recruitment. How many new corals have settled on the reef since the last monitoring session? What is their average size? Did the corals that settled before grow? Then we measure fish diversity, abundance and average size. From this data, we can calculate the fish biomass. This is a very important factor because there are usually fisheries connected to the sites that we regenerate. So, it's very important for people to know that these structures also benefit the fish populations.

Then we look at invertebrates; for this, we have people count invertebrates throughout exemplary modules. Of course, we do not count invertebrates in *all* the modules, but we select, say, 50 modules, and our monitoring team goes out and notes what they find. The invertebrate data is more qualitative and quantitative because it is really hard to find



Life in Pajuda Bay reef: Pair of fingerprint toby (far left), *Pocillopora* sp. recruit (top centre), *Acropora* sp. recruit (above), maroon anemonefish (centre) and feather star (lower left)

everything when you do not want to destroy or touch anything.

Those are probably the three most important aspects. We also do a photogrammetry of every reef to observe changes over time of the whole structure, in terms of growth and overgrowth, as well as structural changes due to the growth of coral, but also to see if it is stable and if there have been any shifts in the system due to storms, for example. These are the things that we measure.

What are your hopes or concerns for the future of coral reefs?

It's important to me to mention that our work with regenerating reef habitat, as well as the work of others in active coral restoration (outplanting live coral onto existing reefs)—all of that work is not a fix for the big problem that coral reefs face: the heating and acidification of the water.

If water temperatures rise further and further, none of the work that any of us do will really matter in 50 to 100 years—no, probably less—in 25 to 50 years. So what we are all doing in these communities is really emergency care. We make sure that enough coral reef organisms and corals can survive until the day when we (humankind) can manage to bring ocean temperatures back down to liveable levels or slow their rise at least.

There is also a certain degree of adaptation that corals can do. So yes, there are corals that can withstand hotter waters. Anyone who has dived in the Red Sea will know that Red Sea corals can withstand much higher temperatures than, for example, Pacific coral species, even though they are the same genus. So, in principle, some corals can adapt. It just takes time.

We are buying that time with our approach. By enabling coral larvae to settle, we are enabling the offspring of survivors in integrated areas to thrive. So, we are enhancing the chances of adaptation for those young corals by providing them with a new habitat.

The second point is that the terracotta structures will not dissolve in an acidifying ocean, whereas calcium carbonate slowly dissolves as the water becomes more acidic. So, at least the habitat structures that we build should be there for a long time, providing spaces for reef organisms even in periods when the live coral suffers.

How can dive resorts get involved in your projects?

What we are also developing is an add-on system that will make it really easy for divers, as well as people who are on vacation, to plant corals onto our structures in an easy and efficient way. In this way, we want to enable hotels and resorts to have their own habitat regeneration programs with our system and enable guests to be part of the regeneration of the reefs in a simple yet effective way. ■

Download the ***rrreefs 2025 Impact Report: Pujada Bay, Philippines****. For more information, visit:* ***rrreefs.com***