What Is "Live-Framing?"

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Vibrant corals and fish denote a healthy mini-reef aquarium. A reef tank's first impression to a person unfamiliar with marine aquariums often evokes comments about the inhabitants' marvelous colors. Others admire the biodiversity and natural appearance. Fellow aquarists may ponder further thoughts concerning the water quality (filtration equipment, water flow, and chemistry) and lighting (the lighting type, spectrum, and intensity). Only a secondary consideration may be granted to the very foundation of the aquarium: the substrates where the corals, fish, crustaceans, and other community members reside. The rocks and internal framework provide vast functions to an aquarium, such as hiding places, elevated platforms near light sources, shade, water current control, and a surface for denitrifying bacteria. As this underwater scaffold assumes a more natural form to best showcase the marine life, the framework planning becomes less noticeable.

Bottom substrates, such as sand, are a separate subject worthy of its many publications and internet postings. This article addresses the hard substrates above gravel beds. The most common is live rock. Many aquarists use live rock since it comes from the ocean, therefore assumes natural forms already encrusted with sea life. The attached microscopic organisms form a denitrifying biofilm; larger, visible animals and algae instantly populate the reef system with beneficial biodiversity. The different shapes and sizes also provide a strong base for heavy corals. The calcareous stone base helps keep the water pH around 8.2. Live rock is imported from oceans around the world, so people wishing to maintain an aquarium's regional theme can accurately do so.

Wild live rock also has a number of disadvantages. It is heavy, which translates into high shipping costs. The freight costs are assimilated into the price per unit weight (depending on type and quality, retail price ranges between US$6.00-$10.00 per pound), unless a bulk order lists the hefty shipping fee separately. Pieces often appear lighter than they actually are, and creating an artificial reef base becomes an expensive ordeal. Large pieces with inherently interesting shapes allow artistic reef designs, but these bulky boulders can be cumbersome to maneuver. Even worse, the rock may slip and mar the aquarium, particularly soft acrylic walls. Smaller pieces are easy to manage, but limit creative forms to "the Great Wall of Rubble." Binding little live rock pieces together with epoxy improves design flexibility. However, that scenario returns to the point dealing with big, rocky chucks. If this technique enables an aquarist to build a huge arch spanning the tank's length, how does one move such a mass when needed? In cases where rocks are stacked upon each other, near-bottom maintenance or even retrieving a fallen object becomes a major ordeal as the obstructing rocks require removal. In addition, the problem remains of other stones balanced upon those pulled. Afterwards, arranging the coral and rock into its original position develops into a nearly impossible tribulation. Delicate and pricy coral precariously balanced on top of live rock stacks can easily topple due to anything from routine maintenance activities to an exceptionally territorial fish!

Another live rock hurdle emerges in the rock life itself. Direct-from-the-ocean uncured live rock often experiences massive die-offs within days after arrival. This death occurs when more sensitive organisms succumb to transport-related stress. The decay putrefies water quality and clouds the tank. Cured live rock is held for several weeks—throughout the die-off phase's duration—and is safer for direct transfer into the aquarium. Cured live rock may exhibit an unimpressive appearance, sometimes resembling plain, calcareous stone with a muddy film, yet it seeds the tank with denitrifying bacteria, algae, copepods, sponges, worms and other desirable reef dwellers. Cured or not, wild live rock can also introduce unwanted hitchhikers: highly predacious mantis shrimp; detrimental, coral-feasting crabs, worms, and snails; nasty stinging hydrozoans, bryozoans, and sea anemones such as *Aiptasia*; and, highly lethal cone snails, to name a few.

Pollution, global warming, and other human activities continue damaging coral reefs worldwide. Marine life harvests for the aquarium industry, including wild live rock, only fuels environmental condemnation. Whereas wild live rock remains on the market, aquacultured specimens provide an ecologically responsible alternative. One type of aquacultured live rock places bare stone on a reserved seabed. Once sea creatures colonize this substrate, it is brought to market. Aquacultured live rock shares the same benefits and drawbacks as the wild version. The second aquaculture method has cured live rock—already screened against undesirable species—placed in large, inland salt water pens to seed barren substrate. This environmentally-friendly live rock is pre-cured with only beneficial organisms, but some aquarists believe the biodiversity is too limited.

Figure 1. Today, this photograph of the author’s aquarium demonstrates the natural beauty attained through live-frames (A). The same live-frame photographed six days after installation (B, inset).

Many aquarists recognize live rock drawbacks, but figure the advantages outweigh the shortcomings. Some retailers tier live corals on platforms made of PVC tubing and egg crate light diffuser—a great, sturdy, lightweight product display. Furthermore, this technique allows unhindered water flow. Similar prefabricated boxes are commercially available, where pieces of rock obscure the plastic supports while other rocks and coral rest on the platform. However, these overtly synthetic supports fail to bestow an aesthetically pleasing exhibit for either private or public aquariums and the rocks remain unsecured.

The good news is all of the positive aspects from both live rock and artificial framework theories can be reaped while mutually eliminating their deficiencies. This strategic blend called “live-framing” hangs rocks and large shells onto a PVC pillar and conceals it, like assembling limbs onto an artificial Christmas tree. Then corals, anemones, and other reef denizens spread across the outer rock and shell. This technology applies to any aquarium size and type, best lending itself to aquariums at least 18 in (46 cm) high, and becomes increasingly effective in taller tanks. As a side note, it even pertains to freshwater tanks, using neutral pH stones, driftwood, and aquatic plants. For a perceived base rock volume, material costs are low compared to an equivalent live rock purchase. The following paragraphs and figures will guide the reader through the process, using my aquarium as a proven, successful example.

Live-Frame Design and Preparation

The first part of the planning process is determining the types of animals to be kept, desired features and general look of the aquarium. At this point, the mini-reef I kept for nine years started as a 20-gallon (76 L) long and moved up to a standard 29-gallon (110 L) aquarium. Indo-Pacific fish and invertebrates, including some hard coral, stocked it. Except for the stone that came with sessile invertebrates, the base material was originally dry tufa rock that the aquarium inhabitants later colonized. Four 36-inch (91 cm) very high output (VHO) florescent bulbs (evenly split between 50/50 and 10,000K bulbs) illuminated the aquarium. I wanted to expand the mini-reef to a 65-gallon (246 L) glass aquarium [3 ft (91 cm) long x 2 ft (61 cm) tall x 1.5 ft (0.46 cm) wide]—a perfect size to sculpt creative seascapes. A return-sump hole drilled into the upper left of the aquarium’s back wall determined the placement of a small, custom-made acrylic overflow box. Bearing in mind the organisms I already had and those I still wanted to procure, I thought back to Atlantic and Pacific snorkeling expeditions: the tropical ecologies studied; the niches filled by different species; the coral reef geologies, towering pillars, and lava chasms; and the entire oceanic ambiance. Of course, the size limitations of any aquarium squelch any true-to-nature plans. Even so, several sections dedicated to naturally occurring features were set in the aquarium’s blueprints—caves, a gradation suggesting a shoreline, an arch, a canyon, and an open sand bed or “deep ocean” zone. Also considered was vertical zonation—the concept of organism distributions within different elevations, and applicable from benthic regions to intertidal zones to alpine ecology. Specific aquarium concepts and the community represented are entirely up to the aquarist. At this planning stage, determine how and where the water will flow within the aquarium. I planned on four powerheads randomly turning on and off every 15 seconds. All but one powerhead hides within or behind a large PVC column and shoots water though a selected opening.

As previously mentioned, live-frame materials are inexpensive and already are likely owned by the aquarist:

- Plumbing-grade PVC and CPVC tubing (various diameters) and end caps
- Nylon nuts and bolts
- Marine-grade epoxy—both putty and paste types work better than liquid/syringed epoxies
- Marine-safe rocks, preferably light tufa stone
- Assorted large sea shells*
- Small seashells, crushed coral and/or sand bed substrate (rinsed clean and dried)
- Optional live rock and/or coral-encrusted rock

*Only select *completely* natural sea shells; never use painted or coated shells in the aquarium.

Recommended tools and supplemental supplies are:

- Soft graphite pencil
- Paper (both letter and tracing)
- Ruler
- Compass and circular stencils
- Bubble leveler
- Knife or razor blades
- Drill and assorted drill bits (include carbide tip bits for rock)
- Hand saw (optional: electric jig saw)
- Files (round, flat, and triangular) and sandpaper
- Stubby screwdriver and pliers or wrench—for securing nylon bolts
- Pallet and stirrers—for mixing epoxy pastes
- Sweeper brush, dust pan, and paper towels
- Disposable latex gloves—to protect hands from uncured epoxy
- Safety glasses and ear plugs—personal protection especially when using power tools

While an existing aquarium can be reconfigured to a live-frame, beginning with a dry tank and rock is far easier. In upgraded my aquarium, planning and fitting occurred in a dry tank; substrates were dry except for the ones incorporated from the existing reef tank. Occasionally, I positioned a live piece in the new aquarium to get an idea of how it would fit, took measurements and notes, and then promptly returned it to water. Some people may want the live-frames resting on top of sandy substrate. I prefer to have the frame rest on the glass bottom, and then pour sand around the base. Such considerations need deciding in the early development or else tall live-frame tops may stick out of the water! Sketch blueprints as seen from the top (Figure 2), front, and sides. My plans called for all major supports to be wide, vertically set PVC tubes, as this method is structurally both more stable and easier to disguise than a lattice of thin pipes. Several tubes bolted together improve stability (specific joining techniques are discussed in the following paragraphs). The frames may support reasonable rocky projections, arches, and similar creations; avoid designing unbalanced, top-heavy frames as they will tip over. While sketches and designs enable the conception of major aquarium features, flexibility is granted to the exact shape or placement of outer surface rocks, especially when using live rock. The blueprints best serve as a guide instead of a hard rule—better ideas may emerge as the project takes physical form.

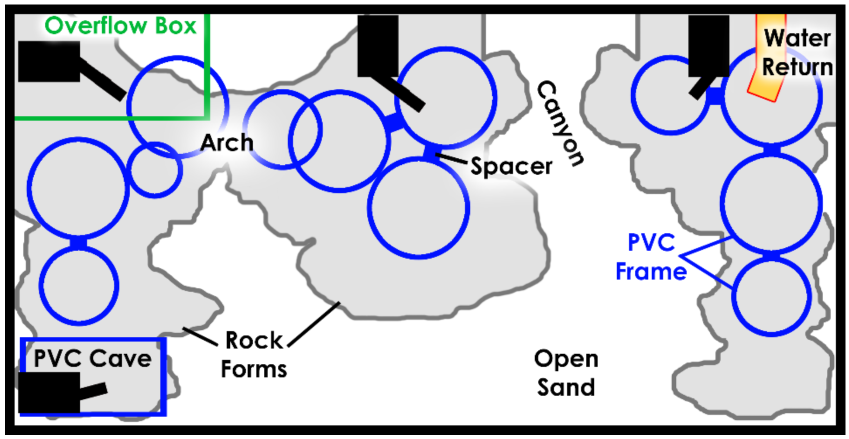

Figure 2. The critical top view blueprint determines column positions relative to one another, takes rock layers into account, and incorporates placement of equipment such as water flow devices (depicted as black rectangles with necks indicating flow direction). This arrangement has three individual “land masses,” all of which extend into tall towers stabilized by small tubes and heavy rock at their bases.

Live-Frame Construction

Having cleared the planning phase, frames may now be forged. Plumbing-grade PVC tubing composes the skeleton. Diameters for my system are 1.5, 3, and 4 inches (3.8, 7.6, and 10.1 cm) and lengths ranged from a few inches tall to the entire aquarium’s height. Scrap tubing works great because the short pieces require little material and it is free; from an environmental standpoint, synthesizing PVC is a toxic process (no need in generating more than necessary). Make sure the scraps are “clean” and were not exposed to toxic chemicals; when in doubt, do not use it.

Mark the PVC tubing with a pencil indicating the cut lines. First, cut the tubing to the proper length. Be sure the area in direct contact with the aquarium’s base is cut straight to maximize stability. The top may receive more leniency as an end cap will cover it. If no cap will be on the top, then cut that area deliberately jagged to emulate a natural form.

Next, mark the tubing where multiple PVC frames will be connected. The most direct means of connection is by nylon nut and bolt (Figure 3). Once that fit is established, disconnect the PVC tubing since the continued work is easiest on individual pieces. The connection process is the same as earlier discussed in this paragraph; only the bolt goes through the spacer before the adjacent PVC frame.

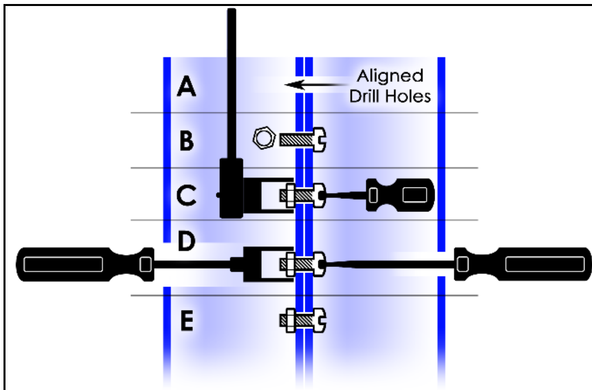

Figure 3. The most direct means to connect frames is with nylon nuts and bolts. To do so, use a ruler to draw a vertical line on each of the two tubes along the contact point. From bottom to top, mark a drill point every 4-6 inches, making sure that the points mirror one another on the two tubes. Drill appropriate-sized holes for the bolts (A). After drilling, slide the bolts into place (B), loosely connecting the two tubes making sure of a good fit. For sections with wide diameter tubing and close to an end, tighten the nut and bolt with a stubby screwdriver and either pliers or a wench (C, socket wrench is pictured). Alternatively, on opposing sides of the connection point, drill holes with diameters wide enough to insert the tools and secure (D). The latter technique is best for central regions or when the tube diameter is too narrow to perform the former. The completed connection (E) should have little of the bolt's thread rod protruding past the nut; nylon bolts are simple to cut if necessary. Doing so reduces the risk of snagging on the bolt and facilitates disassembly, if needed. To further avoid snags or camouflaging difficulties, mount the bolt heads and nuts inside of the tube, as illustrated, instead of externally. If a spacer between the frames is desired, cut the proper length of small diameter—0.5-0.75 inch (1.3-1.9 cm)—PVC and CPVC tubing segments, one for each connection point (not shown).

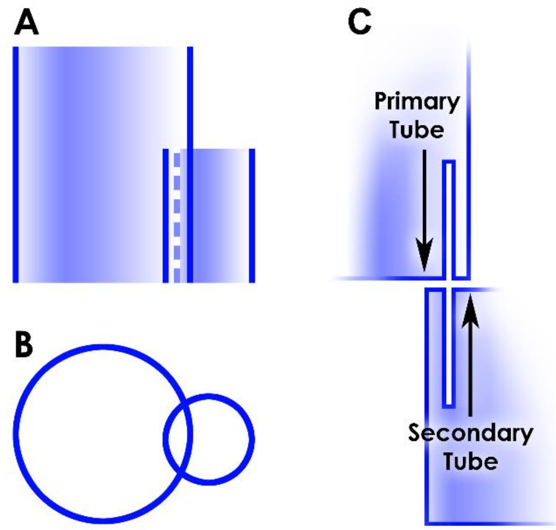

Figure 4. A profile (A) and downward view (B) shows how the smaller, secondary support tube reinforces the larger, primary frame. Figure 4C details how the cut slits enable assembly of the tubes.

The third connection technique is best suited for small, secondary tubes joining to a large primary frame (Figure 4A). Instead of the frames resting next to each other, they overlap, due to long slits cut along the tubes. This method also enables the smaller tube to be excellent stabilizer. First, stack the primary and secondary tubes, end to end (Figure 4B), to identify the overlap points; the bottom of the primary tube touches the top of the secondary tube. Using a pencil, mark these contact points along each tube's circumference. Include marking the adjoining PVC wall thicknesses. Next, measure the secondary tube's length and mark the midpoint. Draw vertical lines along the upright tube, beginning at the top contact marks down to the midpoint. Measure the length of one of these lines (all lines should be the same length). On the primary tube, draw vertical lines—the same length as those just measured—starting at each of the bottom contact marks. After scoring all lines, place the tubes on a level surface next to each other; going from bottom to top, the top of the primary tube's line should end at the point the secondary tube's line begins. With all lines properly measured, use a saw to cut slits through each line. Keep the saw blade at an angle, reflecting the curve of the other tube. Upon completing all cuts, slide the two tubes together through the slits (Figure 4C); for a clean fit, remove bits of unwanted plastic using the saw or files. Finally, lightly sand the edges. For maximum stability, epoxy the tubes together at the junction, but save that during the final frame assembly.

Loosely connect the frame's PVC components, thereby providing a physical reference for the remaining construction. Pencil in caves, concealed powerhead, and other openings into the frame. Two adjacent tubes sharing small openings at the same location enables water flow through the frame (alleviating “dead spots”) and permits fish free swimming access. One of live-frame's advantages is powerhead versatility and nearly infinite current control. For example, a powerhead nozzle given properly aligned holes can shoot water through several primary frames. Another powerhead can swirl water behind the frames thereby reducing detritus accumulation. Consider using magnetic powerhead holders as they improve water flow control, but keep in mind that these holders are thick. Do not yet cut flow sections into the PVC as their exact size and shape may change after installing the outer rock.

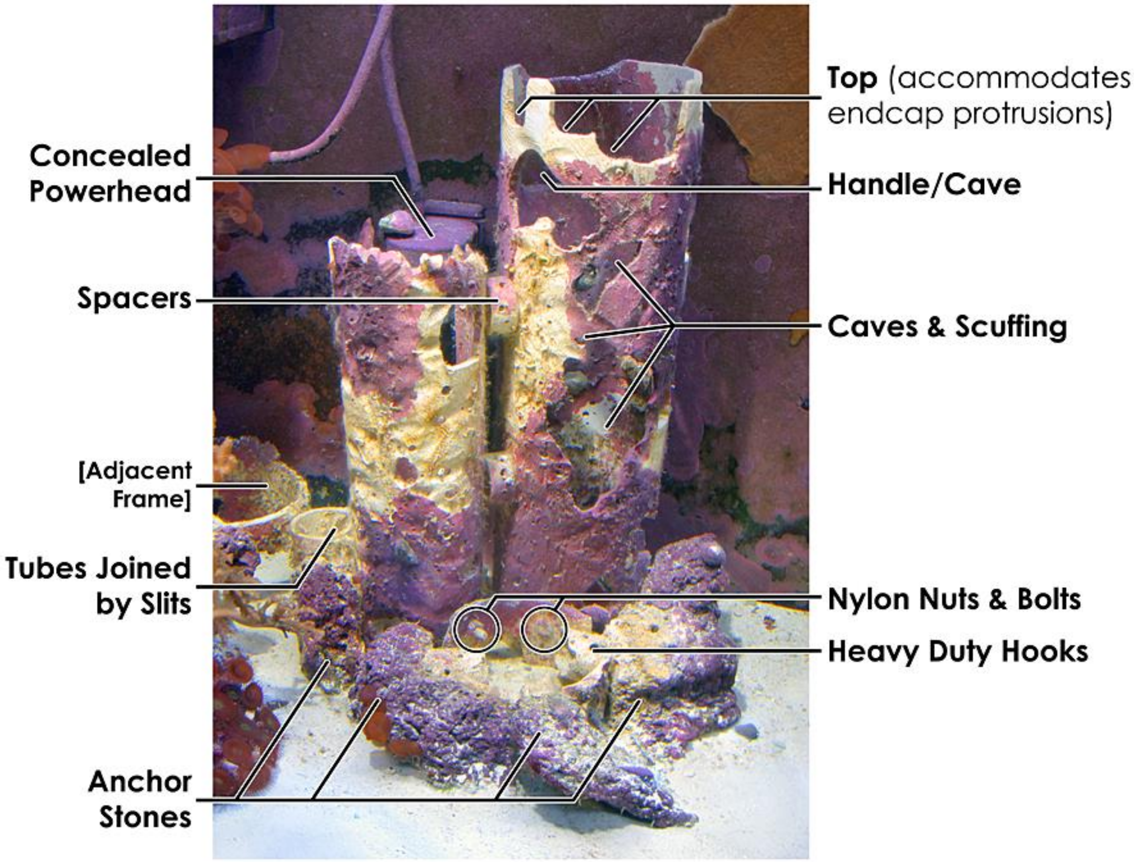

Figure 5. This image incorporates many features of a matured PVC frame. All hooks except for the anchor stones were removed for this photograph. To further stabilize this frame, a large stone (seen in Figure 1 with the hairy mushrooms and large Devil’s hand) rests on top of the short, centered tube. To help move the frame during construction and for future maintenance, a hand grip was excised from the top-end, backside of the tallest tube. Areas with close rock contact lack calcareous algae, but have worms, sponges, and other creatures. Together with irregularly cut caves and weathered PVC surface, the fraction of the pink, algae-rich regions viewable on the fully assembled frame blend with the surrounding live rock. Strategically placed gorgonian branches camouflage powerhead wires.

Methods of Attaching Substrate to the Frame

The next phase fastens rock and shell to the frame. Heavy pieces on the bottom and lighter rock or shell on top provide maximum stability. Large, broken shells provide a fantastic base for the aquarium’s living invertebrates and algae. The mid-Atlantic shells I used were collected on a beach a few hours away from my home. The cracked whelk shells provide splendid caves; oyster shell clusters arranged in natural positions resemble an old oyster bed. As earlier stated, my aquarium runs an Indo-Pacific theme, but even the most discriminating eye sees polyp-encrusted marine forms instead of foreign shells.

The following hook procedure addresses dry shell and stone placement onto the frame; the live rock modifications appear afterwards. The hook technique is highly effective and applicable to the entire live-frame’s span (Figure 6). It requires some effort, as discussed in these numbered steps. Several rocks can be assembled at the same time, but keep in mind the epoxy used and its curing time. Install base pieces first and work up to the top. Heavy rocks hooked at basal points best anchor the live-frame.

1) Position the rock at its intended target on the frame. If the rock requires further sculpting or smoothing, then drill, chisel, or grind the stone into the proper form. For too smooth rocks, drill shallow, small diameter holes along the surface. These artificial crevices provide ideal footholds for zooanthids, coral fragments, and other animals. [NOTE: having the heaviest part of the rock pointing downward is the most stable. However, live-framing allows rocks to be set at odd angles, thereby creating ledges and unique shapes unachievable through routine rubble-stacking. Always balance creativity with practicality.]
2) Note where the rock contacts the frame and drill a hole into the rock at that contact point. Since this hole accommodates the hook, drill it the proper diameter and depth to fit the small diameter PVC or CPVC tubing. Any holes accidentally drilled through the other side of the rock will later be mended. If this core is too smooth, drill small, angled burrows along the edge so that epoxy will grip.
3) Next, determine the hook’s length, taking into account both the amount penetrating the rock and the hook’s overhang within the central PVC frame. Mark and cut that measurement on the small diameter tubing. Using sandpaper, roughen the tubing segment which inserts into the rock. If possible, drill several ¼ inch holes into this area.
4) Insert the small diameter tubing (hole section first) back into the rock.
5) Set the rock against the frame’s top and slide down the rock until the small diameter tubing touches the frame. Mark the frame’s thickness on the smaller tubing.
6) Determine the desired depth of the hook (Figure 6). The hook should have a sufficiently tight hold on the frame such that direct powerhead currents will not budge the rock. At the same time, the hook should be loose enough to glide on and off of the frame without becoming stuck.
7) Cut the hook into the small diameter tubing.
8) Make a final determination where the rock will hang on the frame. Draw a horizontal line across the hook’s exact resting point. Drill a hole into the PVC frame with a slightly wider diameter than small diameter tubing such that the bottom of the hole touches the top of the hook’s resting line. Cut and file the bottom of the hole so that hole has a flat base for the hook (see “Hole Shape from Front” in Figure 6A).
9) With a dry brush, sweep as much plastic debris into the garbage. With a damp paper towel, wipe PVC dust from the hook. Using a bucket of fresh water, rinse the rock and plastic, removing all of the dust. Avoid pouring debris-water into sinks because it may clog drains. Allow the components to completely dry (at least 24 hours). Temperature, humidity, and rock porosity influence drying rates.
10) After all surfaces are dry, generously apply epoxy to the rock’s hole and the hole-drilled end of the hook. Work the epoxy into the rock’s cavities and the hook’s ¼ inch drill holes; these crevices provide the binding agent with a solid grip after polymerization.
11) Insert the hook into the rock, adding or removing epoxy as needed. Slip the rock and hook onto the frame and make final adjustments before the epoxy hardens. Cover large, visibly open epoxy regions with small seashells or crushed coral for a natural appearance (coralline algae will eventually cover the exposed epoxy and plastic). Depending on the rock’s weight and epoxy type, either let it cure on the frame or set it aside.

These basic steps adapt to live rock applications, although working with this substrate is a little more difficult than with dry material. Follow these precautions when using live rock:

- Use hand tools on the stones since electric power tools and salt water puddles can cause shocks if not electrocutions.
- Consider the well-being of the potentially sensitive organisms on live rock; certain invertebrates are extremely hardy and can survive “low tide” periods whereas some sea fans cannot tolerate any air exposure. Before working on the live rock, remove any delicate species, keep the specimens in the aquarium during the host rock’s modifications, and reattach them at a later time. During the live rock alterations, keep the surface moist by periodically dipping it into a bucket of salt water.
- Most epoxies bind better to dry surfaces than wet ones. Know the epoxy’s properties before working on live rock, or determine those properties by conducting a practice run on soaked, lifeless rocks.

- Rinse live rock in a bucket of salt water before returning the piece to the aquarium. Never use freshwater on live rock. [Hint: culture coral and grind stone immediately after water changes, using the waste water for live rock dips.] Let the epoxy cure in the aquarium.

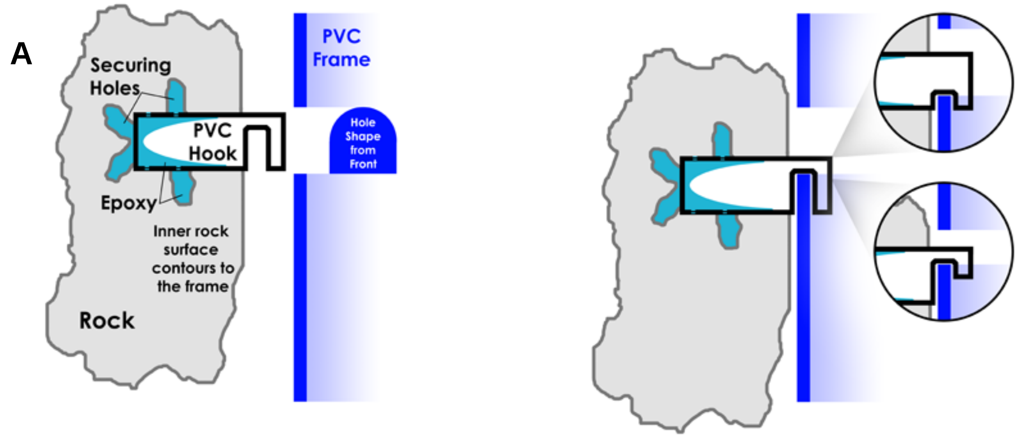

Figure 6. Substrates are best attached to the frame through a PVC hook (A). Epoxy secures this hook. The hooks may be different sizes, depending on the specific circumstances (B). The end of a hook may be cut to reduce the hole size requirement, but be sure the substrate remains stably affixed.

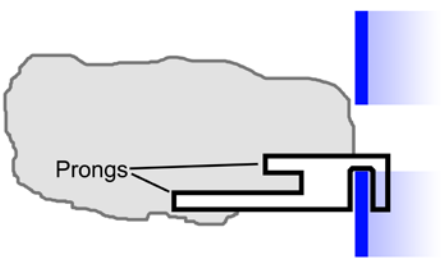

Figure 7. Heavy rocks are reinforced with both large diameter PVC hooks and supporting prongs. This "prong" approach reduced the amount of rock removed to accommodate the hook. Note that the lower prong is longer than the top. Epoxy (not depicted) binds the prongs in place.

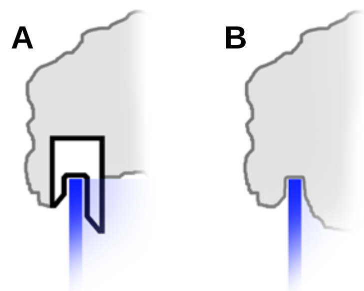

Figure 8. The preferred method of securing large stones to a frame is through vertical hooks (A). The same principles apply to their construction and function as the horizontal hooks seen in Figure 5. Note that the hook's edges closest to the frame are beveled to ease hanging. The alternative method (B) involves sculpting the rock to mold around the frame.

Large, heavy rocks may need additional support, as Figure 7 illustrates. On the lighter extreme, oyster shells and similar substrates can be drilled and bolted directly to the frame. Since the nylon bolt heads remain visible, reserve this technique to the frame's side or back. Decorating and hanging a "plate" of PVC tubing, cut from the same diameter as the frame, is another option.

As the live-frame concept opens to assorted surface designs, so do the very tops of the frames. My aquarium mixes adorned end caps, resting stones, a coral fragment nursery, and an above water extension holding the return water pipe. The exact top selected depends on both the desired effect and practicality. At the frame base, large stones might rest on short PVC stubs, such as the secondary tubing discussed earlier. The best method to secure these stones follows the previously outlined hook procedure, except the hook is vertically slit and embedded into the stone (Figure 8A). Figure 8B and the following text describe a quicker alternative. It involves grinding down the rock's contact area to perfectly fit the PVC frame. One process involves milling soft stone (such as tufa) with the tubing through consecutive clockwise and counterclockwise rotations, until the tube leaves an adequately deep impression. For harder stones or deeper penetration, drill a ring of successive holes outlining the contact region, followed by the milling technique to polish the cut. Successive drilling and milling may be required to achieve the desired result. Regardless of the material cut, removing little bits at a time affords a better excision strategy than inadvertently severing too much at once. Finally, use either freshwater (for dry stone) or salt water (for live rock) to rinse away the dust.

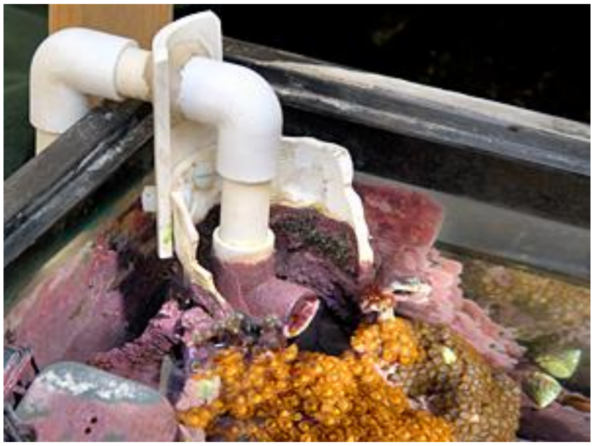

Figure 9. This underwater vantage displays the return filter water, held by a PVC coupling joint and fitted on top of the live-frame (A). Tufa rock, shell, and epoxy disguise the coupling, and the zooanthid colonies blur the line between construction materials. The PVC elbow outlet points in any direction. It is periodically removed for a vinegar soak to free the flow from calcareous algae overgrowth. This coupling is the only part of the live-frame breaking surface tension (B), yet it remains below the clear acrylic splash guards (not pictured). A PVC plate holds the water return tubing; bolting that plate to the coupling with two nylon nuts and bolts allows precise water return positioning. NOTE: to create still water for this photograph, all pumps were turned off, resulting in the low waterline.

Confine heavy, unsecured stones to lower frame points; should they accidentally roll off of their pedestal, little damage will result. End caps effectively crown any frame, especially tall towers:

1) Sand down the top portion of the frame’s outer wall, where the end cap will touch. Remove at least 1/64 inch of PVC.
2) Stabilize the frame’s base with either large basal stones or cinder blocks (to reduce animal stress, use the latter if the large, anchoring stones are live rock).
3) Hang the frame’s highest stones. Using a pencil, draw a line where the tops of these upper stones touch the frame. Break straight stretches with natural, uneven lines. Once a line completely circles the top, remove the stones.
4) Wrap tracing paper around the top of the frame, with the top of the paper flush to the frame’s top. Trace the outline drawn in the previous step. Cut the tracing paper along this line.
5) Place the tracing paper stencil inside of the end cap so that the flat paper top is flush with the bottom of the end cap. Trace the cut line along the end cap’s interior wall. Remove the stencil. NOTE: do not wrap the stencil around the outer end cap wall and begin tracing because this external circumference is larger that the tracing; cutting this line may produce a misaligned cap.
6) Using a small saw (e.g., jig saw), cut the end cap along this interior line. If an outer line will facilitate cutting, use a classic compass before cutting.
    a. Align the compass point and compass pencil so that that they are even.
    b. Situate the compass pencil’s lead to face 90° inward.
    c. Position the compass so the lead is on the end cap’s outer wall and the point in on the inner wall.
    d. While holding the compass perpendicular to the end cap’s base, trace the inner wall line with the compass point. This tracing results in a faint, corresponding line drawn on the outer wall. After the initial compass tracing, darken the outer line with a pencil.
7) Sand down the end cap’s interior wall, removing at least 1/64 inch of plastic.
8) Re-hang the basal and top stones. Place the end cap on top of the frame for a test fitting. Cut or sand the end cap so that the fit clears all rocks and smoothly comes on and off the frame. [NOTE: if the rocks are “live,” hang the rocks on an “as needed” basis, keeping a minimal surface exposure time.]
9) Mark where rocks and shells will fit onto the end cap. Overhanging substrates beautifully disguise the end cap’s form. Consider these points when fixing substrates:
    - Secure large stones with small diameter tubing or PVC slivers (collectively called reinforcement spikes) as performed with the hooks, with one end inserted into the stone and the other through a drilled hole in the end cap, and bound as a single piece via epoxy.
    - Large stones may also be set within the end cap, by cutting out a central cap section contoured to the stone’s shape and applying epoxy binders. REMINDER: avoid top-heavy frames.
    - Fix small stones with epoxy.
    - Anchor shells with either epoxy or nylon nuts and bolts.
10) Drill the holes into the end cap. Cut away areas of the frame to accommodate any reinforcement spikes protruding through the cap. Besides the holes for the spikes, drill ¼ inch holes where shells and small rocks will reside.
11) Scuff the entire outer cap surface.
12) Starting with pieces requiring reinforcement spikes, adhere the large substrates onto the cap. For shells and rocks needing only epoxy, work the binding agent into the lower surface and on the end cap area to which it will join. Work epoxy through both ends of the ¼ inch holes, flatting the excess mounds within the cap—this epoxy later hardens into strong rivets. NOTE: the entire cap may require multiple sessions before completion, where several rocks are adhered, the epoxy sets, several more rocks are placed, and so forth.
13) Slather exposed PVC regions with epoxy paste, topped with small seashells or broken coral for a natural appearance.

The Finishing Touch

After completing all of the live-frame’s components, the frame itself awaits finalization:

1) Reassemble all rocks and shells onto the frame.
2) Cave entrances were already sketched across the PVC tubing. Now, use a pencil to define their exact cut lines. Irregular shapes provide the most appeal. If designed properly, large chunks of frame can be excised—to accentuate the arch in my aquarium, one gaping hole is eight inches tall and wraps approximately 220° around the four-inch diameter tubing. Plan to cut a sturdy tripod into the base—solid bases may collect detritus and other configurations sacrifice practicality.
3) Remove the substrates.
4) Cut the cave openings and file the edges so they are varying thicknesses.
5) Drill holes along the frame where rock will hang so that water circulates and reduces dead spots.
6) Mar the few areas where PVC will remain exposed, making this surface look natural. Add small, random drill holes—together with different diameter drill bits—to look like worm bores. Include wider, partially drilled dimples and pits. After several months in the aquarium and healthy calcareous algae growth, these areas will blend with the surrounding live rock.
7) Apply this same abrasion to visible cave interiors. To further roughen wide caves, cement stony rubble along the inner wall.
8) Tighten nylon bolts connecting multiple PVC pipes. Slide together any primary and secondary support tubes; the fit should be tight enough to require no epoxy.
9) Remove dust with a brush and damp paper towels. Give the PVC frame a final, freshwater rinse.

With the scaffold and substrate components complete, assemble the live-frame in the aquarium. Whether the live-frame sits on glass or gravel was decided in the planning phase, since that decision determined the frame’s height. For the most stable surface, place the frame on bare glass and latch on the basal stones prior to adding sand. However, if the frame ever needs to be removed and later returned, siphon the immediately surrounding sand before returning the frame. An easier method is to sit the frame on top of the sand bed, but this shifting base may result in an unstable live-frame. Hook rooks and shells into their designated spaces.

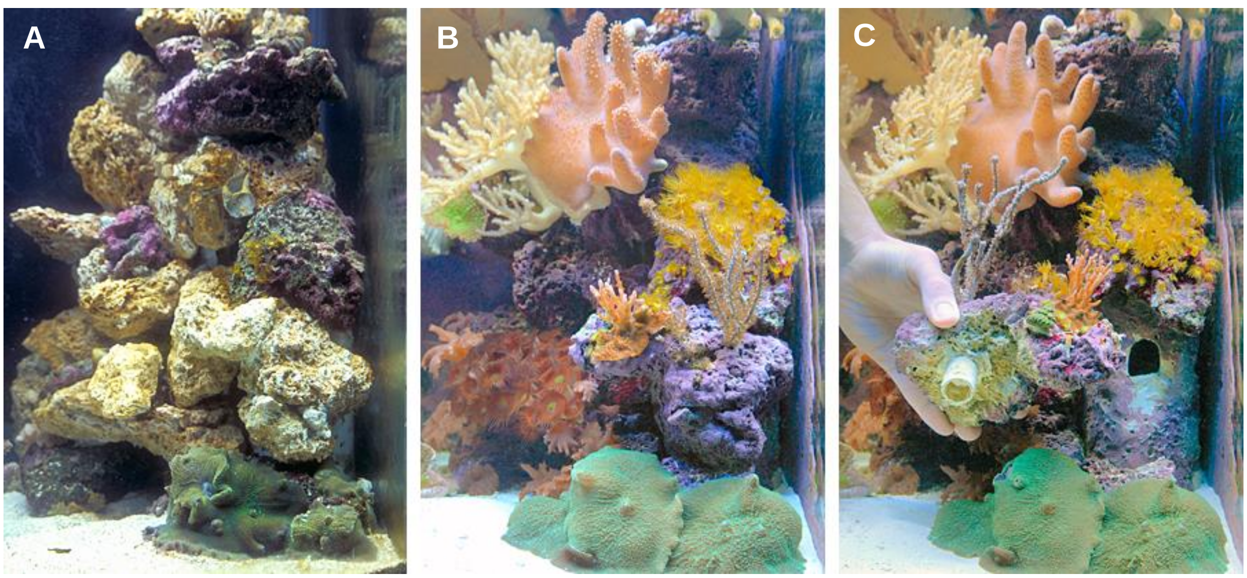

Figure 10. A close-up of the newly installed live-frame shows an initial composition of previously seeded live rock and lifeless substrate (A). Now, this area is a thriving “reef” (B). However, the constituent pieces are easily removable (C).

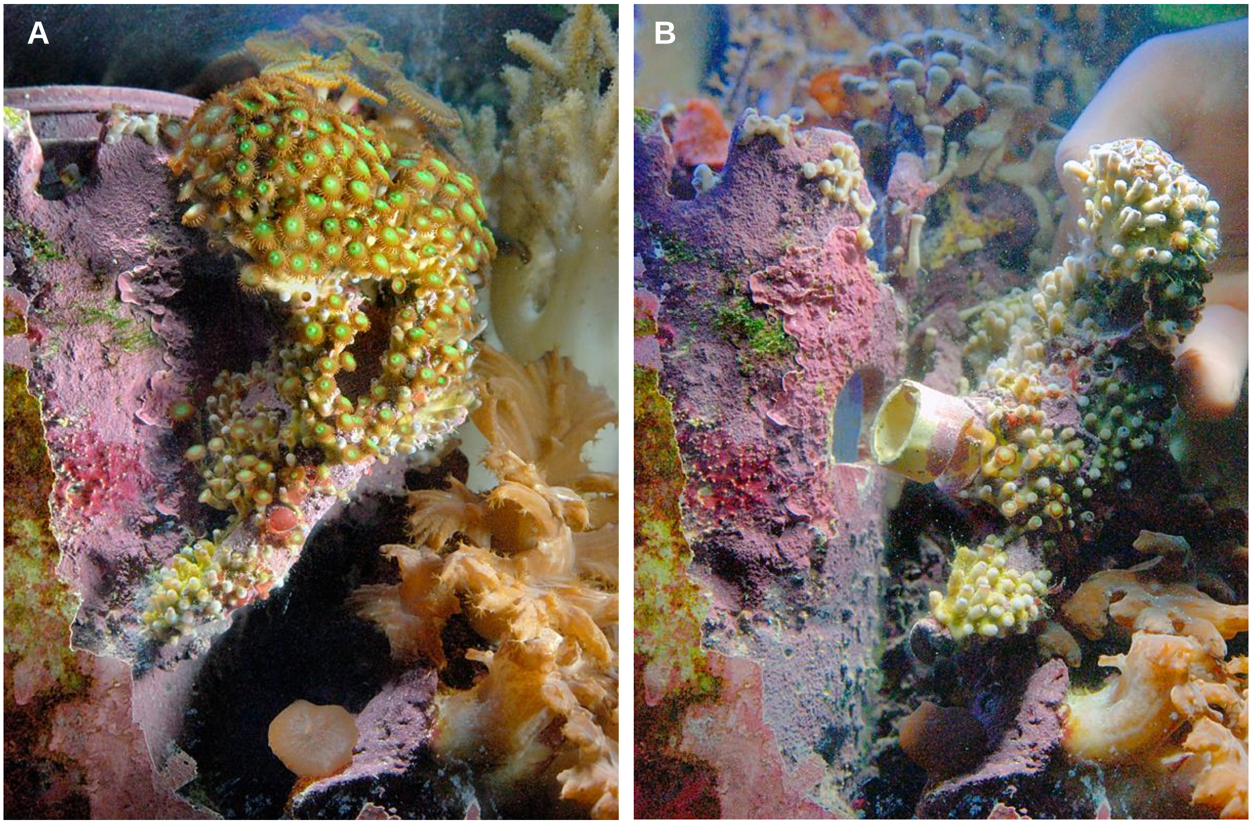

Figure 11. This close-up side view of the aquarium shows both a zooanthid-covered shell and the fully encrusted PVC frame (A). Polyps, algae, sponges, and worms completely cover the PVC frame and epoxy which binds the hook and shell (B).

Discussion

Several months after installing the live-frame, lifeless tufa and shell were colonized by both deliberately-placed organisms and spreading sea life from live rock (which itself was previously seeded tufa). A year or two later, a white feather duster worm species actually spawned *into* the tufa. By this time, nobody could tell the difference between natural live rock and what was seeded. During this entire period, water quality remained excellent: ammonia and nitrites were never detectable even in the previous established aquarium, and the nitrates that were around 2 mg/L in the old system are now undetectable. The improved nitrogen levels suggest that denitrifying bacteria on the rocks shared the same benefits as the invertebrates, which immediately and favorably responded to the unobstructed water flow afforded by the frames' cut-out caves. The pH has always been 8.1-8.3. After switching to the live-frame, I started monitoring calcium, hardness, and magnesium. The calcium and carbonate levels fluctuate slightly, but that variance could be due to the ever-changing hard coral population, which is constantly grown and traded. The original coral fragment nursery is only large enough to accommodate loose mushroom and zooanthid polyps. The area intended to be sandy flats are usually covered with coral fragments slated for market.

Good short-term results are always pleasing, but how does the live-frame endure the test of time? Seven years after installing the live-frame, the aquarium keeps flourishing (Figures 1, 9, 10, and 11). Here are some examples where this design aided aquarium maintenance:

- Some *Aiptasia* that proved evasive in the old system were finally eradicated through a combination of physically removing and treating the piece with a Kalkwasser paste—a task tremendously simplified by the live-frames. Peppermint shrimp (*Lysmata wurdemanni*) eliminated *Aiptasia* that I overlooked.

- Confining clove polyp growth (a notoriously fast-spreading species) to a single, small rock was an easy task. After removing the extensions, that rock was hooked into the frame and looks like part of a large boulder. The same applies to mushroom polyps or corals that are otherwise tricky to fragment and culture, all without disturbing too many surrounding rocks.
- Catching fish is never an easy task, but systematically draining water and dismantling the live-frame reduced the burden.
- Sometimes the razor blade was accidentally dropped when scraping algae. The live-frame’s openness facilitated its retrieval behind rocky forms. When the blade (fallen snail, or any other object) landed in an awkward locality, the obstructing rocks were easily removed and object was collected.

The key to a successful live-frame returns to proper planning. Aquarium system experience plays into those crucial plans. Anyone with basic craftsman skills can physically build a live-frame, but reef tank novices may consider seeking planning advice from veteran aquarists. Should a completed live-frame fail to meet expectations and modifications fail to remedy the problem, remove that component and build a new one. The answer may be as simple as cutting a new PVC central core and re-hanging the same rocks. The same solution applies should one wish to periodically redesign the aquarium.

Whereas planning and construction require far more time than simply dropping live rock into a tank, the long-term aesthetic quality and easy aquarium management make that initial period a worthwhile investment. Besides improving the captive organisms’ care, widely adapted live-frames will also improve environmental stewardship by reducing wild live rock demand. Live-framing reaps these benefits while both empowering the aquarist with greater creative control and improving the aquarium’s organisms’ quality of life.

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