Being There

VR director of photography Lewis Smithingham and lighting director of photography John Engstrom dive into 360-degree storytelling with the series *Invisible*.

By Noah Kadner

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Created by filmmaker Doug Liman's production company 30 Ninjas in partnership with Condé Nast Entertainment and Samsung, *Invisible* is an episodic action series — but more than that, it's a 360-degree stereoscopic presentation that offers viewers an immersive experience when watching with a virtual-reality headset. The story chronicles the adventures of the Ashlands, a prominent New York City family blessed throughout the generations with the supernatural gift of invisibility. The series is set to debut as five six-minute episodes on the Samsung VR distribution platform, with an eye toward future release on addi-

tional 360-video/virtual-reality platforms such as Oculus Rift, HTC Vive and Google Cardboard.

As a relatively early entrant in the nascent medium of 360-degree storytelling, *Invisible* was in many ways a large-scale experiment for Liman and his production team, which included executive producer/director Julina Tatlock, VR director of photography/VR supervisor Lewis Smithingham, lighting director of photography John Engstrom and visual-effects supervisor Chris Healer. "I was brought on to help Doug shoot a camera test for the project back in August 2015," recalls Smithingham. "Doug is amazing to work with because he's so tech-minded and iterative. If you explain something to him, he listens and understands, and then he wants to get his hands dirty."

Principal photography began in January 2016, and proceeded — on location in Los Angeles, Connecticut, New York and Haiti — at a pace of two to three shooting days each month through March, with "postproduction" work conducted throughout. The production elected to work with multiple camera systems, including GoPro Hero4 Black 4K cameras arrayed in various six-camera configurations by Freedom 360, custom rigs designed by

Opposite and this page, top: Gifted with invisibility throughout the generations, the Ashland family now teeters on the brink of their secret being exposed in the 360-degree/virtual-reality story *Invisible*. Middle: VR cinematographer Lewis Smithingham (right) and executive producer/director Julina Tatlock (over Smithingham's shoulder) on set in Haiti. Bottom: Lighting cinematographer John Engstrom.

Photos by John Engstrom, Matthew Grossfield, Julina Tatlock, Kezia Jean and Lewis Smithingham, courtesy of 30 Ninjas.

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Top and bottom: The crew preps the lighting on location in Connecticut. Middle: Brothers Josh and Jason Diamond ready the Jaunt One camera for the location shoot.

Smithingham and Freedom 360 mounted with GoPro Hero4 Black cameras, a single Sony a7S II mirrorless 4K camera rigged on a nodal head, and the Jaunt One purpose-built VR camera. "We shot approximately 80 percent of *Invisible* with the Jaunt," says Smithingham.

In contrast to a traditional motion-picture camera, the Jaunt One has no interchangeable lenses. Instead, the spherical body features 24 fixed and synchronized camera modules, each with a 1½" native HD global-shutter sensor and custom, wide-angle prime optics that offer a 130-degree diagonal field of view and an f2.9 maximum aperture. With its multiple lenses clustered around a vented metal dome, the camera's appearance is akin to a biomechanical spider's head.

The production's GoPros were modified to accept C-mount optics, and Smithingham notes that the crew utilized 1.34mm and 1.07mm Entaniya Fisheye lenses. "The Sony a7S II had a Rokinon [Fisheye] 8mm lens, which we modified," he adds. "I shaved the flange so it had a slightly wider field of view and then put it onto a Metabones Speed Booster. That effectively made it into a

6mm lens, and we were then shooting it on a [panoramic] head." In addition to fixed tripods and monopods, the production deployed cameras on Steadicam, a custom rover and custom drones by Aerobo, a wirecam by Varavon, and motion-control sliders by KFX and Kessler.

"There's a lot of discussion in VR about what you can and cannot do in this new medium," Tatlock notes. "In distribution with the headset, you can actually make people nauseous with excessive movement. Whenever we had a shot we thought might cause someone to get ill, we always covered [the action] static just to be safe. We had to determine what the narrative rules were while working in a medium that is still being invented.

"Simon Crane directed our final episode, and as Doug's longtime 2nd-unit director and stunt coordinator, he came in from an action POV, with very specific ideas of where the camera should go," Tatlock continues. "Those ideas included hanging a camera off of the sixth story of a building and running the rig at top speed in a remote-control car down a Tribeca alleyway. We would have considered both of those shots impossible to do at the start of the show, but both of them are in the final cut. We were constantly pushing things technically and creatively."

Smithingham adds, "As a general rule I think having a fixed horizon really helps. Placing something a long distance away that you can visually key into really helps with potential viewer illness. We target the perspective in such a way that it will feel ergonomically successful to experience for people who are sitting on a couch with a headset — although I personally prefer to view in headset while standing up. We also planned the editing choices and motivated our camera moves so you don't constantly need to twist your neck around to see the key action in a shot.

"One of the things that most VR series do is obsess with first-person POV," he continues. "We didn't do that so much, and I think there are only a few shots in the entire series that are POV. We shot it much more like a regular movie. There are shots that are very low-down in places where human beings could never possibly be, and some shots that are very high up. We didn't think about it in terms of placing you into the scene — we thought about it from the perspective of placing you into the story."

The crew readies the fireplace scene inside the Connecticut location. In the bottom photo, a small LED can be seen strapped to the camera's support; with a 360-degree view, VR cameras demand creative thinking when it comes to hiding lights.

On a VR production, the more traditional roles of cinematographer, gaffer and digital-imaging technician overlap somewhat. This is due to a variety of factors, such as the difficulties of placing movie lighting so it won't appear in the camera's all-encompassing view; the fixed lens of the VR rigs; and the inability to monitor the cameras' native output live during takes.

"Just starting a take is complex," observes Smithingham. "First you make sure the cameras are all on, and then you press 'record.' Then you have to run around the rig and make sure that all of the cameras are actually recording. Next

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Top: Pictured is a direct-from-camera image from the production's shoot on location in New York. Bottom left: Engstrom suspends the Jaunt off of a building in Brooklyn. Bottom right: With a Ricoh Theta camera positioned atop the Jaunt for help with previewing the 360-degree image, Alan Bucaria lines up a shot during the Tribeca shoot.

you have to slate, which is a three-step process for light, sound and motion. The cameras do not accept timecode, so for the Jaunt camera — which is genlocked — the team used a traditional slate as well as a digital slate that plays back a coded signal to attach [in the cloud] the ambisonic audio to the camera take. For the GoPros, which are not genlocked and have rolling shutters, [I built] a custom slate that consisted of a trash can lined with camera charts. A hole was drilled in the top to accept a camera flash or flashlight. When it was time to shoot, the trash can was placed over the rig, the flash triggered — which provided a visual sync — and then the trash can was hit with an object to create a loud sound for the sound sync, and then spun to calibrate for stitching. The C-mount lenses need to be constantly checked for back-focus, so the charts allowed us to do that on every take. Finally, you have to run and hide so you're not in the shot. You're rolling for up to a minute before you can get the action going, and then you tend to run scenes longer than a traditional shoot."

Once the action started, actually seeing what the cameras were capturing was the next major hurdle. "We had these cell-phone cameras that were placed back-to-back next to the VR rig and ran into a hacked system, with which our post department figured out how to do a very-low-resolution, security-camera-style playback," Smithingham explains. "Sometimes we used a hacked Theta S that ran into a Raspberry Pi with Wi-Fi to broadcast the signal; other times we just video-chatted with cell phones strapped to the

Bucaria and Smithingham prep a scene on location in Haiti.

monopod." Healer adds, "The code I wrote to transmit Theta S on a RaspPi is posted on *GitHub* at github.com/themolecule/thetaServer. It was a very useful production tool."

"A key aspect of VR production is making sure your camera department is very aware of how these cameras are designed," Smithingham continues. "You have to know how your camera functions or you can totally destroy a shot. [The cameras] have blind spots due to how the different angles are all stitched into a single sphere, so if you place an actor in the wrong place relative to the camera, you can lose the whole shot. You have to be very cognizant of how these cameras will function in post-production, or else you end up with an insane magnitude of rotoscoping costs. You can just imagine the absurdity of rotoscoping an 8-by-8K, 60-fps moving shot."

Both the Jaunt One and the GoPro array recorded to individual SD cards — one each per camera module. For the Jaunt One, the SD data is imported using the Jaunt Media Manager and uploaded to the private Jaunt Cloud Rendering system, which uses proprietary light-field based stitching algorithms to create a seamless 360x180-degree stereoscopic work product that can be downloaded from the cloud in a variety of formats. The GoPro systems, on the other hand, do not have an importer. The a7S II recorded to internal SD cards at 4K in XAVC S format.

The abundance of digital information made data management another logistical challenge. "At one point, for a multi-cam stunt shot, we had 96 sensors total, which is insane," Smithingham says with a laugh. "Our heaviest day included a stunt in which we destroyed a location. Rolling simultaneously were two Jaunts, with a total of 48 SD cards; two three-camera GoPro rigs; an a7S II; and two 1.07mm single-camera GoPro rigs — for a total of 63 SD cards. I was actually the DIT on that day, and towards the end we were running with a tiny crew — less people to hide. But we also shot some days where we had two units running, which would have added 12 more GoPros to that number. Our DIT Joe Belack had 96 SD cards — both MicroSD and standard SDHC — to import. We were shooting at 60 fps, and the data rate came out to about 60GB a minute, so we ended up somewhere in the range of 64TB of raw footage by the end of the production for a 30-minute show."

Engstrom tackled many of the duties a gaffer would traditionally handle, and hiding lights and cables was

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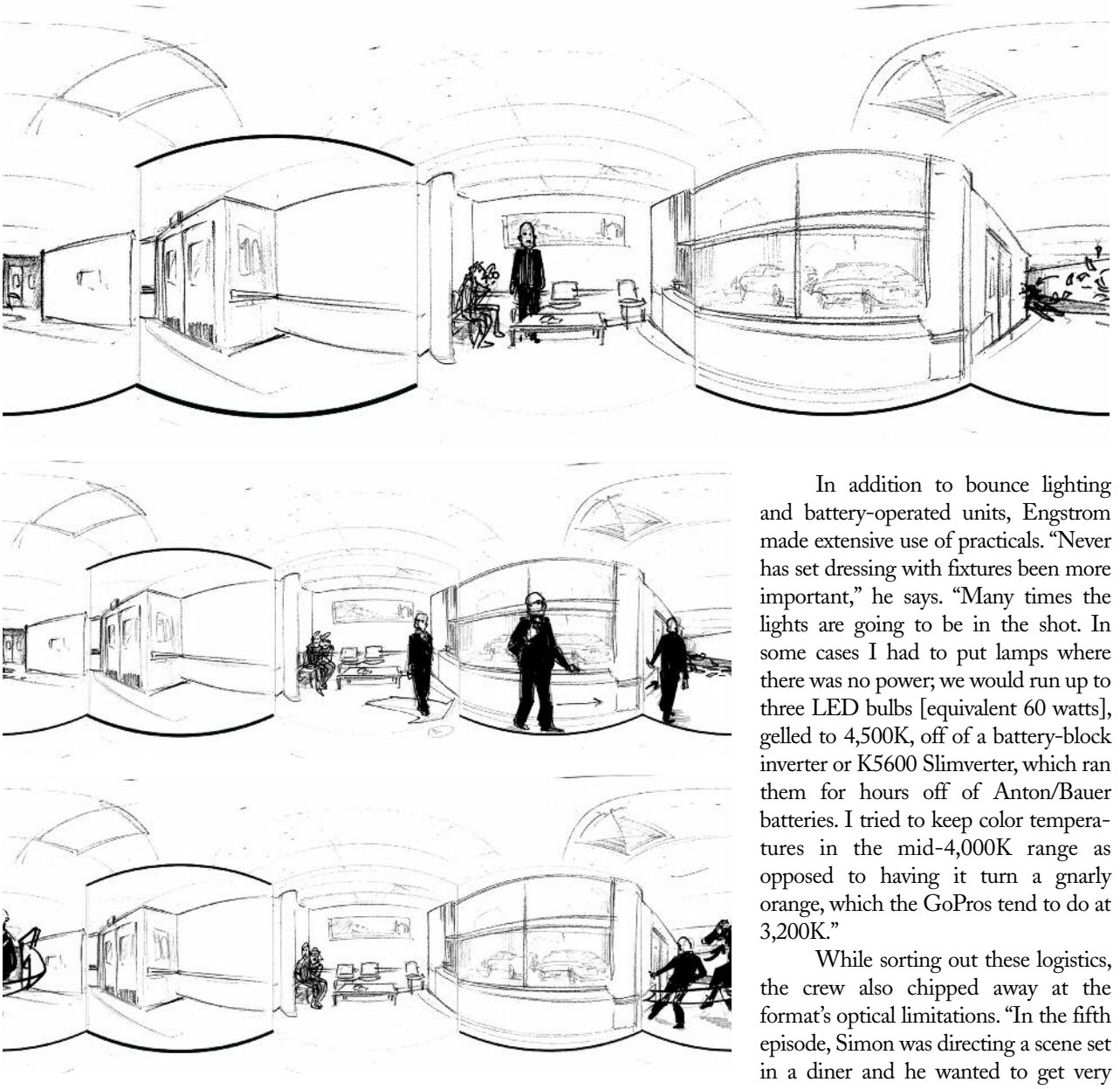

A series of "equirectangular" storyboard images.

one of his primary concerns. "The camera sees out of every window and down every hallway," he says. "It's always been like this in our business, but with VR you're really seeing the whole world. It's a million times harder to hide fixtures, and you need more time."

In many cases there was no way to hide cable in a scene. In those situations, Engstrom deployed battery-powered lighting units, including Dedolight 200-watt HMIs; ETC Source Four Mini LEDs; Litepanels Astra 1x1 LEDs; Arri SkyPanel S60s and S30s; LiteGear LiteRibbons; and Litegear LiteMats, versions 1, 4 and 2L. "There were times when I had to bounce a light from far away, and for that [we used] standard ETC Source Four 750-watt tungsten units," notes Engstrom. "I would have to throw light completely across a scene, from the other side of the room, where I could hide a light and bounce it off of a wall."

In addition to bounce lighting and battery-operated units, Engstrom made extensive use of practicals. "Never has set dressing with fixtures been more important," he says. "Many times the lights are going to be in the shot. In some cases I had to put lamps where there was no power; we would run up to three LED bulbs [equivalent 60 watts], gelled to 4,500K, off of a battery-block inverter or K5600 Slimverter, which ran them for hours off of Anton/Bauer batteries. I tried to keep color temperatures in the mid-4,000K range as opposed to having it turn a gnarly orange, which the GoPros tend to do at 3,200K."

While sorting out these logistics, the crew also chipped away at the format's optical limitations. "In the fifth episode, Simon was directing a scene set in a diner and he wanted to get very close to an actor," says Smithingham. "We'd never gotten closer than 4 feet, because at that distance you may have to deal with major parallax issues, and objects can essentially disappear within a seam in the finished 360-degree clip. So I looked into how the Jaunt's optical-flow algorithm stitches everything together and generates stereo, and figured out a way to 'trick' the computer into thinking something wasn't a solid object and throwing the stitch into a place where it wouldn't overlap the actor. We used a technique called 'dazzle camouflage,' where you break a solid

shape into a confusing pattern — in this case by adding very specific set dressing.

"Dazzle camo is a type of camouflage technique primarily used in World War I," he continues. "It's also known as 'disruptive' camouflage. It reasoned that by painting the ships with confusing patterns, U-boats' stereoscopic coincidence range finders would have trouble determining the shape, size and direction of a ship, because they would not be able to accurately create depth, and thus range, based on a triangulation formula. I reasoned that if the pattern were confusing enough, the optical flow algorithm might have similar trouble and just throw a stitch around the edge of the pattern, or throw a stitch into the pattern in such a way that it would be concealed. So we placed the actors in a narrow space — in front of a glass fridge that was surrounded by odd-colored patterns similar to a Barber's pole. These objects were sometimes closer than 18 inches, but because of their confusing patterns, the algorithm was unable to find depth and threw the stitch around them. This was accentuated by putting brightly colored objects at various depths within the glass fridge. The actor moved between 18 and 24 inches."

Tatlock mentions other techniques the crew learned along the way that greatly enhanced the process of planning and executing their shots. For example, she offers, "You should try to storyboard for 360 with a cube map and, if possible, review [the storyboards with a VR] headset so you can actually see how the story looks in VR. Then trust yourself more than anyone else about what works. A lot of people will get up on a VR stage and say, 'This technique works and that one doesn't.' But maybe you can figure out a better way, and then all of a sudden you've invented a new shot in VR."

Smithingham, Fred Beahm and Michael Vincent handled editorial duties for *Invisible*, using Adobe Premiere with Mettle's SkyBox VR plug-in for live VR headset previews. Meanwhile, Healer spearheaded work at The Molecule in New York. "Our

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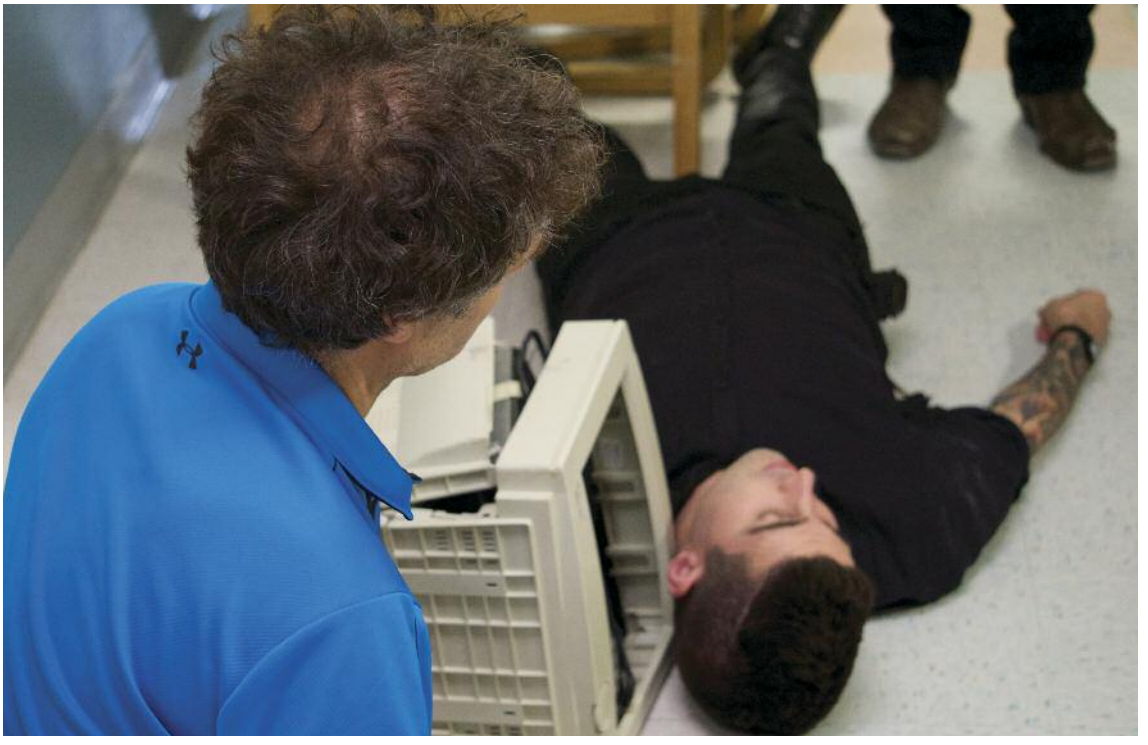

Top: Filmmaker Doug Liman — whose production company 30 Ninjas co-created *Invisible* — views a shot from camera position while Smithingham stands in as a dead man. Bottom left: Liman and Smithingham discuss a visual-effects-heavy shot. Bottom right: Liman uses an Oculus Rift DK2 to preview a quick-stitched shot on set.

primary tool for [stitching the individual camera captures into] 360 VR panoramas is [The Foundry's] Nuke, along with ancillary tools like Hugin, Autopano and Nuke's Cara VR toolkit," Healer explains. "We also built a lot of custom gadgets within Nuke to create our own 'magic toolset.'

"The general approach depends a lot on which camera we're working from," Healer adds. "For example, with the GoPro footage, we receive three to six individual MPEG-4 movie clips for each shot that we immediately decode into JPEG image sequences for stitching. For Jaunt [footage], we could access the cloud renders directly and download EXR frames. Finally, for the Sony a7S II, we transcoded from Sony's native XAVC S-Log 4K format." Footage from the a7S II was a combination of video and stills captured from a nodal head. Video was all at 4K and 30 fps. "There's still a little debate about the ideal frame rate for VR," Healer notes, "and I will admit that I have perhaps fought it the most, but 60 fps seems to be the winner, and certainly for this show we have to conform all things to 60 fps. Footage is interpolated to arrive at that standard, but in 360 degrees, only certain segments of the sphere [feature] motion, so the final shot the viewer sees is a hybrid of re-grained stills and motion footage."

The Molecule was also responsible for creating visual effects and animation using Autodesk's Maya, mapping effects into stereoscopic 360-degree space and dealing with final renders at 4Kx2K latitude-longitude resolution, per eye, at 60 fps. And although a host of technical considerations went into the final product, the effects team at The Molecule also poured plenty of

artistic creativity into the mix by taking stock of other movies that feature invisible characters. "We talked about a lot of them, like *The Invisible Man* [1933], *Predator* and *Hollow Man*," says Healer. "One of the most interesting references was the chameleon effect of an octopus, which can absorb color and texture to effectively camouflage itself while not actually being transparent."

The technical hurdles for The Molecule's crew included transposing tried-and-tested visual-effects development techniques into the 360-degree realm. "In episode one there's a fight sequence in a hospital between a tall invisible character and a much shorter visible character," says Healer. "The invisible character gets stabbed with a pair of scissors, which then float in midair as he continues to fight and the camera dollies through the room. Normally you'd shoot a clean plate of the background and composite the scissors into the action, but it's really difficult to shoot clean plates in VR. You can't really over-scan the frame like you would from a single viewpoint, so you don't get the guaranteed geometry of the shot for the plate, and the stitching in post can distort things so much that they don't match up. The solution we found was to shoot the plates and the action [within the same take]. We'd start a take completely clean, have the actors step into their marks, call action, and then step out to a clean frame again [at the end of the take]. That was the best way to guarantee a clean plate and more consistent geometry. If a clean plate is embedded in the head or tail of a shot, we know that it will not follow a different computational path and will be useful. Each take is in essence a unique solve."

Expanding on geometry concerns, Healer mentions that pixel aspect ratio is a hot topic in VR post. "In the latitude/longitude spherical distribution formats we use, within the area between the center of the frame and the tops and bottoms, the issue is how much distortion you're getting from a pixel's specific position on the sphere," he explains. "It's relatively easy to wrap all of those individual sensor images onto a single

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The production's full VR arsenal included the Oculus DK2 headset, Jaunt One camera, Back-Bone modified GoPro Hero4 Black cameras, Nokia Ozo camera, HTC Vive headset, Structure IO's Structure Sensor, Sony a7S II camera and Samsung Gear VR headset.

sphere, and it's also easy for an OpenGL player on a phone or a headset to decode and present that image to the final viewer. But it's also an unfortunate format because so much data is dedicated to the top and bottom of the frame, which are effectively squished into a single point. The center of the frame, which is typically what you care about the most, contains the least concentrated data. You wish there was a way to dedicate more of the pixels in the sphere to the primary subject of what you're photographing.

"As an alternative to spherical mapping," Healer continues, "the VR team at Facebook has proposed cube mapping. This idea has a lot of merit in terms of dedicating pixels to the most important parts of the image, and simplifies parts of the process. I hope that this gains traction. Spherical mapping in 2D space is an age-old problem, harking back to Mercator and contemplated by Buckminster Fuller, as well as many others."

In order to accurately evaluate color when looking at 360-degree images stitched together from multiple taking lenses, Healer explains, "We use HP LP2475w 24-inch IPS LCD monitors as well as Zalman 2D/3D passive Trimon monitors, which [can accept] a direct output from Nuke." With the GoPro images, he adds, "We'll start with GoPro's Protune and ultimately render out in sRGB color space to match the cell-phone screens and built-in monitor screens most current VR headsets use." For final color grading, The Molecule delivered

4096x4096, 60 fps, top-and-bottom stereo ProRes files to Local Hero Post in Los Angeles, where colorist Leandro Marini worked with Assimilate's Scratch.

With *Invisible* under his belt, Smithingham's enthusiasm for VR as an evolutionary filmmaking medium continues to wax. "I'm a futurist," he says, "so I'm already looking forward to being able to have a new retina implant that is computerized, and a chip implanted into my brain stem that would allow me to turn on VR whenever I want instead of having to use a headset. I know that sounds weird right now, but I think VR in a headset is the 'brick-sized cell phone' of a new wave [of technology] that will become more and more advanced. I read recently that new technology can be defined as something that wasn't around when you were born. So the things that are new to us and seem kind of scary and intense won't be scary and won't be intense for our children and our children's children."

Tatlock also feels the surface has barely been scratched in terms of VR's potential. "I personally really enjoy watching 360 video and playing virtual-reality games," she says. "I'm sure you can find metrics about how long people can comfortably stay in headset — it's foolish to say there's no kind of story you wouldn't be able to do in VR. But it's been our experience that people who watch the first five minutes of *Invisible* will want to keep going as long as the story sustains.

"The challenge right now is that VR is so expensive and it takes so long to stitch everything together," Tatlock continues. "You have to spend money on visual effects for every shot, so no one is making $100 million VR movies just yet. But once that level of storytelling resources is put up against this medium, I think people will want to watch." ●

TECHNICAL SPECS

4096x4096 Stereo Image

360-Degree Digital Capture

Jaunt One, GoPro Hero4 Black, Sony a7S II

Rokinon Fisheye, Entaniya Fisheye