Making Connections

Computational BIM brings order to design complexity in massive architectural projects.

Building information modeling, or BIM, has been around since the 1980s. The strategy of maintaining a database of all of a structure's components and capabilities lets anyone making decisions about the building know exactly what they're working with. The shared knowledge resource is designed to help from conception to demolition, making replacements, upgrades, and tweaks to a structure more easily achieved.

BIM was made possible by the rise of personal computers, and as computing power has exponentially grown, the practice is evolving. Building information models that were once simple spreadsheets can now be rendered in 3D or even 5D—adding cost and time to the physical dimensions of width, height, and depth. Now, the next generation of the technique, called "computational BIM," is allowing architects and engineers to more easily optimize buildings' design and construction for any number of goals—perhaps calculating cost savings from energy use based on optimizing a design for natural light. Sometimes called "parametric BIM," it's the next step toward generative design, turning the database into a design collaborator.

"You always build models to answer questions of some sort," says Matt Jezyk, senior product line manager for AEC Conceptual Design Products at Autodesk. "How tall or wide is this thing? How long will it take to construct? How much will it cost? But those are static representations, and if you need to change something, you have to start over again." Jezyk is one of the founders of computational BIM tool Revit, which became part of the Autodesk family in 2002.

With tools such as computational BIM, making one change automatically updates the entire system, letting you quickly compare options. You can add behaviors and logic to the components of a building information model, modifying the software to make it do what you want it to. "You're building a system that has a set of things you care about in it," Jezyk says. "It's like a sandbox you've constructed: You can do whatever you want as long as you stay inside the sandbox."

Sometimes computational BIM will answer questions you didn't even know to ask and that previously would have been impossible to ask. The Shanghai Tower, designed by SOM and featured in Autodesk's 2011 book, *Imagine, Design, Create*, twists 120 degrees with a 55 percent taper to reduce wind shear. The architects determined that was the optimal design to reduce wind shear by using computational BIM to test myriad possible options.

"In the past it would have required making a physical model and sticking it in a wind tunnel and evaluating it," Jezyk says. "Now you can have a designer simulate the virtual wind and tell the computer, find me the best option." And that option reduced wind loads by 24 percent and material costs by $58 million.

It's not just about creating a building faster or cheaper; more and more, computational BIM is being used to measure quality, especially for massive projects—such as international airports.

AN AIRPORT FIT FOR A QUEEN

When Foster + Partners started working on the design for the Queen Alia International Airport, in Amman, Jordan, in the early 2000s, computational BIM software didn't yet have the capabilities they needed, so they built custom software to design the groundbreaking roof themselves.

That's not unusual for them: The Applied Research + Development Group (ARD) at London-based Foster + Partners is a crack team of architects,

previous pages: The roof of the Queen Alia International Airport was inspired by the canopies of Bedouin tents. **opposite top:** The complex roof is made up of more than 80 separate domes. **opposite bottom:** BIM software helps conceive of a building as data as well as an architectural plan or model.

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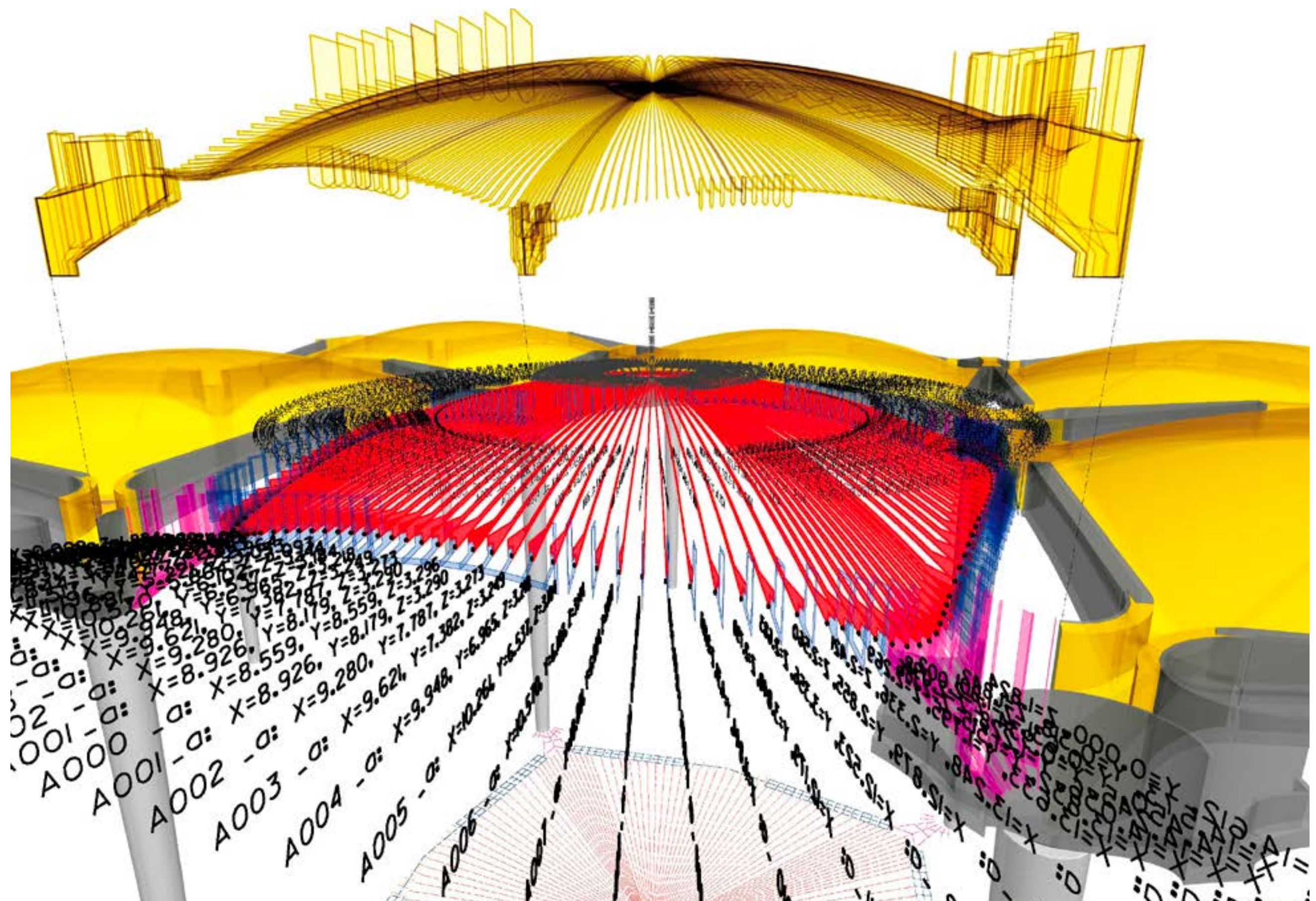
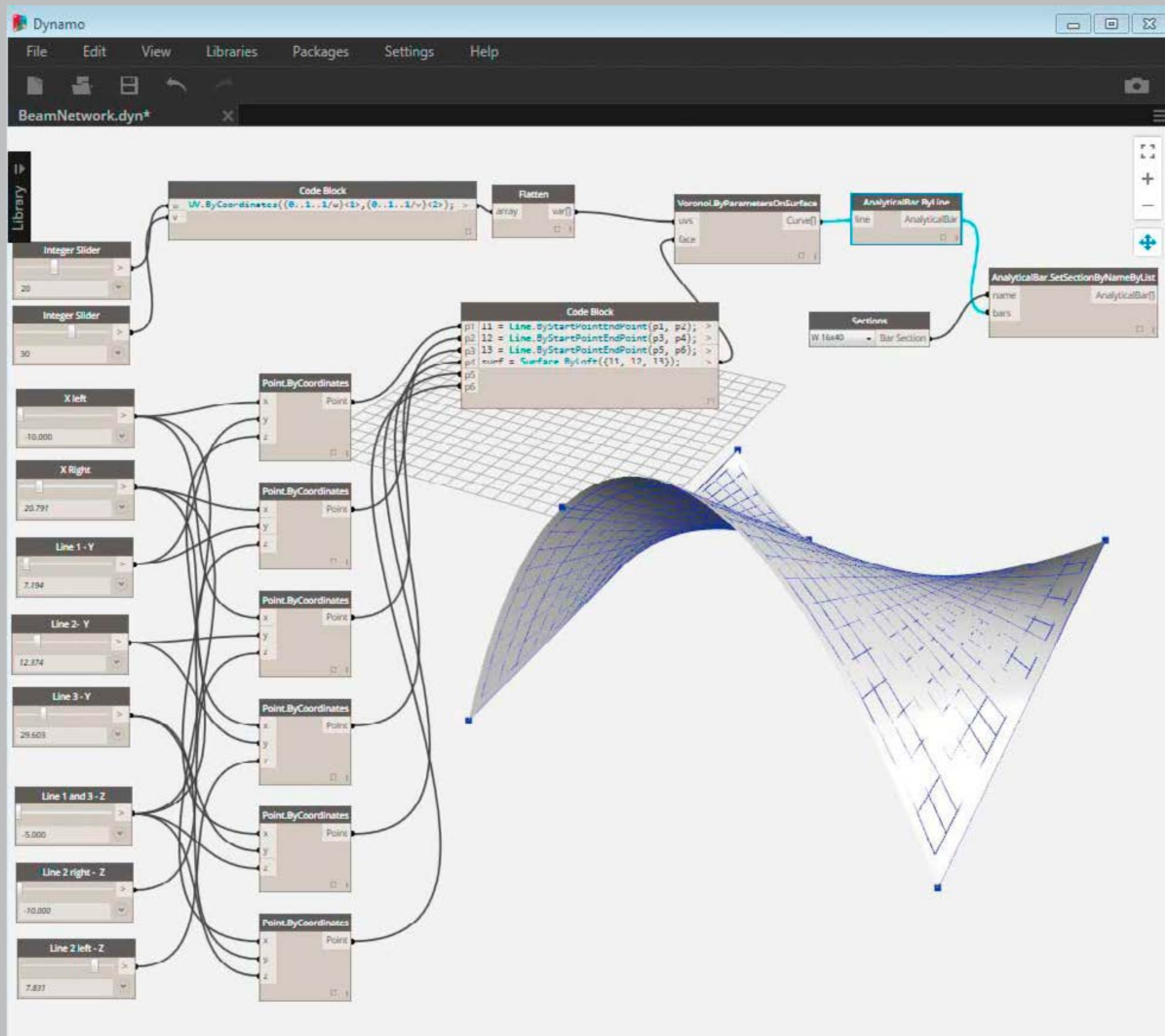


HOW IT WORKS: DYNAMO



Early computational design began with equations and programming scripts. As 3D models became more complex, and as the desire for real-time interactivity took hold, visual programming languages such as Dynamo, which works with Revit and other software, have made computational design more accessible and more powerful. Designers connect "nodes," which can be simple or complex operations, via "wires" that define relationships. All can be adjusted to quickly create and iterate design solutions in real time, and to explore multiple ideas.

engineers, mathematicians, and computer scientists. Led by Francis Aish, an aeronautical engineer by training, ARD is essentially an in-house consultancy that solves unusual problems for any project that needs help, and their expertise is especially called for when working on groundbreaking projects.

With design inspired by Bedouin tents and traditional Arabic geometry, the tessellated concrete roof of the Queen Alia International Airport is made up of many shallow domes. Open-air courtyards on either side of the main terminal provide respite for travelers, and pools reflect sunlight into the building while naturally cooling the air. From the inside, the broad canopy of domes seems to sprout from palm-like soffits, and split beams let in natural light.

Initially, the concrete domes were each going to be produced in whole, but the team quickly realized the quality-control problems that could arise from casting giant glazed domes, each with a radius of 26.7 meters. So the domes were broken down into their most basic parts: eight component pieces for a dome, plus more pieces for edges, cones, and corners. Every one of these components was built in the system as a parametric design, and as the team worked on the tessellated roof, "any single change on the model would propagate from a single module to the entire airport and be followed by an automatic process to produce directly to the drawing sections," says ARD partner Martha Tsigkari, who was responsible for the modeling and automatic updating of the roof.

The new terminal of Queen Alia International Airport, completed in 2013, and the second expansion, completed in 2016, have raised the traffic capacity from 3.5 million to more than 12 million passengers per year, with the potential for further expansions.

Computational BIM software's high-tech output isn't yet the standard, and the construction industry is slow to adapt. "We work all over the world, and there is a wide range of contractor skills. Not all contractors can work with 3D drawings," Aish says. "One for the Queen Alia airport only worked with 2D drawings."

Associate partner Adam Davis did a lot of the underlying work to transform the information from the Queen Alia airport model to the drawings required by the fabricators. "We weren't just producing sections at right angles, but dozens of radial profiles to ensure the curvature of the domes and arches was properly realized. Our software had to understand how to annotate drawings differently depending on the shape of the profiles," he says.

"The drawing extraction is something people take for granted now," Tsigkari says. "Back then it was a hard exercise to make that happen."

Computational BIM has been a tool in ARD's shed for many years, so the team is acutely aware of its progress. "What's changed is that software can compile them in a more digestible format. And that is very empowering and game-changing in many situations," Tsigkari says. She works closely with software vendors to give feedback and beta-test new products; everyone on the ARD team is also a programmer, capable of tweaking software products to make the tools they need. "BIM is not in its infancy, but it's still a teenager. It can do a lot of things and allows for flexibility, but it has not matured yet to what we would like to see."

Foster + Partners is in a good place to influence the future of computational BIM and parametric design. "There's a huge opportunity to close the loop—the building process doesn't end when you hand over the keys. It has to be designed for reuse. We have to look at the entire lifecycle of a building," Aish says. "At the end of the day, it's all about the experience of the people using the building."

And it's about avoiding obsolescence: "A government building has a lifespan of a quarter of a millennium," Aish says. He says they need long-term software stability and open-data formats to maintain crucial information over long periods of time. Using computational BIM to build a nuclear power plant today is fine, but you have to be certain that future engineers will be able to access the data when the time comes to decommission it.

TAKING OFF FOR THE FUTURE

Around the world, Foster + Partners is working on the new international airport in Mexico City, a 470,000-square-meter structure massive even by aeronautical standards.

Like the Queen Alia International Airport, the idea is to use natural light and cooling methods to cut down on energy costs and integrate with the local environment. The entire terminal will be enclosed in a lightweight glass-and-steel shell that looks as if it could take flight itself. The ARD team is using custom scripts and translating the entire spaceframe and cladding system back into Microstation and Revit via VBA and Dynamo, respectively, with the help of bespoke databases.

The shape of the roof is inspired by the perfect tension of a hanging chain. The roof is supported by 21 funnel-shaped columns, creating a smooth distribution of forces. The finished roof structure will harness rainwater and solar energy to achieve LEED Platinum status.

More than 200 people are working on the Mexico City airport's design, which is complicated by the region's soft soil and propensity for earthquakes. Tsigkari leads a team of four working on the development of the spaceframe, and has worked with the design team since the competition. Construction on what Foster + Partners aims to make the most sustainable airport in the world began in 2016 and is set to be completed by 2020.

Existing computational BIM tools still aren't powerful enough to handle the entire Mexico City airport, Aish reports, so they're using a number of tools. "A lot of BIM tools are designed for standard-sized and -shaped

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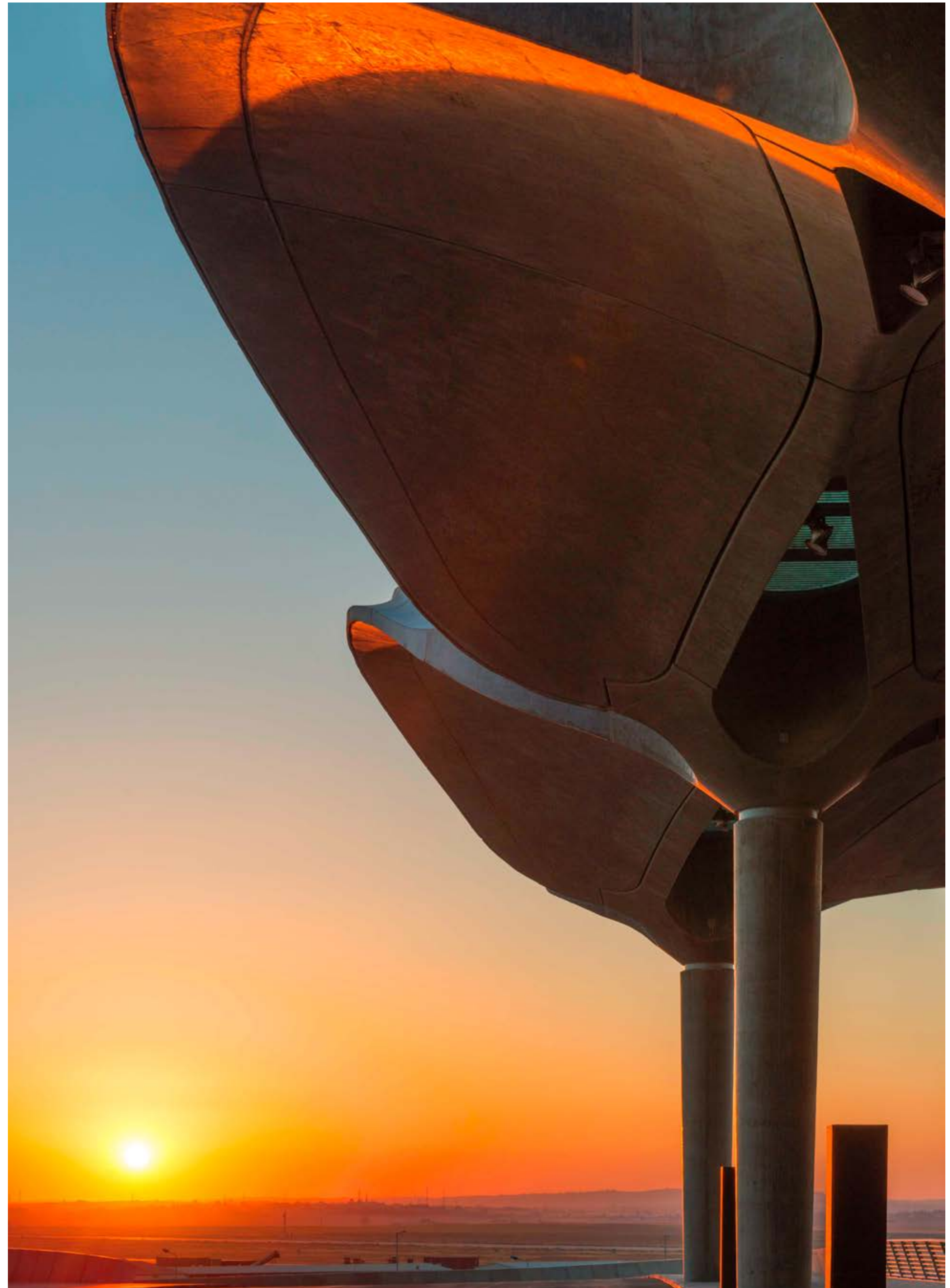
The domes were broken down to 8 basic parts to facilitate their construction; using BIM meant that any change to any component propagated to the whole airport.



"Sometimes there's an answer that works that you never would have come up with. It's not just a pet; it's an active contributor."

opposite top: As it neared completion, the Queen Alia airport revealed its array of connecting domes. **opposite bottom:** Foster + Partners is currently working on the new international airport in Mexico City, a massive project that will further push the capabilities of computational BIM.

buildings," he says. "But unfortunately a lot of our buildings are more complex or larger or both."

Generative design programs such as computational BIM tools are getting smarter, and people who work with the programs are making them better every day. "When you're working with these computer systems, they come up with answers you wouldn't expect. Sometimes there's an answer that works that you never would have come up with," Jezyk says. "It's not just a pet; it's an active contributor."

Will computational BIM ever replace the expertise of engineers and architects? It's highly unlikely. "Traditionally, in any practice, like engineering or design or architecture, there's the master and the apprentice," Jezyk says. And the time-honored tradition of learning from an expert by working with them is ingrained in those professions. "Sometimes there are so many things that are kind of latent knowledge that you can't really articulate. The guy just knows, if you do it this way, it will work. Experts know how to solve an optimization problem in their head because they have done it 50 times."

For all of its usefulness, Aish warns against putting too much stock in computational BIM. "We're in the business of producing elegant buildings. And we've delivered great buildings with pen and paper," he says. "These tools can be very transformational. But they shouldn't be overhyped. Tools allow us to do very interesting things, but they're not magically going to solve all the problems for you. You still need to be a good designer."