

Changing the face of architecture

Generative design provides designers and engineers with new ways to efficiently explore alternative building forms - without manually building the detail design model for each scenario

Writer Jim Paul once remarked that only with the invention of the catapult did engineers begin to attain pre-eminence in world affairs, for it was the use of the catapult that viscerally demonstrated - for the first time - man's ability to control mechanical forces many times more powerful than the human body. It feels as if some similar shift is now happening in architecture, as a new class of software tools, collectively termed generative design, are allowing architects to control intellectual forces many times more powerful than human minds to design and construct buildings that could not otherwise exist.

Humans have always been fond of impressive buildings. China's 2008 Olympics, for example, will probably be remembered as much for two spectacular buildings - the Beijing National Stadium and the Beijing National Aquatics Centre - as for the many world

records that were set there. Better known as the Bird's Nest and the Water Cube, the design, engineering, and construction of both buildings depended heavily on generative design. By seizing the world stage so dramatically, the two buildings raised the profile of generative design and, to some extent, architecture will never go back.

Securing the design contract for the National Aquatics Centre for the Beijing 2008 Olympics was a task worthy of gold medal distinction in itself. Arup and architectural firm PTW of Sydney, Australia, together with CSCEC from Beijing and Shenzhen, beat out 10 qualifiers for this prestigious, world-class project. Arup used MicroStation, TriForma, Bentley Structural, and Bentley's generative design technology for its unique design, based on a natural pattern of organic cells and the formation of soap bubbles.

"Generative design is not about designing a building," explained Lars Hesselgren, "It's about designing the system that designs a building." Hesselgren is director of research at Kohn Pedersen Fox Associates (KPF) and also a co-founder of the SmartGeometry Group, a collective taking the lead in bringing generative design concepts to real-world architectural projects.

By bringing together working architects, academics, and industry in the form of Bentley, SmartGeometry has raised the bar for generative design in actual practice, influenced some of the best minds now entering architecture, and fostered an unusually close collaboration with industry to produce GenerativeComponents, software from Bentley that is currently the lingua franca of the generative design movement.

ARCHITECTURE GETS AN UPGRADE

Generative design proponents agree that it is not that architects are now using computers to do things that could not be done previously. Rather, computers are

Upon completion in 2010, the Aviva Stadium in Dublin, Ireland, will provide a new home for the national rugby and football teams, providing weather-protected seating for 50,000. Built within the constraints of an existing site, the 242 million euro stadium consists of a continuous curvilinear stand enclosed on all four sides. Populous achieved the organic-shape design through a series of GenerativeComponents models.

The challenge was to ensure the concept was maintained from design development through construction stages. The exterior skin enveloped the roof and façade structures, combining both elements in one controlling form. This form needed to accommodate all the tolerances and technical requirements in one 3D model. Certain variables and base principles were established within the GenerativeComponents model, allowing Populous to push the boundaries of the architectural form without compromising on cost and time constraints.



enabling architects to take on design tasks that would otherwise be inconceivably tedious.

"It's like fractals," said Hesselgren. "Ada Lovelace knew something of them in the early 1800s, but to work them out by hand and obtain significant results would have taken her several lifetimes." Similarly, computational techniques exist to work out, say, the interwoven façade of the Beijing National Stadium, but to resolve a particular iteration with conventional CAD techniques would take so much time that, at best, just one or two versions would have been considered.

Added J Parrish, director of ArupSport, the division of Arup at the leading edge of large venue design, and also a co-founder of SmartGeometry, "Using parametrics, I was able to investigate far more alternatives. We built Version 34 because it was better. But Version 1 would have worked fine. Generative design allowed us to get better results in a fraction of the time."

ArupSport provided engineering and design services for both of Beijing's major Olympic venues. Parrish helped pioneer the rapid prototyping face of generative design, and began working with Microsoft's Visual Basic and Excel - "a useful interface" - and MicroStation in the 1970s to quickly design stadiums. By tweaking any of 3,000 to 4,000 parameters, Parrish was able to quickly compare, for example, 50,000-seat positioning schemes, optimizing them for views, distance from the field, and other factors. "I could do in a morning what used to take me a month," he said.

Combined with other new technologies, such as real-time rendering and 3D printing, parametrically-enabled rapid prototyping amounts to a new way of doing architectural design-arriving at optimum solutions via side-by-side comparisons of multiple, slightly different versions, rather than depending on the "flashlight in the dark" of one designer's genius.

A complementary approach is also possible. Rather than using multiple versions to decide what is best based on comparison, architects can instead use computing power to find structural solutions that are self-organizing - that is, not decided on by an individual but arrived at by genetic algorithms that iteratively apply relatively simple rules. The Water Cube's soap bubble-like structure is an example of this approach.

According to the book *Space Craft: Developments in Architectural Computing* (RIBA Publishing, 2008), "Irish physicists Denis Weare and Robert Phelan were able to calculate that the most efficient way to divide a space into cells of equal volume while minimizing the surface area between them was to use a stacked arrangement composed of 75 percent 14-sided shapes and 25 percent 12-sided shapes." So far so good, but since the resulting structure would have 22,000 steel members connected at 12,000 nodes, generating an actual model based on the idea exceeded the reach of conventional design.

Instead, according to the book, to manipulate this complex geometric system dynamically, Arup wrote parametric software that automated the drawing and analysis process. Based on specified design constraints and under 190 different loading scenarios, the algorithm iteratively checked the distribution of forces through the entire structure based on specific member sizes, allowing the team to test different design configurations and receive feedback within 25 minutes.

The result is a spectacular building with a sophisticated structure that is optimized in terms of material weight to strength, achieved with relative ease. In addition to the structural advantages, Arup estimated that \$10 million was saved on design costs alone compared to traditional methods.

Jenny Sabin, a co-director of Sabin+Jones LabStudio, a lecturer at

University of Pennsylvania and a long-time tutor at SmartGeometry conferences, offered her take on generative design. "Architecture is inherently about relationships. I'm interested in the way small, local relationships and simple parameters give rise to complex scenarios - bottom-up design as opposed to top-down. Generative design gives rise to emergent behaviours and forms." By bottom-up and emergent, Sabin is alluding to the natural processes that create complex structures such as termite mounds. Without benefit of a designer, simple, rule-applying units like termites interact with basic materials - in this case soil - to create complexly ordered structure.

Sabin uses generative design in fields only tangentially related to architecture, but which ultimately impact the way that she negotiates complexity in architectural contexts. For example, LabStudio is investigating the way surrounding cellular structure affects breast cancer growth, finding that modeling cell growth patterns with computational techniques is yielding insight into cancer formation.

"Generative design allows us to navigate and generate complexity in a way that technology hasn't achieved before," she explained. "Algorithmic design is not necessarily new, but the tools we now have for approaching bottom-up design are far more sophisticated. It's almost as if the software itself has become a new material to work with."

This iterative, emergent process - people designing better tools to take on interesting projects, and then conceiving more interesting projects to take advantage of the better tools - is at once new, and quintessentially human. By building and using better design tools and creating a culture that gets the most out of these tools, the generative design movement is rapidly becoming humanity's most potent tool for evolving our built environment.

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