Making Waves

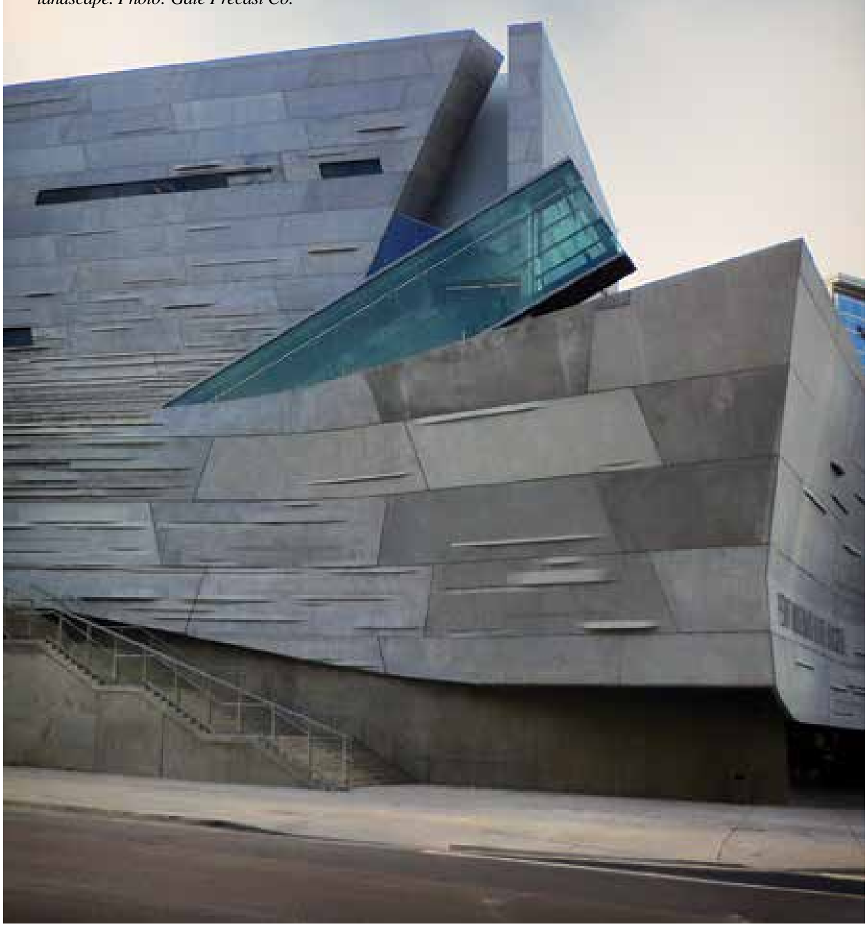
Perot Museum in Dallas uses an innovative and complex pattern of precast concrete panels to set the tone for this educational facility

— Craig A. Shutt

Museums are designed to stimulate curiosity, raise awareness, and inspire visitors — shaping our vision of the past and future. The designers of the Perot Museum of Nature and Science in Dallas wanted to project those attributes onto the building itself, using an innovative concept of projections, striations, and geometric shapes produced with architectural precast concrete panels.

"The museum creates a distinct identity, enhances the institution's prominence in the city, and enriches the city's evolving cultural fabric," explains Thom Mayne, president and design director at Morphosis. "It's designed to engage a broad audience, invigorate young minds, and inspire wonder and curiosity in its visitors."

The 170-foot-tall, 180,000-square-foot Perot Museum of Nature and Science in Dallas features a combination of geometric shapes joined together. The museum is clad with architectural precast concrete panels with projections that ripple across all faces. They represent a sedimentary-like geologic formation pushing through the landscape. Photo: Gate Precast Co.



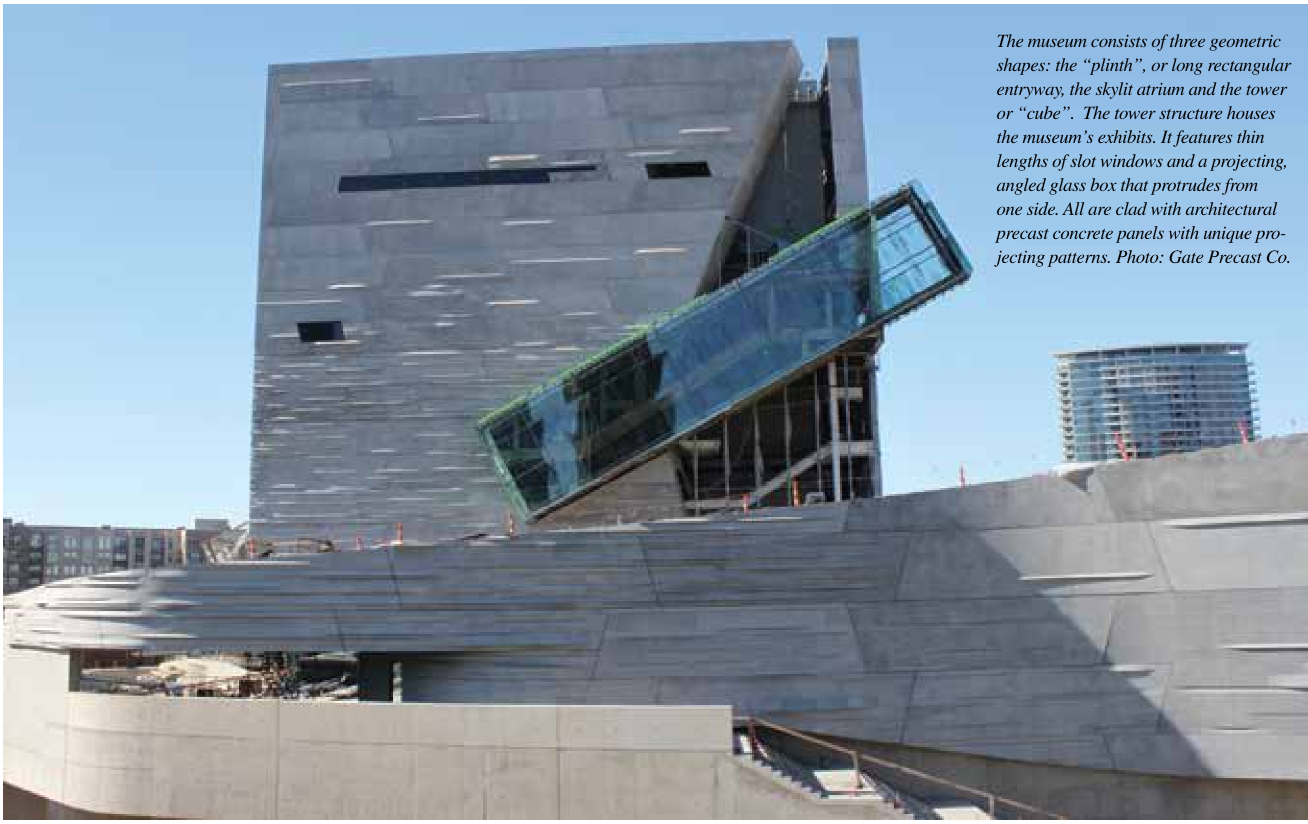
Photos courtesy of Gate Precast Co.

The 170-ft-tall, 180,000-square-ft museum consists of three geometric shapes: the "plinth," or long, one-story rectangular entryway that greets visitors upon arrival; the skylit atrium, which leads visitors up into the exhibition halls via escalators, elevators, and stairs; and the tower or "cube," which features thin lengths of slot windows and a projecting, angled glass box that protrudes from one side. All are clad with architectural precast concrete panels with unique projecting patterns.

Visitors enter through the plinth and take escalators to the top of the building, arriving at a glazed balcony that provides a bird's-eye view of downtown. They proceed down through galleries to reach the ground. "This dynamic spatial procession creates a visceral experience that engages visitors and establishes an immediate connection to the immersive architecture and natural environments of the museum," Mayne says.

A Series of Waves

The immersive architecture begins with the exterior statement. The rippling projections across all faces, extending up the tower, work with curved shapes, both concave and convex, that flow across the plinth's façade. Designers wanted the tower to represent a sedimentary-like geologic



The museum consists of three geometric shapes: the "plinth", or long rectangular entryway, the skylit atrium and the tower or "cube". The tower structure houses the museum's exhibits. It features thin lengths of slot windows and a projecting, angled glass box that protrudes from one side. All are clad with architectural precast concrete panels with unique projecting patterns. Photo: Gate Precast Co.

formation, pushing its way through the landscape. "The design intent was to create a series of waves that gives a dynamic effect on the building that changes throughout the day." The texturing is denser at the bottom of the tower and slowly fades as the cladding moves up to its designed height of 140 ft.

'Ultimately, precast concrete panels provided the simplest erection option and could achieve the complex appearance.'

A variety of options were considered to achieve the unique, random-looking façade texture, says Jeff Koke, senior associate with Datum Engineers. The firm worked with John A. Martin & Associates on the structural design. "We considered various precast and cast-in-place concrete options as well as blown-on gunite and some other options to find the best way to achieve the textural look we wanted," he says. "Ultimately, precast concrete panels provided the simplest

PROJECT SPOTLIGHT

Perot Museum of Nature and Science

Location: *Dallas*

Project Type: *Museum*

Size: *180,000 square feet*

Cost: *$185 million*

Designer: *Morphosis, Culver City, Calif.*

Owner: *Museum of Nature and Science, Dallas*

Structural Engineers: *Datum Engineers, Dallas, and John A. Martin & Associates, Los Angeles*

Contractor: *Balfour Beatty Construction, Dallas*

PCI-Certified Precaster: *Gate Precast Co., Hillsboro, Texas*

Precast Components: *700+ gray as-cast architectural precast concrete panels.*

The architect, steel fabricator and precaster collaborated through building information modeling (BIM). The panels were designed with a 6 1/2 in. nominal thickness with 2 in. recesses and 8 in. projections. Photo: Gate Precast Co.

erection option and could achieve the complex appearance."

The panels minimized material and sped construction because they were designed using a standardized panel shape that maximized modularity, interchangeability, and appearance options. "The panels were very regular in shape to keep them economical," says Koke. "From the back, many of them, especially on the atrium, are similar. That made it easier to create a system to attach them to the building."

Even so, the textural designs took a lot of planning. "This difficult and challenging project pushed precast concrete production to a new level, presenting multiple obstacles in production and quality of diverse, individual components," says Mayne. "Since this was a non-traditional project, thousands of man-hours were spent scheming and dreaming over engineering, production, stripping, and shipping challenges. Every angle had to be proven to be accepted as a best practice."

The architect, steel fabricator, and precaster collaborated through building information modeling (BIM) and web meetings to ensure the architectural intent was satisfied, and that joint locations and panel sizes were accurate.

BIM Aids Design

The precaster, Gate Precast Co., had never undertaken a project quite so complex, notes Todd Petty, vice president of operations. "The project really put a new spin on the term design-build. Morphosis conceived and drew up what they wanted and how the flow of each panel was to be constructed. They were extremely creative in their design about where the outer and inner profiles would start and stop, how deep they would be, how tall the profile would be and the distance the profile would cover as it ran horizontally. BIM was most helpful in locating the panels on the structure, essentially determining where that structure needed to be for the panels to connect to it. Without BIM, this would have been an arduous task."

The panels were designed with a $6^1/_2$ in. nominal thickness, with 2 in. recesses and 8 in. projections. To avoid the appearance of repetition in the panels containing projections (even though there is a considerable amount), a modular concept was developed. Modules were assembled in multiple configurations to eliminate any similar panels being placed close to each other. "Casting polyurethane modules provided a faster means of mold fabrication," Petty notes. "We spent an exorbitant amount on urethane."

'Casting polyurethane modules provided a faster means of mold fabrication.'

Each panel-fabrication ticket noted where projections and indentations were placed in the mold. The tickets were drawn depicting the back of the panels as well. The tickets show panel dimensions, color, detailing, area, connection hardware, stripping and lifting inserts, reinforcing, erection diagrams, and areas for each specific finish. "Most of the tickets are three to four pages long due to the massive amount of information that needed to be conveyed from the engineering and drafting team to the production floor," says Petty.

The crews quickly gained experience with the mechanics of the intricate pours, he adds. "Once they understood how the shapes went together and how the intended flow traversed horizontally from point to point, it got easier."

The most challenging part was not pouring around the formliners, but handling the molds' perimeters, he notes. "The adjacent panels had to match each one around it. Each projection had to meet up exactly wherever it stopped, either on the ends or top or bottom, with all of the panels around it." Each projection was outlined with a $^1/_8$ in. by $^1/_8$ in. rounded, protruding outline that served as a perimeter line around the edge. These had to track correctly in each panel as well as panel-to-panel.

More than 250 forms were built to cast the 660 panels. The molds took in-house carpentry craftsmen up to two weeks to construct, and some were used only once. "There was some repetition in casting the tower portions, but very few forms built for the plinth or atrium were used more than four times," Petty says.

Morphosis designers created the wave patterns and applied them to the modular panels. Gate then had to extract each individual projection or indentation piece from the panel drawing and create a form drawing. They varied in size from 4 in. by 42 in. to 24 in. by 42 in. The mold carpenters used the drawings to create their forms, after which a crew poured polyurethane into the mold to create the negative design of the required shape.

The more heavily profiled panels at the bottom of the cube required 130 individual projections installed in the wooden forms in specific arrangements to achieve the proper look. In all, more than 350 individual module forms were constructed and 1650 pieces were built for the forms.

Creating Curved Panels

Another key challenge focused on the curved panels required to create the undulating flow of the façade across the plinth and atrium. "Radiused panels don't generally create a problem," Petty says. "The challenge arose with the small radiuses required on the atrium panels and even more so on the precast concrete skylights."

The tight curves required the precast to backpan, or form up the back of the panel as well so the concrete stays inside the form as it is cast. The backpan had to be carefully constructed to ensure the vibration pressures from the self-compacting concrete didn't cause the backpan to come loose. Fabricators also had to give these pieces a smooth-trowel A-1 architectural finish because the designers wanted to leave the panel backs exposed and paint them.

The plinth's curved panels posed challenges both because there were so many and because they featured so many different radiuses. Complicating matters was that the panels did not only follow a curve along their face left to right, but also included a flat area on one end or both. To ensure close tolerances, the precaster created master molds so several panels could be cast from the same mold at different widths, accommodating the curves where needed.

"This allowed us to cut down on the number of molds that would be used for just one cast, creating an economical solution," Petty says. "Any time you have the deck space to build a larger mold and simply move top, bottom, and side forms around, you save time and material. It also works better in the field. It ensures that the area will fit up properly and look appropriate."

The plinth panels were curved, with most of them canted, radiused, half canted or half radiused. Photos: Gate Precast Co.

Corners also created challenges. "We try to cast all corner panels, which typically are smaller, sequentially after the main panel, because it offers the best way to ensure the pieces match and can be braced properly," Petty explains. "On this project, most corners had a continued profile to them from the adjacent panel, so we cast the corners prior to the larger panel so it could be cast in the exact location of the mold. Engineering had to ensure that the panel was drawn exactly to ensure the projections joined perfectly, and then production had to ensure it was cast in the exact

Gate Precast Awarded Inaugural Sidney Freedman Craftsmanship Award for Work on the Perot Museum

Gate Precast was awarded the 2012 Sidney Freedman Craftsmanship Award for producing the custom textured cladding panels on the Perot Museum of Nature and Science. The new award recognizes PCI-certified plants for excellence in manufacturing and craftsmanship of architectural precast and glass fiber-reinforced concrete (GFRC) structures and individual components. PRETECSA was named a co-winner of the award for producing the cladding panels for the Latter Day Saints Quetzaltenango Temple in Quetzaltenango, Guatemala.

PCI's Architectural Precast Concrete Services and Manual Committee created the new awards program and serves as its judging panel. Judging is based on precasters' success in overcoming obstacles to production, solutions to formwork or finishing challenges, and the quality of individual architectural precast/prestressed concrete or GFRC units.

Sidney Freedman, the award's namesake, is the staff liaison to the Architectural Precast Concrete Services and Manual Committee and also PCI's director of architectural systems and director of operations and safety. Freedman received his bachelor's degree in civil engineering from Northeastern University in Boston and his M.B.A. from Loyola University in Chicago. Freedman joined PCI in 1973 after working for the Portland Cement Association. His many contributions to the precast concrete industry include serving in editorial capacities for the *Manual for Quality Control for Plants and Production of Architectural Precast Concrete* and the second and third editions of *Architectural Precast Concrete*.

Entries are now being accepted for the second annual Sidney Freedman Craftsmanship Award. For more information on this program, visit www.pci.org or contact Sid Freedman at sfreedman@pci.org.

location in the main mold."

Achieving the proper coloring was not a problem, he notes. "For most projects, color has to be consistent from day to day and from panel to panel. This was less of a factor on this project because the design architect preferred a mottled, 'as cast' texture." Moisture meters placed in the aggregate bins and in the bottom of the mixer coupled with metered water going into the mixer ensured the mix colors stayed within the agreed-upon limits.

"Tree Column" Bracing

Attaching these panels to the museum's steel frame required an innovative connection grid that engineers designated "tree columns." They consisted of long steel-tube "trunks" with frames branching off. "It was simple in concept and was aided by the panels being the same standardized sizes," Koke explains. The framing columns helped tie the floors together and minimized deflection from floor to floor.

The panels were erected horizontally to allow for horizontal slot windows used in selected locations. "It wasn't possible in many locations to have a traditional vertical panel hung from the floor and extend from floor to floor," he says.

Indeed, the floors were as much as 35 ft high and cantilevered 9 ft from the column lines. "The tree columns helped with the differential movement in joints of the panels. They needed substantial bracing to handle the loads floor to floor. But since all the deflection was the same due to the standardization of sizes, the precaster could create $^1/_2$-in. joints and be assured that they would be consistent."

The atrium had a more irregular shape, climbing vertically from ground level at a 45-degree angle into the building's body. A transition panel at level three features a radius, after which the top half moves in the opposite direction. The field of each panel

The precaster had to cast a variety of curved panels with many different radiuses, many of them tight. These curves required the back of the panels to be formed up so the concrete stayed inside the form at the panel was cast. Photo: Gate Precast Co.

in this area was divided into modules approximately 3 ft. 7 in. wide, and ranging in height from 4 in. to 24 in.

These required more adjustments to the tree columns, Koke notes. "Each panel had a custom radius, so we had to work closely with Gate to ensure we had the specific requirements for each to brace it. In most cases, regardless of the radius, the panel backs were straight so connecting them was easier." The atrium contains 100 complex architectural panels averaging 10 ft by 10 ft in size.

The plinth had the most curved panels, with most of them either canted, radiused, half canted, or half radiused. Some curved and canted at the same time. That created the appearance of a twisted panel, but the top and bottom held to the horizontal, providing connection points. The plinth contains 220 panels ranging in size from 2 ft by 6 ft to 8 ft by 28 ft. The panels hanging from the top of the plinth created an overturning moment that had to be

The panels were connected to the structure's steel frame using a connection grid, designated "tree columns," featuring long steel-tube "trunks" with frames branching off. Panels were erected horizontally to allow for horizontal slot windows in selected locations. Many locations didn't allow for traditional vertical panels to be hung and extend floor to floor. Photos: Datum Engineers

The panels were erected in a careful sequence to avoid overloading one side of the structure. Work began at the base and went around the perimeter, connecting each panel to the next and to the frame. Photo: Gate Precast Co.

Erection of the panels required meticulous care, often requiring chain falls and cone-alongs to set them. Photos: Gate Precast Co.

resisted through the roof diaphragm and concrete shear walls.

The tower features the distinctive horizontal striations on all four elevations. It contains 350 panels, totaling more than 70,000 square ft, with typical panels averaging 8 ft tall and 28 ft wide with alternating 20-degree sloped ends.

Erection Required Meticulous Care

The erection process moved "painfully slowly," says Mayne, due to the meticulous care required to load the building properly and match the striations from panel to panel.

"We couldn't overload one side of the structure, so we started at the bottom and went around the perimeter, connecting the panels to each other and the frame," explains Koke. "We wanted to load the building all at once rather than do one side, as there was too much eccentricity to the project." Erecting the panels in this progression also minimized potential damage to the panels from sliding a panel into place between two already set.

The precaster had to provide a "face of panel" dimension to each corner of each panel so surveyors could locate exactly where the panel face should be in its correct erected position.

The most challenging aspect was erecting the under-structure panels where the building cantilevered out at a 12-degree angle. The tower crane lowered the panels into the building, where erection crews took the panel away from the crane with up to seven chain falls and trolleys that hung from previously installed stair-stringers or the superstructure. From there, the panels were raised to the proper elevation and then pulled into place by chain falls and come-alongs hooked to the panels' four corners.

An average of five to eight panels were erected per day on the tower, while two panels were erected per day on the plinth and only one was erected per day in the atrium. Three erection crews, comprising 20 ironworkers, were used. On a typical project with less complexity, each crew could have erected eight to 12 panels per day, Petty notes.

The result of this meticulous work has been great acclaim for the building, a variety of awards (including a PCI Design Award), and a striking aesthetic statement. "The Museum will cultivate a memorable experience that will persist in the minds of its visitors," says Mayne. "It will ultimately broaden individuals' and society's understanding of nature and science."

The precast concrete façade enhanced that achievement, adds Petty. "The Museum is unusual and eye-catching. The use of precast concrete has given the design community greater leverage to develop intricate designs, knowing they can be easily produced. It takes a design team that knows what they want, an owner who can pay for it, and a precaster that is willing to get outside of the box and try something new."

It also makes it clear how aesthetically versatile and innovative precast concrete can be, says Dean Gwin, president and COO of Gate Precast. "The Perot Museum has elevated precast concrete design to a new level. It has led to many new and exciting precast projects for all eight of our plants." ■

For more information on these or other projects, visit www.pci.org/ascent.