one location within the atrium, notes Indrio. "The form is not predictable," she says. "It's not served up to you—it's something you must discover."

During the complicated phasing of construction work that involved the application of both sprayed and cast-in-place concrete, a series of temporary columns supported the growing cocoon structure. Although heavy-duty steel columns had first been considered, the design team worked with the contractor—HBG Construction, Ltd., of London—to erect concrete columns that were removed last year once the sprayed concrete shell had reached its design strength. That approach reduced the cost of the project by nearly £400,000 (U.S.$570,000), says Newman-Sanders.

The geometry of the shell was created using various software modeling programs, including Rhinoceros, developed by Seattle-based Robert McNeel & Associates; SOFiSTiK, developed by SOFiSTiK AG, of Oberschleissheim, Germany; and an in-house Arup product called GSA. Because the shape was constantly changing, no construction drawings of the geometry were created, notes Newman-Sanders. Instead, every concrete element of the structure was computer modeled, and the digital information was then given directly to the contractor.

A stucco plaster finish covers the exterior surface of the cocoon, providing a silken appearance that heightens the cocoon effect, notes Indrio. The imagery is further enhanced by the crisscrossing series of aluminum strips that wrap around the cocoon and serve as expansion joints for the plaster finish; the sprayed concrete shell itself does not need expansion joints because it was designed to accommodate any potential thermal stresses, adds Newman-Sanders.

Visitors to the Darwin Centre Phase II exhibits will take a glass elevator at the southern end of the atrium to the seventh floor of the cocoon and from there will follow a continuous ramp down through the public upper levels of the structure. The ramp, which is typically a 350 mm thick reinforced-concrete slab, cantilevers approximately 2 m off the concrete shell and ultimately brings visitors back to the southern end of the cocoon's fifth floor, where a small bridge reconnects to the elevator.

Eight-story-tall steel columns typically 400 by 200 mm in cross section and spaced at 3.3 m intervals help to form the structure of the glazed atrium. The columns are topped by a structural gutter that provides the horizontal restraint as well as waterproofing for the roofing system, which consists of ethylene tetrafluoroethylene (ETFE) inflated pillows that are approximately 3 m wide. These translucent pillows stretch across the 14 m span of the atrium and are supported on curving steel beams that in turn are connected to the columns.

—ROBERT L. REID

HISTORIC PRESERVATION

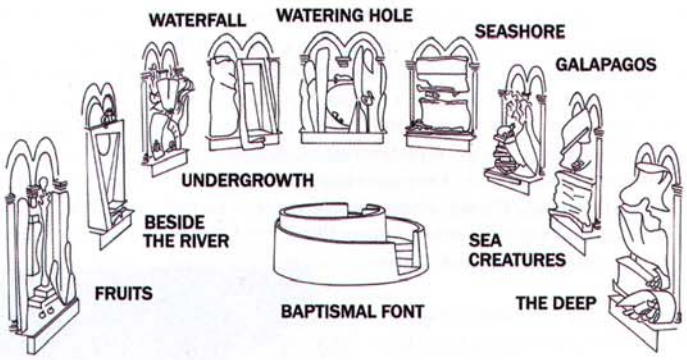
Choir in War-Damaged French Church Restored As 'Chapel of Light'

THE CHOIR of a medieval church in northern France that was damaged during World War II and remained closed for more than 60 years has now been restored and its floor structurally reinforced to support the weight of 13 massive sculptures and a new baptismal font, all designed by the British artist Anthony Caro. The Église de Saint-Jean-Baptiste, a Romanesque abbey church in the small town of Bourbourg, approximately 19 km east of Calais, is a mostly stone structure that largely dates to the 13th century, although some portions are older. Designated a French national heritage site in 1920, the Gothic choir section was heavily damaged in 1940 when a military aircraft crashed into the church and set the roof on fire. Later, parts of the building collapsed and the German army removed the stone floor tiles.

Although other portions of the church were restored after the war, the more heavily damaged choir was simply bricked off from the nave and abandoned. The choir could not even boast a roof until a project that ran from 1965 to 1975 constructed a covering to keep out the rain and installed wooden frames to support the walls, explains Pierre Bernard, the founder of Atelier Pierre Bernard Architecte, in a written response to questions from *Civil Engineering*. An architecture firm based in Amiens, France, Atelier Pierre Bernard Architecte worked on the choir project with Caro.

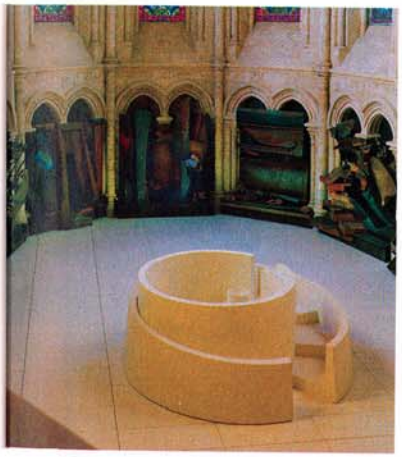
In 1995 an archaeological survey was undertaken as the first step toward replacing the choir's missing floor. Caro visited the site four years later at the request of the French Ministère de la culture et de la communication, which was interested in a public art installation. Although the project faced additional delays, the brick wall that separated the choir from the rest of the church was demolished in 2003, and work eventually began on a new concrete floor.

Commissioned by the Ministère de la culture et de la communication, Caro created a series of works of art for the church, including nine steel, wood, and terra-cotta sculptures based on the theme of the creation of the world, that have been installed in the existing large niches along the choir walls. He also created a spiraling white concrete baptismal font close to the center of the space that is 3.3 m in diameter and rises 1.25 m from the choir's new floor. Four other sculptures were designed for the choir, including two oak towers 5.2 and 5.3 m tall that engage a series of stone columns located west of the font. The remaining two sculptures are located between the towers and the



A military aircraft crashed into the church in 1940 and set the roof on fire, *left*. Later, parts of the building collapsed and the German army removed the stone floor tiles. Other portions of the church were restored after the war, but the more heavily damaged choir was simply bricked off from the nave and abandoned. The restored choir will now support the weight of 13 massive sculptures and a new baptismal font, all designed by the British artist Anthony Caro.

BARFORD SCULPTURES, LTD., ILLUSTRATIONS ABOVE; JOHN RIDDY, OPPOSITE



Anthony Caro created a spiraling white concrete baptismal font 3.3 m in diameter that rises 1.25 m from the choir's new floor.

font. Caro also designed a new altar for the nave and a large sculpture that was installed outside the church on a reinforced-concrete substructure.

The restored choir, called Le Choeur de Lumière (Chapel of Light) in part because its eastward orientation allows the morning light to stream through a new set of stained glass windows, opened in late 2008.

The new concrete floor presented a particular challenge for several reasons, Bernard explains. Although 400 mm thick, it needed to be strengthened with rebar so that it could support the weight of the new artwork and the font, sections of which weighed more than 1 metric ton. Complicating matters, the new floor could not be supported by certain parts of the existing substructure, including particular walls and the tombs of priests, that predated the surrounding Gothic structure. Instead, small niches were created in the lateral brick walls of the choir to accommodate the addition of rebar and a series of steel beams arranged in a north–south direction. The floor steelwork was supported on the lateral niches and the existing substructure of stone columns, Bernard says.

Additional steel beams were installed to support the new steps that bridge the 450 mm difference in elevation between the choir and the rest of the church.

The new floor features an electric heating system that was installed on top of a 60 mm thick incompressible isolation layer of polystyrene. The floor is heated everywhere except directly beneath the font, Bernard notes. A layer of white slabs of unreinforced concrete 40 mm thick designed to match the material, texture, and color of the font was then installed atop the new floor. Each floor slab measures approximately 1,240 by 550 mm.

The firms involved in the project include Cabinet Études Structures et Amènagements (CESEA), the engineering consultant, of Coudekerque-Branche, France; Sotrasen, the concrete consultant, of Cappellebrouck, France; Barford Sculptures Ltd., of London, which assisted with models; and Violier Electrical, of Bourbourg, which was responsible for the heated floor and the lighting for the artwork.

—ROBERT L. REID