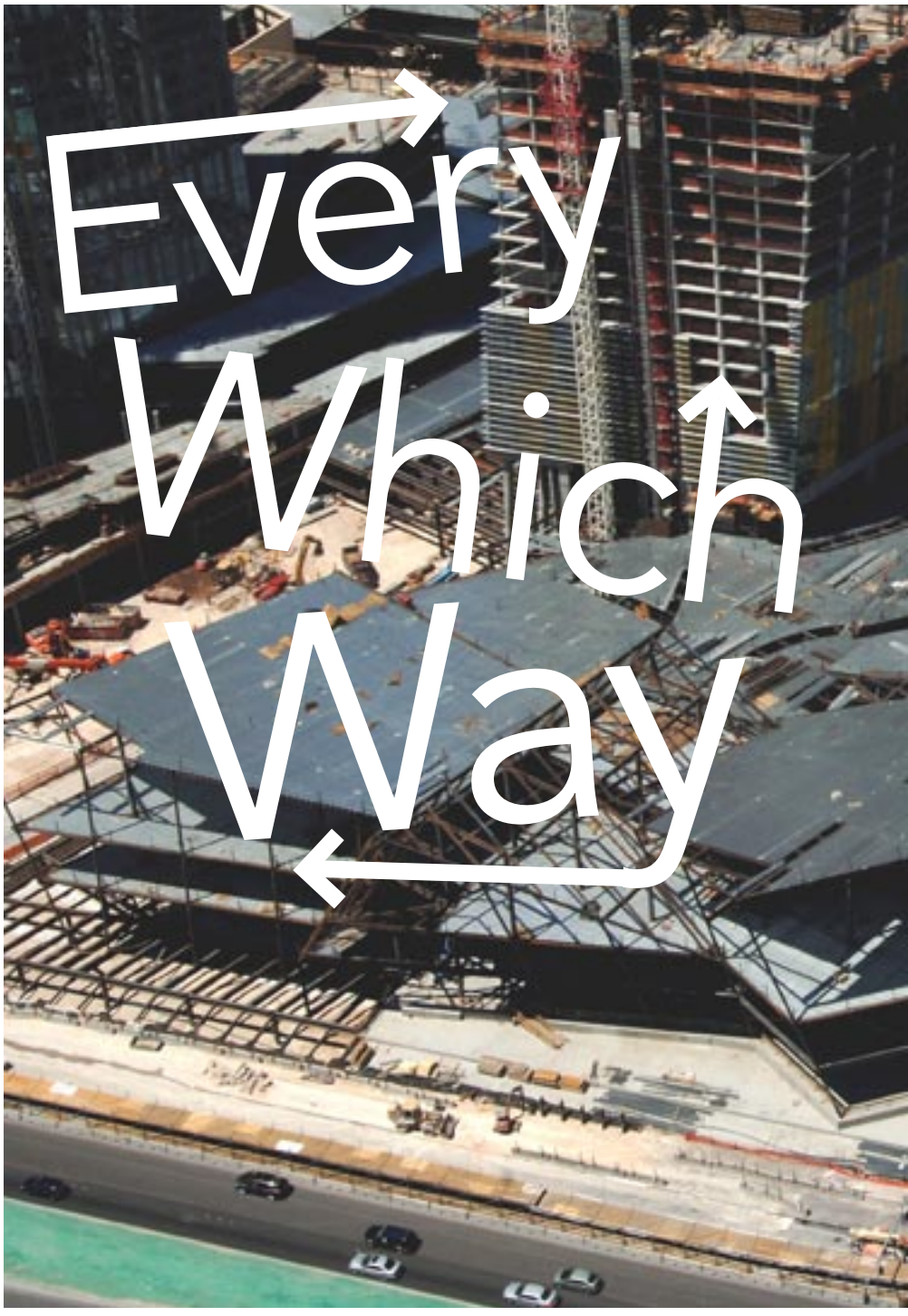
Every Which Way

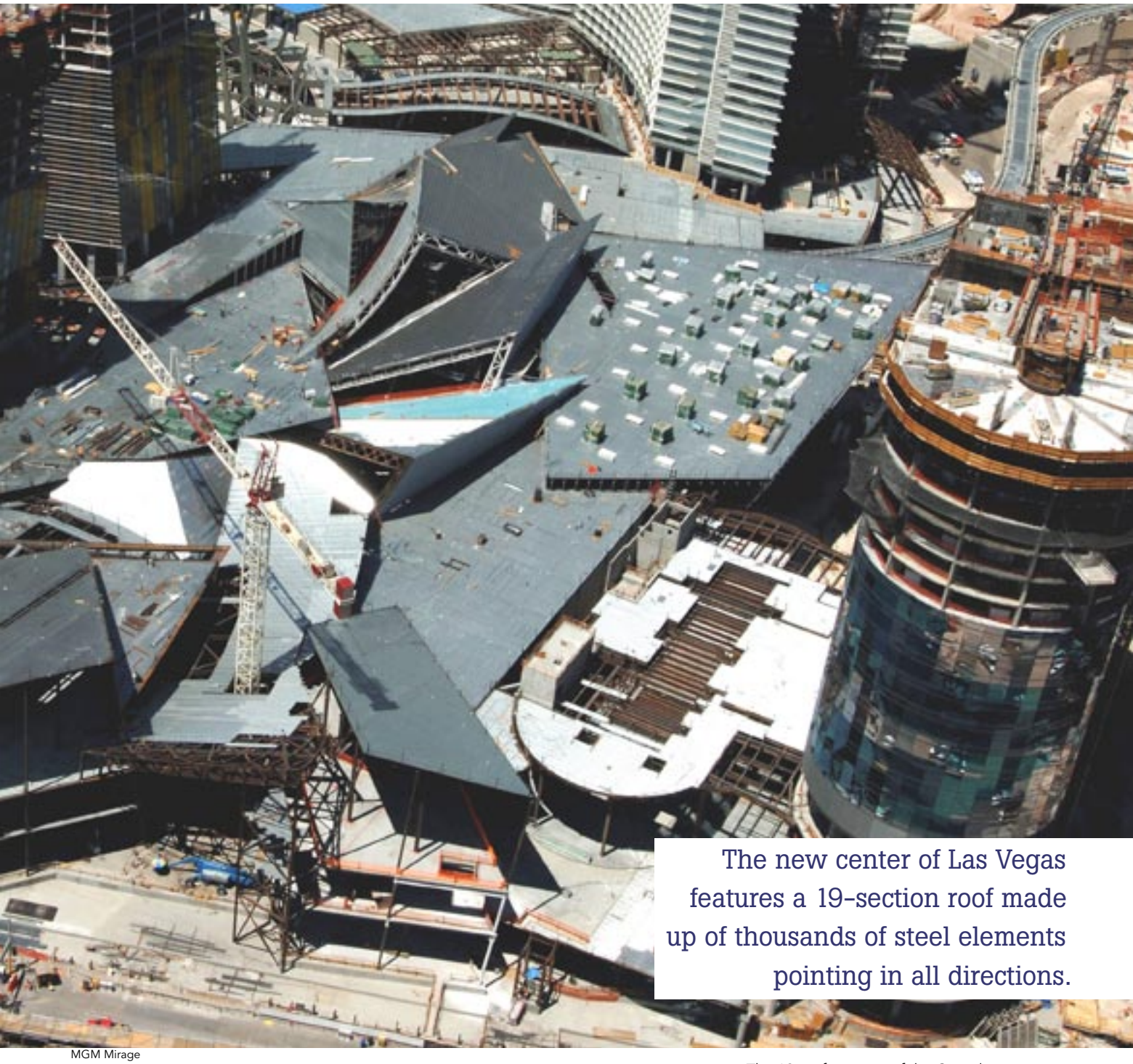


BY GARY PROVENCHER AND DAVE FARRELL

WITH 16,455 PIECES OF STEEL jutting out in every direction, the Crystals at CityCenter in Las Vegas looked more like an engineering mystery than an engineering feat during erection. In fact, the project appeared so jumbled while the steel was being placed that a common question was "Did the building collapse?"

CityCenter is a $9 billion-plus mixed-use development currently under construction on 76 acres along the Las Vegas Strip, and the exceedingly angular Crystals portion is the centerpiece of the complex's retail and entertainment district. A joint venture between MGM MIRAGE and Dubai World, CityCenter is currently the largest privately financed project in the United States; the entire project is scheduled for completion in late 2009.

Designed by Studio Daniel Libeskind, one of eight renowned architecture firms working on CityCenter, the Crystals includes a below-grade garage, two levels of retail, and a one-of-a-kind roof. The garage and levels one and two of the 665,000-sq.-ft facility are typical grid steel-framed construction. The roof is what elevates the project into a class of its own. It is made up of thousands of leaning columns, curving trusses, and straight members that do not line up with any other piece of steel. The roof actually consists of 19 separate structures that are intermingled and overlap one another, including 13 planar roofs and six dramatically sloped arcade roofs; the arcade roofs were the most complex element of the project—and the project was the most complex that Schuff Steel Company has built in its 32-year history.



The new center of Las Vegas features a 19-section roof made up of thousands of steel elements pointing in all directions.

MGM Mirage

The 19 roof sections of the Crystals contain more than 16,000 pieces of steel.

Mind-Bending and Unfathomable

Planning and building the Crystals can be compared to completing a complicated 3D jigsaw puzzle; every piece had to fit perfectly. The design-assist project took 12 months of working through mind-bending mathematical equations and strategic planning to devise an accurate 3D model.

Schuff's project engineer spent four weeks in Australia working with Halcrow Yolles, the structural engineer, and the Australian-based steel detailer, BDS. While in Australia, daily conference calls with the erector, engineer, and detailer were made to Adamson-Associates, the architect of record for the Crystals, and Perini Building Company, the general contractor on CityCenter, to review the progress. WebEX (internet video conferences) were also established to share models with the appropriate parties simultaneously around the world, from Australia to North America.

In total, 16,455 steel pieces were entered into Tekla Structures software. The Crystals roof has no right angles; it does not follow a pattern or have any repetitive placements of steel. Similarly, the connections of the lower floors were "standard" but the roof system required distinctive solutions at almost all end points. More than 500 unique sketches were generated for these roof connections. Each of these connections then had to be manually modeled into Tekla Structures, as no single macro could accommodate these variations.

The modus operandi was to plan ahead and then work backward. The design-assist team first determined where each of

the 80 major trusses went, and from there worked backward to resolve what each truss would support and what would support each truss. With thousands of massive beams, 160 trusses, and 69 pipe columns cutting through one another and leaning at extreme angles—as much as 40°—every piece of steel required calculations to test for load capacity, fabrication, and constructability.

3D modeling was imperative on this project. Again, using Tekla Structures, the design-assist team had the ability to interface with other programs such as Revit and AutoCAD to create BIM models for all of the trades and consultants on the project. Without these advanced software programs, the project would not have been possible; the geometry was unfathomably complex. Additionally, it would have been too cost-prohibitive to manually draw the structure. Using a 3D system, there were practically zero detailing-related errors. In total, the project involved more than 15,000 shop drawings.

Fabrication started in January 2006; the project's accelerated deadline required the use of 14 fabrication shops across the country. Fabrication was completed in March of 2008 for the majority of the project, and the majority of steel erection was completed that July. Over the two-year period, 1,433 truckloads delivered 13,900 tons of structural steel to the project site.

Roof after Roof after Roof…

The 3D model was used to divide the structure into 19 floor sequences—again, 13 planar roof sequences and six arcade roof sequences. Because of all of the construction at CityCenter—including hotel and condominium towers, a convention center, parking garages, a central plant, and infrastructure on the 76-acre site on one of the busiest streets in the world—the site was extremely active and congested.

Materials could not be stored on-site and construction schedules had to be precisely coordinated with the general contractor and executive architect for CityCenter, Gensler, to access the project's tower cranes and street right-of-way and to assure safety egress.

CityCenter's master plan dictated that construction on the Crystals would start at the west side of the project and work toward the Strip. The plan was to start the erection process at the highest point of the roof. However, to guarantee stability of all the leaning trusses and columns, ironworkers had to strategically "jump" around.

All of the six arcade roofs are designed at different angles to connect with the 13 planar roofs. The six arcade roofs converge at the apex of the facility, with the planar roofs on the side. When the entire project is complete, the arcade roofs will be covered in glass to create a massive skylight to illuminate the building's interior, hence the moniker. Stainless steel will cover the planar roofs.

With 160 roof trusses and 69 pipe columns plowing through the structure, erection was planned several sequences ahead of truss installation. Similar to the preconstruction phase, every piece of steel had to be installed one piece at a time. On average, about 40 pieces of steel were hung per day. In cases where angles were particularly intricate or pieces were exceptionally large, only four pieces of steel were hung per day.

More than 90% of the steel connections are bolted, and a total of 52,766 connections were made; some trusses and columns have up to 15 connections. When bolting was not an option, crews performed on-site welding. The banana truss—measuring 6 ft deep and almost 200 ft long—which slopes to the apex of the facility, was among the most critical welding tasks on the entire project. The banana truss was hung with two cranes, and crews welded, in the air, the truss in three different places.

Bryant Surveys, Inc., a third-party surveying firm, surveyed specific points on each truss as they were being set. The firm compared actual vs. theoretical locations to ensure that no point was more than ¼ in. off the theoretical point.

The Las Vegas Automated People Mover (APM) added another dimension of difficulty and uniqueness to the project. The APM, a monorail that stops at major casinos and destinations throughout Las Vegas, runs directly through a sizable section of the Crystals. Schuff worked closely with the APM's designer, Doppelmayr Cable Car, to coordinate the two projects. The APM sits on top of an array of massive concrete columns, five of which are within the footprint of the Crystals and were already in place when erection started. Throughout the entire project, ironworkers had to maneuver around the columns inside the project footprint.

Veer Towers, two high-rise concrete towers that lean in opposite directions, are a separate project at CityCenter but are connected to the Crystals. In the event of a seismic episode, Teflon slide bearing pads, provided by ConServ Inc., support cast-in-place steel embeds measuring 2 in. thick and as much as 5 ft high and attach Veer Towers to the Crystals so that each project can float independently from one another. It is estimated that it will take at least one year for both projects to settle. Veer Towers is expected to settle 3 in. and the Crystals 1 in., at which time the slide bearings will be readjusted. MSC

Gary Provencher is a project engineer and Dave Farrell is a project manager, both with Schuff Steel Company.

Executive Architect for CityCenter
Gensler, Las Vegas

Design Architect for the Crystals
Studio Daniel Libeskind, New York

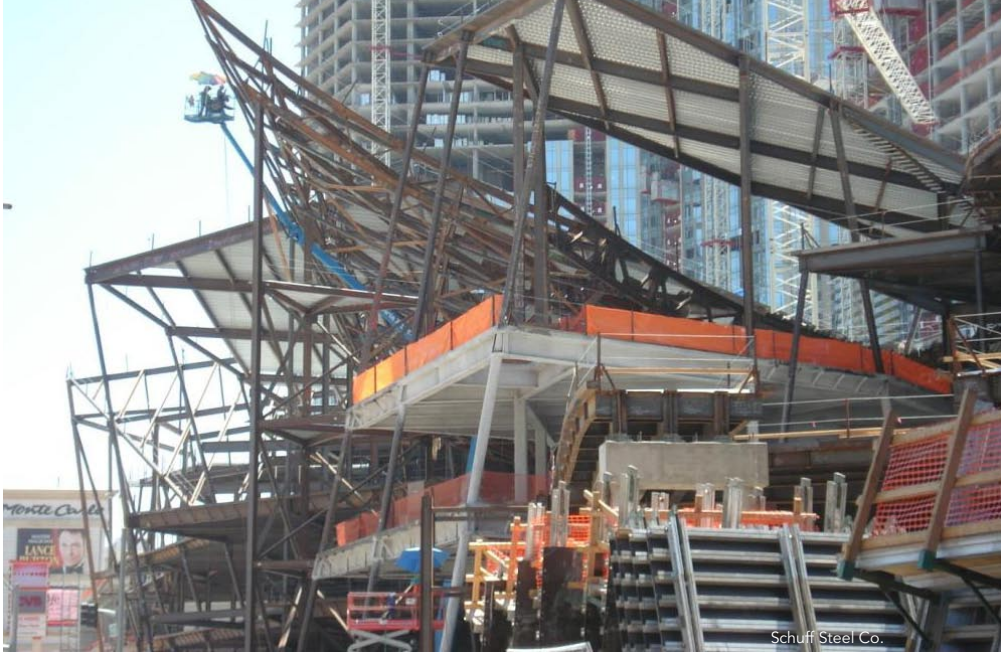
Architect of Record for the Crystals
Adamson-Associates, Toronto, Ontario, Canada

Structural Engineer
Halcrow Yolles, Las Vegas

Steel Fabricator and Erector
Schuff Steel Company, Phoenix (AISC Member)

Steel Detailer
BDS Steel Detailers, Tempe, Ariz./South Brisbane, Australia (AISC Member)

General Contractor for CityCenter
Perini Building Company, Las Vegas



The weights of the various trusses range from 5 to 90 tons.

Of Crystals and Steel

The Crystals, by the numbers:

- 16,455 pieces of steel
- 13,900 tons of structural steel
- 52,766 connections
- 160 trusses, including 80 major trusses
- Weights of trusses vary from 5 tons to 90 tons
- Lengths of trusses vary from 10 ft to 180 ft
- 69 pipe columns
- Length of the pipe columns varies from 20 ft to 84 ft (in three separate shafts)
- More than 90% of the connections are bolted
- Project entailed more than 15,000 shop drawings
- There are no right angles or repetition on any of the 13 planar and six arcade roofs
- Entire project built with recycled steel
- Steel was delivered by 1,433 truckloads
- 150 ironworkers working a total of 250,000 man-hours