

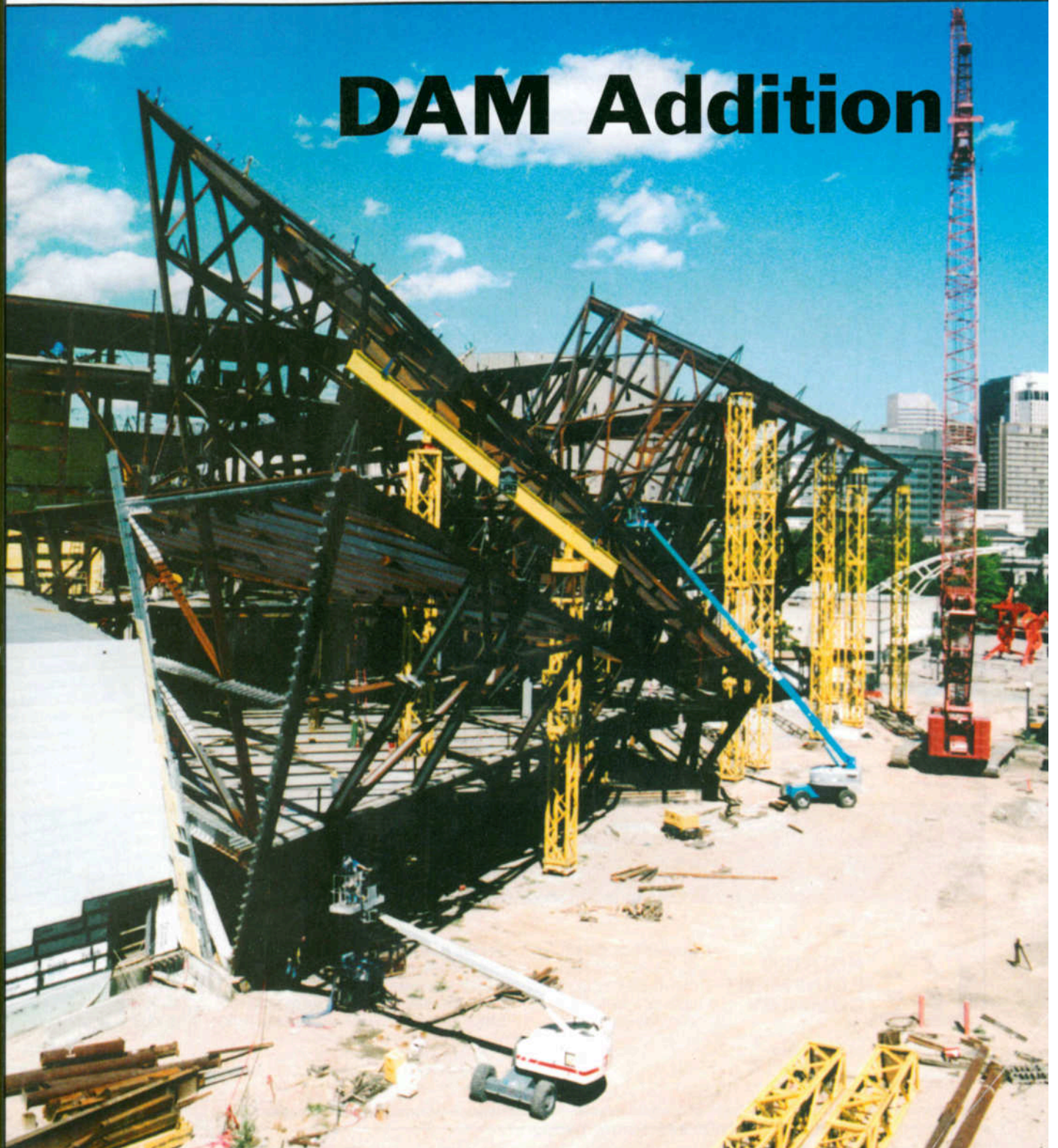
ROCKY MOUNTAIN
Construction

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DAM Addition



DAM: What An Addition!

Intricate geometry, countless angles make steel erection a complex process on this showpiece project; state-of-the software and teamwork make it possible

By Carol Carder

The \$62-million Denver Art Museum addition, the Frederic C. Hamilton Building, is one-of-a-kind, the first structure designed by renowned German architect Daniel Libeskind to be completed in the United States. This geometric explosion of steel and titanium will be as modern on the outside as the modern and contemporary art showcased on the inside. The building has 146,000 square feet of floor space and 175,000 square feet ceiling space as it cantilevers outward and upward from its base. Like a prow of a ship, a wing reaches a height of 100 feet over 13th Avenue, visually connecting to the existing Gio Ponti-designed art museum. As Libeskind says on his website, this icon will form spaces that connect local Denver tradition to the 21st century.

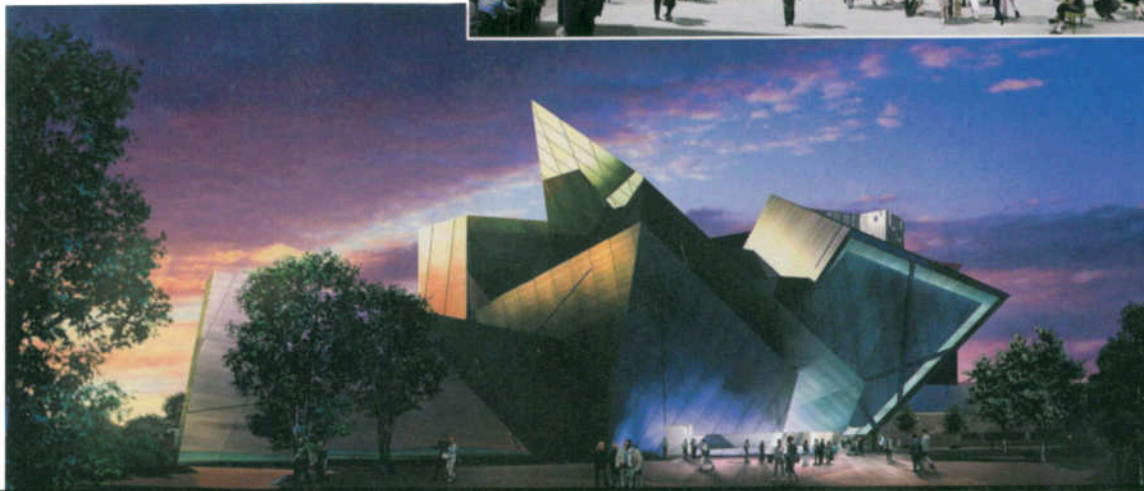
Instead of traditional vertical walls, the building consists of seven radically sloping planes that wrap in continuous lines around the building. In an interview with the Rocky Mountain News in October, Libeskind compared the angles of the structure with the dramatic

formation of the Rocky Mountains and the breathtaking horizon. The steel titanium clad structure required 50,000 bolts and 8,000 pounds of welding material to connect its 2,900 custom joints.

One asks, "How are joint venture architects Daniel Libeskind/Davis Partnership, contractor M.A. Mortenson and its subcontractors successfully erecting such a complex structure?"

"With great teamwork and trust," replies Dave Sandlin, Mortenson project manager. "For the designers to share models, let us manipulate them, then give them back is a leap of faith you can only accomplish in a relational environment."

Bryan Pope, project manager at Zimmerman Metals Inc. of Denver, the steel fabricator, and Joel Hegge, project manager for LPR Construction Co. of



Renderings of the Denver Art Museum addition show what a dramatically unconventional structure it will be, with shard-like projections clad in titanium and glass. Renderings by Miller Hare

Loveland, the steel erector, echo the success of teamwork. "With the extensive team planning, we were all on the same page," Hegge explains. Pope stresses, "The cooperation of everyone from the engineer of record, to the architects, our detailer, LPR, and Mortenson was instrumental in getting the job done on schedule."

Designing with 3-D and 4-D tools

The 3-D modeling software and 4-D scheduling tools are enabling effective communication of the design and the construction sequencing from the engineers to the general contractor to surveyors to tradesmen. Studio Daniel Libeskind shared the geometric design on Form Z software with Mortenson. Arup of Los Angeles, the engineer of record, converted the Form Z geometric design into a virtual software model on X-Steel software. The virtual model specifies the size of the steel members, the dimensions of the foundation walls and the slab-on-grade, the size and locations of the 114 concrete caissons supporting the foundation, and so on. Then Structural

Consultants Inc. (SCI) of Denver designed the connections for Zimmerman Metals, and Dowco Consultants Ltd. of Burnaby, B.C., detailed these connections on X-Steel. Some of the connections, such as four steel members coming together at different angles, challenged the designers.

In the weekly steel team planning meetings attended by representatives from Zimmerman, LPR and Mortenson, the X-Steel virtual model was projected on a large screen and turned to review all sides of the bolted connections and welds. "We could see how things were developing, anticipate erection problems and figure out ways to avoid problems while putting this together," Hegge explains.

Mortenson took the 3-D model to the next level when its designers integrated the heating, ventilation and air conditioning, fire protection, and electrical systems into the virtual model design. Every system is built to the same XYZ coordinates of a known grid so it fits together. The software prints out any conflicts between systems so they can be addressed. Mortenson projected the virtual model on a large screen at subcontractor planning meetings so collisions between the systems could be worked out as a team, deciding what pipe, for instance, has to bend or move. The subcontractor moving a component then worked out the changes on the virtual

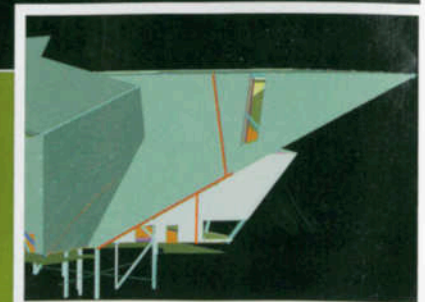
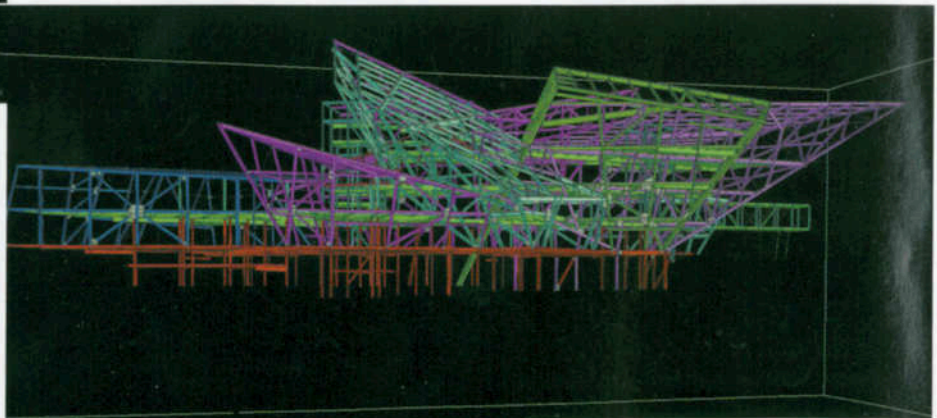
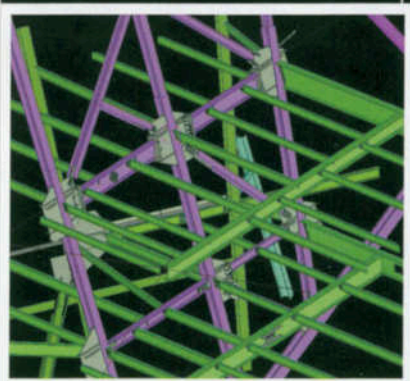
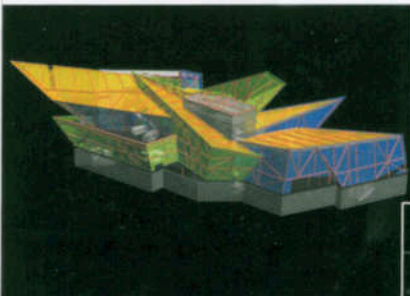
model for the next team meeting. US Engineering Co. of Denver is mechanical contractor; Dynalectric Co. of Denver, electrical; and L. Nothhaft & Son Inc. of Denver, fire protection.

The 4-D scheduling is taking the virtual model and adding a fourth element, the time factor to show sequencing of construction activity. Instead of sending reams of paper for scheduling, Mortenson e-mails the 4-D schedule to subcontractors as an AVI movie clip running on Windows Media. The software gives a graphic representation of the schedule in various colors to represent the trades. Activity can be sorted by craft or type of work, by day, by week, by month, or by one section of the building, such as the foundation.

"We manage our schedule as a critical path schedule and have about 4,000 activities," Sandlin explains. "This 3-D and 4-D software fosters interdependence of all the team members while it allows us to take all the bugs out and eliminate change orders and the need to rework sections before construction activity ever begins."

Steel erection

The radically sloping wall planes put a heavy load on the steel frame. LPR anticipated the loads during construction and chose the shoring support and exact locations for the shoring towers to support steel members during



Top left: Architect Daniel Libeskind produced the structure's geometric design on Form Z software.

Above left: Details of bolts and welded connections as depicted by X-Steel.

Above right: Sophisticated design software creates virtual images of all components of the complex structure. Here, X-Steel provides an elevation view of the structural steel from the east side.

Right: X-Steel exterior view with rain gutters added to the virtual model.

construction. These tall yellow lattice steel ladders supported beams and module units weighing up to 35,000 pounds until they could be tied into the building structure. LPR's structural engineer Curtis Mayes and engineering assistant Justin Mitchell devoted a year and a half to planning before LPR ever started hanging iron. Mayes developed the method of transferring the XYZ coordinates for the total station targets of the surveying system from the virtual model to the steel columns and made the alignment and the structure work, according to Hegge. Mitchell developed the lifting and rigging patterns for the different assemblies. Mortenson and LPR each kept three surveyors working on the project. LPR used four computers on-site, running the X-Steel model for both surveyors and its erectors to reference.

Rather than erect all pieces in the air, LPR built approximately 20 percent of the steel framework on the ground as 50 modules, then lifted them into place with the Manitowoc 888. Modules varied

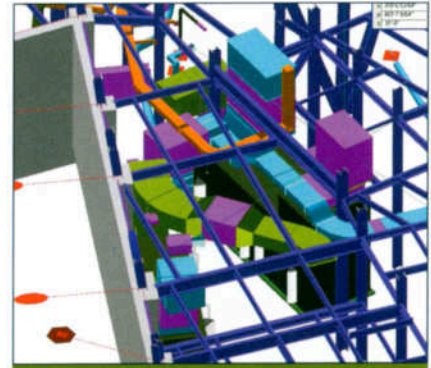
in number of members from two or three up to 25 to 30 members.

As well as installing 50,000 bolts for joints, LPR crews used 8,000 pounds of welding rod and wire. One of these was the largest field weld for full penetration into a base plate Hegge had ever seen. The weld required 200 pounds of welding material for a joint of a W14x400-pound beam.

LPR began hanging iron in October 2003 and topped out Sept. 15, 2004, two months ahead of its projected completion date. The 22-man crew averaged 15 pieces an eight-hour day on a five-day week with practically no overtime.

"This project stretched the flexibility of our systems and the way we typically do things," says Hegge. "Our workers did a great job, and we had tremendous support from Paul Devereux and the other Mortenson staff who came from the Disney concert hall project in L.A."

"For the complexity of the project, it went together very well with minimal field problems," Pope says. The connection plates were shop-welded by Zimmerman to very tight tolerances to ensure proper fit-up and alignment during the erection process. All the structural



This image from Navisworks adds mechanical systems to the structural components.

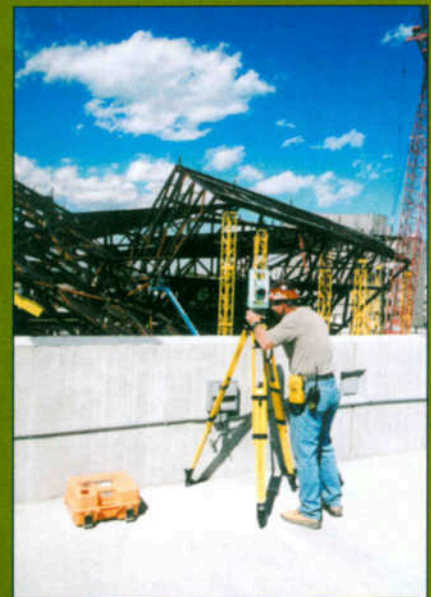
steel (2,740 tons) was fabricated by Zimmerman Metals with some of the raw material (W14x500 and W14x455) coming from Luxembourg due to the unavailability of the material domestically.

Materials and interior

According to Libeskind, one of the challenges of design was responding to the extraordinary range of transformations in light, coloration, atmospheric effects, temperature, and weather conditions unique to Denver. Titanium cladding is his answer. Mortenson built a mock titanium wall on-site to ensure that the planned hanging system is appropriate and to weather-test the material. Titanium is unique, as it does not expand or contract measurably, does not weather and does not rust. The titanium interacts



Left and below: By early spring 2004, the complex process of steel erection was well under way. LPR Construction employed a big Manitowoc 888 for the primary erection and a host of extendable boom lift trucks for secondary work. Yellow towers are temporary supports for structural components. Across the street is the main Denver Art Museum, housed in a once-controversial tower designed by architect Gio Ponti. Hol Wagner photos



Above: Surveying system, supplied with coordinates from the virtual model, aided precise steel erection from roof of adjacent parking garage. Hol Wagner photo

with light at different times of the day, changing color with differing degrees of sunlight, cloud and shadow. The panels angled downward pick up darker reflections from the ground. The velvety finish of the titanium captures and holds the light in an ever-changing symphony of color rather than simply reflecting it back.

In June, workers began hanging the 230,000 square feet of titanium panels manufactured by M.G. McGrath of Minneapolis. This outer titanium skin installed over insulation and sheet metal panels will conclude in the next few months. In November and December, Mortenson closed in a number of walls and the roof so work could continue out of the weather during winter months. Major design work begun by Mortenson for this phase integrated the drywall design into the virtual model. Inside, the building will

have four floors of galleries and a 100-foot-long enclosed walkway over 13th Avenue to the existing Gio Ponti museum building.

A question Andrea Kaulivas Fulton, public relations spokesperson for the Denver Art Museum, has frequently fielded is, "How are you going to hang artwork on all those slanted walls?"

"The answer is simple," she says. "The majority of artwork in an art museum doesn't hang on the exterior walls because you have less control over the elements of heat, cold and moisture."

Also, the lack of windows in gallery spaces is intentional because museum artwork is incredibly sensitive to direct light. Natural light will enter through a narrow fringe of skylights in the atrium space where more durable artwork such as sculptures will be displayed and through glass panels in the lower plaza level lobby.

Mortenson's target date for finishing the building systems and shell is early 2006. Then the museum staff will mount the interior exhibits and open by fall 2006.

"The visitor experience will begin before actually entering the building proper because the building is conceived as a spectacular urban form within the center of the horizon of the city," Libeskind stresses. ■

By late summer, a jib had been added to the 888 as the steel erection neared an end. The structure was finally topped out on Sept. 15. Hol Wagner photos



As steel erection progressed, placement of roof decking and titanium cladding got under way. Photos by Hol Wagner (above), M.A. Mortenson (below)



Above: Metal studs for the exterior skin are applied to the prow jutting out over 13th Avenue in this Dec. 15 view. Overhead walkway crossing the street will link the original building to the new addition. M.A. Mortenson photo

Below: With steel erection completed and skin placement under way, the addition's atrium is a complex mass of girders and beams. M.A. Mortenson photo

