



# Case Study: Milwaukee Art Museum

ARCH 631: Structural Systems  
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# Contents



The Milwaukee Art Museum

The Architect

The Quadracci Pavilion

Design Concept

Building Layout

Structural Features

Summary

# The Milwaukee Art Museum

- Began with Layton Art Gallery (1888) and Milwaukee Art Institute (1918)
- Joined to form Milwaukee Art Center in 1957 and moved into new Eero Saarinen-designed building on Milwaukee waterfront



# The Milwaukee Art Museum

- Museum collection continued to expand throughout the 1980s and '90s
- Attendance increased dramatically, approaching 200,000 annual visitors
- Both factors prompted consideration of an expansion
- Looking for a strong architectural statement, museum officials turned to architect and engineer Santiago Calatrava in 1994
- Calatrava's design was unveiled in March 1996, receiving an enthusiastic response from the community
- The Quadracci Pavilion was completed in October 2001, becoming the first building constructed by Calatrava in the United States



# The Milwaukee Art Museum



# The Architect



- Santiago Calatrava was born in Valencia, Spain in 1951
- He earned a degree in architecture from Escuela Tecnica Superior de Arquitectura in Valencia
- He then pursued studies in the field of civil engineering, completing a Ph.D. from the Federal Institute of Technology in Zurich, Switzerland in 1979

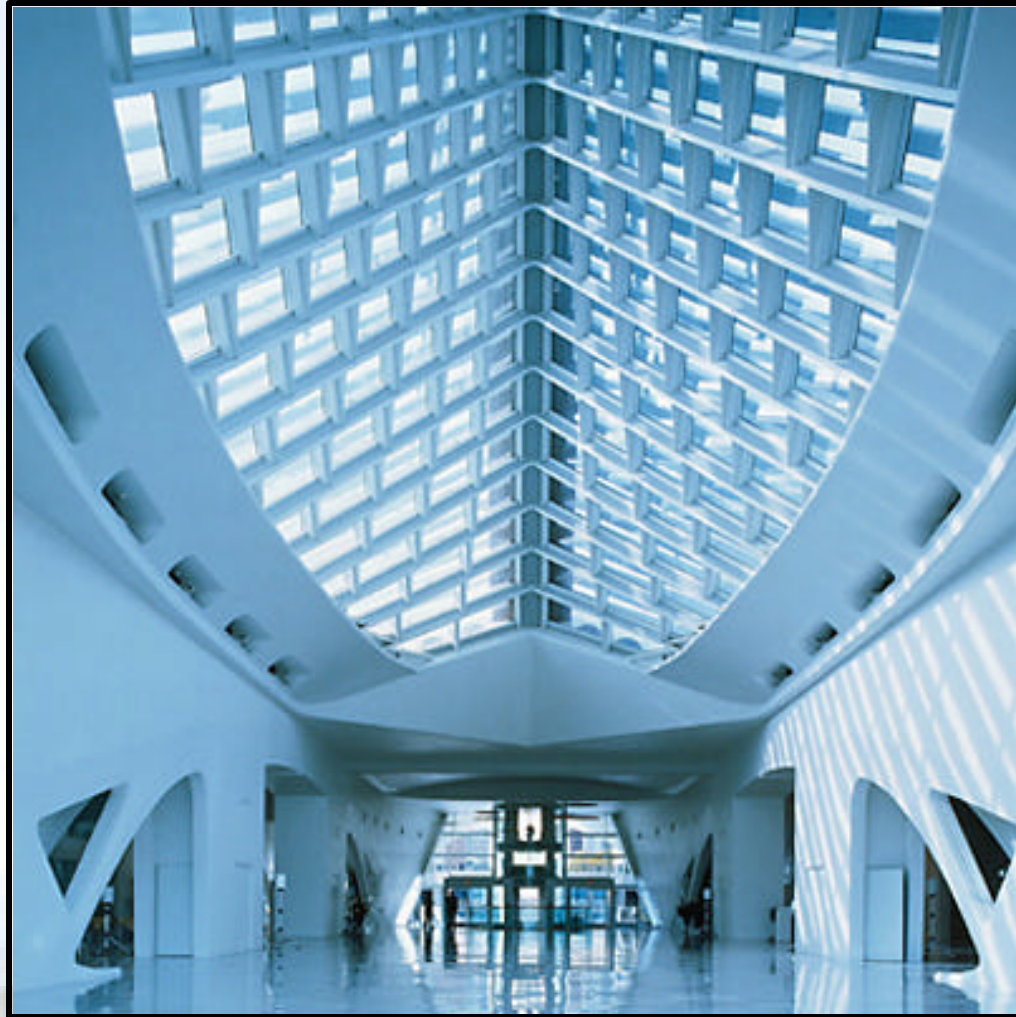
# The Architect

- Calatrava began entering design competitions to gain recognition
- His first winning design was the Stadelhofen Railway Station (Zurich, 1983)
- As he gained commissions, he opened a second office (Paris) in 1989, and then a third (Valencia) in 1991
- The Milwaukee Art Museum expansion became his first major project built in the United States in 2001
- Calatrava earned Time Magazine's "Best of 2001" award and the International Illumination Design Award of Merit for his work on the MAM expansion
- He is currently working on three major projects in the United States, as well as many commissions overseas





# The Quadracci Pavilion



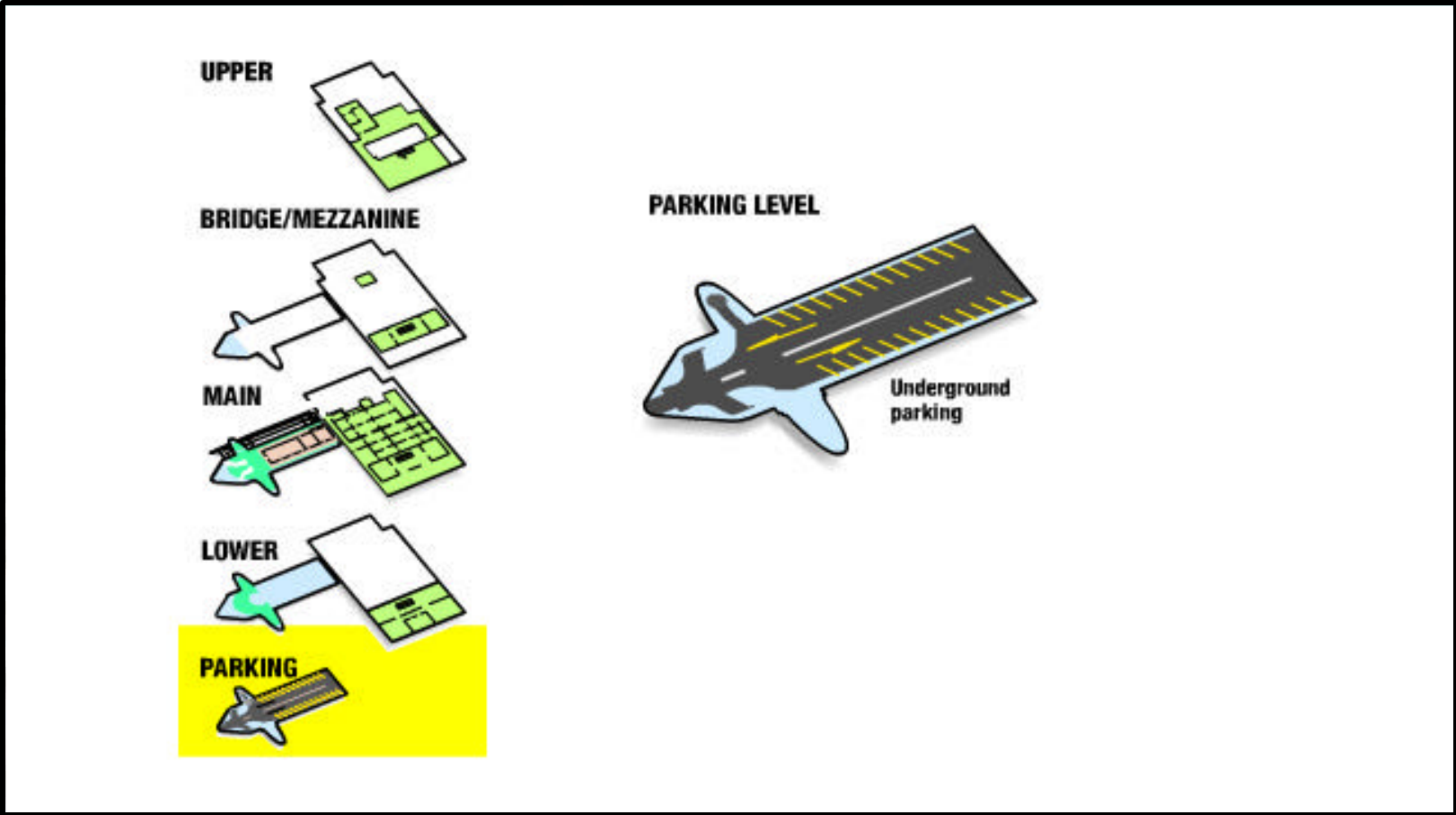


# Design Concept

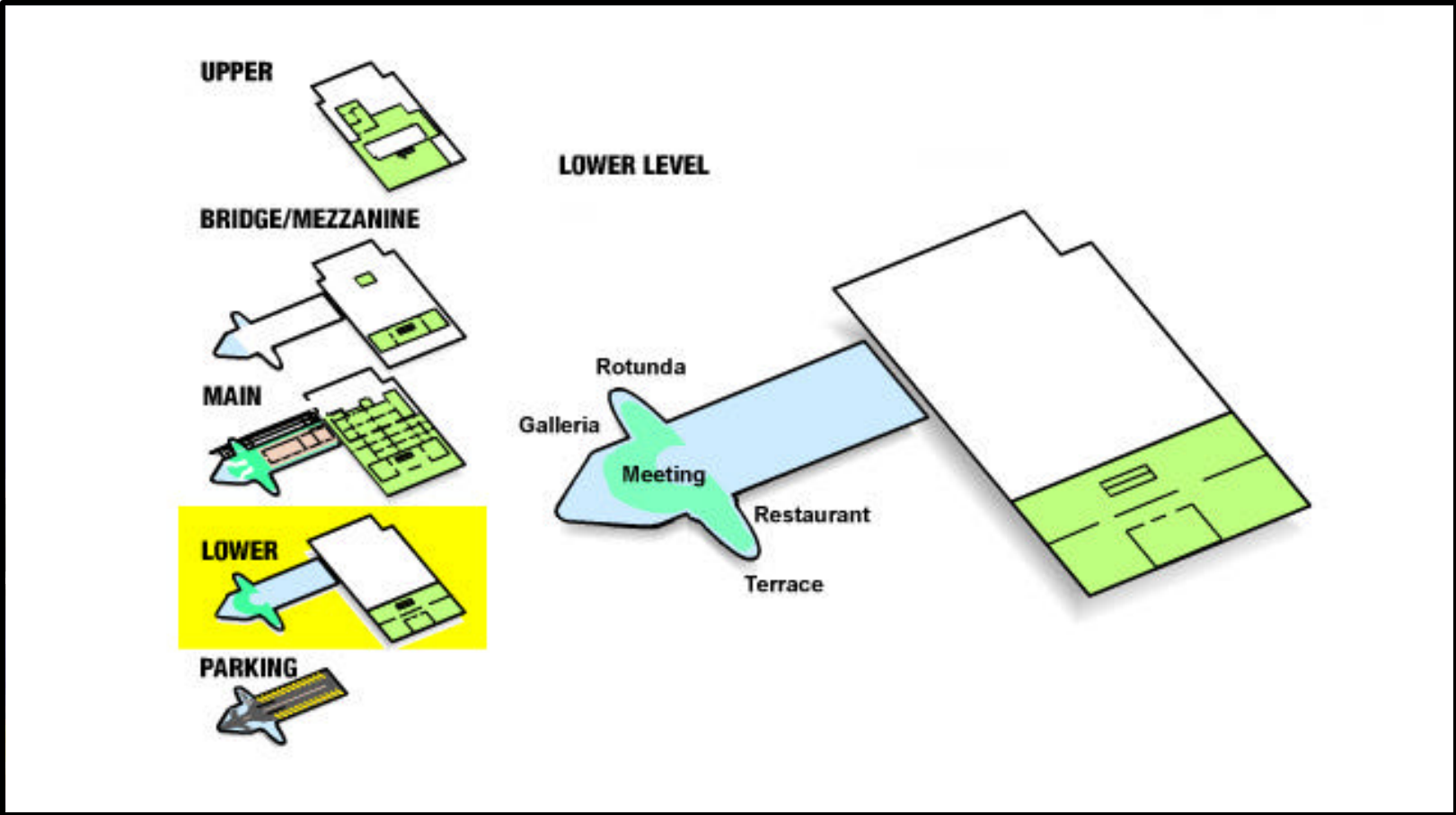
- The City of Milwaukee was looking for a “strong architectural statement in an exciting yet functional building” that would “set an architectural standard for the next millennium”
- Architect Santiago Calatrava’s response was to design a “glowing ‘lantern’ on the downtown lakefront, radiating light in all directions”
- The design features a large pavilion containing a glass-enclosed reception hall with a transparent, boat-like prow facing the lake, as well as a huge, operable wing-like Brise-Soleil sunscreen



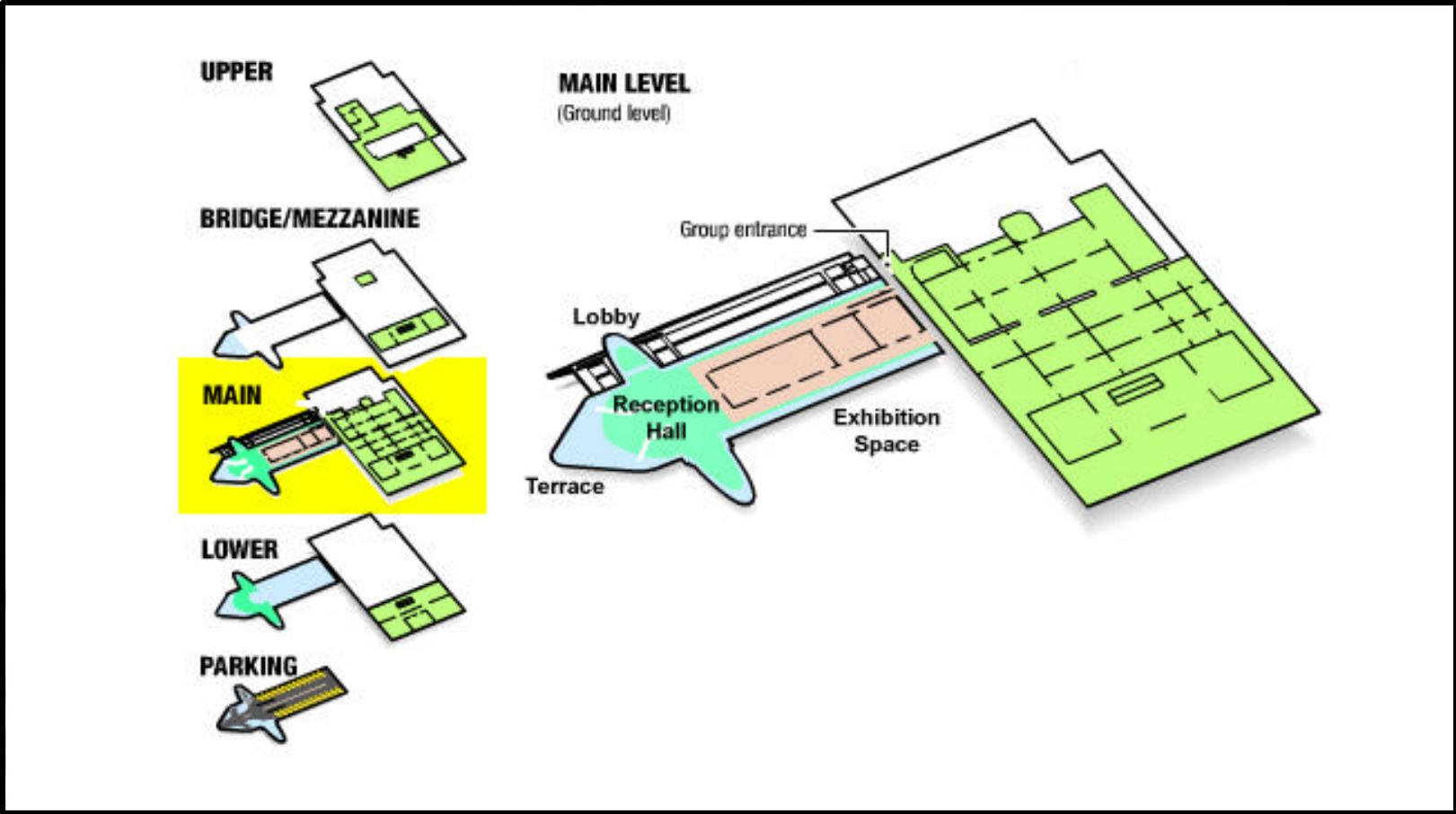
# Building Layout



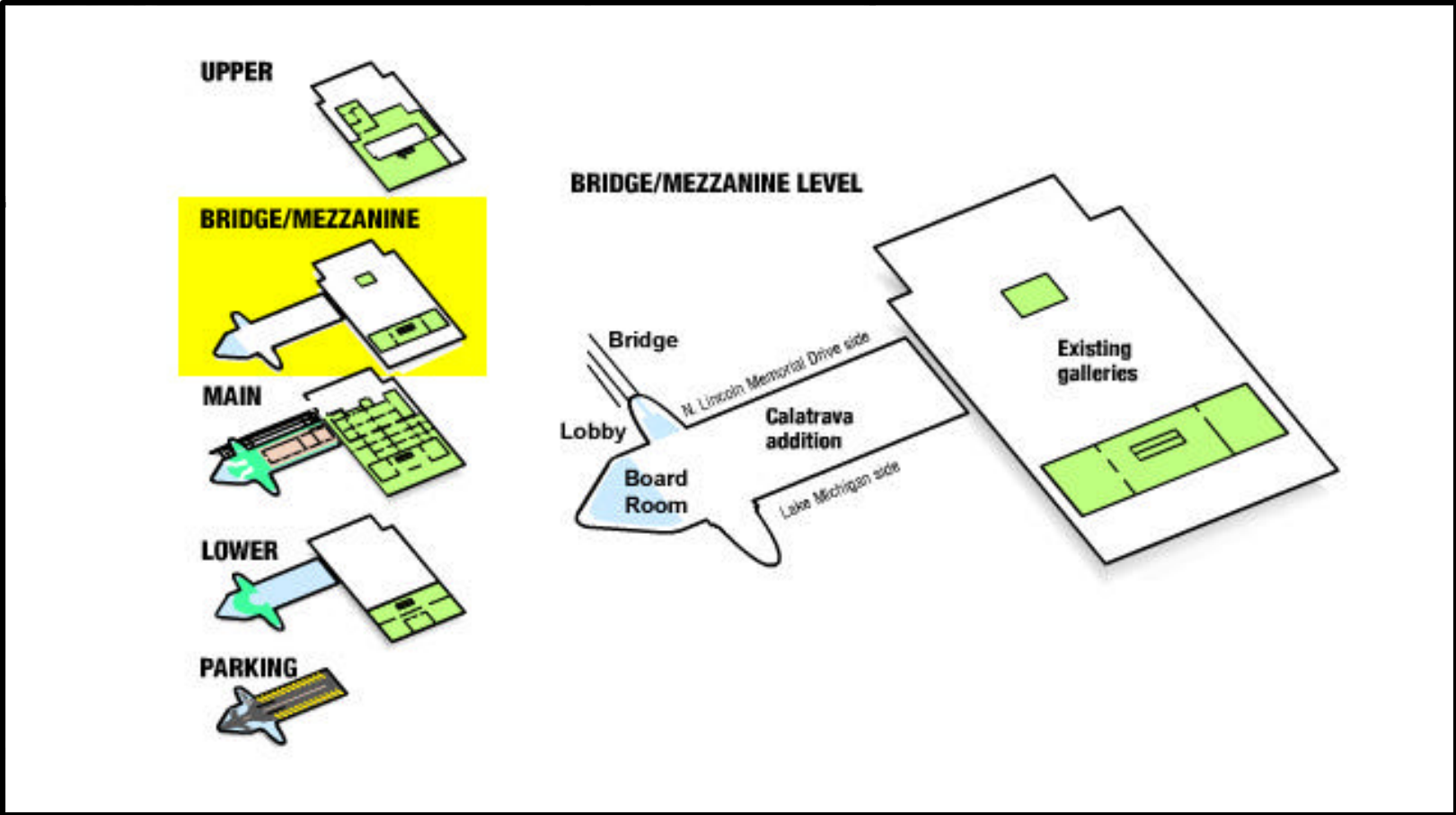
# Building Layout



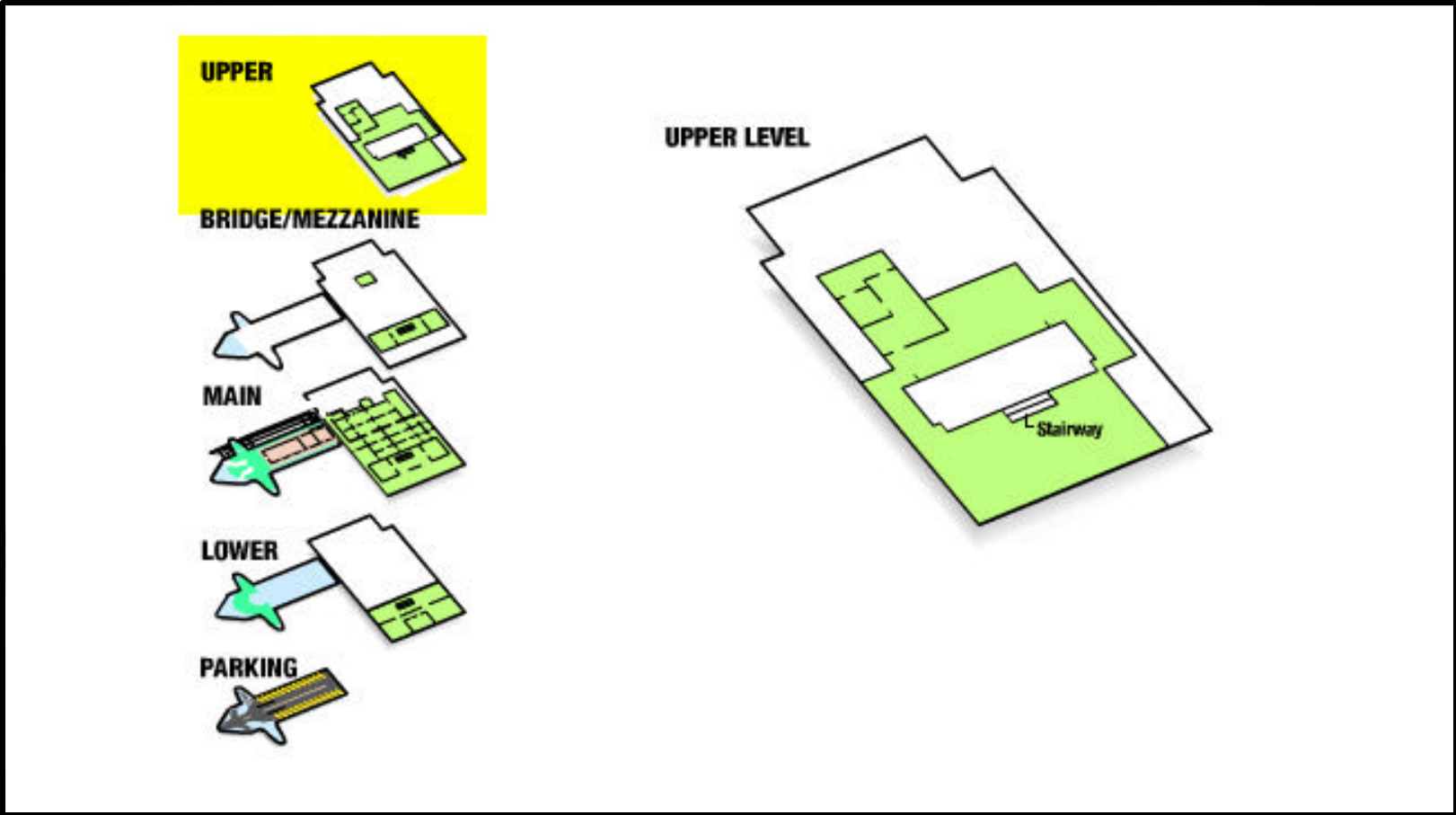
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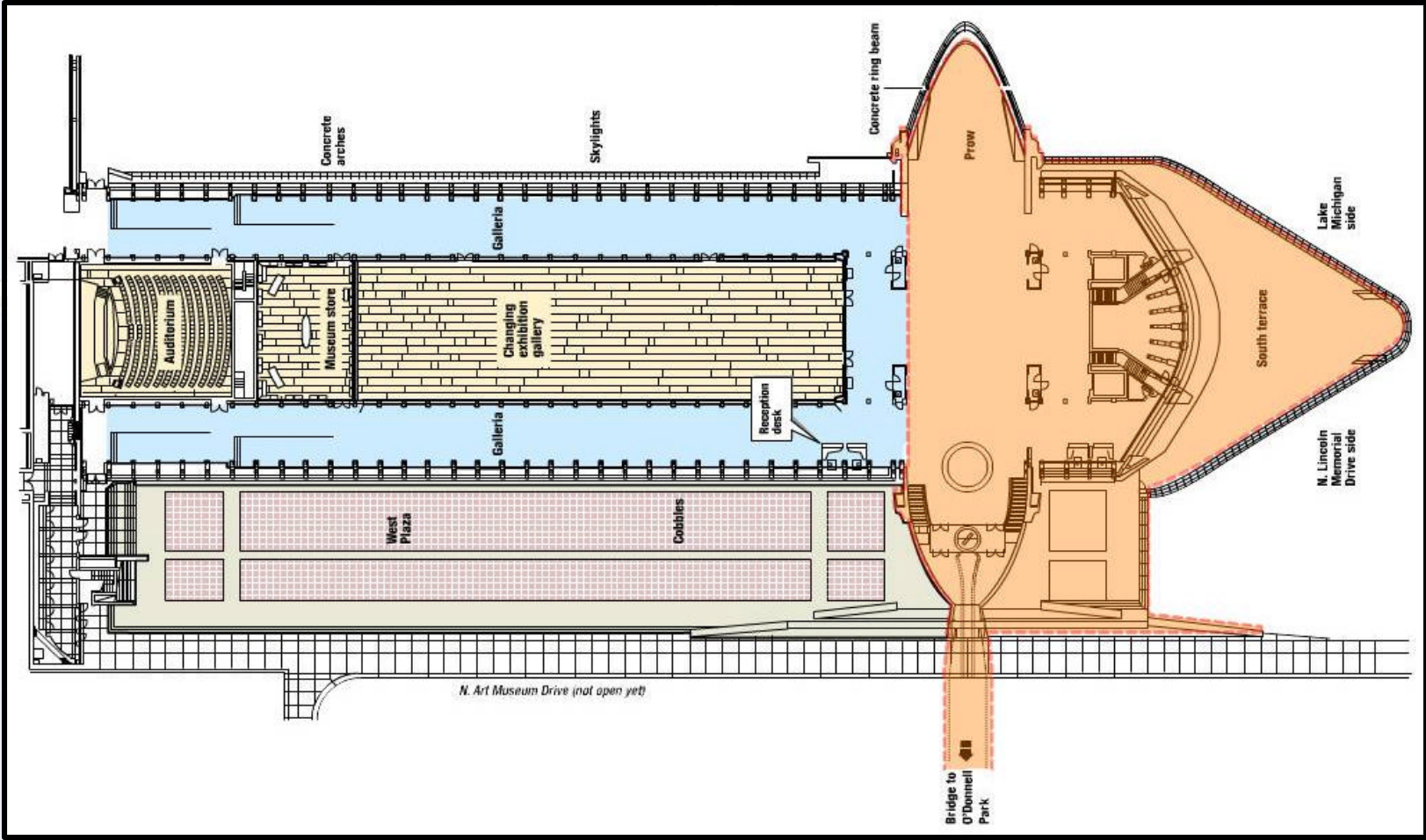


# Building Layout





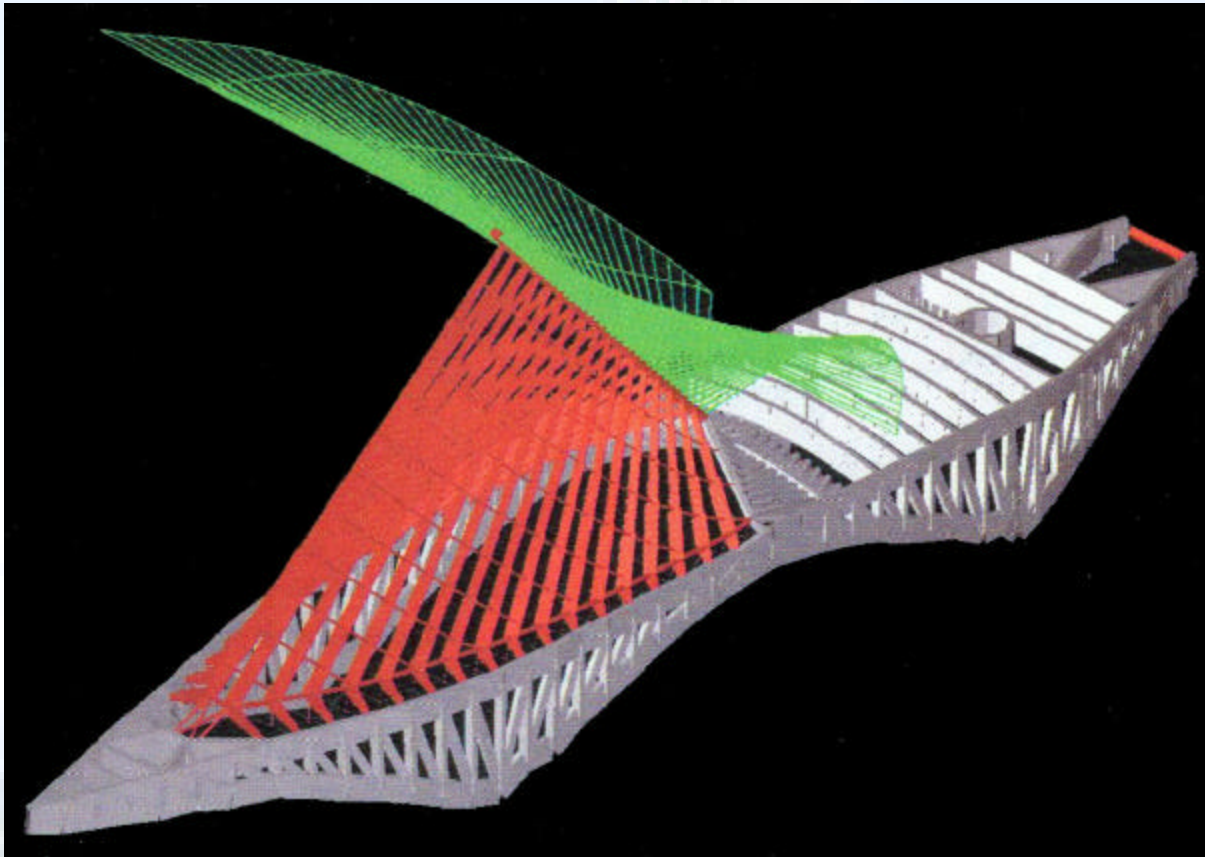
# Main Level Floor Plan





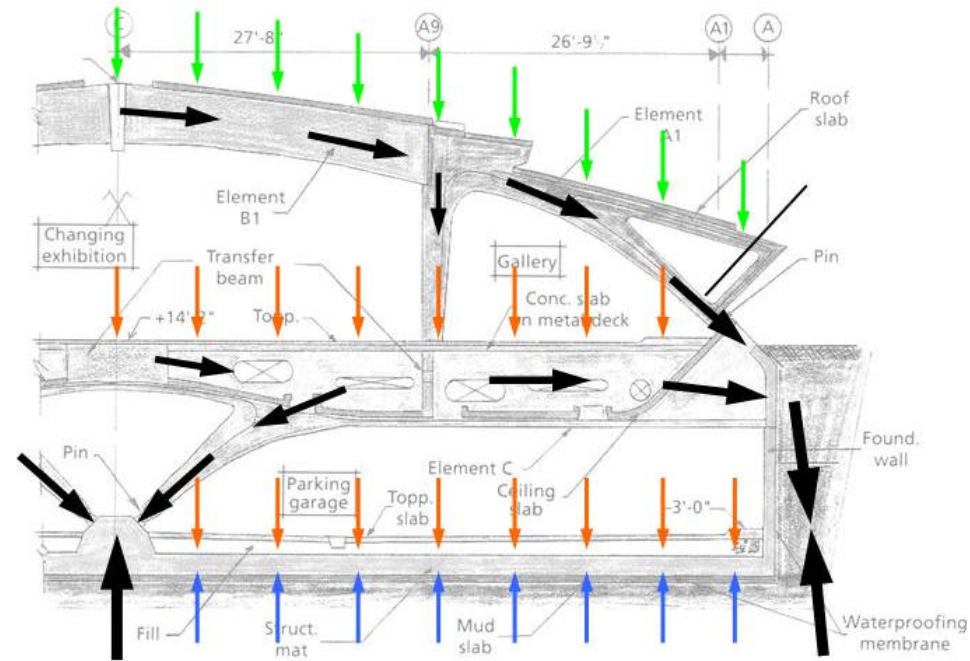
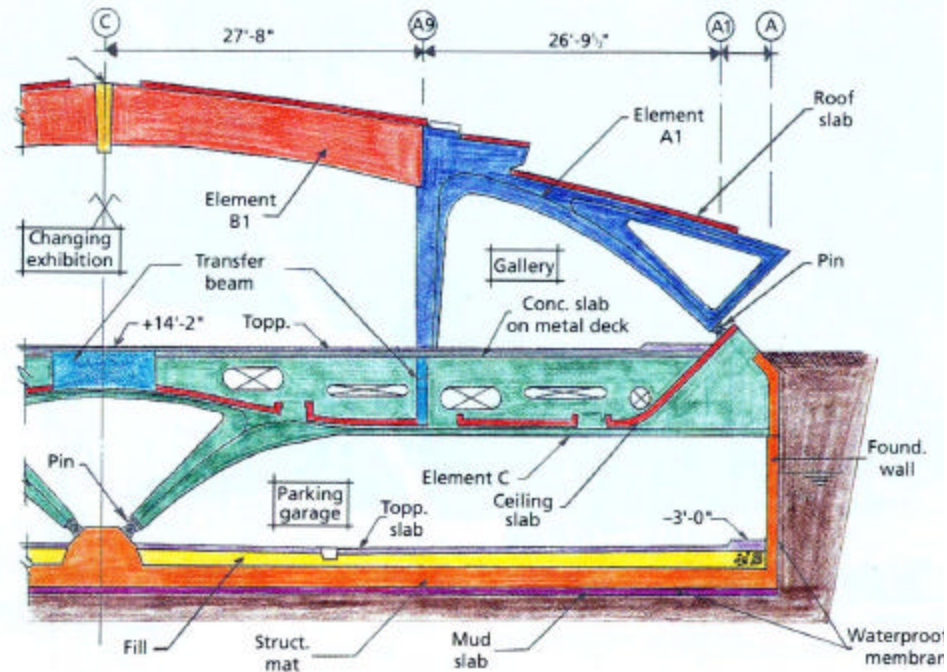
# Structural Features: Finite Element Model

- The complexity of the Quadracci Pavilion required that the mat foundation slab, pavilion, A-frames, ring beams, and Burke Brise-Soleil be designed through a detailed finite element model analysis



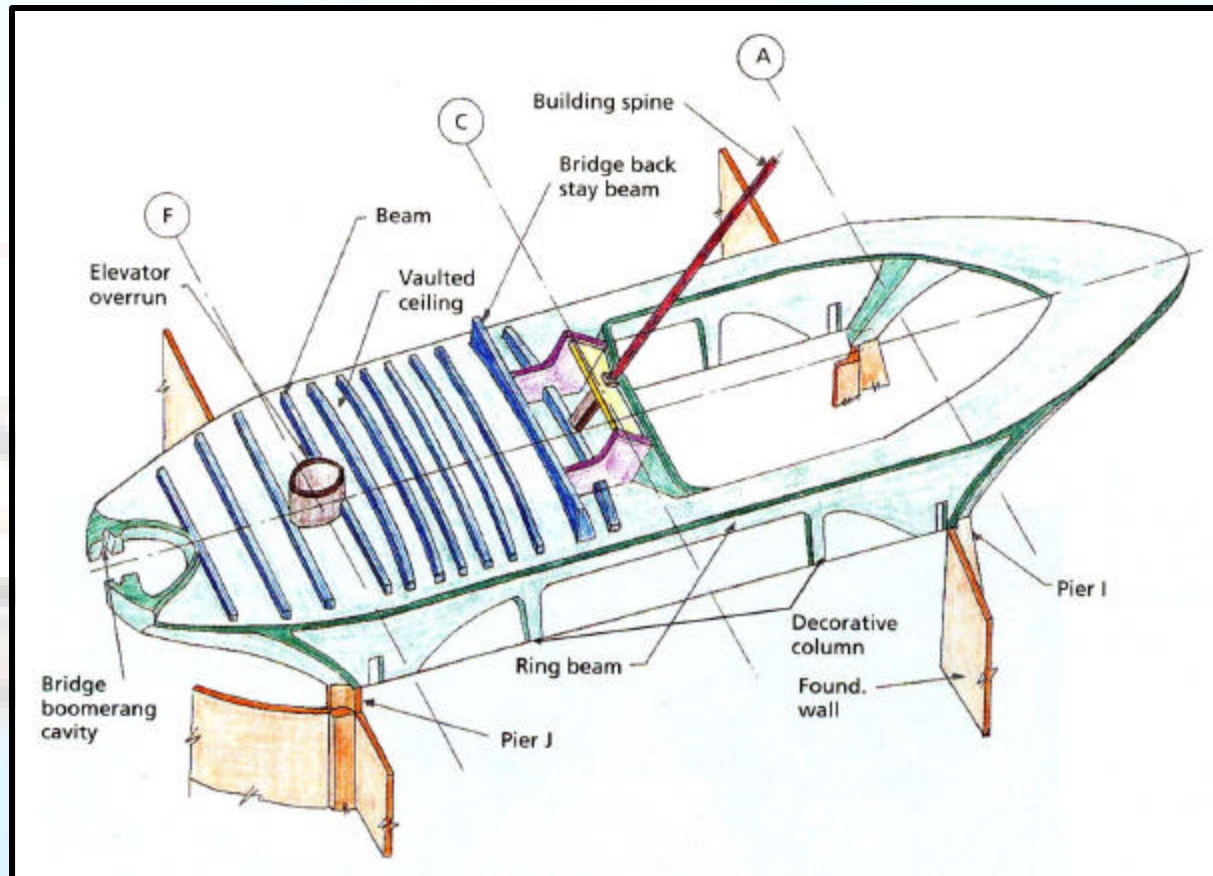
# Structural Features: Building Section

- A quick study of a partial building section reveals the clever arrangement of pinned concrete arch elements which transfers structural loads to the foundation wall and center beam



# Structural Features: Pavilion

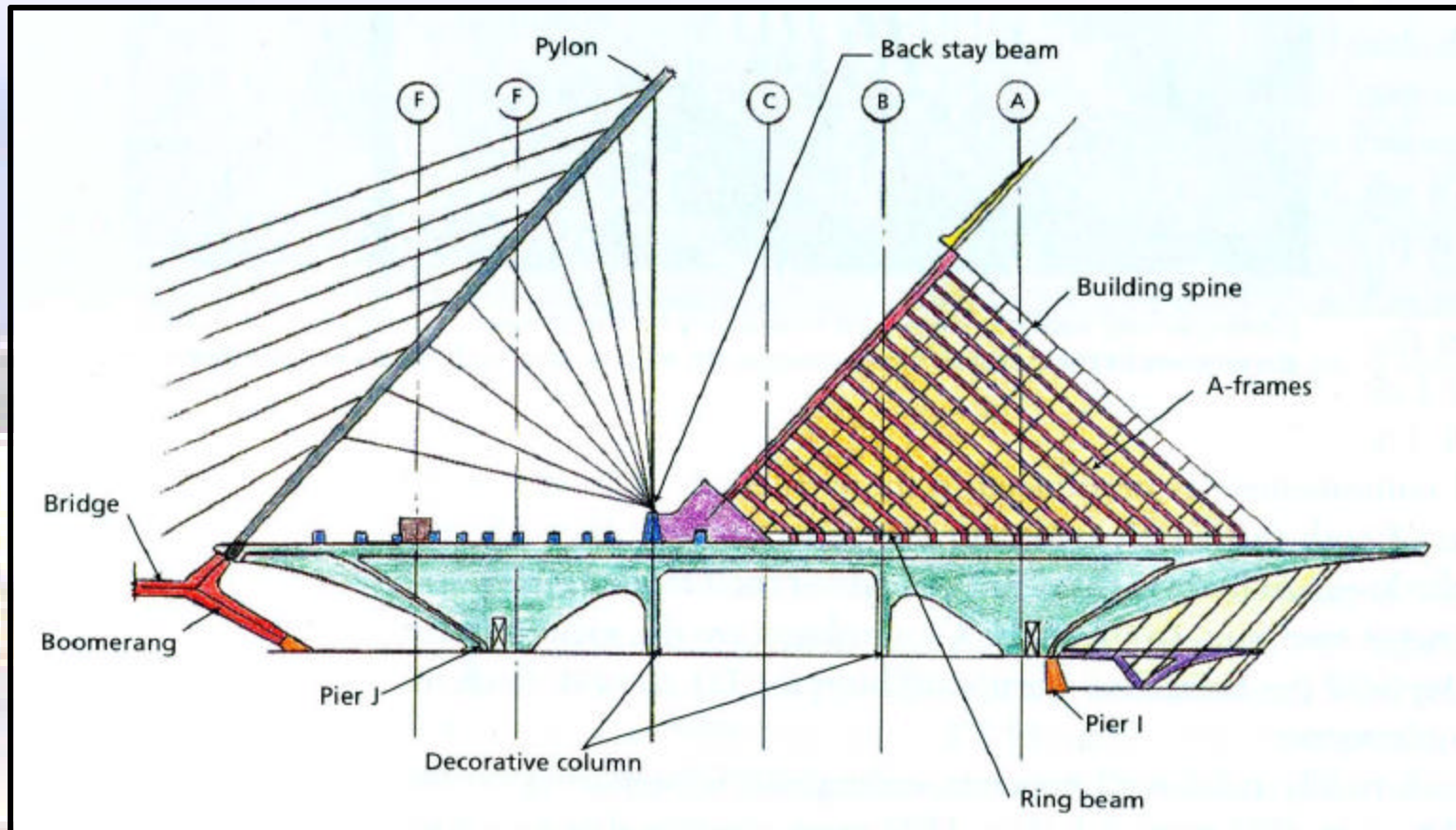
- The mildly-reinforced concrete pavilion supports the back stay beam and east pier of the pedestrian bridge, as well as the A-frames and building spine that in turn support the moveable Burke Brise-Soleil





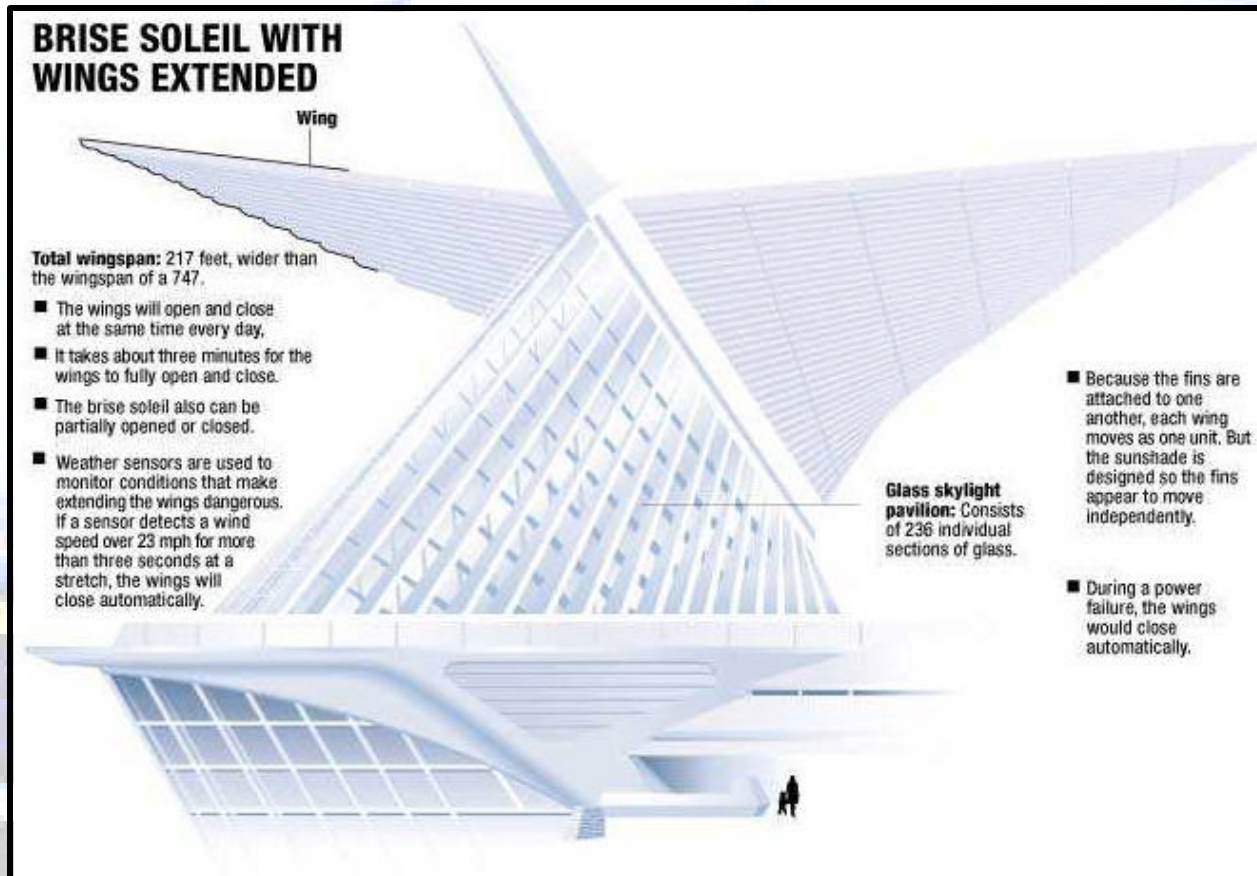
# Structural Features: Pavilion

- The cable-stayed bridge pylon and the Quadracci Pavilion's building spine are aligned on the same axis and are inclined 48.36 degrees toward the Pavilion



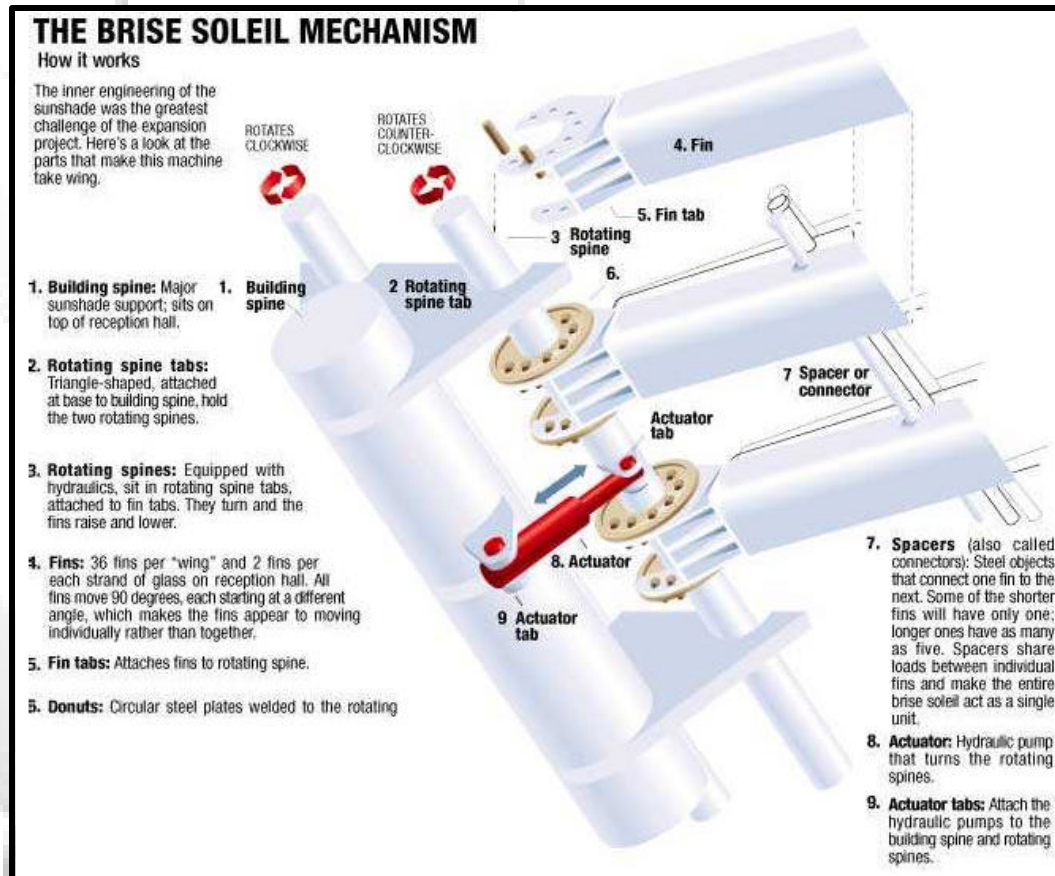
# Structural Features: Burke Brise-Soleil

- The signature element of the Calatrava addition is composed of two large operable wings, each made up of 36 interconnected fins, spanning almost 220 feet



# Structural Features: Burke Brise-Soleil

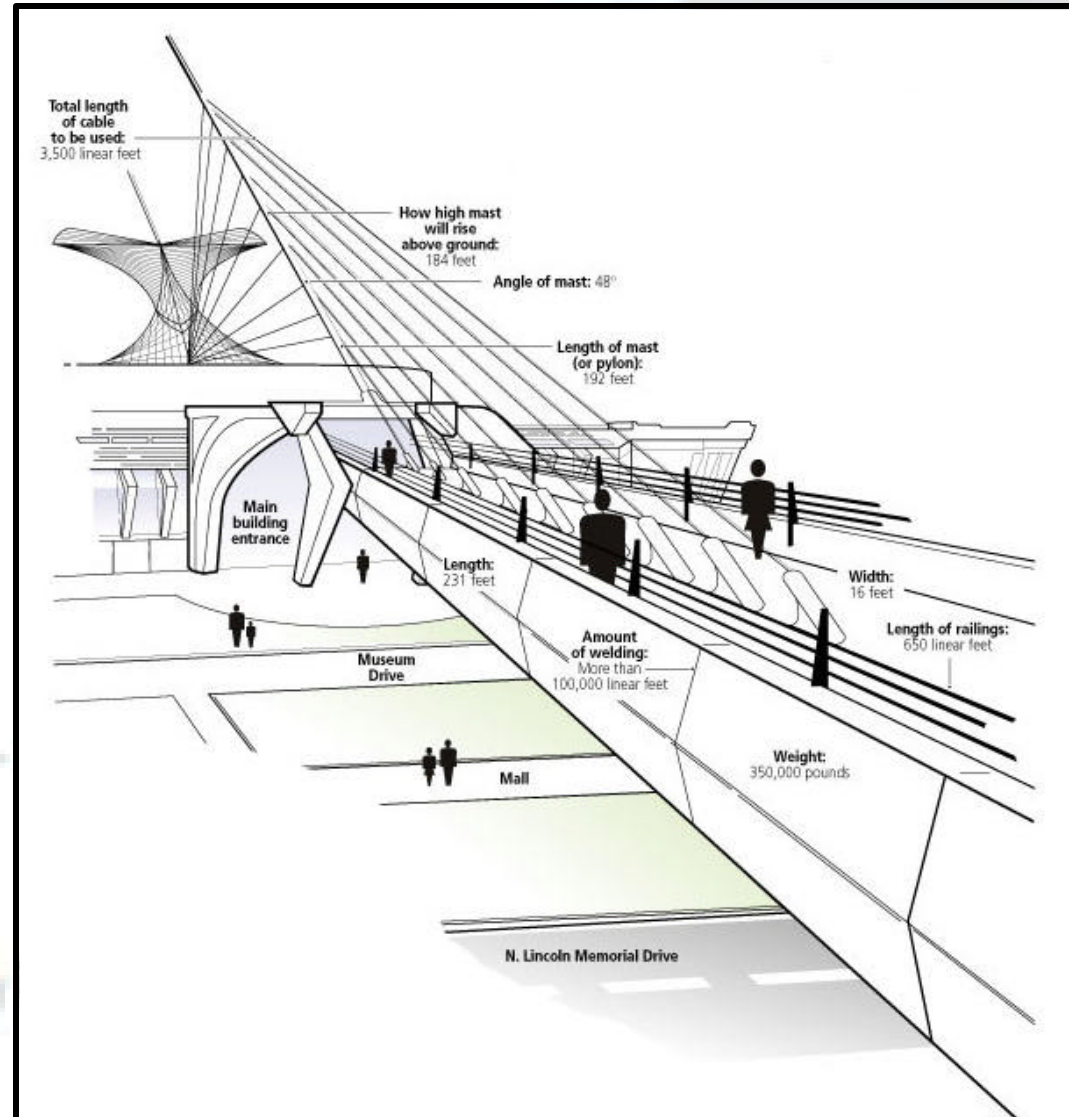
- 11 pairs of actuators operate simultaneously to open or close the wings in unison by turning two rotating spines up to 90 degrees





# Structural Features: Pedestrian Bridge

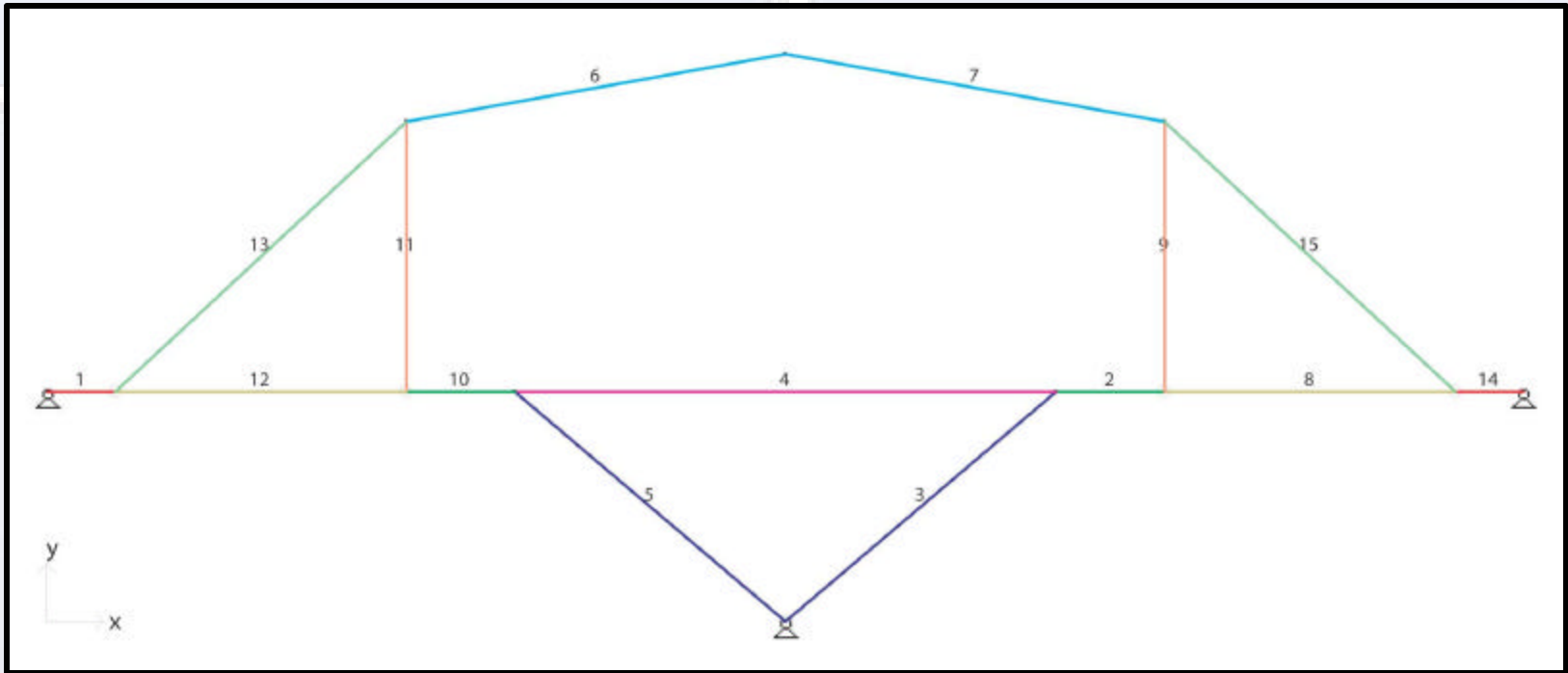
- A cable-stayed pedestrian bridge featuring a steeply-raked pylon and 'boomerang' abutment spans 230 feet across a major thoroughfare, connecting Milwaukee's downtown with the waterfront
- The 192-foot-long pylon supports the 10 major spans of the bridge through 9 locked-coil cables and 18 back stay cables





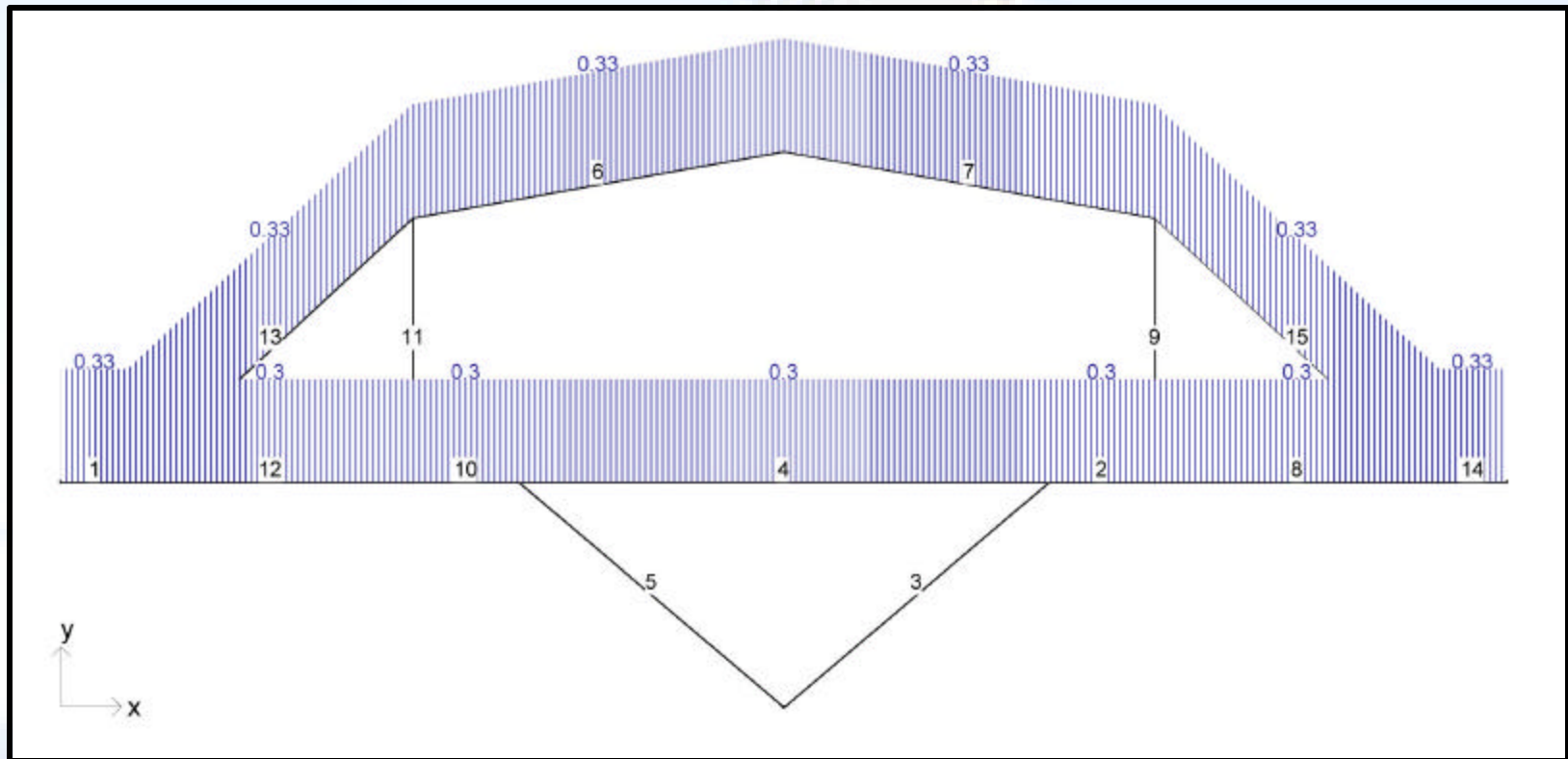
# Structural Features: Multiframe 2D<sup>®</sup> Analysis

- To study the cross-section of the MAM expansion more closely, a simplified finite element model was constructed using Multiframe 2D; arches and non-uniform elements were approximated by multiple straight segments



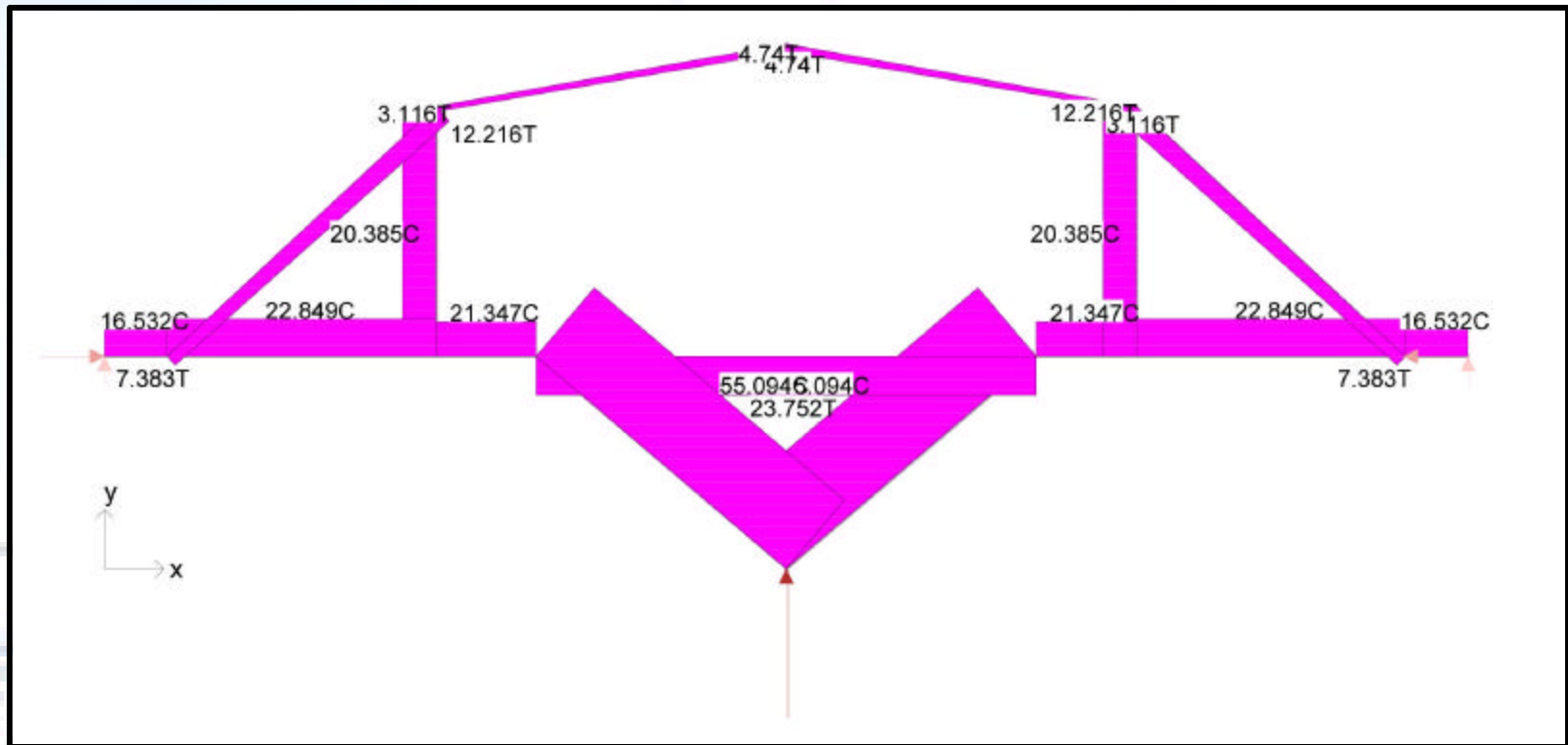
# Structural Features: Multiframe 2D<sup>®</sup> Analysis

- In addition to the self-weight of the members, dead and live loads on the roof and floors were approximated by uniform distributed loads; member sizes were then optimized using the finite element analysis software



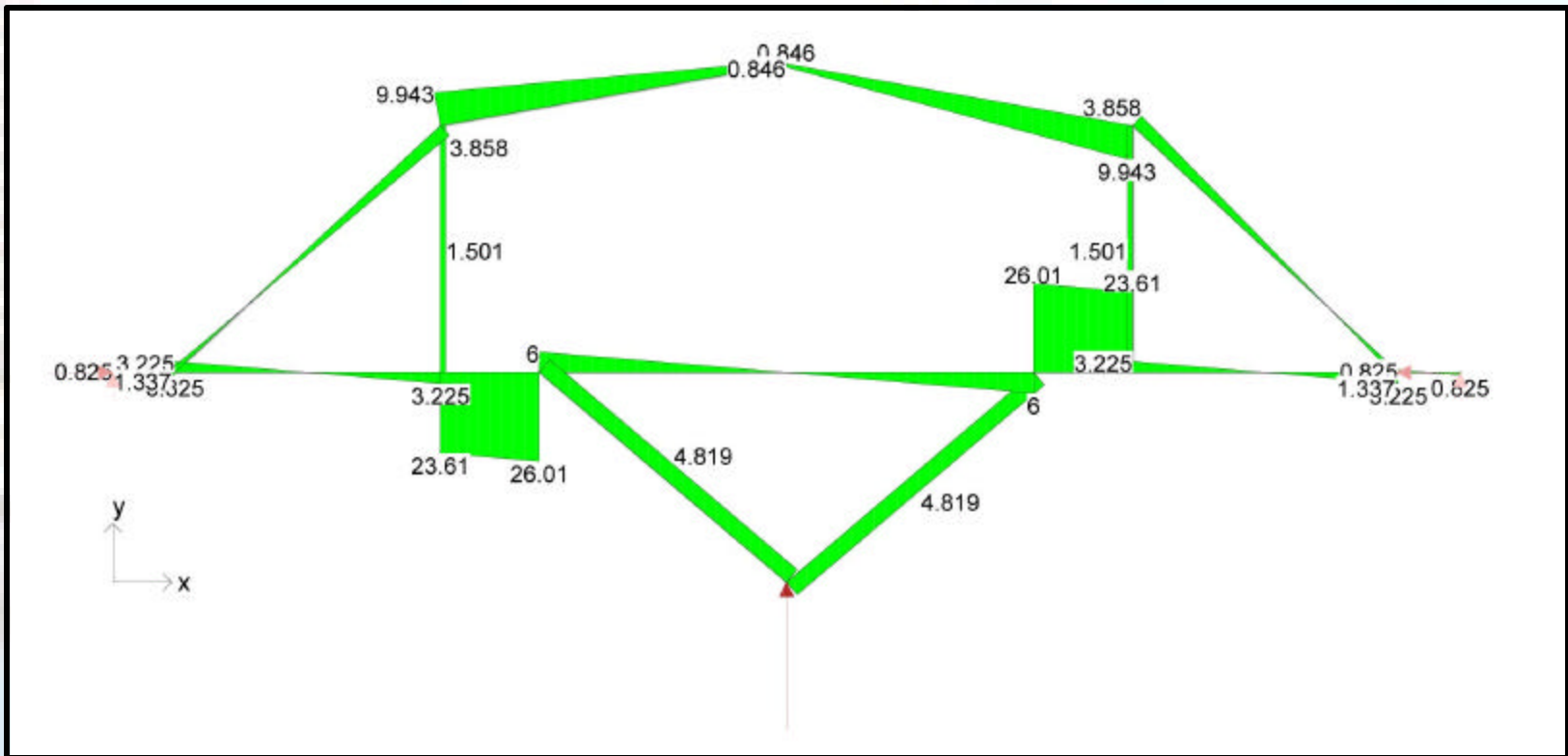
# Structural Features: Multiframe 2D<sup>®</sup> Analysis

- Member reactions indicate that the majority of building loads are transferred through the C1 element to its double-pinned connection with the center foundation beam



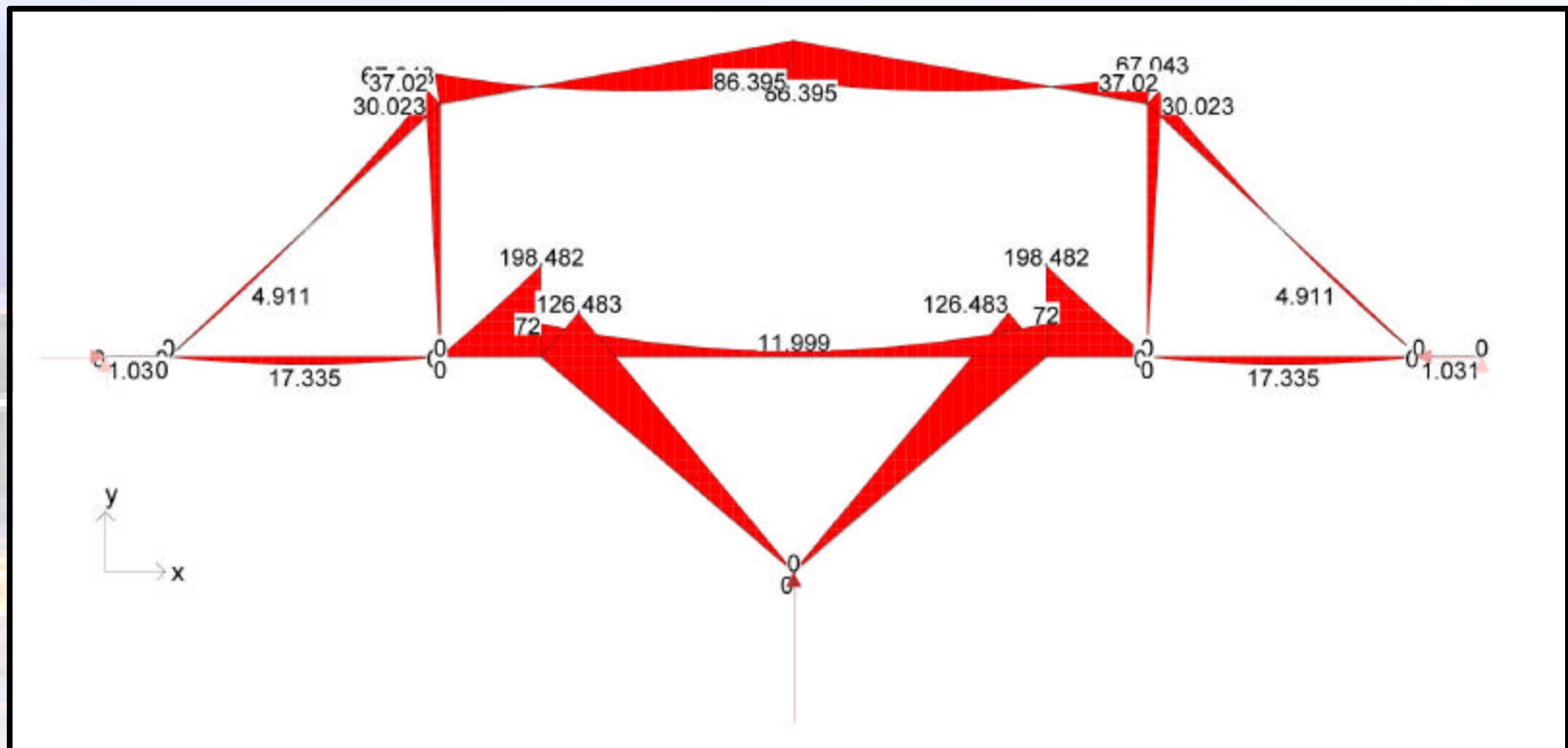
# Structural Features: Multiframe 2D<sup>®</sup> Analysis

- In the simplified model, significant shearing forces are experienced by the C1 element between the gallery columns and foundation arches, while loads remain mostly axial through other elements



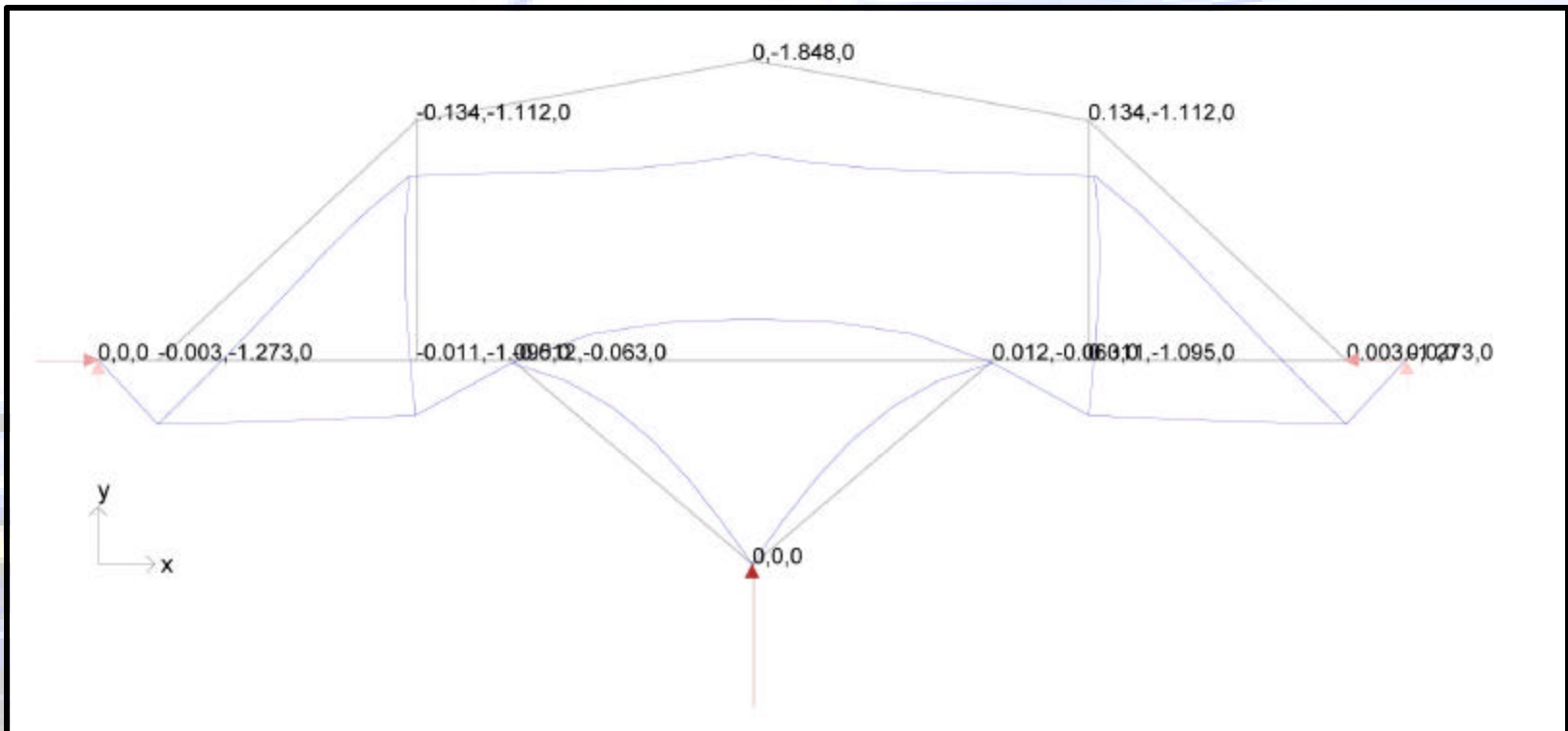
# Structural Features: Multiframe 2D<sup>®</sup> Analysis

- As might be expected, the largest moments are obtained within the C1 elements in the simplified model; in the actual design, moments are minimized through the use of arches, and tension forces are controlled where necessary by post-tensioned steel reinforcement



# Structural Features: Multiframe 2D<sup>®</sup> Analysis

- Through the reduction of internal moments, deflections of the structural elements are also minimized



# Summary

- The recently-completed Quadracci Pavilion, an expansion of the Milwaukee Art Museum, has achieved praise both as an architectural icon and a structural marvel
- Floor plans, elevations, and isometric drawings of the pavilion and attached galleries were provided for reference
- Simplified diagrams explaining the load transfer through a typical gallery section were discussed; the building was shown to have achieved an elegant design solution in its balancing of structural forces
- Results from a two-dimensional computer-based structural analysis of the building's cross-section were presented for comparison
- Calatrava's vision of "a glowing 'lantern' on the downtown lakefront, radiating light in all directions" has been fulfilled with a magnificent structural expression of concrete, steel, and glass



