Museum of Art launched a celebration of the conclusion of a
l renovation project.[i, ii]

The expansive two-phase, 616,000-SF (187,800m^2) project impacted every part of the Museum. The project scope included:

- **Renovation of the original 1916 museum building and the 1971 Breuer building.** The Museum wanted to restore and showcase the historical 1916 building (itself a work of art) and the 1971 north wing, designed by renowned architect Marcel Breuer.
- **Demolition of the cobbled-on east and west wings.** Though they connected the original 1916 building and the 1971 Breuer building, the existing east and west wings interfered with the patron flow in the Museum galleries and were no longer desired.
- **Construction of a new east wing, west wing, and atrium.** These additions gave a new coherence and refreshed aesthetic to the Museum buildings. The new east and west wings replaced the two buildings that had been demolished, and the glass-roofed atrium enclosed the former courtyard and became a new interior space. A new central utilities plant (CUP, designed by Ove Arup), sized for the entire project and containing normal and emergency electrical systems, was also added. In Phase II, Karpinski Engineering extended services from the CUP to the Museum buildings.

Karpinski Engineering (KE) participated in both phases of the project, providing mechanical, electrical, and plumbing engineering, as well as fire protection and life safety design. They served as the local sub-consultant for Phase I (under Ove Arup), working on the 1916 and 1971 building renovations. They were chosen as the lead engineer for Phase II based on their excellence in engineering and dedicated client service.

A project of this scale and scope relied on many contributors. Architecturally, the project was led by Rafael Viñoly Architects PC. Other members of the design team included Ove Arup (MEPT, project Phase I central plant and east addition); Nabih Youssef & Associates (structural); Wallace, Roberts & Todd LLC (landscape architect); Moody/Nolan (civil); George Sexton Associates (lighting designer); Akustiks (acoustical consultant); Hughes Associates (life safety); and Westlake, Reed, Leskosky (auditorium consultant).

Innovation, quality, and professional excellence were integral to this undertaking. Partnering with a world-class art museum for major renovations and additions came with exacting requirements of the engineering design. Aesthetic concerns were paramount, and the engineering design had to contribute to the aesthetic vision. The resulting structure embodies the Museum's desire to create something magnificent.

Founded in 1913[iii], the Cleveland Museum of Art (CMA) serves both local and global communities. Today, it houses a collection of more than 45,000 pieces across 6,000 years of making.[iv] With general admission being free to everyone, visitors can simply walk in and explore CMA's galleries.

At the center of the Museum – both literally and figuratively – is the new atrium. Part of Phase II, it was envisioned as a public gathering space. It was designed to showcase the north façade of the original 1916 building, which had been largely masked by previous additions (now demolished) to the Museum.

The marvel of the 39,000-SF (11,890m^2) atrium is its soaring skylight, which arches from the 1916 building to the 1971 Breuer building, uniting all four wings of the museum. Structural engineering firm Nabih Youssef & Associates designed the skylight's trusses, and the German engineering firm Gartner designed the skylight's glazing system.

...on supports through which piped, heated and cooled, water can ...ated and cooled: In the winter months, the system melts snow and eliminates condensation. In the summer months, it reduces solar and conduction heat gain to the atrium space. The atrium roof mullion system was calculated to provide over one million BTU of heating and 25 tons of cooling into the space to offset roof losses and gains—which is approximately 38% of the atrium's total heating load and 12% of its total cooling load. The system also neutralizes the threat of condensation brought on by the gallery spaces that abut against the atrium, which are kept at a uniform temperature and humidity year-round, and are designed with positive air pressure to drive moist air out and keep inadequately conditioned air outside the galleries from entering.

The KE team designed and coordinated the installation of the piping that conditions the skylight panel mullion support system. The piping is self-balancing (a design feature recommended by Gartner and completed by KE) and uses symmetrical distribution. Because of the skylight piping system, natural light is not obstructed by snow or condensation, and Museum visitors have a clear view of the sky.

It wasn't enough to just design and specify the piping system. The project team wanted to verify the constructability of the design and created physical mock-ups of the piping connections to the support system.

The skylight system was designed to withstand severe weather conditions. With Cleveland's winters, snow accumulation is a particular concern, and the arched roof had to be leak-proof and avalanche-proof. KE had to design a drainage system that would carry the melted snow off the roof and away from the building while preventing the melted snow from re-freezing before removal. Working with the architect, other project engineers, and roofing contractors, KE engineers devised a solution. In keeping with the Museum's vision, the resulting custom-designed gutter is redundant, leak-proof, and aesthetically pleasing. Bi-functional drains are spaced along the gutter, and an alternating circuit heat trace runs through the gutter to melt ice and snow.

Another key feature of the atrium is the radiant floor system. Heated or cooled water circulates through piping embedded in the floor, maintaining both occupant comfort and the critical environment needed for intermittent art displays in the atrium. The system offsets the atrium's cooling and heating requirement enough to reduce the required air flow for conditioning the atrium; the decreased air flow represents an estimated $35,000 per year reduction in fan energy.

The KE team helped the construction team meet significant constructability challenges for the installation of the atrium lighting. The atrium's track lighting, for example, is an integral component of the atrium ceiling's truss structure. Not only was it carefully placed and controlled for both daylight and the multiple functions of the space (e.g., art displays, social events, etc.), but the wiring had to be concealed in such a way as to adhere to the aesthetic vision for the atrium. The KE design team engineered constructability solutions that eschewed the "means and methods" approach. The team worked with the contractors to help them understand how to wire the lighting in keeping with the Museum's requirement that the engineering contributes to the aesthetics.

The engineering design for the galleries (both Phase I and II) had to protect and preserve the Museum's collections, while providing a pleasing and comfortable experience for Museum visitors. Following concepts established in Phase I of the project, KE's mechanical engineers designed HVAC systems that could meet the galleries' tight tolerances for temperature and humidity—70 degrees Fahrenheit and 50% relative humidity in all galleries (as well as art storage and restoration areas) at all times. Multiple-zone, constant volume air handling units with cooling-coil bypass, reheat coils, and humidifiers were used to maintain the critical environment. Humidity is provided via clean steam, using a steam-to-steam generator and stainless steel tion removes both particulate and gaseous content from the air

The new east (by Arup) and west (completed by KE) wings each contain a section where three of the four walls are outside, all-glass walls. They are designed with two glass facades with a conditioned air cavity in between, which forms a barrier between the interior and the exterior's harsh conditions. In January 2014, when put to the test by actual outside temperatures around 5 degrees Fahrenheit (-15°C), the glass did not frost or fog.[v]

The need for creativity and inventiveness was not limited to the project's new construction. The Phase I renovations of CMA's two existing buildings presented their own design challenges in terms of updating systems to serve the Museum's current and future needs.

As the local sub-consultant tasked with engineering design for renovating the original 1916 Museum building, Karpinski Engineering faced a twofold objective: to restore this historic building and to update it to serve the Museum's current and future needs.

The 1916 building's galleries were originally illuminated by laylights (skylight panels below a glass roof system). But in the intervening years, the laylights fell into disrepair. Many were covered with plywood and replaced by artificial lighting. Above the laylights, hundreds of buckets collected water leaking in from the skylights above. One of KE's tasks was to restore the building's naturally-illuminated state.

Restoring the laylights and skylights brought another challenge: controlling the heat gain introduced by the sun. To eliminate the possibility of condensation on the newly-restored laylights and skylights, dew point sensors were installed on the skylights. The sensors detect when there might be a possibility of condensation, and they trigger a response that controls the indoor conditions using hot water finned elements and a series of dampers that inject dry, conditioned building relief air into the cavity between the skylights and laylights.

Further, in a building of this age, not designed for modern mechanical systems, where could the huge air handling units and air distribution go? The original 1916 building foundation had been dug out by hand, and a central portion of the basement area had never been excavated. The twenty-first century team dug out the remaining basement area, and it became home to new air handling units that could handle modern air conditioning loads.

The new location of the air supply equipment, along with the increased airflow, turned KE's attention to the building's old, leaking ductwork. The existing air supply ducts were located within wall cavities and extended from the basement to the building's three floors. To replace it would have required removing brick walls, replacing the ducts, and restoring the walls. Instead, KE's innovative design allowed the 90+-year-old ducts to be reused, circumventing huge costs for ductwork replacement. Using Aeroseal—a new, latex-like sealant—the vertical concealed ducts were spray-coated on the inside until leaking duct joints and penetrations were sealed. To verify that the presence of the sealant would not present any environmental threat to the artwork, the Museum curator thoroughly tested it before approving its use.

Across from the 1916 building, in the 1971 Breuer building, is Gartner Auditorium. The goal of its renovation, also part of KE's responsibilities, was to provide audiences with a quality concert experience. The auditorium required improved acoustics, air conditioning, and sightlines. These objectives necessitated nearly a complete gut of the auditorium, with renovations to the entry vestibules, projection booth, platform, ceiling, and seating. Karpinski Engineering redesigned Gartner Auditorium's HVAC, fire suppression, and lighting systems.

nd made stringent demands on the HVAC design, which included humidification. The KE team worked with the acoustician to align the engineering design with the acoustic and vibration criteria PNC (Preferred Noise Criteria)-15, concert hall level. The air conditioning uses over-sized ductwork; special diffusers that don't generate turbulence; and sound attenuators at the air handling units. All the while, the team coordinated their design with the space requirements to ensure that the equipment would fit into the auditorium's fixed-size, poured concrete space.

Gartner Auditorium's lighting uses an extension of the Museum's control system, with specialized dimming enhancements for visual effects. Given the building's poured concrete walls and CMA's desire to conceal unsightly electrical conduits, the electrical team had to do more than merely run new wiring. They had to coordinate with design architect and contractor, as well as provide extensive on-site construction administration, to meet CMA's objectives.

The auditorium's McMyer Memorial Pipe Organ blower loft required special attention. Not only was its HVAC system going to be refreshed, but the organ itself was going to remain in place during construction. The air distribution system serving the organ blower loft was revised to provide the airflow, temperature, and humidity required for the organ components and controls to maintain sound quality after organ tuning. The KE team worked with the contractor to accommodate the organ pipes, building an enclosure to protect them, provide air conditioning, and keep dust out during the construction period.

With aesthetic concerns being paramount, and with priceless artwork to exhibit and protect, intensive scrutiny was given to quality. In terms of KE's engineering design, the technical requirements were exacting. For example, space temperature and humidity requirements needed to be maintained, because they are critical to the protection of valuable artwork. Piping could not run above the artwork, and mechanical system noise needed to be unnoticeable. (Indeed, CMA had an acoustician to test and verify that noise levels were within acceptable levels.) Air quality was another consideration the design provided for.

But quality also applied to the aesthetic side of the engineering design. As noted above, the engineering design needed to contribute to the aesthetic vision. In the galleries, for example, KE's engineers located items that impact aesthetics (such as fire and smoke detectors, receptacles, and temperature/humidity sensors) not only according to code, but according to the architect's vision of symmetry and elegant lines of sight. In the galleries and throughout the Museum, every electrical receptacle was coordinated, and not one was placed without the Museum's approval. The goal was to integrate these necessary components into the Museum's design.

As design moved into construction, it was imperative that construction be carried out with exactness in order to meet the design intent. As a result, project oversight and quality assurance were priorities, and there was an intensive level of construction administration. For example, the construction manager had a full-time team member to provide quality control and oversee the whole project, quality-wise (a CM superintendent in Phase I and an architect in Phase II). The owner's representative scrutinized the work and construction process. And there was a separate third-party commissioning authority. . To help with construction, KE's designers provided not only plans, but many sections and hand drawings that showed how various systems were to be put together. KE staff were deeply involved in construction administration, attending meetings, answering questions, and seeing that construction met design intent. Additionally, KE's proximity to the Museum – less than four miles (6.5K) from the project site – gave the team ready access and availability.

During Phase II, the CMA project team applied lessons learned in Phase I to improve the construction workflow. At the contractor/construction level, many hours were spent performing 3D model coordination and clash detection using Building Information Modeling (BIM). In certain cases, equipment had to run through very tight

...etween pipes, ducts, and electrical conduits. Phase II experienced a ...s for Information (RFIs) and change orders compared to Phase I.

One KE engineer, who worked on the Museum project from start to finish, commented that the collaboration between all stakeholders made the project successful. He witnessed a "remarkable" buy-in and ownership of the Museum's aesthetic values on the part of the architects, engineers, owner's representatives, construction managers, and contractors.

The Museum staff was involved in design, so the engineering team worked directly with the owner to understand what they were looking for. Museum staff members who would be operating and maintaining the facility provided input on system operations, how systems were controlled, and on the access and clearance needed for maintenance. The project team was also supported by the Museum's IT and security staff, who had to contend with both construction teams and, during certain portions of the project, Museum patrons.

Owner/Architect/Consultant (OAC) meetings and construction meetings, according to KE team members, were collaborative and solution-oriented. Project stakeholders were all at the table. Project team members, said one KE team member, respected one another's roles in the project. Team members tackled potential problems, where they occurred, up-front to avoid the cascading effect of delays on the project. The focus was on working out issues rather than assigning blame.

This was a visible project within the community. The project received regular local media coverage, updating people on construction progress and providing reports on the project financial status. (It also received national media coverage from *The New York Times* and *The Wall Street Journal*.[vi]) With a reported final cost of $320 million (US), the project finished at $30 million less than the $350 million anticipated.[vii]

This massive investment focused on serving the Museum and its patrons for years to come. Indeed, according to CMA, the renovation and expansion "prepares the institution to meet the needs of the public for the next 100 years."[viii] Throughout the project, the utmost care and attention was given to providing an environment that would preserve and showcase the Museum's artwork and artifacts. It is a project designed to outlive the team that made it happen.

As a result, visitors can now experience the Museum's collections in a magnificent, cohesive space whose finished elegance only hints at the engineering that enabled its completion. And the public has responded positively: The Museum recently reported its highest attendance in over a decade, with 501,314 visitors during the 2012-13 fiscal year (a 39% year-over-year increase).[ix]

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[i] http://www.clevelandart.org/about/press/media-kit/cleveland-museum-art-celebrates-significant-accomplishments
[ii] http://www.cleveland.com/arts/index.ssf/2014/01/the_cleveland_museum_of_art_an.html
[iii] http://www.clevelandart.org/about/about-the-museum/history-and-mission
[iv] http://www.clevelandart.org/about/press/general-museum-information
[v] http://www.cleveland.com/arts/index.ssf/2014/01/glass_box_galleries_and_atrium.html
[vi] http://www.clevelandart.org/join-and-give/support-the-transformation/renovation-and-expansion-project/overview
[vii] http://www.cleveland.com/arts/index.ssf/2014/01/the_cleveland_museum_of_art_an.html
[viii] Ibid.
[ix] http://clevelandart.org/about/press/media-kit/cleveland-museum-art-celebrates-significant-accomplishments