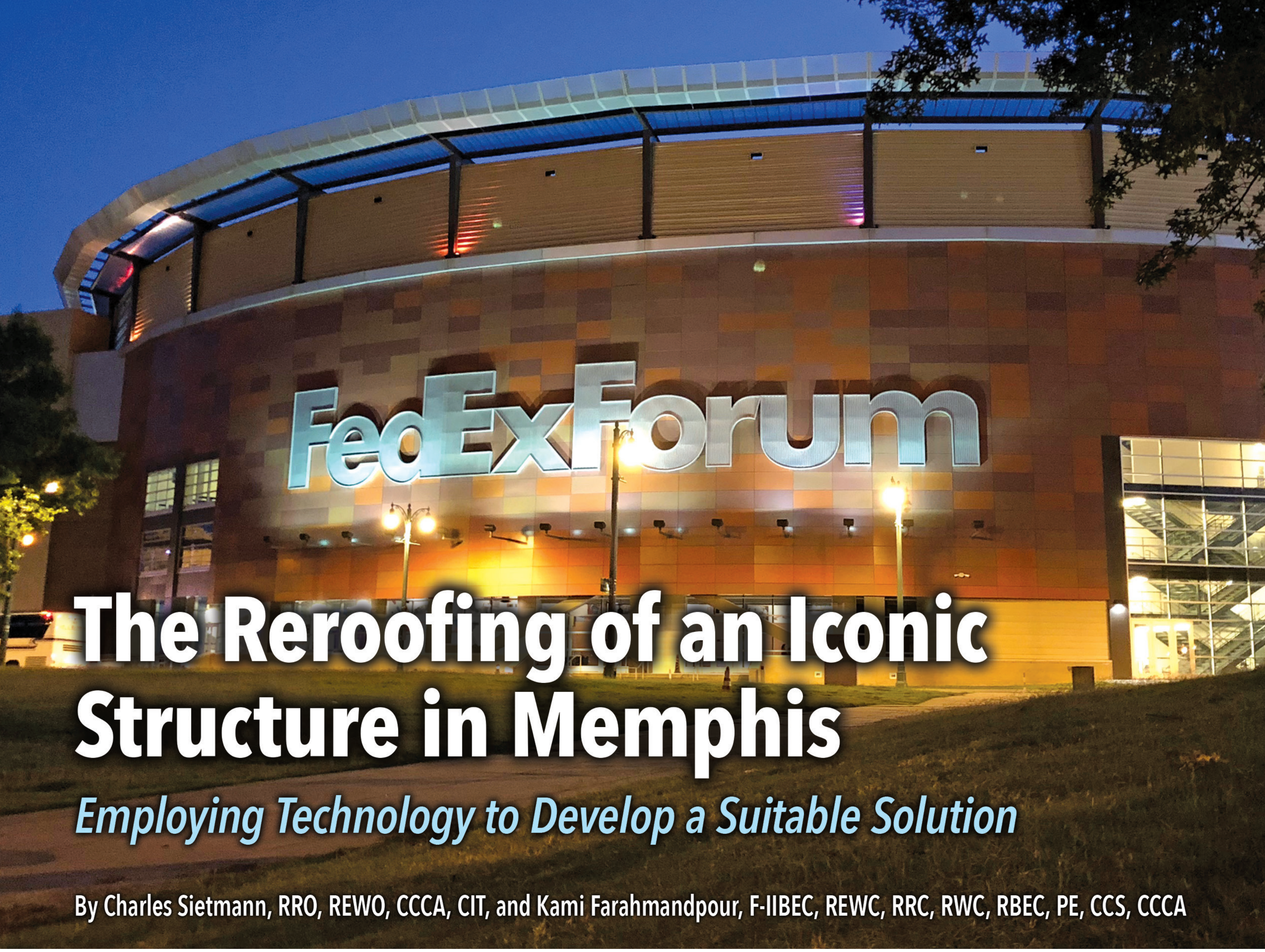

The Reroofing of an Iconic Structure in Memphis

Employing Technology to Develop a Suitable Solution

By Charles Sietmann, RRO, REWO, CCCA, CIT, and Kami Farahmandpour, F-IIBEC, REWC, RRC, RWC, RBEC, PE, CCS, CCCA

Figure 1. FedExForum exterior.

When the 14-year-old thermoplastic olefin (TPO) roofing system at the FedExForum's main dome exhibited leaks, the owners commissioned an evaluation of its condition. The evaluation and subsequent replacement of the roofing system posed several technical challenges.

The evaluation included several diagnostic tools, including high-voltage leak detection, up close and unmanned aerial system (UAS) visual surveys, a thermographic survey using a UAS, and microscopic examination of roof samples removed in the field.

The evaluation indicated that the existing TPO roof membrane exhibited craze cracking extending to its reinforcing scrim, and breaches at numerous locations. Prior repairs and roof coatings had not controlled the ongoing deterioration. The investigation also indicated that the perimeter of the dome exhibited widespread moisture saturation of the insulation. In addition, the upper areas of the dome were primarily dry with localized indications of prior water infiltration, which had resulted in cupping of the existing polyisocyanurate insulation. As a result, the investigators concluded that the membrane had reached the end of its service life.

Based on the findings of the evaluation, the investigators developed three distinct options for the rehabilitation of the roofing system and presented the advantages and disadvantages of each to the owners.

The repair approaches considered the project schedule, which was primarily driven by:

- prescheduled activities at the arena,
- logistical requirements of the site,
- the owner's requirement to have a reliable and long-lasting system,
- requirements for FM Global approval of the roofing system,
- the feasibility of achieving consistent installation quality, and
- cost considerations.

Based on these factors, a hybrid tear-off and re-cover strategy was selected. The upper portions of the dome roof where the existing insulation was found to be dry were re-covered, and the lower portions were torn off and replaced. Both roofing assemblies had to be approved by FM Global for conformance to their requirements and then properly integrated to ensure continuity of the existing and new air barriers.

The construction phase of the project also posed challenges, primarily due to ongoing events at the arena, and difficulties accessing the 135-ft-tall (41-m-tall), 470-ft-diameter (143-m-diameter) dome.

This article provides a detailed description of the evaluation performed by the team, the development of various rehabilitation options, and the bidding and construction-phase challenges.

Figure 2. Overall aerial image of existing dome roof showing the roof sections.

BACKGROUND INFORMATION

Completed in September 2004, FedExForum is an iconic structure in Memphis, Tennessee (**Fig. 1**). The facility serves as the venue for NBA and NCAA basketball games, concerts, and other major events. The facility primarily consists of several interconnected buildings: the dome structure that houses the main arena, several multilevel buildings that house support and administration areas, and a parking structure. This paper focuses on the dome structure; the evaluation of the support buildings' roofs is beyond the scope of this article.

The dome structure consists of a steel frame with 36 perimeter columns and trusses, each forming a 10-degree sector of the dome (**Fig. 2**). The original roofing assembly of the dome consisted of a 20-gauge steel deck supported by the steel framing, two layers of rigid insulation panels, and a single-ply 45-mil-thick TPO roof membrane. A building wrap, apparently serving as an air barrier, had also been incorporated into the roofing system between the upper and lower layers of rigid insulation.

Drainage on the dome roof consists of a perimeter trough, or gutter, that collects stormwater and directs it to several drains around the perimeter of the roof. Overflow drainage is achieved through several large through-wall scuppers in the perimeter parapet wall of the dome. This perimeter parapet wall, which is approximately 4 ft tall, extends around the entire circumference of the dome and encases structural steel members that serve to support a decorative halo around the outermost perimeter of the roof.

Earlier in the life of the structure, leaks and deficiencies through the seams of the dome's TPO roofing system prompted repairs. Those repairs consisted of applying a stripping ply of EPDM membrane over all seams of the TPO membrane. Over the years, periodic water leakage issues had also prompted several other repairs, including numerous patches, coating application, and localized replacement of the membrane in some areas of the gutter. These repairs had not effectively provided a long-term solution to the leaks. As such, the investigators were retained to evaluate the existing roofing systems. The objectives of the evaluation were as follows:

- Evaluate the cause(s) of water leakage and extent of deficiencies that contribute to water leakage.
- Evaluate the overall condition of the dome roof to assess the viability of restoring/rehabilitating the existing roof without a complete tear-off.
- Develop repair/replacement options to address the roof issues. Analyze advantages and disadvantages of various options.
- Assist the owners in evaluating various options and selecting a suitable option.

EVALUATION

The evaluation included a review of available background information, including drawings and information on locations of prior leaks. The field investigation portion of the evaluation commenced with development of a roof plan indicating approximate locations of prior known water leakage issues. This roof plan was then used for documentation purposes during a review of building interior areas. In many locations, rust staining or water staining was observed on the fireproofing material at the underside of the steel roof decks where leaks had been previously reported. At several locations, the fireproofing had spalled, exposing surface corrosion on the structural steel members. Intricate leak control devices consisting of tarps, hoses, and garbage cans had been placed in areas of active water leakage. Most of these locations were concentrated around the lower perimeter of the dome roof and were primarily used as service and storage areas. Therefore, they did not impact the day-to-day operations of the facility. Additional prior sporadic water infiltration had also been reported in the center portion of the dome, including near the edge of the main court area, and at various areas below the dome, with reported water accumulating in draped acoustical insulation sections.

Following the interior review, an exterior visual review of the roof surfaces was performed. During the review, every segment of the roof was numbered and recorded to ensure field observations were recorded in a systematic manner (see **Fig. 2**). In some areas, particularly at the large FedExForum logo stretching across the dome, extensive deterioration of membrane top coating was observed. Additionally, craze cracking, mostly occurring linearly along the machine direction, was observed throughout the roof; this craze cracking appeared to coincide with machine direction of the membrane. In some areas where craze cracking was most prominent, several prior repairs consisting of coatings (multiple applications in some areas), sealant or mastic application, and/or patching had been implemented.

In addition to the coating repairs, all TPO seams had been previously repaired by applying a stripping ply of EPDM over all seams. In some

Figure 3. Unmanned aerial system in use.

areas, the stripping ply of EPDM had debonded from the substrate. Visible punctures and evidence of physical damage to the membrane were observed in a few locations. Protrusions through the membrane were observed at a limited number of locations; these were likely due to insulation fasteners backing out. The roof membrane and underlying insulation also exhibited significant cupping in many locations, suggesting exposure to moisture and subsequent drying of the insulation.

The visual review was supplemented with an aerial review and infrared thermographic survey performed using a UAS equipped with a gimbal-mounted remote thermal imager (**Fig. 3**). Several areas of the dome roof along the perimeter exhibited thermal anomalies (**Fig. 4** and **5**). Some of the thermal anomaly locations coincided with areas that had been previously repaired. Other thermographic anomalies correlated with the extent of craze cracking of the roof membrane. These observations of thermal anomalies indicated that moisture intrusion through craze cracking, and through the resulting tears, had saturated the lower areas of the roof. Similar craze

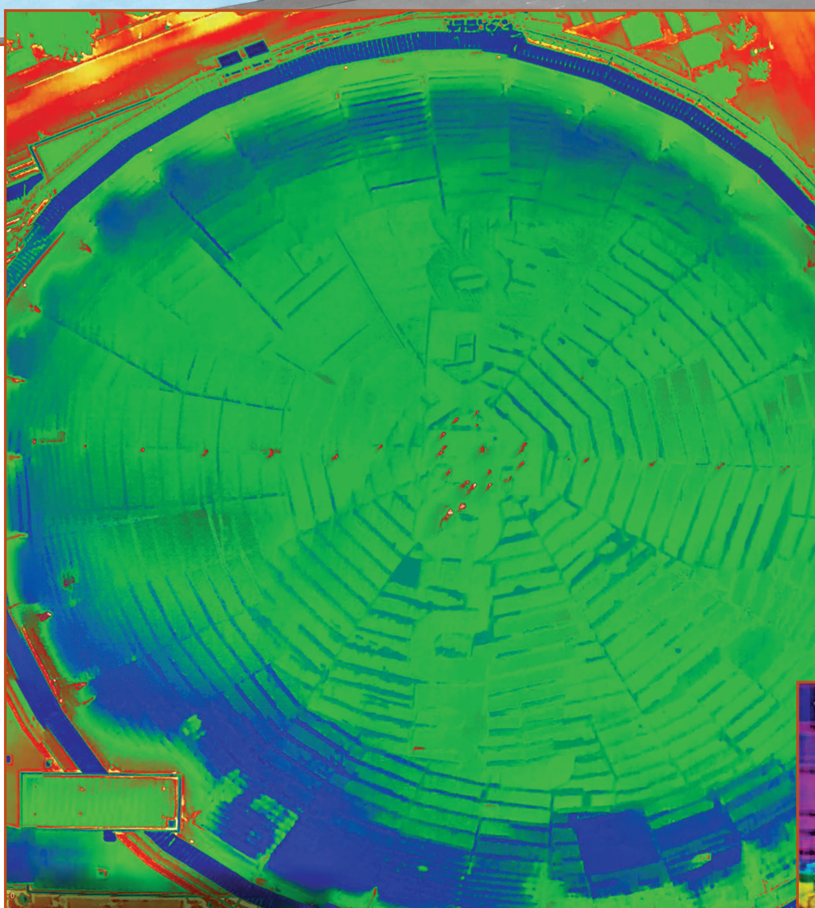

Figure 4. Stitched overall thermal image. Colors between blue and red typically indicate varying degrees of moisture within the substrate, with blue being colder areas, and red being warmer areas. Note the brighter green areas along the lower perimeter of the dome; these represent lower surface temperatures and were primarily areas of suspected saturated insulation.

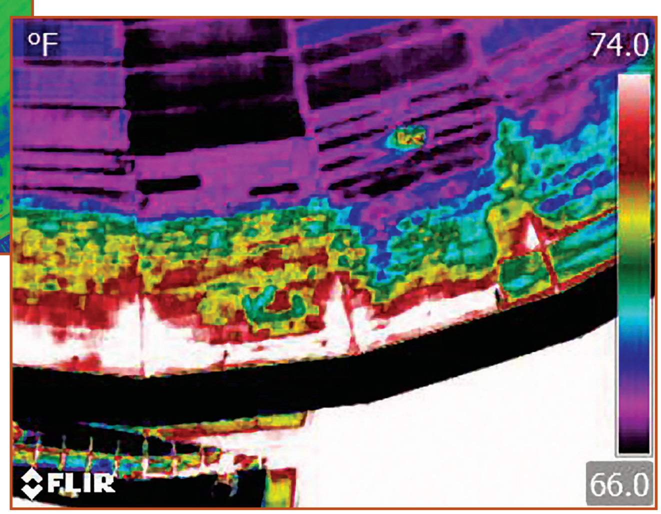

Figure 5. Close-up thermal image at the lower roof. Note thermal anomalies along the lower perimeter of the dome.

cracking was also observed at the upper areas of the dome. However, our infrared thermographic survey did not indicate presence of moisture accumulation on the upper dome areas. This finding was attributed to two factors: (1) as water runs down the dome, the lower areas are exposed to more water, causing more water penetration through the roof membrane deficiencies; and (2) water that penetrated through the roof membrane also runs down the dome through the insulation joints, accumulating in the lower areas. Based on these observations, it was concluded that areas where water penetrated the roof membrane on the upper dome evaporated through the moisture-permeable air barrier. However, the rate of wetting and moisture accumulation at the lower dome areas exceeded the evaporation rate.

Figure 6. High-voltage electronic leak detection testing being performed.

Nondestructive electronic leak detection was performed over most of the dome roof (**Fig. 6**). The testing was performed in general accordance with ASTM D7877, *Standard Guide for Electronic Methods for Detecting and Locating Leaks in Waterproof Membranes*,[1] using a high-voltage method. This method was deemed the most appropriate method of electronic leak detection because the dome roof could not be readily wetted and maintained wet during low-voltage testing. The high-voltareas and re-covering of the existing roof on the upper areas

3. Complete removal and replacement of the roofing system

An order-of-magnitude cost estimate for each option was developed using input from a regional contractor. In addition, a list of advantages and disadvantages, along with approximate life-cycle costs for each option, were developed. Options 2 and 3 provided the most attractive overall life-cycle costs. However, the full replacement was determined to not accommodate the owners' required project schedule, which had to end prior to the start of the basketball season.

DESIGN PHASE

Based on our evaluation of various options and consideration of the project specific requirements, option 2 (localized replacement along the lower areas and re-covering of the existing upper areas) was recommended. It was further recommended that a single-ply PVC/ketone ethylene ester (KEE)/alloy membrane be selected for the new roof membrane for the following reasons:

1. A single-ply membrane system weighs less than multi-ply systems, reducing the amount of materials that would need to be transported onto the roof. Given the size of the roof and its access limitations, the single-ply system could be installed faster and with lower labor and transportation costs.
2. A 50-mil-thick fleece-back PVC/KEE alloy single-ply roof membrane is available in an off-white color without the need for any coatings to meet reflectivity requirements; this product would be more energy efficient than other options, particularly in the Memphis-area climate zone.
3. A PVC/KEE alloy single-ply membrane was deemed more durable, resistant to punctures, and resistant to chemicals than other considered membranes. The higher initial cost of the selected membrane was readily justified because of its reliability and extended service life.

After selection of the roofing assembly configurations and membrane type, an analysis was performed to evaluate the required wind uplift resistance of the new roofing system. The FM Global-approved assemblies that met

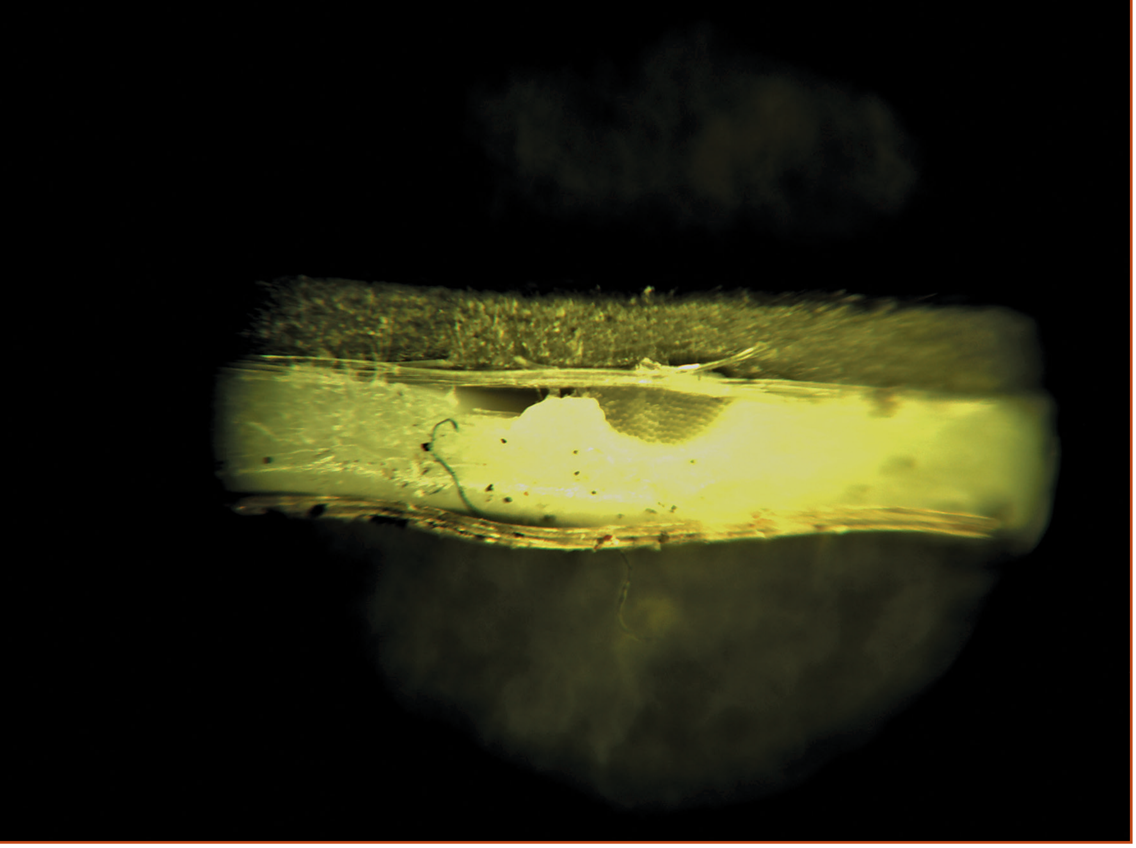

Figure 7. Microscopic examination of existing membrane. Note the void adjacent to reinforcement.

age leak detection testing identified numerous membrane breaches in the test areas. The breaches were recorded and roughly correlated with the extent of thermal anomalies detected through the infrared thermographic survey.

Destructive testing followed, with exploratory openings being made through the roof at various locations. The openings were made at representative locations, at areas of known water leakage, and at locations of thermal anomalies detected through the infrared thermographic survey. These openings confirmed the presence of moisture within the roofing system in many areas where thermal anomalies were detected. The openings also revealed that the existing assembly at the dome roof was unique in nature. The assembly consisted of two layers of polyisocyanurate insulation sandwiching a vapor-permeable air barrier. The encountered air barrier was a high-density spunbond polyethylene building wrap, which is commonly used in exterior wall construction as an air barrier, but is uncommon in roofing applications. Based on the openings made, the extent of the moisture within the lower portions of the dome roof assembly appeared to be pervasive. However, despite the presence of localized areas of insulation cupping and staining on the insulation facer, the upper areas of the dome roof were found to be relatively dry.

Roof membrane samples were removed from several openings and were selected for microscopic examination. For each membrane sample, three cross sections of the roof membrane were cut and examined under a variable magnification digital microscope. The investigators used their in-house equipment to evaluate the depth and potential cause(s) of the observed membrane crazing. Sections cut away from the apparent tears and crazing in the membrane indicated that the craze cracking had extended to the reinforcing scrim, and that there was a thinner TPO top coating than TPO bottom coating (**Fig. 7**). In one section, nearly the entire top TPO coating had been diminished. This condition was likely due to exposure to elements over the years that reduced the top coating thickness. In addition, in several examined sections, voids were observed near the reinforcing scrim; these were likely due to the original manufacturing process.

The results of our evaluation indicated that the dome roof was in poor condition. Given our findings, it was apparent that the leaks experienced at the FedExForum main dome were due to ongoing deterioration of the roof membrane. The deterioration of the roof membrane was determined to be at an advanced stage and could not be reliably controlled through localized repairs alone. Therefore, a more comprehensive repair program was needed.

The owners were presented with three options, as follows:

1. Localized replacement along the lower areas and recoating of the upper areas
2. Localized replacement along the lower

the wind uplift criteria were reviewed to identify those that met all the design criteria. This meant that two separate roofing assemblies—one for the re-cover areas, and one for the tear-off areas—had to be identified. Both assemblies had to use the same membrane and accessories to simplify field installation. During this phase of the design, consultation with the membrane manufacturer's technical department proved invaluable.

The PVC/KEE alloy membrane system being considered offered several options for attachment, including mechanical attachment or an adhered system. Mechanical attachment of the membrane would have eliminated any issues with the attachment of the existing insulation. However, mechanical attachment would have also resulted in concentrated uplift forces to be applied along the batten strips. The mechanical attachment of the system would have required an additional evaluation to ensure the roofing system's interface with the structure would not be adversely impacted.

Ultimately, for the re-covered areas at the upper portions of the dome, a mechanically attached coverboard and a fully adhered roof membrane system were selected. An assembly with a mechanically attached gypsum-fiber roof board, a self-adhered vapor retarder, adhered insulation and coverboard, and a fully adhered roof membrane was selected for the replacement areas along the lower dome.

Typical details were developed for the two different roofing assemblies; these details included, but were not limited to, drain and penetration details, as well as details for wall interfaces, scuppers, roof hatches, and door thresholds. Roof plans showing the extents of the areas requiring full roof replacement were developed and correlated with the infrared survey. The interface of the self-adhered vapor retarder with the existing air barrier was detailed at the transition of the fully replaced area to the re-covered area to ensure continuity. The vapor retarder was lapped under the existing air barrier, and the air barrier was secured to the vapor retarder with self-adhesive tape.

The cupped areas of the insulation on the upper roof were specified to be repaired on a localized basis using unit prices. Detailed field notes taken during the evaluation phase enabled the designers to develop a fairly exact estimate of the required unit-price repairs.

The design phase also included a careful analysis of the site logistics, facility event schedules, and a new FedExForum logo with exacting color requirements. All these requirements were to be specified prior to bidding the project to minimize the potential for change orders.

The owners also expressed a desire to provide lighting around the perimeter of the large FedExForum logo. However, at the time of the roof design, the exact configuration of the lighting system was not known. Therefore, the support of a future lighting system had to be designed to provide the flexibility to accommodate various lighting options and placements. To accomplish this, a steel grillage system was designed to be connected to the steel deck. The design of the system had to consider wind loads under worst assumed conditions and provide infinite flexibility in placement of lighting fixtures around the perimeter of the logo. Details were developed for engineered lighting supports. In the end, the owners decided not to include installation of lighting supports in the project, but they have the option to do so at a later time if desired.

BIDDING AND VALUE-ENGINEERING PHASE

A sophisticated contractor with sufficient resources was needed to ensure timely and

Figure 8. Staging area and crane in use.

proper completion of this highly complex project. Local availability of skilled and sophisticated contractors with the resources to complete this project was limited. The owners also expressed the desire to improve diversity in the project through minority participation. The project was privately bid to local, regional, and national contractors.

Qualified contractors were invited to participate in an on-site prebid meeting. The project description and scope of work were discussed in depth, and site-specific issues such as security, staging, access, and phasing were also reviewed. Bidders conducted a site tour to review the logistics of the project.

During the bidding process, several value engineering opportunities were discussed. Stainless steel fasteners had been originally specified for the coverboard attachment but were replaced with coated fasteners meeting FM Global approval. Stainless steel termination bars were also replaced with aluminum termination bars.

In lieu of the originally specified three layers of polyisocyanurate insulation on the lower dome areas, two layers of insulation were included, which still met the specified minimum R-value. All other system characteristics remained as specified in the design documents.

After receipt of the bids, a follow-up interview was conducted with the lowest responsible bidder to further review the schedule, logistics, and project costs. The project was ultimately awarded to this contractor,

Figure 9. Roof re-cover in progress at the upper dome.

Figure 10. Roof re-cover in progress at the upper dome.

Figure 11. Tear-off in progress at lower dome. Note the signs of moisture on the existing insulation.

which was also the most qualified and was able to meet the bidding document requirements.

CONSTRUCTION PHASE

Exterior access to the main dome roof during construction provided its own challenges. Personnel access was achieved by use of a stair tower placed on the top level of the adjacent parking garage. The stair tower reached the freight elevator penthouse roof, and additional ladder access was needed to reach down to the lower dome gutter areas. To reach the top of the dome, workers had to traverse the rounded slope of the dome.

Transportation of materials to the top of the dome roof posed the biggest logistical challenge. The use of a large crane (a mobile crane with 100-ft [30-m] tower, luffer boom, and large outriggers) was required to reach the central area near the top of the dome (**Fig. 8**). Use of a smaller crane with less reach and capacity was also required during tear-off of the lower dome areas.

Once the materials were placed on the roof, moving materials around the roof posed its own challenges due the dome's shape and the narrow gutter area around the lower dome (**Fig. 9** and **10**). The steel beams around the perimeter of the roof also made it difficult to navigate through the gutter area. Materials had to be strategically placed, and supported, around the dome to limit material movement issues while on the roof, and to avoid overloading of the roof structure.

Given the configuration of the dome and the adjacent attached buildings and parking decks, the crane had to be placed on the east side of the dome and remain at that location throughout the duration of the construction. This required the closure of the street and setup of a staging area for an extended period of time. The need to maintain a proper exit path through the staging area had to be closely coordinated with arena operations and scheduled events. However, because the exit path would only be needed during events, and the crane would not be active during such times, overhead protection was not deemed necessary.

On event days, contractor work hours were limited from sunrise to 3:00 p.m. Scheduling was further complicated on days when a morning dew was present on the roof surfaces, making access to the top of the dome slippery and difficult. Access to the exterior side of the through-wall scuppers, which were over 120 ft (37 m) above grade, was also difficult due to the adjacent structures. Depending on the location of the scuppers, the use of tall ladders or long-reach personnel lifts was required.

Other logistical concerns throughout the construction phase included noise, odor, and dust issues. If not controlled, these issues not only would impact the arena itself but also could impact the adjacent buildings and businesses. Thanks in large part to a responsive contractor, these issues were minimized.

In total, approximately 225,000 fasteners and plates were necessary to attach the layers of coverboard and insulation. The installation of the mechanical fasteners into the metal deck created noise that echoed throughout the building interior and therefore required close coordination with building operations.

The areas designated for full replacement were reviewed during tear-off and appeared to correlate with the extents of the thermal anomalies observed during the evaluation phase's infrared survey (**Fig. 11**). No changes in the

Figure 12. Work progress around the dome.

Figure 13. Completed work, including the new logo.

limits of the tear off areas were needed. This was primarily due to the comprehensive nature of the evaluation phase, which provided the designers with valuable information.

Although the design documents included the possibility of some steel deck replacement, the steel roof deck appeared to be in good condition and did not require extensive repairs. Repair of cupped insulation on the upper dome areas was also not needed, as the mechanical attachment of the coverboard was able to address the

Figure 14. Work progress at the lower dome.

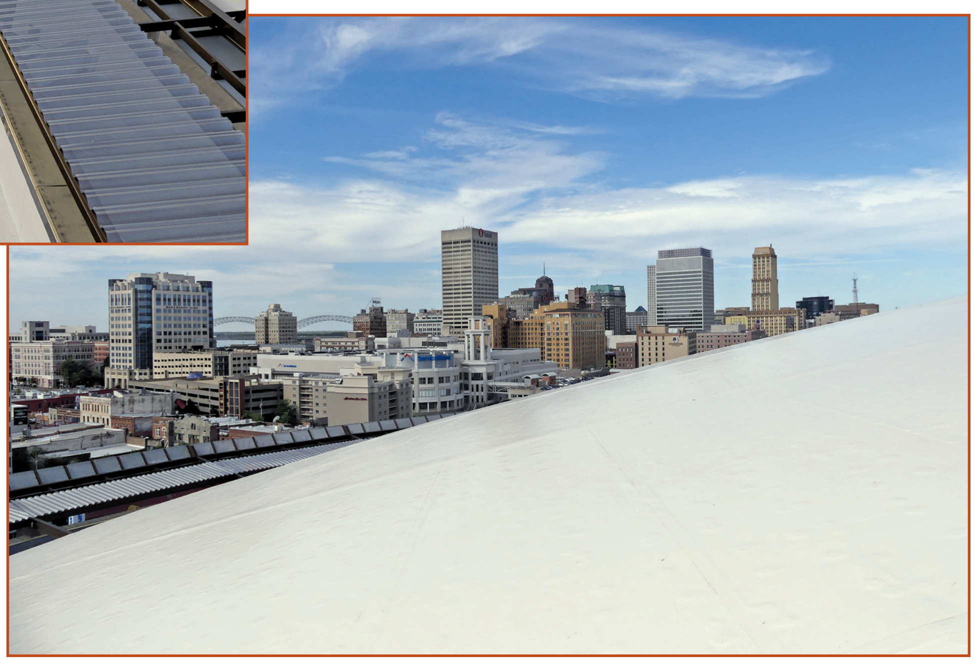

Figure 15. The completed roof overlooking downtown Memphis.

cupping. The savings in the construction phase of the project allowed for replacement of several dome penthouse roofs, which also made use of the exterior access that had been provided to access the dome.

The project was successfully completed on time and within budget, with minimal change orders (**Fig. 12–15**). Although basketball games and other events under this beautiful new roof have been impacted due to the ongoing COVID-19 pandemic, we know this venue will be home to many significant events for years to come.

REFERENCES

1. ASTM International. 2014. *Standard Guide for Electronic Methods for Detecting and Locating Leaks in Waterproof Membranes*. ASTM D7877, West Conshohocken, PA: ASTM.

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