Online exclusive

Historic Industrial Building Reuse and the Building Enclosure

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THE INDUSTRIAL REVOLUTION in the United States brought about large-scale industrial facilities throughout the country. During the late 19th and early 20th century, these industrial facilities were generally constructed using mass masonry. Mass masonry structures are composed of multiple-wythe brick masonry and may include stone, concrete masonry units, cast stone, and terra cotta. Mass masonry was common for industrial structures during this period, as brick masonry could be fabricated from local materials and could be manufactured in a size that was manageable for the labor force. In addition, this type of construction was adequate for the industrial use requirements of the period, as the load-bearing masonry walls had a long service life (**Fig. 1**).

Over time, these facilities were often abandoned, whether it was from industry shifting toward production overseas; requirements for a new, modern industrial space; or closure of businesses. With a shifted focus on sustainability and the preservation of historic structures over the last couple of decades, preservation and reuse of historic industrial facilities has become more prevalent. However, these facilities are often inadequate for the requirements of modern-day industrial use, which results in an adaptive reuse approach. Adaptive reuse often changes the occupancy type of the structure and requires restoration of the facility along with physical modifications to accommodate the intended occupancy and to meet the current design requirements for the new occupancy type. Due to the location, history with surrounding communities, desired industrial aesthetic appearances, and sustainable use of existing materials, adaptive reuse projects have been presented as viable alternatives to new construction. Reuse of existing building stock in-situ is a sustainable building option for multiple reasons: the structure and exterior enclosure are existing and the embodied carbon/energy within the existing on-site materials is retained; there is a reduction in the materials which must be provided and transported to the site for construction; and the historic integrity of the structure can be preserved. While the cost of new materials is avoided and historic tax credits are often granted, owners/developers should be prepared for specialized costs, such as including additional evaluation and design needs stemming from working with existing conditions, unexpected existing problems that will require solutions during construction, the cost of skilled restoration labor for the mass masonry, and the cost of replacement materials which will maintain the historical integrity of the structure.

Design considerations for restoration and adaptive reuse involve knowledge outside what is typically understood for new, modern cavity wall construction. A lack of understanding regarding the building science related to the original construction and the design considerations for the correct performance of the building enclosure for its new occupancy type can result in multiple challenges during construction and future occupancy of the structure. It is important for the design/consulting team to communicate an understanding of the cost, effort, and design of the building enclosure system which is required for adaptive reuse of historic mass masonry structures. An understanding of and investment in design and evaluation for adaptive reuse projects can prevent costly errors during construction and potential errors that will affect the structure's ability to meet the requirements of its new occupancy.

Figure 1. *Overview of previous industrial mass masonry structure during construction of adaptive reuse project.*

RESERVOIR SYSTEMS

When compared with modern-day cavity wall construction, a mass masonry building enclosure functions differently. While cavity wall systems are intended to function as a barrier system with a drainable cavity, a mass masonry building enclosure is a reservoir system that is designed to interact with moisture. A mass masonry wall (reservoir) system impedes bulk water from reaching the interior of the structure during a wetting event by shedding a majority of the water at the exterior surface. Water absorbed past the exterior surface into the masonry is retained and subsequently released once the wetting event has passed. Depending on the exterior and interior environmental conditions, water absorbed within the masonry wall has the potential to dry to the interior or exterior of the wall.

Originally, the potential for moisture drive to the interior was accommodated, intentionally or unintentionally, by leaving the interior masonry exposed or by installing interior finishes with high permeability. This was conducive to drying that may occur through the interior masonry face. Additionally, when compared with modern-day structures, these structures did not have the same requirements or considerations for energy efficiency. Often, during the cold months, excess heat was provided to the interior environment of industrial facilities through radiant heaters, while in hot months, fenestration with large, operable panels provided ventilation.

The excess heat during the cold months resulted in drying of the reservoir systems to the exterior, while the lack of air conditioning during the hot months mitigated colder interior surfaces' propensity for condensation. Modern HVAC systems, which heat, cool, and often dehumidify buildings, along with requirements for higher R-values of the wall assembly, were not factors for these structures during the period when they were constructed; thus, they are important factors to consider for adaptive reuse.

In the past few decades, an increasing number of these mass masonry industrial structures are being converted to modern living spaces. Often, these renovations include the addition of insulation to the wall assembly; less permeable interior finishes, which are frequently moisture sensitive (**Fig. 2** and **3**); and a conditioned interior environment. Conditioning the interior environment, installing insulation, and applying moisture-sensitive interior materials create conditions which can result in moisture-related damage. This elevated moisture within the interior finishes presents a potential for biological growth.

Adding insulation to the exterior walls to meet modern and code-required R-values

Figure 2. *View of moisture-related damage to interior finishes.*

Figure 3. *View of low permeability barrier installed at wall interior.*

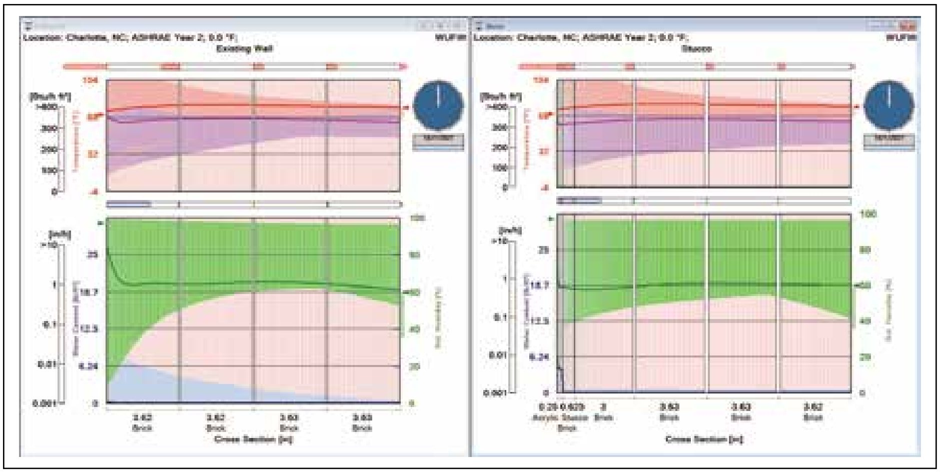

Figure 4. *WUFI analysis results in animation still.*

Figure 5. *Representative view of masonry requiring restoration.*

requires special consideration for mass masonry (reservoir) systems. Historic preservation requirements, requirements of the intended occupancy, and design analysis of the hygrothermal response changes to the building enclosure system and changes to the building enclosure system requirements are integral parts of a mass masonry adaptive-reuse project.

BUILDING LAYERS AND DESIGN ASSESSMENT

Assessing historic structures for adaptive reuse requires a multifaceted approach. As a first step, the designer/consultant should compile and review the structure's existing history and documentation. Expectations for historic integrity and allowable modifications should be identified and agreed upon, as they will guide design decisions. Once existing information regarding the structure is known, an evaluation of the code requirements for that occupancy and the modifications of the existing structure required to meet them can be performed.

It is important for the designer to properly assess the modifications to the building envelope system that are necessary for the new occupancy requirements. Understanding the performance of the in-place mass masonry structure and any potential adjustments to the system(s) is critical to ensure the system(s) will function as intended. This is accomplished through an understanding of building science, use of hygrothermal analysis, and proper detailing. The Glaser method, known as a dew-point analysis, provides the location of the condensation temperature. However, this method is limited in the information it can provide, as it does not take into account multiple factors, such as built-in moisture and driving rain, and is based on a steady-state condition. Fraunhofer IBP developed Wärme Und Feuchte Instationär (WUFI) software to perform dynamic hygrothermal analysis. WUFI is a valuable tool for understanding modifications to mass masonry construction that are required for adaptive reuse projects. WUFI provides the designer with an evaluation tool to understand how the modifications to the reservoir system will affect its hygrothermal performance (**Fig. 4**).

SITE EVALUATION

Masonry restoration and evaluation will be required as part of adaptive reuse. Over its lifetime, a mass masonry reservoir system will have a number of maintenance-related items, including but not limited to repairs of cracking within the masonry; repair of spalled masonry units; repointing mortar joints that have cracked, recessed, or separated from the brick masonry units; removal of biological growth; removal of abandoned fasteners or abandoned steel elements; and repairing abandoned penetrations (**Fig. 5**). Cracking must be evaluated to determine if there are underlying conditions that need to be resolved to prevent the cracking from reappearing after the masonry has been repaired and to identify potential structural issues.

In addition to general maintenance items, the porosity of the brick masonry may need to be evaluated. Over time, brick masonry expands from its kiln-fired volume and increases in porosity. Increased porosity allows for additional water to be absorbed into the masonry and for the water to travel further within the reservoir wall system.

Increased porosity of the brick and anomalies within the brick masonry can prevent the masonry from properly impeding the movement of moisture to the interior during a wetting event and can result in overloading of the reservoir system or in bypasses through the reservoir system. This can allow for bulk water intrusion or for an increase in the moisture present at the interior face of the masonry.

EVALUATION CONSIDERATIONS

On-site testing is recommended as part of the mass masonry evaluation and adaptive reuse design process. Because mass masonry reservoir systems behave more as an integrated unit compared with modern veneer cavity wall systems, evaluation of mass masonry walls for water intrusion can be more difficult than evaluation of a cavity wall system. Testing is often limited to a few components at a time and may not capture the multiple components contributing to overloading of the mass masonry wall during a single test. The familiar testing approach of starting at the base of the area of concern, moving horizontally, and then moving vertically is also applicable to testing mass masonry. This should include care to isolate testing areas and prevent overspray and runoff from impacting locations outside of the test. However, documentation of the condition and locations of the areas tested prior to the current test is a key factor in understanding what conditions are contributing to the overloading of the masonry system. There is a potential that the previously tested areas will contribute to the overloading of the system, resulting in water intrusion observed during a later test. When evaluating mass masonry walls for water intrusion, two key factors help to interpret the results and guide the recommendations:

- system vs. condition and
- failure mode.

Water intrusion through a mass masonry reservoir system may be the result of an inability of the building envelope system to meet the requirements demanded of the system as designed and/or it may be the result of degradation or anomalies within the building envelope system. It is important to distinguish which aspect of the system is being evaluated during testing: its adequacy or its condition. A system that has performed well in the past may have additional components installed that result in moisture-related failures of the assembly or may be introduced to additional requirements that are outside of its original design. These can include installation of new interior finishes, installation of additional thermal resistance, installation of new exterior applications to the mass masonry, or changes to the interior environmental conditions. Evaluation of the interior environmental conditions, destructive testing to evaluate components which may have been added to the mass masonry system, evaluation of site and roof drainage, evaluation of observed cracking to determine if there are underlying conditions, and evaluation of potential rising damp provide information on whether the existing building envelope system needs to be modified to adequately meet the current performance requirements. Evaluation of the condition of the masonry for maintenance items such as cracking, debonding of the mortar from the masonry, recessed mortar joints, biological growth or foreign materials, condition of the fenestration and the installation, porosity of the masonry, and spalling provides insight into the restoration efforts which will be required to restore the system back toward its original level of performance.

The failure mode observed while testing provides valuable information to assist the designer/consultant with recommendations and repairs. The quantity of water intrusion observed should be noted to inform the designer of the severity of the issue they are attempting to address. Water intrusion through mass masonry may be observed as a damp portion of the masonry wall that does not result in bulk water intrusion, a damp portion of the wall that results in bulk water intrusion through multiple gaps and cracks within a masonry wall area, or bulk water intrusion that is confined to a condensed entry point. While a damp interior masonry surface may not result in bulk water intrusion, it can contribute to failure of interior coatings and finishes by increased moisture drive to the interior and by increasing the moisture content at the interior finish-to-masonry interface. When water passes through masonry, or cementitious materials such as mortar, it can transport minerals from within the masonry and deposit them on the face of the masonry; this is known as efflorescence. Coating failure from elevated moisture or vapor drive typically consists of unadhered pockets of the interior coating (**Fig. 6**). When opened, efflorescence within the unadhered coating pocket is often observed.

Water intrusion that starts as a damp portion of the masonry and results in bulk water intrusion through multiple anomalies within an area of the masonry wall points to overloading of the masonry reservoir system, which may require greater effort to restore the mass masonry.

Water intrusion at a condensed interior entry point indicates a more direct pathway through the masonry wall (**Fig. 7**).

SITE EVALUATION PROCEDURES

The following are evaluation procedures that can be utilized when assessing mass masonry reservoir systems.

ASTM E2128

ASTM E2128, *Standard Guide for Evaluating Water Leakage of Building Walls*,[1] provides an outlined standard for evaluating water leakage of building walls. This includes, but is not limited to, references to AAMA 501.2, *Quality Assurance and Diagnostic Water Leakage Field Check of Installed Storefronts, Curtain Walls and Sloped Glazing Systems* (Monarch Type B-25 brass nozzle testing);[2] ASTM E1105, *Test Method for Field Determination of Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls, by Uniform or Cyclic Static Air Pressure Difference* (spray rack testing);[3] and AAMA 511, *Voluntary Guideline for Forensic Water Penetration Testing of Fenestration Products*.[4] The primary purpose of ASTM E2128 is to "recreate leaks that are known to occur," not to "demonstrate code compliance or compliance with project documents unless such deviations are actually related to the leakage problem."[1]

Modified ASTM E1105

A modified ASTM E1105 procedure is available for testing of masonry (**Fig. 8**). It is titled *Using Modified ASTM E1105 to Identify Leakage Sources in Building Wall Systems*.[5] This modified procedure recommends utilization of a similar water application rate, but instead of a 15-minute test duration, a 30-minute test duration is specified. This modified method lists

Figure 6. *Representative view of unadhered pockets of interior coating with efflorescence behind unadhered coating.*

Figure 7. *Representative view of damp portion of wall with water weeping from anomalies at the interior masonry surface.*

Figure 8. *Representative view of Modified ASTM E1105 testing of mass masonry.*

construction of a negative pressure chamber on the interior as optional.

Masonry Absorption Testing In-Situ

When evaluating masonry for absorption of water at the exterior surface, two methods currently exist: RILEM tube testing and ASTM C1601, *Standard Test Method for Field Determination of Water Penetration of Masonry Wall Surfaces*.[6] The data obtained from this testing provides information regarding the porosity of the brick masonry and whether options to reduce porosity should be considered. This test method is also useful in evaluating coating materials as previously described to determine the efficacy of the material being used in conjunction with the masonry of the structure. A baseline reading of the material must first occur, followed by application of the coating material and subsequent testing to compare the results to determine if the material is functioning as intended.

RILEM Tube Testing

Technical committees, through *Reunion Internationale des Laboratoires d'Essais et de Recherches sur les Materiaux et des Constructions* (RILEM), developed a testing method for evaluating water absorption rates of masonry exposed to water at the exterior surface. This testing method is commonly called the RILEM tube test. This procedure involves using a graduated cylinder with an open end attached to the wall using putty to ensure a tight seal. Water is filled to the appropriate level (the water level loosely correlates to wind loading) and is allowed to remain within the cylinder for a measured period of time. At the end of the intended test time, the water level is measured, and an absorption rate is calculated from the change in water level over time and from the surface area of the wall that is exposed to the water in the RILEM tube. When utilizing RILEM tube testing, different sample locations should be tested, including the face of brick, mortar T-joints, mortar bed joints, and mortar head joints.

ASTM C1601

ASTM C1601[6] measures water penetration of an in-situ masonry surface. This test involves mounting a minimum 12 square foot, closed chamber to the exterior side of the masonry specimen. The chamber is positively pressurized, and water is introduced within the chamber as a sheet flow down the face of the masonry. The water applied to the masonry is drawn from a well with an initial water volume and is returned to the well through an outlet at the bottom of the chamber, creating a closed testing system where water can only escape by absorption into the masonry. The change in water volume over time and the change in water level at the end of the test correlate to the water absorbed into the masonry through application to the exterior surface.

Both RILEM tube testing and ASTM C1601 have benefits and limitations. RILEM tube testing is easier to set up and less time-consuming compared with ASTM C1601 testing. A RILEM tube test can be completed by one person in the span of 15 to 30 minutes, with multiple RILEM tube tests running at the same time. An ASTM C1601 test can take between four and six hours to complete and often requires two people to set up. However, the exposed masonry surface area during a RILEM tube test is 0.88 square inches, compared with the minimum exposed masonry surface area during an ASTM C1601 test of 12 square feet. According to an article by the National Concrete Masonry Association, "A study conducted at the University of Wyoming concluded that 1,665 tests would need to be conducted for every 12 ft^2 (1.11 m^2) of wall surface being evaluated in order to achieve a sample error of 10% or less [8]. Hence, drawing any conclusions about the water penetration characteristics of an entire wall assembly based on 50, 100, or even 500 tests can be speculative at best."[7] This does not mean that data from RILEM tube testing is not useful, but rather that there are additional limitations on the conclusions that can be drawn from the data. RILEM tube testing provides a simple and portable evaluation tool to make relative inferences regarding the absorption performance of the masonry. However, if the designer/consultant desires to measure and report in-situ surface water absorption rates for masonry, ASTM C1601 should be utilized. Both tests are best used to test before and after results for a mass masonry wall. While an absorption rate is obtained from ASTM C1601, the test does not include pass/fail criteria.

Air Leakage Testing

ASTM E779, *Standard Method for Determining Air Leakage Rate by Fan Pressurization*[8] is a quantitative test for measuring building air leakage. ASTM E1186, *Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems*[9] is a qualitative test for identifying potential sources of air leakage. Both test methods use a mechanically produced pressure differential across the building envelope (pressurization and/or depressurization). ASTM E1186 has multiple methods for utilizing tools to identify air leakage locations, including infrared thermography, hand-held or theatrical smoke, pressure chambers, and bubble gun testing.

Detailing

As mentioned earlier in this paper, mass masonry walls do not conventionally contain drainage planes and do not have cavities containing insulation or open cavities where insulation may be installed. When designing repairs or retrofit conditions needing bulk water and water vapor resistance, the wall must be treated as a barrier system. As will be discussed, this simply written requirement can create other issues for the designer which also must be addressed.

Because mass masonry walls provide water shedding and reservoir retention, the first approach to reusing mass masonry walls is to repair the existing masonry components back to original conditions, or as close as is possible with modern methods. This includes items discussed previously. The specifics of masonry repair can be found in many different publications and are not covered in detail within this paper. However, the proper design and specification of the mortar joints will impact how well the wall can shed water.

As noted earlier, the design of the new mortar joint is critical. Not only the joint shape, but also the pointing mortar's composition should be carefully selected. Depending upon the historic nature of the wall and whether the original wall design is legally protected by historic regulations, a designer should specify the mortar joint geometry to be concave. Many historic masonry walls were constructed with joints struck flush with the wall face or raked back from the wall face. In some cases, the authors have seen joints raked as much as ½ inch back from the wall face. Numerous studies have been performed and results published regarding how these types of mortar joints have far inferior resistance to water absorption compared with a concave struck joint. During repair design, the use of a concave struck mortar joint should be considered. The concave shape helps the joint resist moisture intrusion. The mortar composition should be soft or softer and should have porosity similar to or greater than the existing mortar. Throughout history, mortar joints have been the "sacrificial" portion of a mass masonry wall and were softer than the surrounding brick. If any conditions were to place stresses on the wall, including the natural expansion of the brick masonry units over their lifetime, the mortar joints would degrade to prevent the alternative face spalling of the brick masonry units. To replace historic mortar with a more modern, harder mortar may cause internal stresses to fracture the now softer masonry units, rather than the mortar joints. To match the existing mortar strength, petrographic and/or chemical tests should be performed on wall samples. At a minimum, mortar much softer than modern mortars should be selected for historic masonry mortar pointing. This is a durability design decision, though, and should be thoughtfully considered. If the reader wishes to know more about selection of specific historic mortar mixes and why concave joints resist bulk water better than other joint geometries, numerous articles and research results can be found within the industry and academia addressing the specifics of these topics.

The historic nature of mass masonry walls predicates that most were constructed prior to the mechanical conditioning of interior spaces. The reuse of buildings built with mass masonry walls creates a state where the mass of the wall alone must separate interior and exterior environmental conditions. These environmental conditions may often be on opposite ends of the environmental spectrum, such as hot/humid outside and cold/dry inside. Also, given the mass of a mass masonry wall, there is intrinsically some insulative value, but not to a degree which would help prevent condensation on the colder side of the wall. In addition, masonry, being an absorptive material, will naturally allow water vapor to be transported from the high-pressure side of the wall to the low-pressure side. This makes the design of a water-resistant exterior wall using existing mass masonry a difficult endeavor. No matter the final design solution, the wall design and expected wall performance should be coordinated with the design of the HVAC system. It is likely the HVAC system may have to accommodate thermal and humidity conditions affected more by the exterior environment than would occur in a more modern building. A discussion about HVAC design is beyond the scope of this paper, though, and will only be touched upon, as mass masonry walls are impacted by the differences between the interior and exterior environments.

Given that the nature of mass masonry requires the mass of the wall to respond as a barrier to air and vapor transmission, design options are rather limited. Bulk water must be controlled at the exterior masonry face. Vapor transmission could be controlled at the interior or exterior face but, given that the bulk water should be controlled at the exterior face, the design should not develop a condition where any moisture could be trapped within the mass of the wall between interior and exterior control layers.

There are multiple ways to make a mass masonry wall perform better as a barrier system to liquid water. These are typically in the form of coatings which are applied to the exterior surface of the building. The desired efficacy and aesthetic results will influence a designer's decision as to which method is selected. Any method selected may affect the final appearance of the building and could impact any historic designation the building may carry.

More difficulty is imparted to a mass masonry renovation project when designing approaches to thermal barriers. Raising the thermal resistance of a mass masonry wall requires adding insulation to the wall. Adding it to the interior side of the wall, which is the only place to physically locate it without changing the exterior aesthetics, changes the thermodynamics of the wall. The interior masonry face, which was once exposed to the conditioned or tempered interior air, is now thermally separated from the interior, making it colder. Depending upon the geographic building location, this could make the interior masonry face reach temperatures where condensation of interior water vapor could occur, should that vapor be allowed to pass through the insulation. Interior vapor barriers may be used but could also create a condition where moisture within the masonry which evaporates toward the building interior could become trapped within the wall behind the vapor barrier. This approach may influence the selection of the liquid water barrier design for the exterior masonry face. In this case, it would be imperative to use a liquid water barrier with high permeability, allowing any water vapor within the masonry to dry to the exterior of the building and not become trapped behind the interior vapor barrier. Interior vapor barrier selection should also be very carefully considered with some consideration toward "smart" vapor barriers, which can change permeability depending upon the level of humidity present.

As can be expected at this point, the hygrothermal changes stemming from modern exterior wall renovations are complicated and difficult to determine through general knowledge of thermal movement from hot to cold and vapor movement from high pressure to low pressure. This is where WUFI analyses performed on the original wall design and then on various design options can greatly help the designer better understand how a new wall design may respond to the environmental conditions and whether over time, it will have an opportunity to dry and remain within the parameters where condensation and the possible biological growth associated with moisture and many building materials do not form.

Water-Repellent/ Waterproof Coatings

Often, water repellents and waterproof coatings are used interchangeably; however, there are important differentiating factors that should be understood prior to approaching restoration. The National Parks Service brief "Assessing Cleaning and Water-Repellent Treatments

Figure 9. *View of cotton mill constructed in 1897.*

Figure 10. *Representative view of new fenestration installed in existing mass masonry wall opening.*

for Historic Masonry Buildings"[10] describes water-repellent coatings as breathable, meaning they allow vapor to pass through the system while keeping liquid water from penetrating the surface. Conversely, waterproof coatings are intended to seal the surface from liquid water and vapor.

While the first line of defense against water intrusion should be properly repointed and repaired masonry, often water intrusion may still appear, whereby alternative options such as coatings as described may be considered. If moisture intrusion continues following proper repairs, consultation with an architectural conservator should be made to determine applicable systems and approach strategies.

These coating systems are often inaccurately prescribed to remedy bulk water intrusion without understanding the function of the wall system. Most historic masonry structures have survived hundreds of years without the use of coating materials and, if properly maintained, should continue to function as designed.

Detailing coatings around wall openings, such as windows and doors, can be rather difficult. In a wall containing a drainage plane, fenestrations can be sealed to the barrier creating the drainage plane. This creates continuity of the water barrier from the drainage plane to the fenestration. With coatings applied to the building exterior, or those which are absorbed into the masonry units, creating a continuous system requires removal of the sealants around the fenestrations and application of the coating to a point beyond where a proper seal may be made between the fenestration and the wall. Ideally, all fenestrations would be removed prior to installing the coating. This allows the coating to wrap the entire fenestration opening. However, water-repellent coatings are often the type which is designed to penetrate the masonry and can be relatively transparent. Ensuring the fenestration sealant is continuously sealed to the coating around the perimeter of all fenestrations cannot be ensured without water testing the fenestrations following the completion of the coating and installation of the fenestration sealant. It should be noted that these systems often have wind- driven rain warranty limitations, are limited in their warranty duration, and generally require maintenance after 10 years.

CASE STUDIES

Terracon has been involved with several projects where historic industrial buildings, namely mill buildings in the southeastern US, have been repurposed for multifamily residential or office buildings. The historic appearance of the building was desired to be retained while providing a conditioned interior for the occupants. With most of these projects located in the southern US, the design cooling load was high, and the vapor drive was predominantly from the building exterior to the interior. The locations of the air and water management planes required scrutiny. Selection of building enclosure improvement materials and detailing of transitions between components went through several iterations and reviews to determine the best solution for the given conditions.

Case Study 1

A former cotton mill constructed in 1897 was reimagined as a high-end apartment complex (**Fig. 9**). The two-story structure consisted of brick mass masonry wall construction with stucco applied over the brick at various locations. The spaces include primarily residential units, leasing office, recreational space, fitness room, and clubhouse. Construction consisted of interior and exterior renovations, including window replacement. The existing window systems were 12 feet tall with segmental arched tops replaced as part of the renovation. The arched head and jamb interfaces were mass masonry with the sill finished in concrete (**Fig. 10**). Shortly after the building opened, leaks were reported by residents at windows. Water testing was performed on the assemblies isolating the fenestration system and the surrounding construction independently. Windows installed in mass masonry construction require particular attention to detail, as the interfaces surrounding the windows provide opportunities for moisture to penetrate the masonry and migrate beyond the system and into the interior space. Upon investigation, it was determined that water intrusion was a combination of the assembly construction including sealant joints as well as migration through the masonry adjacent to the fenestration. Recommendations provided to the client first included the repair of the fenestration assemblies. Because the fenestration assemblies were customized, limited modifications could be provided

Figure 11. *Representative view of cracking in stucco.*

Figure 12. *Representative view of forensic water testing.*

to mitigate the moisture surrounding the opening; therefore, the perimeter of the assembly was detailed using masonry sealer.

Case Study 2

A firehouse constructed circa 1890 comprising a load-bearing, multiple-wythe brick masonry structure with a wood-framed interior was remodeled in the 1930s, including the installation of cement stucco on the brick masonry wall exterior. At some point in the building's history, cement stucco was also applied to the interior. A second coat of softer, possibly gypsum-based stucco was added to the interior over the cement stucco. When the building was adapted to be a conference center, modern HVAC systems were added and due to its location in the southeast US, and the numbers of people who can fill the conference center, it is often in cooling mode, which is also drying the interior environment.

In recent years, the building owner had repaired numerous problems with the exterior and interior stucco (**Fig. 11**). The exterior cracks had been repaired in 2010 and 2016, yet the interior continued to experience water damage in the form of the soft stucco coat spalling and the interior paint bubbling. Terracon was contracted to do visual observations and water testing to determine the source of the water intrusion and interior damage (**Fig. 12**).

The visual observations and testing revealed numerous locations where liquid water was infiltrating the stucco substrate (**Fig. 13**). Through capillary flow and the drying of the exterior wall to the building interior, a significant amount of liquid water and water vapor were damaging interior finishes (**Fig. 14**). Difficulty arose in understanding which exterior conditions created which interior damage. Water from testing was revealing itself on the interior in locations unexpected by the testing team.

Figure 13. *Representative view of original fenestration.*

Figure 14. *Representative view of soft stucco wrapped into the window rough opening.*

For this reason and to ensure a continuous barrier system could be installed around the entire building, a waterproof coating with high permeability was specified for the exterior. All the windows were specified to be replaced, which allowed the coating to wrap the window openings and the perimeter sealant to bridge between the window frame and the coating at every window.

Because the application of the coating would likely trap some of the existing moisture within the wall and create a condition where the path of least drying resistance was toward the interior, the owner was advised the interior repairs would need to wait for a couple of months. This was to ensure most of the walls would be dry enough to not create further problems with interior finishes. The interior finishes were also addressed. The soft stucco was recommended to be removed and replaced with cement stucco, which would be less susceptible to moisture damage. To help allow the wall to dry to the interior, high-permeability paint was specified.

In addition, the roof was nearing the end of its serviceable life. This allowed the design team to develop a parapet cap solution, making the new coating continuous with the roofing system. Therefore, the entire building enclosure would be continuous and tight from the grade to the roof.

CONCLUSION

In closing, historic industrial mass masonry buildings are a popular candidate for adaptive reuse, such as multifamily dwellings and commercial buildings. These new uses within historic enclosures present design and performance challenges which can create conditions detrimental to interior construction and air quality and have negative impacts upon the users. By understanding the building science behind how mass masonry walls perform and how the changes to the interior environment influence performance, the designer can better make repair decisions and material selections, which can extend the life of the building and provide a sustainable and financial benefit for the building owner.

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