Use of Advanced Documentation and Analysis Technologies at the Shaughnessy House Conservatory in Montréal

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Conservation of a greenhouse with a warped cast-iron structure provided a foundation for implementing advanced documentation and analysis technologies.

Fig. 1. The Shaughnessy House, 1923 René-Lévesque Boulevard West, Montréal, Québec. View from Dorchester Street (now René-Lévesque Boulevard), after 1910. The conservatory appears at the far left. Courtesy of the McCord Museum.

This paper considers an expanded role of documentation technologies in the representation and preservation of architectural heritage. In the field of heritage preservation, there is a growing need to accurately represent and analyze historic buildings and structures using digital technologies. Implemented survey methods can play an essential role in documenting both the tangible and intangible qualities: architectural, historical, physical, and material. Through the lens of a case study, the preservation and restoration of the Shaughnessy House conservatory in Montréal, Québec, this paper examines how advancements in documentation and analysis technologies—point-cloud scans, BIM software (Revit by Autodesk), and THERM (Two-Dimensional Building Heat-Transfer Modeling)—together with fundamental heritage and material considerations, have served as a successful basis for an architectural heritage conservation project. The Shaughnessy House conservatory, given its complex geometries, decorative elements, and warped cast-iron structure, provides a foundation for the implementation of advanced documentation and analysis technologies for heritage conservation.

Traditionally, the documentation of heritage structures has existed in a two-dimensional space: survey plans, photographs, drawings, schedules, and analysis reports. In the last decade and a half, there have been developments in the use of Building Information Modeling (BIM) software for use in a heritage context. Maurice Murphy defines this application, Heritage Building Information Modeling (H-BIM), as "a novel solution whereby interactive parametric objects representing architectural elements are constructed from historic data." H-BIM pursues the modeling and documentation of architectural elements according to artistic, historical, and constructive typologies.[1]

The Square Mile House and the Shaughnessy House

The construction of the Shaughnessy House in 1874–1875 by William T. Thomas (1829–1892) was characteristic of its bourgeois setting on the western edge of downtown Montréal in the second half of the nineteenth century. The Square Mile neighborhood (sometimes referred to retroactively as the "Golden Square Mile") was developed on the southern flanks of Mount Royal.[2] It was characterized by opulent homes, landscaped gardens, tree-lined boulevards, and proximity to prestigious institutions, including McGill University.

Heritage Montréal describes the Square Mile as "where the men who had built both the country and the city lived."[3] It housed the dominant figures of the political and economic landscape of Montréal and Canada in the nineteenth and early twentieth centuries. By 1900, it has been said, up to 75 percent of the wealth in Canada was controlled by those living in the Square Mile.[4] The Shaughnessy House was conceived as a three-story, semi-detached residence for two prominent families associated with the construction and consolidation of the Canadian Pacific Railway.

The Shaughnessy House residences were built in the Second Empire style, characterized by their mansard roofs, large bay windows, symmetrical facades, and ornamented stone, woodwork, and iron roof cresting. One of the distinctive elements of the house is its ornate glazed conservatory, constructed as an addition in 1910. The conservatory, an exposed cast-iron structure, features curved glazing, and decorative cast-iron elements (Fig. 1).

Threat of Demolition and the Canadian Centre for Architecture

Following the Great Depression of the 1930s in Canada, many owners of the bourgeois mansions of the Square Mile moved away, and the residences were transformed into more modest apartments and rooming houses. In the 1950s and 1960s, zoning changes permitted the construction of high-rise buildings in the Square Mile. Civic and commercial developers acquired and built on available land, leading to the demolition of many of the great mansions. By 1983 only 5 percent of the mansions south of Sherbrooke Street in the Square Mile had survived demolition.[5]

The Shaughnessy House itself was threatened by demolition in the 1970s. The widening of surrounding streets and construction of access routes to the Autoroute Ville-Marie in the 1950s and 1960s had considerable impact on the immediate surroundings of the Shaughnessy House, which "found itself alone in the middle of a quadrilateral coveted by property developers."[6] In 1973 the property was listed for sale; developers were keen to acquire this prime piece of real estate. However, every development proposition involved destruction of the Shaughnessy House.[7] The same year, it was purchased by Phyllis Bronfman Lambert, an architect and heritage-preservation activist, and designated a National Historic Site of Canada.

Lambert founded the Canadian Centre for Architecture (CCA), an international research institution, museum, and archival center, in 1979. The Shaughnessy House was rehabilitated and integrated into the CCA building during its construction (1987–1989). The CCA building was conceived as a "main addition" to the Shaughnessy House, according to the design of architect Peter Rose, with Lambert as consulting architect.[8]

Today, the Shaughnessy House is one of the last remaining mansions of the Square Mile that is publicly accessible. Its heritage value is recognized by all three levels of government in Canada—federal, provincial, and municipal. The cast-iron conservatory is listed as a "character-defining element" by the Canadian Register of Historic Places.[9]

By 1989, nearly 80 years after its original construction, the conservatory required extensive repairs. It was restored with the rest of the Shaughnessy House, according to the plans of Rose and Lambert. The conservatory's original single-pane glass was replaced with half-inch-thick curved, insulated glazing units. The cast-iron structure was disassembled, repaired, and reassembled in its original location. At this time, several modifications were made to its original design. Notably, the cast-iron structure, thought to have originally corresponded to the color of the adjacent Montréal limestone, was painted in a dark green to contrast the grisaille color palette selected by the 1989 design team for the exterior woodwork (Figs. 2–3).

2020 Conservation Mandate

By the late 2010s the Shaughnessy House conservatory required another conservation campaign. Many of the interventions of the 1989 restoration had reached the end of their useful life and threatened the heritage components, namely the original exposed cast-iron structure. At this time, significant corrosion was observed on the exterior of the conservatory. Several decorative cast-iron elements were missing. Considerable condensation was observed inside the conservatory, both on the glazing elements and the interior surfaces of the cast-iron components. Resolution of difficult maintenance issues in the decades since the last restoration campaign had been attempted by applying caulking throughout the conservatory.

In 2020 EVOQ Architecture was engaged by the CCA to design and execute the interventions necessary to preserve and restore the conservatory, and where possible, improve the envelope's thermal performance. Given the highly specialized nature of conservatories, no off-the-shelf conservation solution was available. Therefore, all interventions had to be carefully considered custom responses to the as-found conditions.

Use of Documentation Technologies

A secondary aspect of the 2020 conservation mandate required EVOQ to update the CCA's existing 3D digital model, created in the Revit software by Autodesk, in order to attain a higher level of detail (LOD) of the conservatory and to correspond accurately to the as-found site conditions. The CCA's existing base model had an LOD of 200, which is typical of models used for general building maintenance and planning purposes. A base LOD of 300 was prescribed for the improvements to the conservatory model; some decorative elements were modelled to an LOD of 400 to produce conservation documents and details of the ornate structure. Though the client prescribed the model's LOD in this case study, the purpose of the model and its required accuracy should always be defined at the onset of an architectural heritage conservation project. This project served as a first case study in the CCA's vision to utilize a central Revit model for all future building construction and conservation projects. In this way, the model will act as a "living archive" of the site, documenting changes as they occur with each progressive construction project.

Documentation and representation of the conservatory's existing conditions would have proven challenging with traditional survey methods and computer-aided design and drafting (CAD). First, the conservatory's geometry is complex and highly detailed.

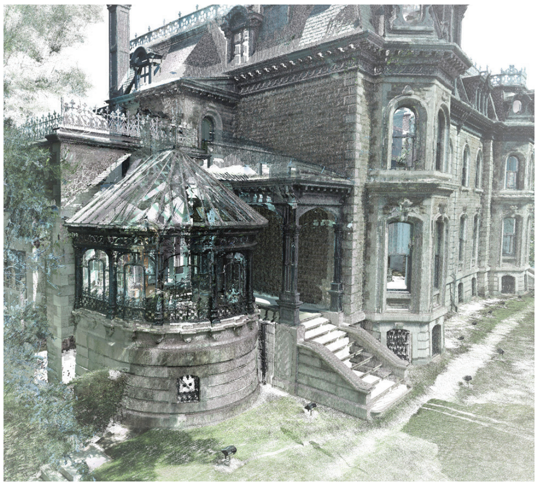


Fig. 2. The conservatory at the start of the restoration work in 1985. Courtesy of the Canadian Centre for Architecture.

Fig. 3. The conservatory in 2020. Photograph by EVOQ Architecture.

Fig. 4. Point cloud scan of the Shaughnessy House and the conservatory, 2022. EVOQ Architecture.

Second, the cast-iron structure had settled and warped in the century since its construction. No two cast-iron elements were still identical: each possessed various degrees of deviation caused by warping. Precise measurements of deviations, details, and complicated geometries of the structure would have been time consuming and challenging, especially given difficult access to the conservatory's roof structure.

Data Acquisition and Processing

EVOQ was required to implement an organized and comprehensive H-BIM methodology for the realization of this project. To begin, the conservatory was laser scanned to generate a point cloud, a geospatial data set consisting of individual points defined by their x, y, and z coordinates. Laser scanners can register millions of points per second, rapidly capturing highly accurate surface data. Depending on the scanner's capabilities, these points can be captured between 1 mm to 2 mm apart, even when scanned from a distance of 10 meters or more. Generally, multiple scans need to be performed from different locations as objects may obstruct the scanner's view. Each scan creates a partial point cloud, which is merged to establish the global point cloud, providing a holistic view of the site. This raw data is then processed and clarified by eliminating "noise," the extraneous information captured by the scanner, such as non-pertinent objects.

The point cloud is then imported into the BIM software, in this case, Revit (Fig. 4).

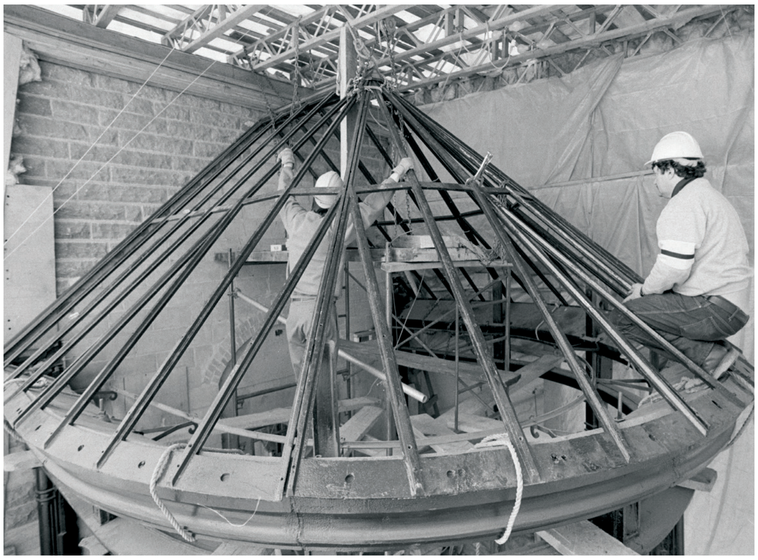


Fig. 5. Reinstallation of the structural roof elements of the conservatory during the 1989 restoration campaign. Depicted working practices may not conform to current safety regulations. Courtesy of the Canadian Centre for Architecture.

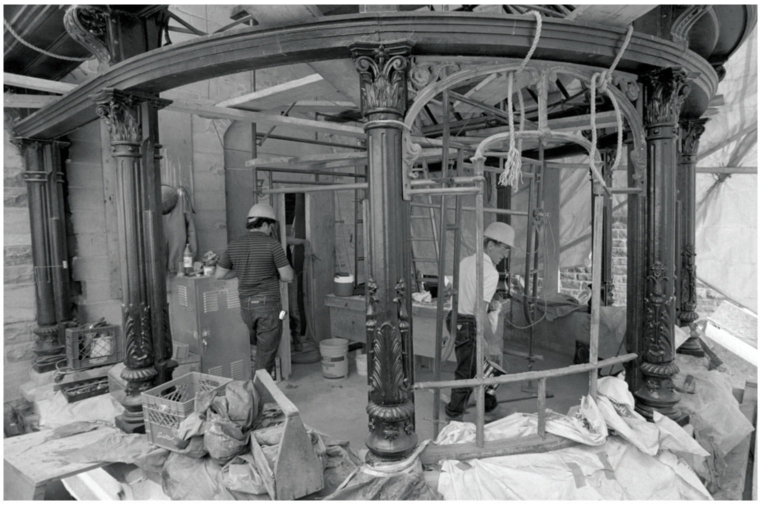


Fig. 6. Reinstallation of the conservatory's cast-iron window mullions during the 1989 restoration campaign. Courtesy of the Canadian Centre for Architecture.

Point clouds can be powerful tools for heritage representation when integrated with BIM technologies. They provide an accurate basis for measuring, modeling, and verifying geometries. Laser scanning allows for rapid documentation of as-found conditions compared to traditional survey methods. Interior and exterior scans for a small-scale project like the conservatory can be performed in approximately eight hours, including the scan of the surrounding landscape. This quickly provides holistic, accurate information of as-found conditions, compared to traditional survey methods, which were estimated to have taken upwards of a week for two or more surveyors in this case.

However, point clouds have their limitations. Scanners, and the resulting point clouds, can capture only the surface conditions of geometries. Assembly details and surfaces beyond what the scanner registers are not captured in the point cloud. In this case, the CCA provided point cloud scans of the interior and exterior of the conservatory through an external point cloud scanning service.

Traditional Investigations and Research

The accurate representation of heritage buildings and structures cannot rely on the foundation of point clouds alone. There are too many gaps in information, both quantitative and qualitative, to provide a holistic understanding. In this case, EVOQ researched the CCA's existing archival documentation to trace the conservatory's evolution from its original construction to the 1989 restoration. More information than what was available in the point cloud was also required to understand the assembly details of the conservatory, since the scan can register only surface conditions. Additional research was undertaken to identify common practices at the time of construction for this type of structure.

This research produced archives of original plans and photographs from the conservatory's past restoration campaign. The photographs documented the daily operations of the construction site in 1989, providing vital insight into the assembly details that were not evident in the point cloud (Figs. 5–6). The photographs proved to be particularly invaluable for the team's understanding of the construction and became a primary reference source for the remainder of the project.

Remaining gaps in information were resolved with traditional survey methods. Exploratory openings were undertaken on site in conjunction with structural and building-envelope consultants, to understand material compositions and qualities. These efforts were documented with measured surveys, sketches, and photography.

Parametric Modeling and H-BIM Libraries

BIM is traditionally used for new construction projects. It is an "integrative tool for the design, representation, production, and long-term management of the built environment."[10] The software combines multi-dimensional visualization with parametric geometric databases, which can be assigned non-geometric information and data. The model information can be leveraged to produce documentation (floor plans, elevations, sections, details, perspectives, schedules, etc.) in a semiautomatic way.

H-BIM workflows differ from traditional BIM workflows since the model must correspond to the as-found conditions. Standard BIM object libraries do not typically have sufficient detail or parametric capabilities to accurately represent heritage building components. The construction of libraries of custom parametric object families for heritage preservation projects is, therefore, a fundamental requirement for H-BIM methodology.[11] In this case, a breakdown and identification of each individual conservatory element was performed before the modeling process began. This discretization provided a greater understanding of the conservatory's structural system and identified elements that required further investigation to understand their assembly.

Following the identification of each element of the conservatory, fundamental features were outlined for the parametrization of the corresponding custom object family in Revit. These features included geometric attributes, relationships with adjacent components, constraints, and other non-geometric variables such as material information. Identification of constraints was especially important for establishing accurate relationships between adjacent elements in the subsequent modeling phase.

A library of custom H-BIM families should be created according to the needs of a project, using the point cloud scan and survey data as reference. In the case of the conservatory, this library included structural elements (columns, ring beams, roof structure), envelope components (curved and flat glazing elements, gutters, downspouts), decorative elements, and interior components. The modeling process of each H-BIM custom family began by tracing profiles

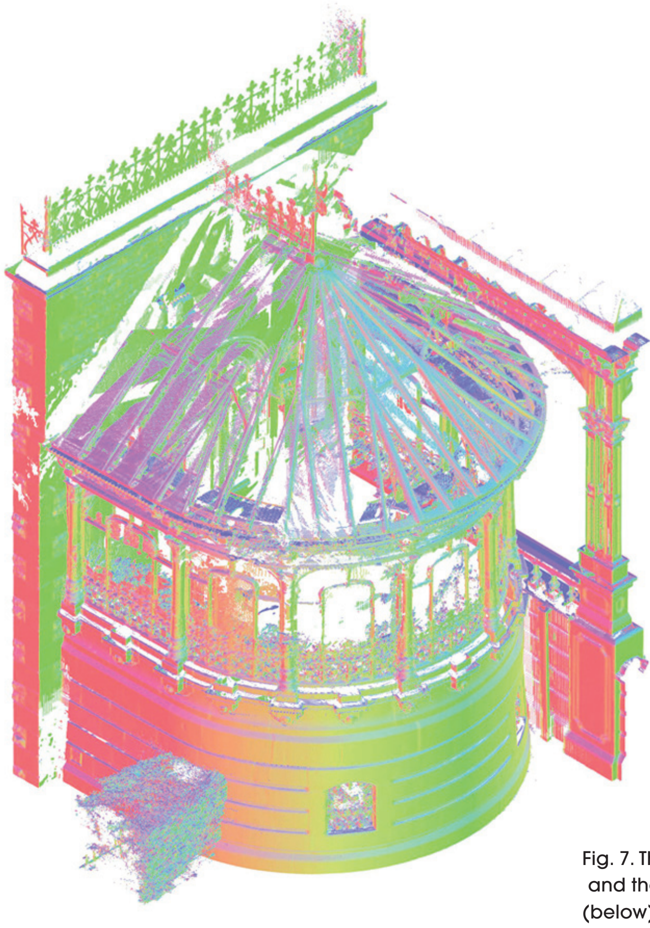
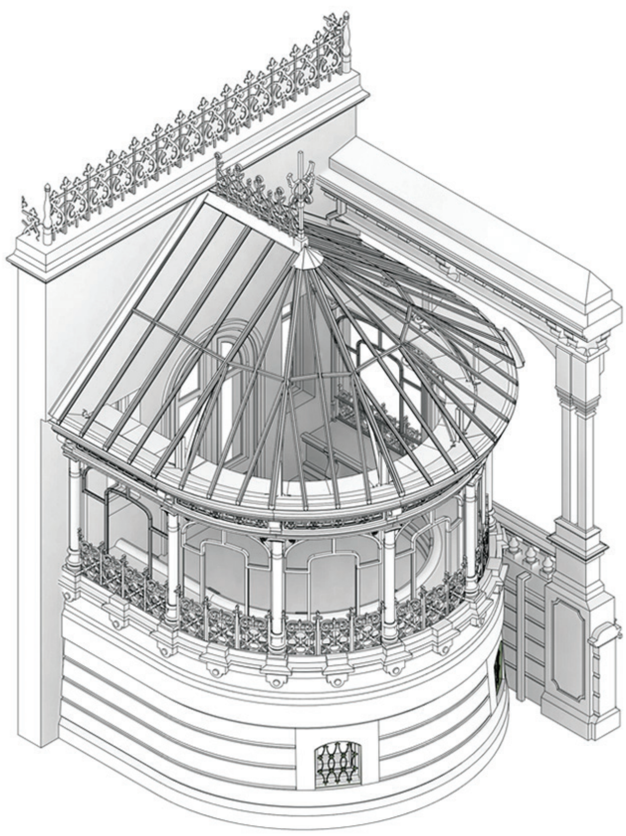


Fig. 7. The point cloud scan (left) and the resulting H-BIM model in Revit (below). EVOQ Architecture, 2022.



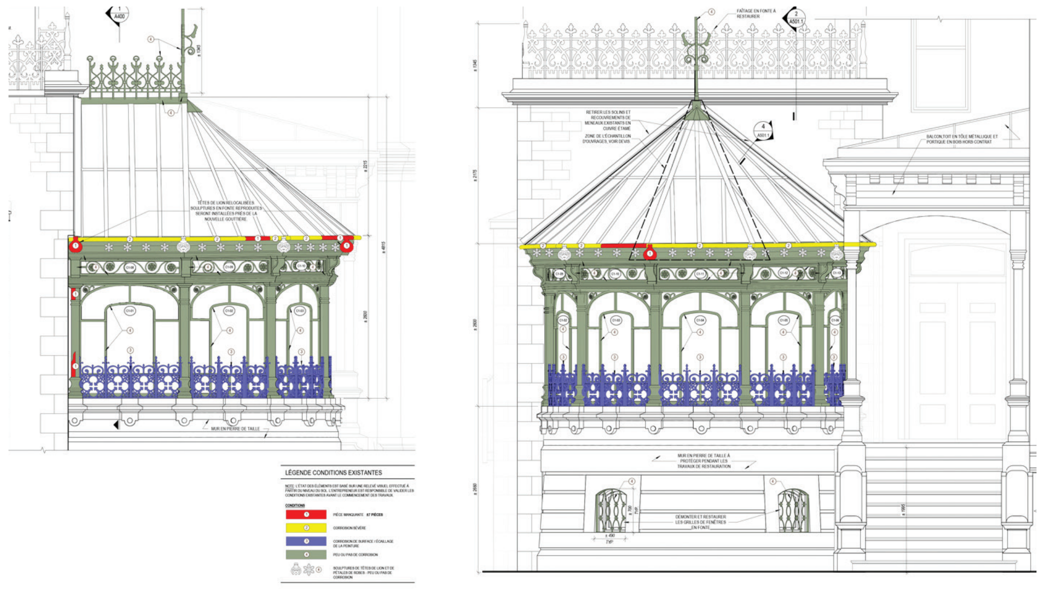


Fig. 8. Elevations of the conservatory, prepared as part of the conservation documents using Revit. The drawings illustrate the levels of deterioration of the cast-iron elements. EVOQ Architecture, 2022.

of multiple cross sections of the point cloud in Revit. Since the point cloud contains large amounts of information, sections were taken with narrow view depths to focus on each individual conservatory element. After the profiles were traced, their dimensions were cross-referenced with secondary data sources for accuracy. The profiles were used to identify dimension constraints, symmetry axes, and other guides. 3D model families were typically created using extrusions, sweeps, and revolves of the profile, or combinations thereof. Each family was further controlled by a series of fixed and adjustable parameters, identified before the modeling process began. This allowed for a high degree of control and accuracy in the 3D model. For example, each portion of the conservatory's ring beam elements had a standard radius parameter and section profile but required adjustable vertical deviations due to the warped nature of the structure.

Following the creation of parametric model families, individual model elements were mapped using the 3D surface of the point cloud, a process which Murphy refers to as "reverse engineering."[12] In doing so, the H-BIM model contains information beyond the object's surface concerning its material composition and methods of construction (Fig. 7). The final H-BIM model of the conservatory was generally accurate to the point cloud scan within a tolerance of 10–25 mm or less, which is typically considered to be highly accurate for heritage conservation projects.

It is possible to input additional data associated with model components that describe other pertinent non-geometric historical and conservation data. For example, in the case of the conservatory, the levels of deterioration of the cast-iron elements were input into their corresponding individual model elements. The levels of deterioration were programmed to appear as different colors in certain 2D views in Revit, allowing for a succinct reading and analysis of their condition (Fig. 8). Ramona Quattrini et al. extend this concept to propose the integration of cultural and historical memories, maintenance programs, and temporal data that represents events that occurred throughout the building's life.[13] The components of an H-BIM library have the potential to provide a detailed reading of the analyzed heritage data and can also be used to produce technical conservation documentation.

Design Iterations and Conservation Documents

The mandate for the 2020 conservation of the conservatory called for improvements to the envelope's thermal performance. Many of the observed deteriorations could be attributed to the envelope's low thermal efficiency and construction details where maintenance proved difficult over time. However, this was a challenging undertaking: the original cast-iron structure possesses the most significant heritage value, yet is, by its very nature, a significative thermal bridge. Working together with building envelope and hygrothermal specialists, UL Solutions Inc. (UL), EVOQ's design strategy focused on altering the interior dew point of the conservatory to minimize harmful condensation.

Thermal Design Iterations

The performance of the proposed construction details was compared to the as-found assemblies to ensure hygrothermal improvements. Multiple iterations of construction details were tested in critical areas of the conservatory. These tests were performed by UL using THERM software, a program developed at Lawrence Berkeley National Laboratory for modeling two-dimensional heat-transfer effects in building components. Though Revit has the potential to

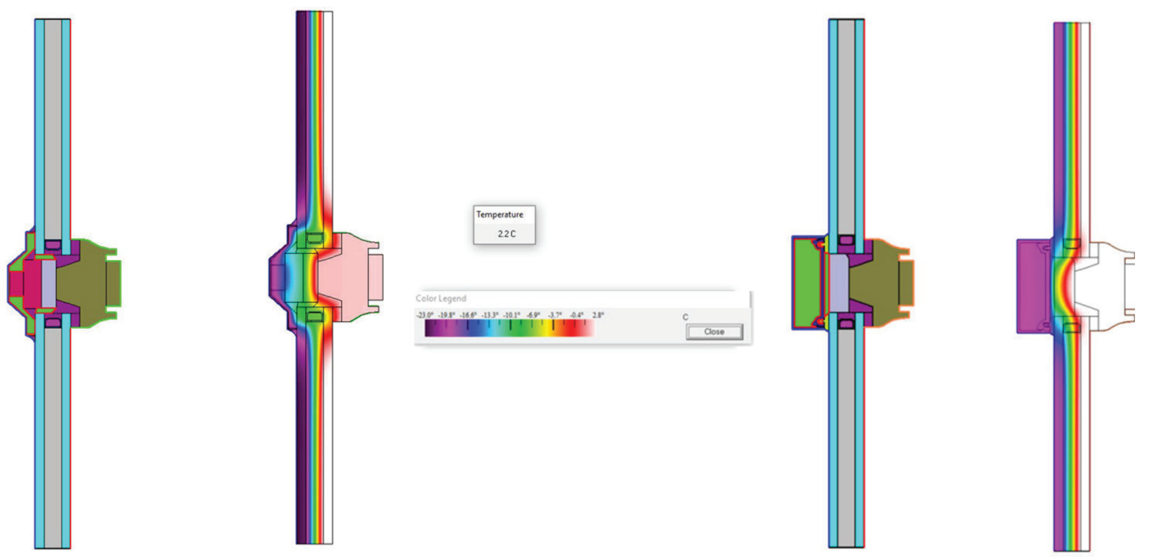


Fig. 9. THERM simulation of the as-found roof mullion assembly (left) compared to proposed construction detail (right), illustrating improved thermal efficiency. UL Solutions, 2021.

perform thermal analyses through the use of plug-ins or integration with other software, THERM was the preferred standard software of the hygrothermal consultants in this case.

THERM is a fully integrated simulation environment originally conceived to model thermal properties of windows, but its applications are also especially useful for modeling thermal bridges. First, a cross-section of the component to be analyzed is imported into the THERM software. In this case, 2D sections were exported from the updated conservatory Revit model for analysis. The sections reflected the information gathered in previous project phases: analysis of original documentation, material findings of exploratory openings, and model geometries validated against the point cloud scans. Then, all external boundary segments were automatically located by the software, to which material properties were assigned such as emissivity and air temperatures. A heat-transfer analysis was performed, outputting graphic results in various formats: isotherms, flux vectors, or color infra-red images. The program can solve complex heat-transfer problems more accurately than traditional calculation methods, especially those related to thermal bridging, which can cause unanticipated temperature gradients.[14]

EVOQ and UL utilized THERM's graphic capabilities to quickly analyze heat-transfer problems at critical areas of the conservatory and to compare the impacts of different material choices and assemblies on their thermal performance. These simulations did not assume to accurately reproduce the actual conditions of the conservatory; instead, they aimed to better target the weaknesses of existing details and determine possible solutions for performance improvements. Notably, these simulations tested new window and roof mullion compositions, junctions with the masonry of the Shaughnessy House, and various glazing thicknesses and Low-E coatings, amongst others (Fig. 9).

Conservation Documents

After updating the H-BIM model to a higher LOD to accurately represent as-found conditions and validating the performance of proposed hygrothermal interventions, the Revit model was leveraged for the production of conservation documents. This included a construction drawing set for the preservation and restoration of the conservatory that was tailored to the unique parameters of the project. Semiautomatic extraction of geometric, numeric, and graphic data from the Revit model facilitated this process.

Typical plans, elevations, sections, and detail drawings were populated with the conservation data associated with the individual parametric Revit model elements. In some instances, this information was represented graphically, such as the previously mentioned mapping of the cast-iron deteriorations on elevation drawings. In other cases, the information was presented numerically, such as quantities and tolerances of distinct glazing elements in schedules. Though the glazing elements could be categorized into distinct types based on their profiles, their individual dimensions were all adapted to the warped cast-iron structure. Through graphic and numeric representation, the unique design constraints of the project were thus more easily indexed and accessed.

The construction documents also contained detailed 3D visualizations of complex geometries that would have been difficult to represent accurately with traditional 2D drawing software, such as CAD. These views were fundamental for the understanding of the conservatory's assemblies. Length, surface area, and volume calculations for the installation of new materials were easily performed to prepare project cost estimates.

Conclusion

The preservation and restoration of the Shaughnessy House conservatory provides insight into the expanded role that documentation technologies play in the representation and conservation of architectural heritage. The use of point clouds and H-BIM methodologies offer numerous advantages for preservation projects, both in the indexing and representation of collected data.

Additionally, H-BIM models can be leveraged for simplifying the process of design iterations and used in conjunction with other advanced documentation software, such as THERM, for the simulation of heat-transfer effects. The model and its associated data can be extracted and refined for the production of project-specific conservation and construction documents. As the field of documentation technology is still emerging, its benefits to the broader implementation within heritage preservation are still being studied, and its impacts are yet to be fully defined.

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