The Importance of Building Envelope Commissioning for Sustainable Structures

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ABSTRACT

In order to be rewarded for environmentally conscious design and construction, the United States Green Building Council's (USGBC) LEED^{TM} rating system (USGBC 2002) requires that all buildings and structures satisfy a required commissioning process that, in the words of the USGBC, is intended to "verify and ensure that fundamental building elements and systems are designed, installed, and calibrated to operate as intended." This concept, which arguably is nothing more than a broadly worded restatement of what we already know to be good design practice, has taken on added significance in the context of environmentally conscious, or "sustainable," design. This is particularly true with regard to the effects of uncontrolled rainwater penetration and moisture ingress at the building envelope. Proper selection, use, and integration of the materials, components, and systems that compose the building envelope are critical to the long-term durability and performance of any building or structure and, as such, should be fundamental to the mission of the USGBC and the commissioning process required to achieve a LEED rating.

This paper will expand upon our findings (Lemieux and Totten 2004) on one award-winning example of sustainable design in the United States to explore how a more formal LEED commissioning process for the building envelope could arguably have changed the outcome of this project. Specifically, we will briefly discuss how issues related to material selection, interface detailing, and construction combined on this project to adversely affect the durability and performance of the building envelope, followed by a proposal to enhance the LEED commissioning process to include a more formal building envelope commissioning program. As currently written, the LEED reference guides and rating system do not provide a structured outline for building envelope design and construction, an area of practice that, by some estimates, accounts for up to 80% of construction litigation in the U.S. each year (Lemieux and Driscoll 2004).

INTRODUCTION

Designed and constructed almost entirely of rapidly renewable and/or recycled building materials and systems, the Phillip Merrill Environmental Center has been recognized both regionally and nationally in the U.S. as the first project to achieve the "platinum" rating under the U.S. Green Building Council (USGBC) LEED™ rating program. As a symbolic representation of the owner and its mission (a not-for-profit, environmental advocacy group), the overall design aesthetic, placement on the site, and creative use of passive heating and cooling, rainwater recovery, storm water management, and similar innovations have been widely recognized as unique and successful by design professionals and the sustainable design community. However, the location and exposure of this building, the architect's choice of materials, and the manner in which those materials have been incorporated into the building envelope have nonetheless created a series of challenges for the owner with regard to the long-term maintenance and care of this structure.

The general contractor for the project retained the authors' firm after construction was completed. The building was experiencing uncontrolled rainwater penetration at several elements and interfaces, and portions of the façade were beginning to deteriorate within a year of being

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constructed. We were asked to examine and identify the entry points for rainwater, investigate the effect that wind-driven rain was having on the building interfaces and the façade elements, and to provide recommendations for repair.

We examined the choice of materials selected, how the interfaces were detailed, and the various envelope details used to construct the building, both as designed and as built. A visual survey of the structure was completed. Our investigation of this property included, but was not limited to, the following.

Field Water Penetration Testing

Field water penetration testing was conducted at selected areas of the building envelope in accordance with the methods and procedures outlined in the following standards.

- ASTM E-1105, *Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Curtain Walls, and Doors by Uniform or Cyclic Static Air Pressure Differential* (Modified—No air pressure differential)
- AAMA 501.2, *Quality Assurance and Diagnostic Water Leakage Field Check of Installed Storefronts, Curtain Walls and Sloped Glazing Systems*
- Informal, diagnostic "spray" and "flood" testing of selected builtup and standing seam metal roof surfaces and assemblies, dormer interfaces, scuppers, and related conditions

Although ASTM E-1105 and AAMA 501.2 were not specifically developed to verify the as-built performance of the materials, components, and systems that compose the building envelope at this property, they are routinely utilized, in whole or in part, to diagnose the point(s) of entry and leak paths(s) for rainwater penetration of buildings and structures. When combined with actual rainwater penetration surveys and interviews with building occupants and maintenance/ engineering staff, these test methods have proved very useful in re-creating the effects of both static and wind-driven rain events so that appropriate and necessary repairs can be developed to substantially reduce or eliminate uncontrolled rainwater penetration on both new and existing buildings and structures.

Document Review and In-House Research

Documents provided and/or included in our in-house research for the investigation and repair of this property included:

- Original architectural drawings and selected technical specifications
- Selected manufacturer's shop drawings for the pultruded fiberglass windows
- The LEED rating system and reference guide by USGBC (2002)
- Builder's guide for a mixed-humid climate (Lstiburek 2000)

In addition, we were also provided with a copy of the preliminary repair details developed by the architect of record for this project for further review and comment relative to the repair concepts developed as part of our investigation of this property.

BACKGROUND

Defining "Green"

Understanding and properly responding to environmental conditions that can affect the long-term durability and performance of a building or structure have long been fundamental tenets of good design practice. However, understanding and evaluating these factors in the context of good sustainable, or "green," building design is a relatively new twist on an old theme. Balancing the desire to create environmentally conscious buildings and structures with the responsibility to provide reasonably maintained and reliable shelter from the effects of sunlight, wind, and precipitation is an increasingly complex task whose importance has been made even more significant with the growing recognition of the USGBC and the LEED rating system. Effectively striking this balance is fundamental to good sustainable design practice and, as such, can also be considered a guiding principle of "green" building design.

The LEED Rating System

LEED is a point-based rating system with required prerequisites developed by the USGBC to provide a definitive and quantifiable means by which commercially developed buildings and structures can be properly evaluated, and rewarded, for their use of materials, components, and systems that are environmentally conscious and promote healthy and productive living and working environments. As a yardstick for sustainable design and construction, the LEED rating system (USGBC 2001, 2002) has enjoyed relatively rapid growth and acceptance among design professionals in the U.S. and, as a result, is a system, and a concept, that is now widely reflected in advertising and marketing literature produced by manufacturers and suppliers to the design and construction industry. In addition to the seven required prerequisites, the current version of LEED (Version 2.1) allows for a maximum of 69 total project points in the following six areas of design development:

- Site development
- Water efficiency
- Energy efficiency
- Material and resource selection
- Indoor environmental quality
- Innovation and design process

Depending upon the goals set for each project by the design professional and the requirements of the end-user, the following ratings can be achieved using any combination of credits awarded under the above-referenced categories:

- Platinum: 52 to 69 points
- Gold: 39 to 51 points
- Silver: 33 to 38 points
- Certified: 26 to 32 points

Although the LEED rating system was developed by the USGBC to provide guidance and a method of rating commercial buildings and structures built in the U.S. that incorporate environmentally conscious building materials and methods, the system is currently being expanded to include residential buildings and structures, as well as interior spaces and build-outs within existing structures through several pilot programs.

When considering the design and construction of a building exterior, energy efficiency and material selection are arguably the most critical categories of the LEED rating system. However, material selection is also a category whose stated goals—the use of recycled, salvaged, or renewable construction materials—must be carefully weighed against the long-term durability, serviceability, and performance of the building envelope. A failure to do so can result in a building that is environmentally conscious but, in many respects, "naked" in its own environment.

A "PLATINUM" CASE STUDY

Base Building Design and Innovation

The Phillip Merrill Environmental Center is located near a coastal environment on the eastern shore of the United States, in what can be defined as a mixed-humid climate (Lstiburek 2000). The building is exposed to large volumes of wind-driven rain and high humidity during the summer months. The structure contains many innovations and breakthroughs in the area of sustainable design. However, the choice of products for the building envelope and the manner in which they were detailed create many problems for this structure. Following is a summary of some of the unique technologies and design functions included in this property that have contributed to the success of this project.

- Water usage in the building is less than 10% that of a conventional office building, similar in size and occupancy levels. This is accomplished by several means, including the use of waterless urinals and composting toilets. A very extensive rainwater collection system filters and recycles rainwater for fire suppression, hand washing, mop sinks, desiccant unit makeup, laundry, and gear-washing equipment. This redirection of rainwater eases the volume of storm water flow out of the building and into the surrounding watersheds and ecosystems carrying pollutants with it and lessens the need to draw from groundwater wells or from municipal water systems. Hot water is provided by a solar hot water heater, which reduces energy consumption.
- In the area of energy conservation, the building utilizes passive solar heating by capitalizing upon its large expanses of glass on the south and east elevations. Operable louvers and shades are positioned at these elevations to help minimize summertime heat gain, enhancing cooling and reducing electric bills, while still allowing winter sun to enter and passively heat the building (Magwood and Mack 2000). Structurally insulated panels (SIPs) were selected for this structure instead of conventional framing to reduce the use of wood and increase the insulation value of the structure. Photovoltaic or solar panels are utilized to convert solar energy to electricity and power, and a complete energy management system is used to monitor and maximize the building's energy usage. A ground-source heat pump is used in conjunction with a desiccant dehumidification unit to remove the need for a mechanical system for air conditioning, and the heat pump also assists with heating the building in the winter. Sensors on the interior measure the light supplied from the windows, and, when sunlight is abundant, the amount of electric lighting is minimized.
- Material selection focused on supplying recycled, salvaged, and rapidly renewable materials to construct the building. The absence of interior walls and finishes also greatly reduced the need for additional materials found in more conventional structures. A great majority (80%) of the materials were locally found within a 300 mile radius of the site. Materials incorporated included cork flooring, harvested to allow the tree to regenerate cork within five to seven years, and bamboo for stairs and flooring, which can be replenished naturally if harvested every three to five years.
- Natural daylighting, wonderful views of the surrounding natural habitat, passive natural ventilation and mechanical ventilation, combined with no-VOC paints and adhesives and natural materials, direct venting and nonrecirculating of air in rooms where chemicals might be used improve the health and well-being of occupants and visitors alike. Also, operable windows have been installed with a light at the base to indicate when environmental conditions are right for windows to be opened.

The Building Envelope

The building envelope consists primarily of exposed, engineered-wood "parallam" columns, beams, and trusses, galvanized steel roofing and siding, pultruded fiberglass window systems, and SIP panels. The SIP panels consist primarily of a center core of rigid insulation board sandwiched between an inner layer of oriented strand board (OSB) and an outer layer of either exterior grade plywood or OSB protected by a second layer of exterior grade plywood. Exposed wood

Figure 1 *Overall view of the Phillip Merrill Environmental Center from the southeast.*

Figure 2 *Debonding sealant at roof penetration, contributing to uncontrolled rainwater penetration.*

elements were treated after installation with semi-transparent, breathable water repellent. Frame joinery between the SIP panels and the adjacent parallam structural elements, metal siding, and window frames were to be back-sealed and protected by exposed wood batten strips. See Figure 1 for an overall view of the Center.

Investigation and Repair

Although our investigation revealed a variety of both design and construction defects that resulted in direct, uncontrolled rainwater penetration through the exterior walls and roof of this property, we were particularly struck by the impact that material selection alone appeared to have on the overall performance of the building envelope. In the context of sustainable design, this was especially noteworthy in that the advantages relative to the LEED rating system that may have been associated with the use of SIP panels, parallam wood structural elements, wood batten strips, and similar energy-efficient and renewable resources also appeared to have further complicated the already difficult task of properly installing and integrating these materials into a fully functional building envelope. This was particularly evident at façade interface conditions on this project, where the surface characteristics inherent in the parallam products and the manner in which they are assembled proved extremely difficult to effectively seal and properly integrate with the surrounding SIP panels, galvanized steel siding, metal copings, and related construction. Given the relatively rapid development of in-service warping, twisting, and checking of these products evident during our investigation, we concluded that the somewhat unique use of wood products on this project, while effective in conveying the design intent of the architect and vision of the owner, nonetheless created a building envelope that, in our judgment, was extremely vulnerable to moisture-related deterioration and, as such, would very likely be difficult and costly to effectively maintain, requiring frequent and carefully monitored routine maintenance and periodic replacement of wood façade elements by the owner.

Figure 3 *Parallam interface condition with remedial application of silicone sealant in an attempt by the contractor to address uncontrolled rainwater penetration at roof. See Figure 12 for changes that eliminated this penetration.*

Based on our survey of actual rainwater penetration that occurred on the project since substantial completion, as well as our own field water penetration testing at representative sections of the building façades, the following conditions were determined to be the primary sources of rainwater penetration on this building:

- entry at interfaces between façade elements (joints between SIP panels and parallam columns and beams)
- entry at window locations at painted aluminum mullion covers
- entry at roof terminations and irregularities
- entry at penetrations and interfaces between the walls and roof and roofing penetrations.

See Figures 2 through 6 for specific envelope failures found during our investigation.

Figure 4 *Uncontrolled water penetration at window "gang" mullion system observed during field testing with the leak path and volume consistent with leakage observed by the owner during actual rain events.*

Figure 5 *Voids below wood batten strips at exterior face of SIP panels allowed for uncontrolled rainwater penetration.*

Figure 6 *View of condition shown in Figure 5 from interior.*

When considering the range of potential repair options available for this project, we recommended that careful consideration be given both to the long-term durability and performance of the materials themselves in this climate, as well as to the manner in which those materials would be detailed at each of the façade interface conditions to produce a fully integrated, weathertight building envelope. In addition, because the building would remain occupied and in use throughout the repair process, we also recommended that the repairs be developed in a manner that would allow for full implementation from the exterior, with minimal interruption to the daily use and occupancy of the building. Striking an effective balance between each of these considerations, particularly in the context of sustainable design and the prerequisites associated with the LEED rating system for material and resource selection, proved difficult and, ultimately, resulted in a final recommendation to the architect that he/she consider adapting a "rainscreen" approach to guide the repair process.

Using the rainscreen philosophy as a guiding principle for the repair program, the architect developed a series of façade details that would, in essence, allow the primary drainage plane for the exterior wall system to reside inboard of the exposed wood spandrel panels and batten strips. In this configuration, it was determined that the impact of continued in-service deterioration of the wood façade elements on the weathertight integrity of the building envelope would be significantly reduced, thereby allowing the façade to function as originally intended by the architect while also providing a layer of protection for the UV-sensitive products and materials to be used at the primary drainage plane. However, in reviewing these details in the design development phase, it also became apparent to us that the use of parallam wood products as a structural element that would remain expressed on the building exterior after the repairs were complete would remain a difficult hurdle to overcome.

See Figures 7 through 12 for various repairs that were completed under the guidance of the architect of record.

Why Commission the Building Envelope?

Although the skill and foresight with which this building was originally conceived is undeniable, it is conceivable that a more formal building envelope commissioning (BEC) process on this project would arguably have further benefited this property by requiring both the design and construction teams to adapt a more uniform, integrated, and rigorous process for the design and construction of the building envelope. Specifically, this type of BEC process would very likely have allowed several opportunities (required "milestones," if you will) for the architect and contractor to uncover and resolve problems related to material selection, design, inter-

Figure 7 *Existing pultruded fiberglass window frames with new aluminum overclad snap covers to improve the joint profile for perimeter sealant.*

Figure 8 *New turned-down metal drips to direct rainwater away from the spandrel panel below.*

Figure 9 *View of new flashing and sealant around typical parallam structural connection at building envelope perimeter.*

face detailing, durability, and performance at the building envelope that ultimately led to premature, moisture-related deterioration of selected façade elements and uncontrolled rainwater penetration into the conditioned spaces of this property, thereby eliminating the need for repair and replacement of major façade elements that, arguably, undermines the fundamental intent of resource conservation and the goals of the architect for a sustainable, or "green," design for any project. Specifically:

During the Schematic Design Phase. If the LEED rating system (perhaps through a more detailed BEC process) emphasized more clearly the importance of long-term durability and performance at the building envelope, then the architect's initial material selection process for this project might have eliminated, or certainly cast significant doubt upon, several of the products ultimately selected for use on the primary building facades at this property.

During the Design Development Phase. If the LEED rating system (perhaps through a more detailed BEC process) emphasized more clearly the importance of interface detailing at the building envelope, then the architect's initial attempts to detail and specify the materials, components, and systems under consideration for the building envelope at this property (particularly at the interfaces) would arguably have exposed several of the concerns encountered in the field that led directly to uncontrolled water penetration. This is particularly true with regard to issues related to materials incompatibility, substrate irregularities (particularly at critical bond surfaces for sealant), and unusual joint profiles/configuration at the interfaces between the parallam structural elements and the surrounding construction (which included SIP panels, pultruded fiberglass window frames, and corrugated steel siding and roofing), all conditions that ultimately led to uncontrolled rainwater penetration and/or moisture ingress into and through the building envelope at this property. In fact, it is entirely conceivable that a more formal BEC process on this project during this phase would have resulted in more rigorous debate among the design team regarding the decision to use the parallam wood product as an expressed structural element on the building exterior, particularly given both the surface-oriented and cross-sectional

Figure 10 *View of new flashing assembly at typical parallam connection above roof line.*

Figure 11 *View of the Center from the southeast after the completion of in-situ façade repairs.*

voids that are inherent in that material and the difficulties associated with integrating that product with the surrounding construction to create a serviceable, durable, weathertight building envelope. Arguably, several of the concepts ultimately adapted to guide the repair of this property (in particular, the "rainscreen" concept at the spandrel panels) might have arisen out of this debate early in the design process and then be incorporated into the design prior to the development of the contract documents for construction.

During the Construction Document Phase. If the LEED rating system (perhaps through a more detailed BEC process) emphasized more clearly the importance of a design peer review by an independent, third-party commissioning agent/consultant who specializes in building envelope design, integration, and performance, then many (if not all) of the concerns outlined above would arguably have been recognized during this process and subjected to more rigorous debate among the design team and, more importantly, with the owner/end-user before being included for bidding in the final contract documents for construction. Final decisions related to material selection and the impact of those decisions on the initial construction cost, as well as the long-term maintenance burden of the owner/end-user (often erroneously referred to as "value engineering"), would arguably have been subjected to rigorous debate and, as a result, perhaps led to additional refinement of interface detailing and consideration of alternative and/or supplemental building materials designed to improve the long-term durability, serviceability, and performance of the building envelope at this property.

During the Bidding Phase. If the LEED rating system (perhaps through a more detailed BEC process) emphasized more clearly the importance of an independent, third-party commissioning agent/consultant during the bid review process (in particular, one who specializes in building envelope design, integration, and performance), then his/her

Figure 12 *View of completed repairs at the south elevation of the Conference Pavilion, including changes to the roof and drainage system. Left picture shows original construction. The roof element shown in Figure 3 has been removed to correct water ingress at this penetration.*

review of the bids on this project might have revealed several concerns related to material substitution at the building envelope of this property (for instance, potential changes in grade associated with the plywood spandrel panels and wood batten strips and the decision to use surface-applied water repellents and similar products in lieu of naturally decay-resistant wood products) that may, as yet, shorten the service life of the building envelope if not properly maintained (and certainly result in an additional maintenance burden for the owner/end-user).

During the Pre-Construction Phase. If the LEED rating system (perhaps through a more detailed BEC process) emphasized more clearly the importance of pre-construction mockup testing and periodic plant visits to verify the constructability, integration, and performance of representative façade materials, components, and systems, then most, if not all, of the concerns noted above could arguably have been revealed and corrected prior to the start of actual construction. This concept is particularly critical for lead times associated with potential changes in manufacturing (such as extrusion dies and assemblies) that may be required to address concerns revealed during mockup testing. Off-site quality assurance programs currently under development by trade associations (AAMA, in particular) and several state agencies (State of Florida) are a logical extension of the BEC process that could, by reference, be incorporated as part of this program.

During the Construction Phase. If the LEED rating system (perhaps through a more detailed BEC process) emphasized more clearly the importance of on-site quality assurance inspection, field performance testing, and periodic follow-up visits to manufacturing facilities supplying building envelope materials, components, and systems for this project, then several of the as-built construction defects that contributed to uncontrolled rainwater penetration on this property might have been discovered, and corrected, prior to occupancy of the building.

Hindsight, of course, is 20/20. However, several of the concepts ultimately adapted to guide the repair of this property (in particular, the "rain screen" concept at the spandrel panels that allowed several of the more vulnerable, natural wood façade elements to reside outside the primary weather barrier for the property) might have arisen earlier in the design process under a more formal BEC program and, therefore, perhaps been incorporated into the design prior to the development of the construction documents for this project. Regardless, one fact is clear: The commitment of both the architect and general contractor to the significance of this property as a symbol of sustainable design and construction excellence has since resulted in the cooperative development and successful implementation of a repair program that has addressed uncontrolled rainwater penetration at this property without significant sacrifice to the fundamental principles of the USGBC that formed the basis of this project and initial rating.

A BUILDING ENVELOPE COMMISSIONING PROGRAM

The LEED rating system requires commissioning as a prerequisite to achieving a rating. This is indicated in Prerequisite 1, "Fundamental Building Systems Commissioning," under the "Energy and Atmosphere" portion of the rating system (USGBC 2002). However, the rating system reference guide (USGBC 2001) under the title "Design Approach" does not specifically indicate that building envelope commissioning is required. The reference guide is by no means a standard, as its intent is to provide general guidance to the designer. The text within the guide states that testing of the envelope systems should be completed on untried systems in unforgiving climates. As many of the materials and methods of detailing for sustainable structures remain unique to green architecture, including the case study building, it is our opinion that commissioning of the envelope is essential for the newer materials and systems that designers are attempting to integrate.

The process of commissioning the envelope covers many of the same aspects of other systems that are commissioned, including HVAC. Additionally, envelope design choices can drastically affect the HVAC requirements of the structure and the interior occupants' comfort levels. The building envelope and the related HVAC systems should not be decoupled in the design phase. This fact has been, and continues to be, documented in papers and publications showing the benefits of proper building envelope design. However, the skills required and level of understanding of how to accomplish proper envelope design are still lacking from the global design profession within the United States.

In order to complete the commissioning process, a qualified design professional (licensed architect or engineer) should be retained by the owner or the mechanical commissioning agent to review and comment on the architectural drawings and specifications at predetermined milestones in the design development and construction document phases of the project and complete other commissioning requirements. The commissioning agent should have specific knowledge of building envelope design and construction, as well as a thorough understanding of USGBC guidelines and the LEED rating system and the commissioning process.

After carefully reviewing our own practices for successful building envelope design peer review and quality assurance services, as well as the Building Envelope Coordination Program developed by McCarthy Construction (Nash and Crow 2003) and similar programs currently under development by owners, developers, and general contractors with whom we are familiar, we respectfully offer the following BEC program for review and consideration as part of the LEED rating system.

Project Pre-Planning and Introduction of the BEC Program

Representatives from the building envelope commissioning agent will meet with the owner, owner's representatives, architect of record, mechanical engineer, LEED consultant, contractor (if already determined and hired), and the commissioning authority and other applicable members of the design team to discuss the project during a preliminary meeting for the building envelope commissioning agent's involvement as a subconsultant to the commissioning authority and to better understand what LEED credits the owner wishes to achieve. The initial LEED scorecard should be made available to the commissioning agent prior to this meeting, as well as any drawings and specifications already prepared. From this meeting and the scorecard, the commissioning agent should be able to develop a list of building envelope elements that may potentially affect the credits the team is intending to capture and what elements may be improved to maximize other potential credits that the team may be able to pursue, based on the owner's needs. The commissioning agent will also identify what systems of the envelope may likely require a more thorough review.

Schematic Design

The architect of record, the mechanical engineer, the LEED consultant and, if appropriate, a separate building envelope consultant, and the owner and owner representatives should meet to discuss the design intent, to complete design charettes to determine potential design options and building enclosure systems, to discuss the owner's requirements, and to develop an initial LEED scorecard. As part of this process, the design team should identify and review the overall design intent of the building envelope systems (barrier versus rain screen versus cavity wall), material selection choices, interface complexities, budget restraints, and site-specific climate concerns that the envelope design will need to address. The design team should consider whole building integration and the interaction of the building enclosure with the mechanical systems. This set of charettes may be done separately from initial charettes with the LEED consultant to aid the team in determining initial project decisions and direction. The architect will then need to prepare initial schematic designs and three-dimensional models of the intended structure and site-specific building orientation.

Design Development and Outline Specifications

The architect of record and other members of the design team with the building envelope consultant should review and research materials for the various systems and assemblies now identified as potential systems that will satisfy the owner's requirements. In developing the design, computer modeling for a variety of different attributes and elements that will affect the system should be completed. Various systems and sections should be evaluated and compared. The design team should model sections and different combinations of materials and assemblies for vapor drive, moisture storage capacity, environmental impact, geographic implications, siting, exposure, microclimate/macroclimate, solar/shading, thermal efficiency, and rainwater resistance, especially to wind-driven rain. Energy modeling and moisture analysis modeling should both be completed. Computer modeling for heat and moisture transfer should be completed on wall, roof, window, and similar building envelope components and assemblies. Moisture transfer modeling will aid the designers in deciding if the envelope they have picked may experience long-term or short-term moisture problems. Various programs are available to complete the moisture-modeling task, with the better programs being based on long-term historical climate data and region-specific wind-driven rain data. Energy modeling is useful in refining the thermal design characteristics that can, in turn, be used to optimize the mechanical system's design. From this, a refined set of design documents should be developed, including initial material specifications.

Preliminary Construction Documents

Depending on the project stage for the design team, the commissioning agent will review one set (50% to 95%) of architectural drawings and applicable specification sections for the building envelope—a set that has enough defined information on the envelope for this review—and provide comments. The commissioning agent will perform an initial value engineering review, if applicable, and indicate areas where cost trade-offs can be used to enhance the building envelope systems (the systems intended for heat, air, and moisture control for the enclosure). During this portion of the commissioning process, the design team may need assistance in developing conceptual details and may require additional information for the building envelope systems. The commissioning agent will also provide comments as they pertain to LEED on the elements of the building envelope.

One or more meetings will need to be held with the design team, the owner and owner's representatives, the commissioning agent, and the LEED consultant to discuss design options and costs as well as systems and elements that should not be eliminated and the inherent risk in doing so. "Value engineering" decisions will be critical during these meetings. Interface conditions will need to be discussed. Items that should not be removed from the project as a means to save up-front dollars include interface flashings, preconstruction mockups, and any and all areas of envelope redundancy that are critical to the durability of the structure. It has been our experience that with many of the up-front dollars saved by, say, eliminating flashings, the dollars for repair are much more than twice the cost.

Final Construction Documents

The architect of record and other members of the design team will now proceed with finishing the construction documents, including all drawings and technical specifications. The final assemblies and systems identified will have to again be checked to ensure that they will satisfy the owner's requirements. Additional computer modeling, including energy modeling and moisture analysis modeling, will likely need to be completed, depending on changes being made to the documents based on the initial review comments by the commissioning agent. The modeling should be useful in refining the decisions made during the design development phase. The impact of preliminary cost estimates may lead the team to look at a variety of alternatives. The design team will need to explore different and timely/more cost-effective means to achieve the same end but without sacrificing core objectives of the commissioning process. The design team should emphasize long-term durability and performance of materials and components and systems that compose the building envelope and consider the impact of each design decisions on the "whole building design." Mechanical systems should be concurrently examined with the building envelope decisions.

If the process is managed properly by the architect, this step should be relatively easy in that proper materials are already in the budget for the project and adequate detailing is the only remaining hurdle. The commissioning process will help to ensure a more complete set of CDs as the design team will likely be more thorough in selecting materials, not only as a renewable resource, but for long-term durability and performance. The interfaces and detailing completed should be at a much higher level than noncommissioned projects, partly based on the initial commissioning review.

Final Peer Review Prior to Bidding

The commissioning agent will review one set of the architectural drawings and applicable specification sections for the building enclosure and provide comments and concerns on the envelope design as it relates to heat, air, and moisture transfer. The commissioning agent will also provide comments pertaining to LEED on the elements of the building envelope. The commissioning agent will also review and comment on all components of the building envelope systems, paying particular attention to the requirements in the specifications for samples, technical data, mockups, performance testing, and the details and interfaces as shown on the drawings. The objective of this review is to identify details, requirements, or methods that may compromise the watertight integrity and thermal performance of the building in order to call these identified items to the attention of the architect of record and the owner for their action. Issues such as constructability and materials compatibility need to be examined by the commissioning agent and specific guidance should be supplied via written documentation to the owner and the architect of record at each phase of review. Materials that appear to be poor choices based on durability and a potential for rapid replacement need to be identified, especially on sustainable projects, where product replacement requiring new resources in a short time frame should be examined versus the use of a more durable product that may not be as environmentally appropriate on first selection.

If any details, plans, or specifications are modified by the architect of record, the commissioning agent will need to review these prior to issuance of the design documents. If elements recommended for change have not been completed, the commissioning agent should provide written documentation to the owner, indicating what risks may be associated with not implementing these items.

The peer review process is an important step in assisting the architect of record in making good decisions on the selection of materials and method of integrating those materials into a durable building envelope.

Bid Review

The commissioning agent should be available to provide assistance to the owner and the architect of record in reviewing submittals, if included with the bid, for any proposed product substitutions for building envelope elements, to determine the risk or equivalence of the proposed substitution.

Submittal Review

Concurrent with the review of shop drawings by the architect and engineer of record, the commissioning agent will need to review shop drawings prior to release and fabrication for building envelope requirements and provide written comments to the owner and architect of record. Where appropriate, they should provide comments on LEED credits as they pertain to the envelope.

Building Envelope Pre-Construction Coordination Meeting

Prior to beginning construction, the commissioning agent will need to participate in one kickoff meeting with the various members of the design and construction teams, including, but not limited to, the owner, owner's representatives, architect of record, mechanical engineer, LEED consultant, general contractor, all subcontractors that will be involved in the construction of the building envelope, including, but not limited to, the roofing, wall system, flashing, sealant, fenestration, concrete, steel, HVAC, and electrical, interior framing and drywall contractors, the mechanical commissioning authority, and other applicable members of the design and construction team. This meeting will be to discuss construction sequencing and the coordination of trades and the reporting that will be completed during construction of the building envelope and related other elements. This meeting may also be in conjunction with project and LEED kickoff meetings to discuss the LEED submittal process and responsibilities of the different parties.

Building Envelope Pre-Installation Meetings with Individual Trades

The commissioning agent will participate in each of the pre-installation meetings to review and discuss critical aspects of the construction, as well as to reemphasize the importance of coordination among the trades to ensure the successful integration and weathertight installation of the various materials, components, and systems that compose the building envelope.

Field-Constructed Mockups and Performance Testing

Field-constructed mockups need to be included in the contract documents to verify the constructability, integration, and performance of the materials, components, and systems that compose the building envelope.

The commissioning agent should review mockup construction of each element and interface determined in the specifications to be included in mockups. The commissioning agent will have to be present during performance testing to provide observations in written format to the owner, architect of record, and general contractor for resolution of concerns observed during this performance testing. This includes field air and water penetration testing of representative areas of the building envelope as specified by the architect of record and/or as recommended by the commissioning agent and accepted by the owner, the architect of record, and the general contractor.

On-Site Construction Observation and Quality Assurance Services

The commissioning agent will need to review the contractor's quality assurance inspection plan. Depending upon the scale and complexity of the project, the commissioning agent should be retained to assist the architect/engineer of record with his/her review of contractor submittals pertaining to the building envelope to verify their conformance with the contract documents and prerequisites of the LEED rating system.

To ensure that the findings and recommendations accepted by the owner and the architect of record are properly executed and tested in the field, the commissioning agent will have to provide periodic, on-site review of the work in progress during the course of construction at the building envelope. A written record of deficiencies should be maintained by the commissioning agent and forwarded to the architect and engineer of record, owner, and general contractor in a timely manner throughout the construction process, together with a written record of how and when each deficiency was corrected in the field.

During this process, it is anticipated that the commissioning agent will participate in weekly or biweekly building envelope quality assurance meetings chaired by the general contractor, with the appropriate subcontractors in attendance, to review and discuss issues and concerns noted by the commissioning agent during the previous week and what action will be taken to address those concerns. Our experience suggests that a minimum on-site presence of two days per week will be required for most projects.

Project Close-Out

A final walk-through and "punch-list" survey of all deficiencies remaining on the project should be completed by the subconsultant/commissioning agent, architect/engineer of record, and owner. The subconsultant/commissioning agent can complete additional testing and commissioning of the envelope at this stage. Under LEED, if all systems go through additional commissioning at the project end, the project is eligible for an additional credit.

Building Envelope Maintenance Guide and Training

The commissioning agent should prepare a building envelope maintenance guide necessary to properly train on-site engineering and maintenance staff on the proper maintenance of the building envelope. This guide should also include a collection of all necessary close-out documents related to the building envelope, such as warranties and information on the materials utilized, including the appropriate catalog information and supplier, manufacturer, and ordering/contact information. The owner and staff should also be given guidance as to what elements will typically require outside contractor assistance for maintenance.

Unfortunately, much of our work on the building envelope is completed after structures are built, as our firm and other, similar firms are typically called in after the structure has had long-term problems, many of which are tied to original design decisions and not just a lack of maintenance. As LEED requires commissioning, and it is recommended that untried building envelope systems be commissioned, it makes more sense for these services to be attained as part of the building process.

CONCLUSIONS AND RECOMMENDATIONS

Based on this case study, we have several recommendations for the "green" architecture community in general, and most of these also hold true for all types of buildings.

Commission your building envelope. Many of the problems on the case study building could have been prevented with appropriate building envelope commissioning. Many of the material alternatives that could have been utilized for the façade elements would not have affected some of the credits that the design team was pursuing. However, even if the rating level desired by the design team needs to be sacrificed in order to create a more durable building, the resultant structure would be more in line with the intent of sustainable design.

Materials have limitations and appropriate uses. Understand and remain within these limitations, and ensure that if you are going to "experiment" with them, it is not going to create long-term problems. Material selection and detailing are critical elements, particularly in the context of good sustainable design practice. Understanding the limitations (with regard to long-term durability and performance) of products and materials considered by LEED to be renewable/rapidly renewable resources and how to properly apply and detail those materials is an important aspect of basic design. Failure to do so can result in a building that may be environmentally conscious on the surface but, based on the climate in which it is situated, strapped with long-term durability and maintenance problems.

Check the appropriateness of the "sustainable" products used. If a product is listed as sustainable and another product is not, this does not mean the "nonsustainable" product is not the appropriate one to use. If the second product is not directly identified as sustainable but has a 50-year life span and the sustainable product has a 15-year life span, run an analysis on the embodied energy, off-gassing (on the interior, less or none is best; outside on the façade, less is best, but some may be okay if not affecting occupants at all or the environment), and other factors used to select the sustainable product, and in the long run, the second one may be the more sustainable. We may not be able to utilize only "green" type products to keep rainwater, moisture, heat, and air properly controlled. There are many products that can be utilized that will do a better job of achieving these goals that may not meet all of the environmental concerns. We should continue to strive to build structures better and develop products to better meet the sustainable and environmental factor constraints. At the same time, we should reduce the risk of exposure of products we have chosen, if we wish to stay strictly "green," and remain within their limitations. If that is not possible, we should utilize the product that is most appropriate for the intended use and still has the least environmental impact and embodied energy and is cost-effective. This is a difficult balance to achieve. Many waterproofing and water-resistant or higher moisture-tolerant products may not meet all of the environmental and sustainable factors. However, if they protect a building from rot and other moisture-related damage, increase the longevity of the structure, and reduce the risk of damage to occupants' health, they may very well be the most suitable and appropriate product for this use.

Understand the site's rainfall and climate zones. In addition to understanding orientation to sun for passive solar and photovoltaics and wind for natural ventilation, the designer should understand rainfall directions and the amount of rain and wind-driven rain and have a defined and continuous rain and moisture management plan. This plan will not have building materials that exceed safe storage capacity, will not allow interfaces to have direct water and air infiltration paths, and will redirect water via drainage planes, flashings, and other methods to the exterior or defined storage area for reuse.

Life span analysis of the structure should be part of the rating system, so as to not have new building stock required to replace this building in less years, thus outweighing some of the reasoning behind the structure and the basic tenets of good design practice, especially in the context of sustainable design. Flexibility in expansion and change of use, if needed, should be examined as part of this process to maximize the building's longevity. Build flexibility into your façade to facilitate easy change out of more limited life span elements (commercial wraps, etc.) to increase the longevity and life span of the façade.

Continue to build and design sustainable and green buildings and push for integration of greening more buildings and for code changes. We can build better and build with more environmentally friendly products, so the design community should continue to push in this direction.

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