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SMART BUILDING COMPONENTS – UHPC MULLIONS

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Abstract

The versatility of UHPC is well showcased through its evolution as an integral component of wall systems in the USA. Mullions in particular have become of great interest to architects due to UHPC's numerous exceptional properties and characteristics. As a material choice it provides the necessary aesthetics in form and texture to mullions that excite the imagination of architects, while the durability and strength of the material appeal to the practicalities of project demands. This paper will present two projects that demonstrate the evolution of design concepts using UHPC in superior wall assemblies. The prototype wall system known as Liquid Wall utilizes UHPC as a curtain wall system, and incorporates the entirety of UHPFRC possibilities for a wall solution. That discussion will lead into the presentation of the mullions utilized on the completed Perez Art Museum in Miami.

Résumé

La polyvalence du BFUP est manifeste par son évolution comme composant à part entière des systèmes de murs aux Etats-Unis. Les meneaux en particulier ont suscité un grand intérêt de la part des architectes en raison des nombreuses propriétés exceptionnelles du BFUP. Lorsqu'il est choisi comme matériau il fournit pour les meneaux l'esthétique en termes de forme et de texture qui éveille l'imagination des architectes tandis qu'en termes de durabilité et de solidité il offre une réponse pratique aux attendus du projet. Cet article présente deux projets qui montrent l'évolution des conceptions dans l'utilisation du BFUP dans des assemblages de mur de qualité supérieure. Le prototype de mur connu sous le nom de ''mur liquide'' utilise le BFUP comme un système de mur rideau, et intègre toutes les possibilités du BFUP pour une solution de mur. Cette discussion nous amènera à la présentation des meneaux utilisés pour le bâtiment, déjà construit, du Perez Art Museum à Miami.

1. INTRODUCTION

The full utilization of mullions as multifunctional components in building wall systems is a key differentiator between adequate and exceptional design. Whether the intent is ornamentation or invisibility from an aesthetic point of view, the mullion's work goes well beyond that of mere façade. Working in concert with the other wall components (glass, structural support, thermal barrier, water barrier, vapor barrier, and maintenance systems) to form a skin, an identity for the building's exterior, and a means of protection for those within. The mullion, though seeming a simple element, has many demands that require superior material performance for elegant and efficiently designed wall systems.

2. MULLIONS

Mullions are vertical building components that separate building openings such as windows or doors. Mullions are critical features in the building envelope design. They can be key in defining the tone, sculptural quality, or accent of the building's outward appearance. As a major contributor to the initial impressions of a structure, mullions set the stage for the overall impact of a building's design intent (Photos 1).

Photos 1: Steel, aluminum, stone, concrete, wood, brick clad and glass mullions
[images Lafarge]

The creative minds of architects and designers often expand on this to include as much performance as possible while maintaining the pure concept of a slender and decorative element within a building envelope. The performance that is required of modern day mullions is expanded upon in this paper with an emphasis on what trade-offs are involved with favoring one performance criteria over another and how these trade-offs impact the mullion as an aesthetic component.

3. CURTAIN WALLS

Curtain walls are a type of building envelope construction attached to the primary structure of the building. They hang off of the building like a "curtain", hence the name curtain walls. Curtain walls typically provide no load carrying capacity other than their own dead load and transferring vertical loads to the primary structural system.

Advantages of curtain wall systems include smaller wall sections, faster erection, lighter structures, structural design freedom, and better lighting. The ability of the design team and contractor to treat the structure and the envelope as separate entities allows for individual design and construction of the building systems. This allows for less direct coordination and impact from changes in the design of either system and allows for independent scheduling during the construction process. The connection of the curtain wall to the structure becomes the critical coordination item and is typically not altered by changes to the curtain wall's composition nor the structural system. Once the attachment mechanism has been determined and capacity confirmed, the layout of the attachments becomes the primary item for coordination. [1]

Photos 2: (left) Rotman Business School, Toronto, ON curtainwall w/ Ductal® UHPC flat panels and (right) Dumbo Lofts, Brooklyn, New York louvered rainscreen curtainwall [images Lafarge]

The Dumbo Lofts project utilized a rainscreen building envelop that featured Ductal® UHPC louvers which also acted as sunshades (photos 2). The panels were 18'-0" by 11'-0" (5,32 m by 3,25 m) and featured tapered fins that where 4" (10 cm) wide in the back and 1 ¼" (3,2 cm) at the nose. The overall depth of the louvers was 10" (25 cm), providing a slender and lightweight profile. The rainscreen wall as pictured is hanging in front of the aluminum glass wall, which spans from floor to ceiling. It is not hard to imagine incorporating the glass directly into these panels creating mullions out of the fins. With additional detailing the UHPC panels could have eliminated the need for the aluminum window frames and provided more continuity in the building façade. The structural design of the Dumbo Loft panel is very efficient (Fig. 1). The thicker "sill" portion of these pieces acts structurally to support the vertical fins, which in turn support the horizontal head element. Using UHPC allowed for that element to remain slender and within the design intent of the architect, as well as, creating a slender element for the head and jambs. Creating a monolithic curtain wall eliminates the need for the numerous connections that would be required of a system with separate, head, mullion, and sill pieces, and the resulting engineering required.

The remaining sections will address mullions as they are featured in curtain walls. There are a number of other building envelope systems in which mullions are also utilized. However, for this initial discussion focusing on the most practical applications of UHPC mullions, it is appropriate to confine commentary to curtain walls.

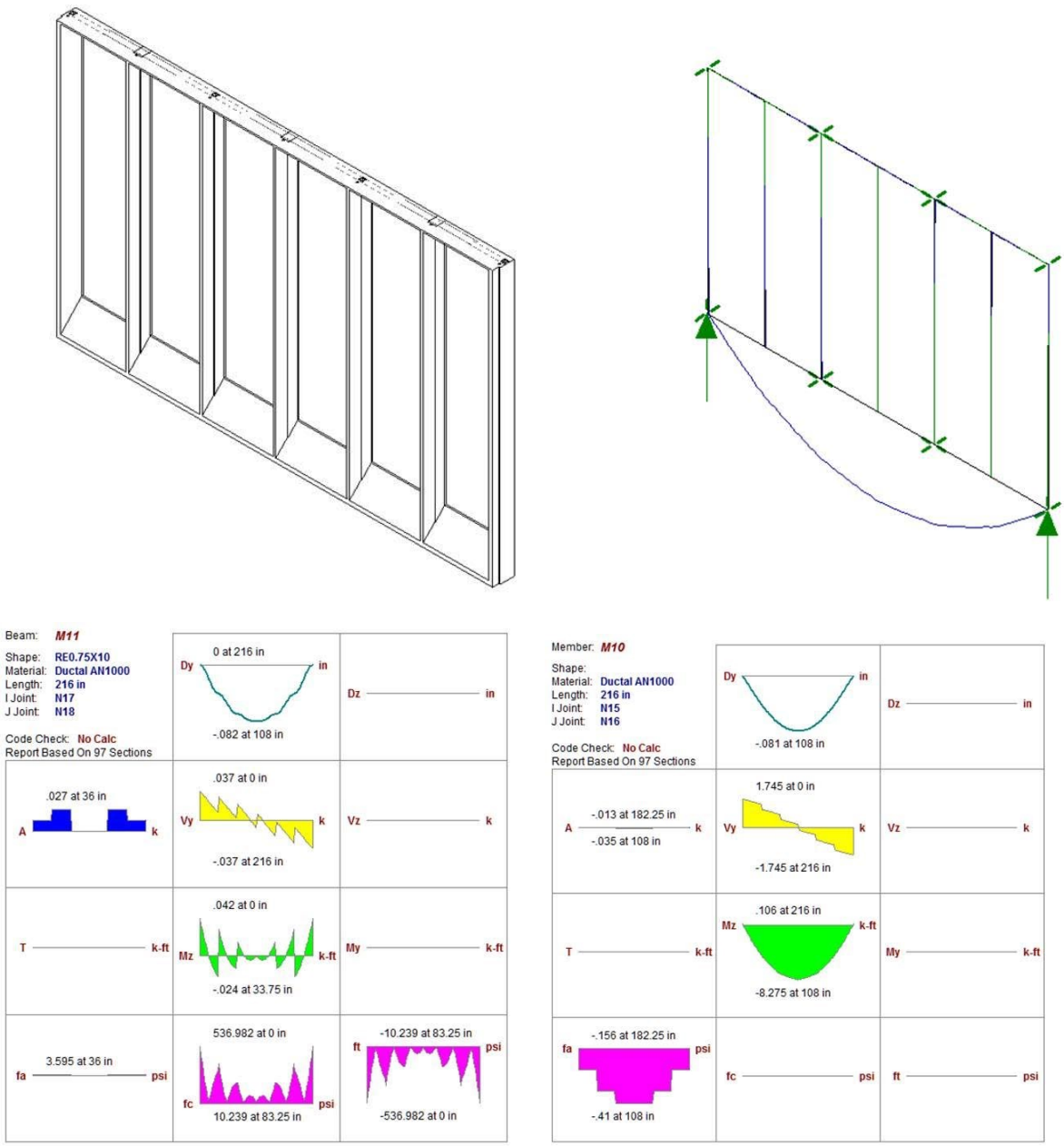

Figure 1: (left top) Dumbo RISA model, (right top) Dumbo moment diagram, (bottom left) head element analysis, and (bottom right) sill element analysis
[finite element analysis, Gate Precast Company]

3.1 Façade Barrier Layers

Building envelopes provide buildings with their general appearance, transfer of external loads to the primary structure, and the durable shell to keep the elements out. Beyond these global concerns related to design, there are localized threats to building performance that must be addressed by the external skin. The main layers of protection that curtain walls or any building envelope provide are as follows: a weather shield, waterproofing, thermal insulation,

vapor barrier, and air barrier. These five barriers of protection constitute the driving considerations that form the decision making process of building envelope design.

UHPRFC provides very advantageous properties in regard to providing a weather and water barrier (Fig. 2). In addressing thermal, vapor, and air penetration, incorporating insulation, a vapor barrier, and appropriate joint seals can be addressed through the proper detailing of the curtainwall system. It is recommended that the necessary connectors and barrier systems are cast directly in to the UHPC precast pieces to eliminate additional installation processes. See the design example Liquid Wall (section 3.3) for an illustration of how this could be done.

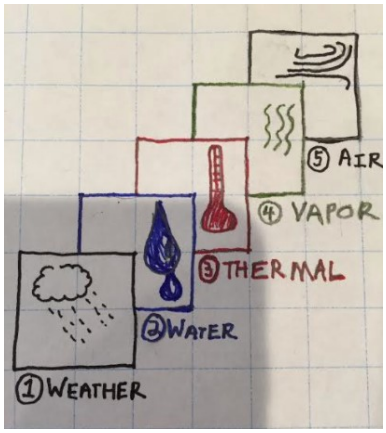

Figure 2: The five critical protective layers a curtain wall must provide (UHPC excels at providing a barrier to those shaded in the lower left)

3.2 Design Strategy – Minimize Components and Discontinuities

Mullions act as a separation between open spaces in a wall and therefore constitute a global discontinuity in the protective layers of a building envelope. The number of components that comprise the mullion section dictates the number of local discontinuities within the details of the mullion. Minimizing the number of discontinuities within the mullion section will reduce the impact the mullion global discontinuity has on the overall performance of the building envelope. This concept, though simple in a logical sense (less is more), is often tricky to implement in design due to material constraints that are often at odds with one another regarding the functional requirements.

Ideally, mullions could be designed out of a single material that would provide all the necessary characteristics to enhance or minimize the impact of this discontinuity in the building envelope while holding the glass, screen, or door casing in place. This would suggest a solution that would involve integrally manufacturing the mullion with the opening component (window, door, etc.). By doing so the amount of caulked and sealed joints would be reduced, again making this an efficient UHPC solution and greatly reducing the maintenance required with caulked joints.

3.3 Design Example – Liquid Wall [2]

The Liquid Wall was featured in the 2010 New York City chapter of the American Institute of Architects exhibition of innovative curtain wall design. The architect Peter Arbour, with a team of collaborators from RFR Consulting Engineers, decided to use Ductal UHPC because it could be cast into various forms, and with its exceptional strength they were

able to design a thin and therefore lightweight cross section. The goal was to create a unitized building envelope that would break away from the status quo of the ubiquitous extruded aluminum mullion that characterizes metal and glass walls (Fig. 3).

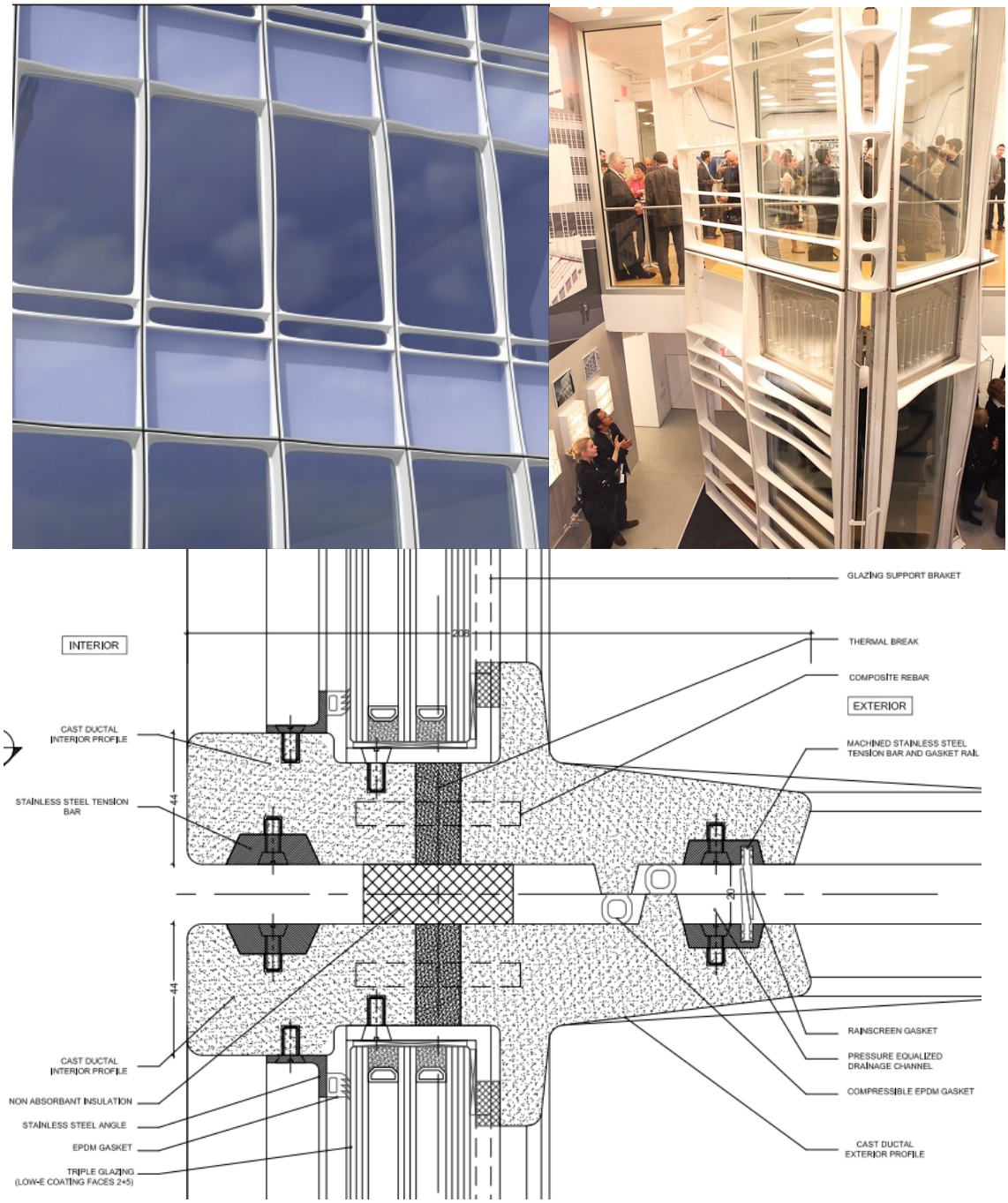

Figure 3: (left) Rendering of building façade with Liquid Wall, (right) Liquid Wall at AIA NY and (bottom) UHPC mullion detail protecting against weather, water, thermal, vapor, and air penetration creating a complete curtain wall solution [Images RFR Consulting Engineers, Peter Arbour [2] and Lafarge]

The design intent relative to the curtain wall material was to create contour and intricate detailing which would capture the fluid nature of UHPC in a visually stunning way. The design incorporated all necessary layers of protection for the interior of the building using a 2 cycle casting process. The front face was cast first with a thermal break system imbedded in the casting. Once this cast was fully cured it was turned over and imbedded into the 2nd cast of the backside of the unit, essentially binding the two casts together. After the entire unit was cured, the glass could be inserted with an L bracket to hold it in place. Digital models were used to create the extremely complicated polystyrene forms. The polystyrene forms were then used to make the rubber forms the UHPC would be cast in.

4. FAVORABLE MATERIAL ATTRIBUTES FOR MULLIONS

4.1 Aesthetics

The goal for many modern curtain walls is to have the mullions that call little attention to the eye in the overall effect of the building's glass skin. To establish minimal impact to the texture, form, and size of the mullions becomes critical. Other systems utilize this separation as a means of accent or decoration, in these cases the material that the mullion is made from must be aligned with the overall aesthetic for the exterior planes of the building. Use of color, angles, curvature, and edges develop the static image of an exterior wall's appearance. Natural conditions such as rain, mist, snow, and surrounding environment will impact how the façade will look at different times and can't be overlooked in the material considerations [3].

The decision to incorporate metal mullions or mineral based mullions is made first (Table 1). Those materials are usually determined to provide an aesthetic for the building that enhances the surrounding environment. In urban areas this would mean the surrounding buildings and in an open area it would be the natural elements around the building [4].

Table 1: Types of Mullions – Decision Driven by Global Aesthetic Scheme

Metal (standard)	Typically aluminum or steel mullions (Industrial Design Intent)	Most likely not appropriate for UHPFRC substitution
Stone Derived (standard)	Mineral based or stone mullions (Organic Design Intent)	UHPFRC provides high performance solution
Decorative	Imprinted, etched, formed geometries, or contoured mullions	UHPFRC provides high performance solution
Invisible	Glass or minimized aluminum with steel (Uninterrupted glass wall)	UHPFRC provides potential replacement of aluminum and steel composite mullions

4.2 Design Example – Perez Art Museum of Miami [5]

The Perez Art Museum is an exceptional example of UHPC being selected as the material for mullions to respect the overall design intent of the project. Figure 4 shows the vertical UHPC mullions used to bring the beauty of the Biscayne Bay and surrounding park space into the interior of the museum. The thin and sinuous members were also capable of withstanding high wind loads from hurricanes and the durability requirements of the harsh marine environment. "Concrete as a structure and a finish," is how Christine Binswanger, Partner at Herzog & de Meuron described the intent behind using UHPC elements in the glass wall. Conventional concrete was used extensively on the project to contrast with the vegetation

surrounding the building. UHPC provided the same tonal qualities, while being slender and less bulky than conventional concrete, preserving the design intent.

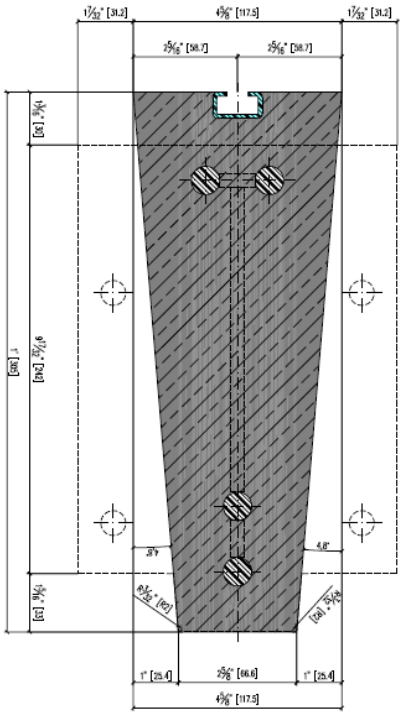

Figure 4: (top) Perez Art Museum Miami, (bottom left) UHPC Mullions, and (bottom right) UHPC Mullion Section Detail [Images Lafarge]

The superior performance of UHPC in regard to strength and durability make it a great selection for exterior applications exposed to various severe forces and elements such as the PAMM mullions. To better understand how these mullions would perform, extensive full scale tests were performed prior to fabrication to validate the structural design and material performance (Fig. 5). As expected, the UHPC mullions performed as anticipated and demonstrated the necessary requirements for this application.

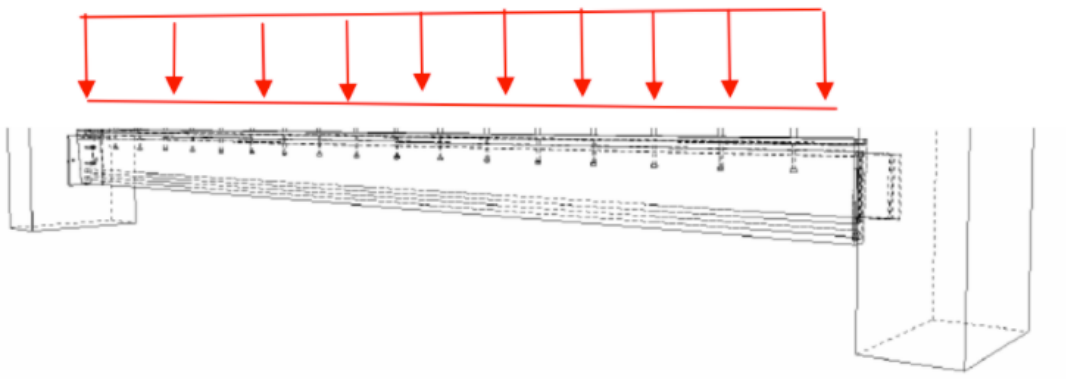

Figure 5: Test configuration – bending resistance PAMM mullions
[Test diagram Knippers Helbig, Advanced Engineering]

5. CONCLUSIONS

The manner in which UHPC is evaluated as a mullion, in this paper, is meant to demonstrate an approach that can be used in considering UHPC for other cladding and general building components. Through examples and evaluation of material properties with respect to the aesthetic and functional criteria of curtain wall design it has been demonstrated that UHPC is a smart and efficient choice as a mullion in many situations.

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REFERENCES

[1] Hoffman, Sydney (editor), Architectural Precast Concrete, Third Edition – Section 2.4.5: Column Covers and Mullions, 2007.
[2] Moore, Heidi, 'Concrete in Motion', *EcoBuilding Pulse,* http://www.ecobuildingpulse.com/news/concrete-in-motion, (The American Institute of Architects, August 01, 2011).
[3] Holl, Steven, "Parallax", (Princeton Architectural Press, New York, 2000) 31.
[4] Kazmierczak, Karol, "Review of Curtain Walls, Focusing on Design Problems and Solutions", BEST2 - Design and Rehabilitation Proceedings – Session EE4-1, Portland, April, 2010 (National Institute of Building Sciences, 2010) 3-4, 8-9.
[5] Martin-Saint-Leon, Jean (editor-in-chief), "Perez Art Museum Miami", *Ductal Solutions* **15** (May 2014) 22.
[6] www.genuinestone.com, "Material Fact Sheet Limestone", (Natural Stone Council, 2010).
[7] Issa, Mohsen A., Khalil, Atef A., Islam, Shahidul, and Krauss, Paul D., "Mechanical properties and durability of high-performance concrete for bridge decks, *PCI Journal,* July-August 2008, 120-122.