INTERACTIVE PANEL 3
Architectural Design - Architectural UHPC:
The designers' and precasters' perspective on complex architectural elements, European production techniques and North American building requirements

Panel Chairs: Kelly Henry, M.Arch, MBA, LEED AP, Lafarge North America, a member of LafargeHolcim; and Larry Rowland, FACI, LEED AP, Lehigh White Cement Company

Expert Panel Members:
- Robert Anderson, Director, Davis Brody Bond, LLP Architects and Planners
- Roger Becker, P.E., S.E., Vice President Technical Services, Precast/Prestressed Concrete Institute
- Mickael Moos, General Manager Civil Engineering, Fixinox France
- Joel Foderberg, CEO, IconX, LLC

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Interactive Panel 3: Architectural Design - Architectural UHPC:
The Designers' and Precasters' perspective on complex architectural elements, European production techniques and North American building requirements

Co-chaired by Kelly Henry from Lafarge North America (a member of LafargeHolcim) and Larry Rowland from Lehigh White Cement Company, this interactive panel on Architectural Design was comprised of panel experts from the Precast/Prestressed Concrete Institute (PCI), Fixinox France and IconX, LLC. Keynote speaker, Robert Anderson from Davis Brody Bond, LLP, Architects and Planners (Washington, DC), provided valuable insight by sharing his own experiences in the realm of ultra-high performance concrete (UHPC) design; highlighting some of his firm’s recent and current projects that have utilized UHPC.

Panel 3, "Architectural Design - Architectural UHPC", began with the following introductory presentation by Kelly Henry.

Prior to opening the interactive portion of the session, short presentations were delivered by each panel member to provide background and motivate audience questions. Panel member names, affiliations and presentation titles are listed below:
1. Robert Anderson, Davis Brody Bond: *UHPC in Design* - pg. 3

2. Roger Becker, Precast/Prestressed Concrete Institute (PCI): *UHPC - Precaster’s Point of View* - pg. 6

3. Mickael Moos, Fixinox France: *Connections for UHPC Panels, Europe - State-of-the-Art* - pg. 8

4. Joel Foderberg, IconX, LLC: *Where do we go from here?* - pg. 9

The Interactive Panel received questions from the audience via live audience interaction software and direct participation to engage in a panel discussion based on that input. This State-of-the-Art Report provides copies of *partial presentations*, along with brief summaries. A partial list of transcribed questions from this session is provided in Appendix A.

*Due to large content, a selection of relevant/key slides are provided from each presentation. For more information, please contact: (co-chair) Kelly Henry: kelly.henry@lafargeholcim.com

1. Presentation by Robert Anderson: *UHPC in Design:*

The National Great Blacks in Wax Museum
Mr. Anderson's presentation began with a brief discussion regarding his extensive design experience on culturally significant, high profile projects such as the “National September 11 Memorial & Museum” in Manhattan, New York and the “Smithsonian National Museum of African American History and Culture” in Washington, DC. He then described his experience in the design and construction of the St. Elizabeth East Gateway Pavilion (“Gateway DC”), project in Washington DC, which utilized UHPC.

The Gateway DC project proposal received from city representatives consisted of a 1-page white paper, outlining the following project goals and requirements:

- parking for 15 food trucks
- seating for 350 people
- a 20,000 square foot covered, open-air market and park (combined)
- a pedestrian-accessible roof structure that would extend the park over the covered space
- a 9-month design-to-completion schedule

Once completed, the fast-tracked project located adjacent to Martin Luther King Jr. Avenue SE, would provide a civic space for the intercity Ward 8 neighborhood of southeast Washington, DC. The combination of a cast-in-place UHPC concrete deck/roof and architectural precast UHPC elements provided high performance solutions, enabled timely completion and led to award winning-results.

Mr. Anderson discussed the development process, from concept to completion, focusing on the highly specified production of 180+ unique architectural UHPC precast panels that act as safety barriers for the elevated space as well as a rain screen and architectural feature of the cantilevered roof park.

Since no two UHPC panels are alike, extensive modeling was required to design these essential features of the project. The panels, produced by Gate Precast in Memphis, Tennessee, weigh approximately 1,500 pounds (680 kg) each and are only 1.75” (44 mm) thick, ranging in size from the approximate average of 15 x 10’ (4.5 x 3 m). The resulting award-winning project is a functional, multi-use green space that provides an anchor for the Ward 8 community.

Mr. Anderson then presented an overview of the “National Great Blacks in Wax Museum” project in Baltimore, Maryland; a 130,000 square foot expansion of the existing 5,000 square foot museum. With a project design goal to yield a maintenance-free building, Davis Brody Bond selected a UHPC and channel glass façade.

The vertical façade assembly will use ribbed UHPC panels combined with glass channels, an excellent system that creates an air cavity. The elevated fascia wraps around to form a visible UHPC soffit; clear glass is used in conjunction with UHPC ribbed areas to create windows where desired. The museum design also features a pedestrian-accessible roof that will use the ribbed facade as roof safety barriers.

2. Presentation by Roger Becker: UHPC - Precaster's Point of View
Mr. Becker, Vice President Technical Services, Precast/Prestressed Concrete Institute (PCI), discussed the opportunities and challenges presented by UHPC for precast producers. To illustrate this topic, Mr. Becker referred to the Dumbo Townhouse project at Pearl and Water Streets in Brooklyn, NY. The project utilized precast molds made to specific requirements because the as-cast UHPC surfaces serve as the building façade.
The UHPC panels, produced by Gate Precast, are designed to take advantage of the material’s self-compacting characteristics, so they do not require any of the sacking and patching procedures which are typically employed to produce ordinary architectural precast elements. Tapered block-outs were used to form architectural fin profiles in the panels. The producer used several specialized techniques including sandable resins to produce flawless block-out surfaces and precisely placed lifting inserts so that the panels could be handled with existing panel handling equipment. Mr. Becker also noted that proper engineering and placement of lifting hardware and anchoring panels back onto the structure could present challenges when producing the thin UHPC concrete panels. See Appendix A for images from this presentation.

3. Presentation by Mickael Moos: Connections for UHPC Panels, Europe – State-of-the-Art

Mr. Moos, General Manager Civil Engineering at Fixinox, France, began his presentation with an overview of his firm and their experience in the production of specialized hardware for precast panels. Concrete anchor configuration and project solutions are tailored, based on structural conditions and panel design geometry. Various engineered solutions in the form of hardware configurations were shown for panels as thin as 1.6” (40 mm) thick, weighing as little as 550 lbs (250 kg) and as heavy as 6,000 lbs (2,700 kg) were shown. Anchor design depends on panel configurations, weight, thickness, orientation and the need to create an offset between the back of some panels and the face of the structure. The pros and cons associated with UHPC panels were reviewed and the related challenges that ultra-thin panels present for anchoring and hardware placement were discussed. Mr. Moos concluded with a review of why they have selected stainless steel as the material of choice for their hardware.
4. Presentation by Joel Foderberg: Vision for UHPC - Where do we go from here?

**ACI-318**

- ACI 318 provisions possible affected by UHPC characteristics
  - Variation of ultimate strain of concrete from typical
    - Does compatibility of strains apply?
  - Variation of modulus of elasticity, $E_c$
  - Does the rectangular stress block approximation still apply?
  - Increased tensile strength effects
    - Effect minimum steel requirements?
    - Size reinforcement required?
  - Shear provisions require more testing.

**ADVANTAGES**

- Lighter weight
- Good transfer of formliner texture.
- High durability
- Low Permeability
- Artistic

**DISADVANTAGES**

- Cost
- Batch Plant upgrades?
- Longer Cure Time
- Special Curing Requirements
- Handling?
- Fewer Finish Options

**POTENTIAL**

- Other Uses
- Insulated Composite Sandwich
- Seismic Designs
- Blast Protection
- Atriums
- Large Cantilevers
- OTHER IDEAS???
Mr. Foderberg, President of CEO of IconX, LLC highlighted practical concerns that designers, concrete producers and owners should take into account, when considering the use of UHPC in their projects.

First, Mr. Foderberg presented a basic cost comparison for the production of UHPC vs. standard concrete elements. Context was added regarding the potential savings made possible by the superior structural attributes of UHPC components. The potential barriers were also discussed with respect to (taking advantage of) UHPC’s enhanced attributes. Specifically: the lack of clear guidance for designing and constructing structures within US building codes; the lack of specific provisions for UHPC use in ACI 318; and the lack of established engineering standards for designing UHPC elements. He concluded with a review of innovative UHPC applications and encouraged participants to get involved in the discussion about this revolutionary product. See Appendix A for more on this presentation.
APPENDIX A - Interactive session

Below is a partial list of audience questions selected for discussion during this session, along with. The topic is: "Vision for UHPC - Where do we go from here?"

Table 1.

1. Can UHPC replace steel beams as structural elements?

- Robert Anderson says "yes"; he sees an application for UHPC as structural elements.
- This brings up the point that UHPC can be connected with most standard concrete connections, depending on the thickness.
- Beam connections were used for the Museum of European and Mediterranean Civilizations (MuCEM) in Marseille, France.
- When the structural element is intended to be exposed or an architectural feature, it makes sense to use UHPC elements; not where you are going to cover it up.
- The niche for this material is cultural / societal structures that will last and last.
- UHPC structural elements will be coming soon to an infrastructure/bridge near you. This will help drive innovation and market acceptance then become more widely used for buildings.
- For more information in regard to UHPC beams, see the publication FHWA-HRT-13-060, Ultra-High Performance Concrete: A State-of-the-Art Report for the Bridge Community.
- There is a Danish precaster doing it now.
- The panel believes that a good example application is where UHPC can replace steel when there is a need for fireproofing, light-weight or specific architectural features, etc.

2. Are there issues with finishing UHPC for architectural features?

Do the steel fibers “stick out” of the hardened surface?

- Yes, but only on the inside/backside of a panel. The face is smooth and fiber free.
- There are numerous different types of fibers; some less obtrusive than others.
- Some producers such as TAKTL® will exclusively use non-metallic fibers for architectural applications.
- Producers like Ductal® (by Lafarge) use steel fibers. As a result, the back surface of their UHPC panels may have rust spots where steel fibers are exposed. The rust stops at the concrete surface but can degrade the appearance on those hidden surfaces.
- The rust will not penetrate into the matrix of the UHPC.

Follow-up, formwork question: Roger Becker's presentation reviewed the importance of precise formwork. Are there any tricks for reducing the costs of forms?

- High density foam can work and result in savings.
- Cornices are a pain for precasters; designers should work with their producers to efficiently transfer loads and simplify fabrication.
- PCI is exploring the use of a 3D-printer to create formwork.
- It is key to understand the geometry of the structure in order to maximize form use? Multiple uses result in less cost.
3. How do we get the building code to allow UHPC in buildings?

- As UHPC becomes more common in infrastructure and other engineered structures, a body of specifications will be developed. Specifications will drive code adoption. Getting the codes out and into use will accelerate the use of UHPC.
- More use of UHPC will drive down the price.
- One important development step will involve researching ways to develop complex molds and designs that take advantage of UHPC’s high performance attributes. This will help eliminate the current theoretical $3-$4/sq. ft. cost premium over traditional architectural concrete. Form liners might be one answer for this.

4. How does UHPC compare to RC in terms of heat loss/transmission?

- Kelly Henry: the mass is very small so there is more heat loss due to less thermal mass.
- It is important to insulate UHPC panels to make up for the loss of the thermal mass effect in traditional concrete.
- It is important to account for this difference. For instance, according to ASHREA 189.1, insulation requirements change because you no longer have a mass wall.
- The industry is very familiar with insulated wall panels (sandwich panels), so insulating UHPC walls is similar in approach.

5. Can you explain how the thin panel connectors work, since there is not a lot of material to imbed a connector into?

- Fixinox has the ability to imbed to 1.2”. The presentation showed a couple options.
- They sometimes use a cast-in channels, giving flexibility of connection points.
- Keep in mind there is a tradeoff for these thin panels since they are light. You can achieve a lot of design redundancy with a few connection points.
- TAKTL® uses “Undercut Anchors” that can work on panels as thin as 3/8”.
- Although building codes favor designing for ductile failures instead of brittle failures, concrete connections are typically designed assuming a brittle failure. This does not account for the ductility of UHPC. Assuming brittle failure modes can result in a factor of safety of 2-3 times what you design for.

6. How much longer before we start to have North American Design Guidelines and Codes for UHPC?

- The panel consensus was that it would take more than five-years for the U.S., especially if it has to come through ACI.
- The French, Japanese and Swiss have versions of design guides in place.
- It starts with project specifications.
- If ACI 239 issues a standard with mandatory language, it will move much faster than going through ACI 318.
- Maybe ACI is not the right organization to produce the specification. It could take 20 years to get through ACI 318.
- PCI could do it similarly to GFRC codes that they publish, although PCI does not yet have a UHPC Committee.
Table 2. Questions asked by the audience during Panel 3.
Note: The “Score” is the number of participants who voted (via audience interaction app) for a particular question to be asked. This indicated a level of group interest; allowed the panel to prioritize all submitted questions; and ensured that questions of higher interest would be more likely to be addressed during the allotted time.

<table>
<thead>
<tr>
<th>Questions</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you think there is a place for UHPC beams to replace the steel?</td>
<td>4</td>
</tr>
<tr>
<td>Are there issues with finishing UHPC for architectural features?</td>
<td>4</td>
</tr>
<tr>
<td>Do the steel fibers stick out?</td>
<td></td>
</tr>
<tr>
<td>How do we get the building code to allow UHPC in buildings?</td>
<td>1</td>
</tr>
<tr>
<td>How does UHPC compare to RC in terms of heat loss through the concrete?</td>
<td>3</td>
</tr>
<tr>
<td>Can you explain further; how do the thin panel connectors work since there is not a lot of material to imbied a connector into?</td>
<td>3</td>
</tr>
<tr>
<td>How much longer will it be before we start to have North American Design Guidelines and Codes for UHPC?</td>
<td>2</td>
</tr>
<tr>
<td>Do we know how much longer it will be until we have a North American Design Guide for UHPC?</td>
<td>1</td>
</tr>
<tr>
<td>Are there other techniques for re-using mold work to get different elements out of a singular mold?</td>
<td>2</td>
</tr>
<tr>
<td>Are there any non-steel wall connectors used with UHPC?</td>
<td>2</td>
</tr>
<tr>
<td>When UHPC panels get thinner, or less than 1.5 inches, are there issues with transportation and handling (i.e., cracking)?</td>
<td>2</td>
</tr>
<tr>
<td>Apart from integral color, are there other design options for UHPC?</td>
<td>2</td>
</tr>
<tr>
<td>How did you treat the joints to make the panels the weather and moisture barrier?</td>
<td>2</td>
</tr>
<tr>
<td>Are there skylights in the Saint Elizabeth’s pavilion?</td>
<td>1</td>
</tr>
<tr>
<td>Are the elements typically with synthetic or stainless steel fibers?</td>
<td>1</td>
</tr>
<tr>
<td>Can geopolymeric UHPC be a low cost alternative to PC based UHPC?</td>
<td>1</td>
</tr>
<tr>
<td>Is there any documentation on the modulus of rupture for UHPC?</td>
<td>1</td>
</tr>
</tbody>
</table>

The following questions were submitted however; there was not sufficient time to address them.

- Why use UHPC for the Saint Elizabeths project? What sort of efficiencies did you gain?
- What difficulties did Gate encounter while casting St. Elizabeths or Dumbo?
- Is UHPC very different in the casting techniques from typical premixes?
- Because UHPC projects seem to be a thinner than typical precast projects, how does that affect the development of an attachment system?
- Are there any large hurdles for attachment systems used in Europe to be accepted in North America?