NEW DEVELOPMENTS IN Concrete Construction

PHOTO: COURTESY BLOCK USA

LEARNING OBJECTIVES

After reading this article, you should be able to:

+ DESCRIBE new trends in green building codes and standards that are affecting choices in concrete construction.
+ LIST several new techniques for designing and constructing buildings with concrete structures or finishes.
+ DISCUSS materials used in concrete mixes that replace or supplement Portland cement.
+ EXPLAIN how new construction techniques and materials are making concrete building systems more durable, reducing waste in erection, or producing less expensive buildings.

BY C.C. SULLIVAN AND BARBARA HORWITZ-BENNETT

Concrete has long been a reliable building material for commercial and institutional projects. Yet recent trends, including the growth in hospitality and urban rental project starts, as well as mixed-use towers and transit-oriented developments (TODs), have made concrete an even more valuable structural solution.

A number of macro-level changes in the building industry have added impetus to specifiers and contractors who regularly work with concrete. One is the emergence of sustainability certifications and green building codes that make concrete an even better material choice than in the past. The second is the use of technology to

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enhance concrete system designs and enhance their constructability or longevity. Third, better concrete mixes and finishing techniques are creating new uses for the material.

Fourth, new techniques for forming and pouring concrete—in concert with these unique mixes and finishes—are making inroads on job sites around the country. They add such benefits as cost effectiveness and enhanced durability to a material that is already known for both of these qualities.

SUSTAINABILITY AND THE CODES

The latest wave of updated energy codes, sustainability codes, and certification programs has brought good news for project teams choosing concrete. The material's strength, service life, recycled content, and other green qualities have been a boon to architects, construction executives, and building owners seeking to meet these newer standards and code requirements.

For example, the new International Green Construction Code (IgCC) contains quite a number of enforceable minimum standards such as construction material and waste-management requirements, recycled and locally produced material mandates, and very low levels of volatile organic compounds. In fact, for the VOC requirement, concrete is "deemed to comply" as a flooring system and as a wall system. Not only is exposed and polished concrete a trendy designer choice, it's also a way to integrate a green structural approach with readymade interior and exterior finished surfaces.

Furthermore, the IgCC requires buildings to comply with the International Energy Conservation Code (IECC), again giving concrete an advantage on account of its inherent air-tightness and thermal mass properties. Similarly, the material's longevity enables buildings to meet IgCC's 60-year service life requirement.

Two other recent developments that concrete designers and builders should be aware of is CalGreen—described as the country's greenest state building standard—and expanded seismic requirements in the International Building Code (IBC).

While the U.S. Green Building Council's LEED programs have always been voluntary certification systems for sustainable building, CalGreen is now enforcing many of these standards as a statewide mandate, while covering both interior and exterior products and applications. Used as a basis for the IgCC, CalGreen is also anticipated to receive attention from states outside of California.

As for the IBC, changes in seismic force calculations are recategorizing some regions of the country from a low seismic-risk distinction to moderate and, in some cases, high seismic risk. Consequently, projects in those affected regions will now require additional structural reinforcement, anticipated to affect beam-column joints and expansion joints in concrete structures.

BIM AND CONCRETE, TOGETHER AT LAST

While growing numbers of concrete designers and contractors are switching from CAD to building information modeling (BIM)—and realizing a number of benefits such as rapid design changes, visualization capabilities, and fabrication advantages—the nature of concrete in some cases is actually limiting these benefits.

For example, the precision of BIM models doesn't always take into account such factors as concrete's allowable tolerances or slight curves, known as camber, within the installed concrete members. Because there are such a wide variety of concrete mixes, joint placement, and reinforcement designs, Building Teams report it can be difficult to build a BIM object library of standard components.

As a practical matter, BIM's clash detection function has less impact on the concrete contractor's work than it does on other trades, says one expert, simply because the concrete is usually finished in the project's early stages. Meshing the concrete model with the other trades and systems does, however, provide a better basis for planning the concrete work.

On the other hand, one arena where 3D software is making strides is in translating complex concrete designs into fabricated concrete. A number of U.S. building teams have watched the work of Europeans in this regard, including the Amsterdam-based architecture firm UN Studios, who may be considered pioneers in this realm, says Geoffrey Goldberg, AIA, owner, GG+Associates Architecture, Chicago, and associate clinical professor, University of Illinois at Chicago School of Architecture. "The firm is using complex 3D software tools to generate complicated and interesting designs," he explains. "They output these forms to full-size templates to make the concrete formwork, which eases the construction complexities. This process provides a clear path from the designer's ideas to the contractor's fabrication."

EXPLORING ADAPTIVE REUSE AND CONCRETE

Because the practice of reusing existing resources is so sustainable, more and more design and construction teams are considering such options when concrete upgrades are in order.

"For concrete buildings, the structural frame and foundation often have the greatest inherent value because of their longevity, previously embodied energy and resources, and ability to be repurposed in many ways," says Blaine Brownell, AIA, LEED AP, an assistant professor at the University of Minnesota School of Architecture.

For example, at Navy Pier's parking garage in Chicago, James McHugh Construction added reinforcing steel and concrete cladding to all the columns in order to strengthen them for the garage's vertical expansion and the addition of four new floors.

Similarly, at a parking garage at Chicago's Midway Airport, the load-carrying capacity of downturn beams had to be increased due to the addition of security equipment placed on a supported floor that was originally intended to be a parking floor, according to Dave Alexander, senior vice president with James McHugh Construction. "The beams received added external reinforcing steel, which increased the load-carrying capacity, and the added concrete provided fireproofing to the new assembly," he says.

The nature of concrete makes it rather accepting of material additives and new systems, so Brownell anticipates that this kind of repurposing will only increase in frequency in the future.

Moreover, as part of Loughborough University's Freeform Construction Project in the U.K. (www.buildfreeform.com), researchers are developing a 3D printer capable of building complex concrete forms by depositing layers of liquid concrete based upon computer-generated directions. While the technology is still in the R&D phase, several industrial partners are currently reviewing its commercial viability, and researchers anticipate that it could eventually be used in high-end construction.

MIXING IT UP

When it comes to environmental responsibility and carbon footprint, practitioners are seeing ways to reduce the amount concrete used in projects, says Blaine Brownell, AIA, LEED AP, an assistant professor at the University of Minnesota School of Architecture (www.arch.design.umn.edu). Because concrete is the world's most widely used building material, and its crucial ingredient of Portland cement has the largest embodied energy of any concrete ingredient, manufacturers and researchers are investing time and effort in options for reducing, and in some cases, replacing cement.

Whether it's fly ash, slag, silica fume, or other supplementary cementitious materials (SCM), says Dave Alexander, senior vice president with James McHugh Construction (www.mchughconstruction.com), Chicago, project teams are seeing cement substitutes in virtually all mass-produced high-performance concrete these days.

Even beyond the cement content and SCMs, concrete mixes continue to change as designers and construction professionals discover how innovative combinations can produce assorted performance characteristics. "Concrete mixes are becoming less about sand, cement, aggregate, and water than ever before," says Alexander. "The advent of additives such as viscosity-modifying admixtures, corrosion inhibitors, crystalline admixtures, pervious admixtures, and many others has changed the face of concrete mix design." Today's concrete mixes are designed for a variety of purposes, such as:

- Allowing water to permeate or preventing water infiltration without the need for waterproofing.
- Blocking the leakage of radioactive materials in a hospital or lab.
- Preventing the rusting of the reinforcing steel within the concrete.
- Enabling the liquid concrete to flow a hundred feet or, alternatively, to be stiff enough to pour and immediately strip the form.

Another trend has been increasing the percentages of recycled content in concrete mixes. For instance, the CTLGroup (www.ctlgroup.com), a Skokie, Ill.-based group of researchers, analysts, and consultants, is now designing concrete mixtures that contain up to 85% recycled material, utilizing such resources as recycled concrete aggregate, recycled asphalt pavement, and recycled concrete wash water.

Two Minnesota-based companies recently combined forces to create a concrete mix made from a high percentage of recycled materials and won an American Society of Civil Engineers (ASCE) award for their final product. Taking advantage of the cementitious content already present in the recycled concrete materials, American Engineering Testing and Cemstone were able to reduce the Portland cement portion of the mix to just 2%, and achieve a compressive strength of greater than 4,000 psi.

PHOTO: COURTESY SYNTHEON

Composed of innovative polymeric spheres that have been specially formulated for use in concrete, Elemix additive distributes uniformly, resulting in a lighter weight product at structural strengths that produce durable, energy-efficient concrete that reduces construction costs, resists cracking, and supplements naturally occurring aggregates.

Another much larger concrete producer is now replacing up to 15% of Portland cement with plain limestone, and reducing emissions by 10% with the same workability, set time, and strength levels as conventional Portland cement-produced concrete.

Other innovative concrete products include an additive called Elemix, which consists of expanded polystyrene beads in the form of polymeric spheres. This product is creating lighter-weight concrete at the same structural strength of comparable commercial mixes while enhancing the concrete's thermal properties, pumpability, and cracking resistance.

Although it's been on the market for a number of years, self-consolidating concrete (SCC) is gaining traction as more contractors recognize its benefits as a highly flowable mixture that fully consolidates without any vibration or mechanical consolidation. "SCC is advantageous for placements with dense reinforcement or complex formwork and is capable of filling formwork completely without honeycombing or surface defects, producing a more aesthetically pleasing surface," states Matthew D'Ambrosia, group chair of the materials consulting, energy, and resources practice at CTLGroup.

In addition, SCC is available as a low-water-content mixture that creates more of a high-slump product that holds together well, according to Matthew R. Sherman, PE, and associate principal with Simpson Gumpertz & Heger (www.sgh.com), Waltham, Mass.

On the development and testing side, another newer product that CTL has been involved with is ultra-high-strength concrete (UHSC), a product type capable of reaching compressive strengths of more than 20,000 psi. Although special materials, mixing procedures, and processing techniques are sometimes required, the inherent fiber reinforcement in UHSC often eliminates the need for steel reinforcement, according to D'Ambrosia, an expert in concrete materials behavior and member of several American Concrete Institute (ACI) committees.

D'Ambrosia also sees shrinkage reducing admixtures (SRA) as gaining popularity. "SRA has many benefits in practice and is especially fitting for use in industrial flooring to reduce the number of joints by increasing spacing," he says. "They have been used in structures that are corrosion sensitive in order to reduce the risk of cracking."

Although somewhat less mainstream, a few newer innovations, including pollution-reducing concrete and self-repairing concrete, have attracted the eye of people like Brownell, who is well-regarded as a scholar on the subject of advanced architectural materials. Pollution-reducing concrete is a product developed by a large Italian cement producer called TX Active; the material mix employs photocatalytics to reduce pollutant sources. In fact, according to test results, researchers have projected that covering 15% of visible urban surfaces with products containing this additive would ultimately reduce pollution in a city the size of Milan by as much as half.

As for self-repairing concrete, Brownell calls attention to a group of researchers under the name Natural Process Design (www.naturalprocessdesign.com), who are developing a concrete mixture that proactively embeds repair material into the hollow fibers of the repair matrix. Then, if any cracking begins, the repair material is released and automatically patches the crack.

DECORATIVE IDEAS FOR CONCRETE

Not only is the larger concrete industry looking to environmentally friendly alternatives such as fly ash, but such alternative mixtures are actually providing benefit to decorative concrete contractors as well. "We need time to perfect our finished surface and with the use of fly ash, we get a strong finished product," explains Chris McMahon, president of Architectural Concrete Design (www.architecturalconcretedesign.com), Levittown, Pa. "This is without the worry of an accelerated set due to reactive cement, because the fly ash only becomes 'cementitious' after the cement begins to hydrate."

McMahon, who has been working the concrete business for almost 30 years, also likes to use recycled concrete as a sub-base, namely because it compacts better than crushed aggregate. He also mixes recycled glass into the concrete surface to lend an aesthetically pleasing, light-catching decorative look. "Many clients are now asking for logos or designs to be sandblasted into the concrete to add an artistic dimension," explains McMahon. Overall, decorative concrete finishes have found a valuable niche in heavily trafficked areas such as shopping malls, restaurants, hospitals, train stations, and even office buildings.

In terms of recent decorative trends, Michael S. Smith, president of Concrete Artisans (www.concreteartisansllc.com), Broomall, Pa., sees micro-toppings as the newest rage for concrete restoration and high-end modern frescos. In particular, polyaspartic coatings, which are fast-drying polyurea finishes with a high film build, are gaining market share over cementitious coatings. However, Smith cautions that some of these products can create membranes and should not be used in colder climates due to the risk of efflorescence delamination.

Another trend, says Smith, vice president of ACI's Eastern Pennsylvania and Delaware chapter, is combining decorative techniques such as stencils, stamping, coloring, and staining to create a new look. "Color choices, textures, and faux techniques are endless, affording designers their dreams in relatively inexpensive reality," he says.

For example, newer designs include engraving surfaces and exposing underlying concrete, and treating surfaces with dyes and tints over stains to create interesting color schemes. The use of white cement is a technique for increasing the range of colors and their intensity, according to Jamie Farny, market manager buildings, Portland Cement Association (www.cement.org), Skokie, Ill.

Farny is also impressed with a newer staining product, which contains infrared pigments and is capable of minimizing heat build-up on concrete surfaces, effectively reducing surface temperatures and the urban heat island effect.

In the grand scheme of things, McMahon sees decorative concrete as establishing itself as a replacement material for stone, offering a number of benefits including lighter weight, flexibility in its configuration and dimensioning capabilities, and reduced reliance on traditional masonry trades.

At the same time, McMahon insists that color hardener is a must to achieve the look of stone. "If you want the concrete to look like stone, it has to wear like stone," he advises. "Otherwise, the concrete eventually wears down without the help of color hardener to increase its surface strength."

Fortunately, advances with color hardeners are enabling thinner dyes to penetrate deep into the concrete—as opposed to pigments, which only provide a topical coating. The result is the look of stone

PHOTO: COURTESY DAVIS COLORS

A broader range of integral colored finishes is now available for exposed concrete flooring, as pictured here at this recently finished Trader Joe's store floor.

at one-third the cost, with the same durability and strength.

Another popular aspect of decorative concrete is polished and exposed concrete flooring. Traditionally used for slabs on grade in retail and industrial applications, these trendy and low-maintenance systems have already moved into institutional and commercial facilities. "A polished flooring system is easy to maintain, there are no annual maintenance costs, and there is no replacement of the floor finish," explains Brad Christopher, PE, SECB, president and senior principal with the civil and structural engineering firm LBYD (www.lbyd.com). Birmingham, Ala. "The polished concrete lasts the life of the building and is environmentally friendly as nothing has to be adhered to it," he says. "And there are a variety of color options to choose from."

Fitting well into the industrial-look design style trend, including elements like exposed beams and air ducts, retail stores are taking on a warehouse look, which is complemented by the exposed flooring, notes McMahon. "I think the psyche the retailers are trying to put the consumer in is that it's a discount store, as they don't have the more upscale look of carpets or tiles," he says.

Smith defines polished concrete as "modern terrazzo." While decades ago craftsmen would combine concrete with marble chips and then rub the surface clean, either by hand or with rubbing stones attached to sticks, this labor-intensive process and the skilled tradespeople have today become cost prohibitive. Today, rotary planetary grinding and polishing machines can quickly grind the marble chips to expose their inner beauty. Then a surface hardener is applied, and the flooring is polished to a high sheen.

However, McMahon still believes that diamond polishing is a very labor-intensive process because it requires many passes over the floor. "I like the look of polished concrete, but it is very expensive, as opposed to staining and sealing. We're talking $17 per square foot versus $5 per square foot," he says. "You end up cutting the floor several times to really get a dense, high-polished floor and, for some contractors, it's just not cost effective."

While there's nothing like the sharp look of a professionally polished floor, Sherman points out that it can be difficult to achieve a uniform appearance and get a good finished look in spaces which are next to embedded items and slab edges.

PHOTO: COURTESY NEWLOOK INTERNATIONAL/DAN MCCORMICK/EAGLE VIEW CUSTOM CREATIONS

At the ExplorationWorks science museum in Helena, Mont., concrete staining was used to create a river running across the floor in the entry area.

INNOVATIONS IN CONCRETE FORMS

Because concrete building erection is a relatively time-consuming and labor-intensive process, any innovations in concrete forms that reduce materials, speed up construction, or increase efficiencies have an instant audience. For example, pre-manufactured modular panelized systems are employed to replace loose frame board, which cuts down on the amount of debris. Clamp systems for wall forms are enabling contractors to have walls standing and ready for rebar and pouring within the same day. And newer, column-mounted table systems are increasing erection times by up to 30%.

"The big difference with the column-mounted table systems is you're transferring the loads into the columns and walls of the building itself. This enables faster erection as you're utilizing the structure itself as you build," explains Paul Treacy, a concrete superintendent with James McHugh Construction, who recently used the system on a Chicago high-rise project.

TAKING ADVANTAGE of High-Lift Grouting

Unlike the time-consuming and labor-intensive process of traditional low-lift grouting, in which load-bearing masonry walls are laid and grouted in five-foot increments, newer high-lift grouting enables entire walls of up to 24 feet to be laid in one shot.

"The wall is grouted from the top using a concrete pump, grout hog, or bucket, allowing the grout to drop to the bottom in one grouting operation," says Brad Christopher, PE, SECB, president and senior principal with LBYD, Birmingham, Ala. "Grout in the top eight feet of the wall is then consolidated with a vibrator."

While the wall does need to be cleaned out at the bottom to ensure that the concrete is fully filling the wall's base, these cleanout patches can be covered up with veneer on the exterior, and with a base board or below the slab-on-grade for the interior walls.

The key to high-lift grouting success, says Christopher, is self-consolidating concrete because it's a highly flowable, workable mix, capable of doing the most thorough job when it comes to filling up all the cells throughout the wall.

In a nutshell, Christopher explains, "The advantages of high-lift versus low-lift grouting include less labor, less reinforcing steel, a safer working environment with less job site concrete truck traffic and scaffolding construction, and reduced fuel costs with fewer trips required to transport grout."

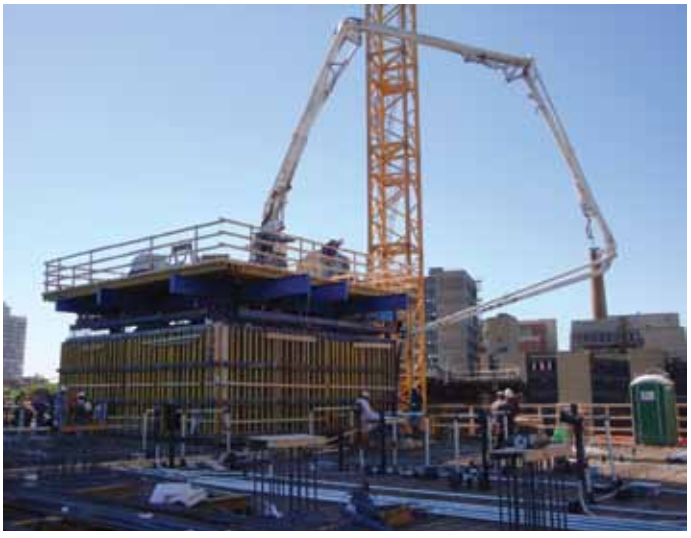

PHOTO: COURTESY DOKA

At this condominium project just north of downtown Chicago, a super climber system relies on powerful hydraulic cylinders to lift the working platform and formwork without the need for a crane.

Treacy, who has been working in the concrete high-rise market for 20-plus years, also likes the newer self-climbing systems for shear walls, namely because the technology doesn't require a crane for high-rise applications. Thanks to powerful hydraulic cylinders, the systems can safely support and lift a full working floor, including a concrete placing boom, formwork, workers, and equipment.

While the self-climbing technology is rather expensive, U.S. construction sites typically rely upon one to two cranes, whereas in Europe five or six cranes are often used. So anything taken out of the crane's workload on a U.S. project makes a big difference, says Treacy.

On the design side, Brownell is interested in some of the newer form-liner technologies, which provide a high level of control over surface geometry, texture, and even photographic treatments. He points out that formwork is one of the hidden environmental downsides of concrete structures because it is used in such significant quantities and often dumped in the landfill after use. "Any strategy that minimizes the disposal of formwork material is positive," he says. "When approached from this perspective, more expensive forms that are more easily reused or recycled—such as metal or some plastics—are more environmentally friendly than single-use forms."

At the same time, Treacy notes that traditional wood forms are also available with greater density, so they can be employed for as many as 70 placements. "Typically, if we're making a panelized system, we'll go for the higher-density plywood, but if we're using it in a loose-frame situation, where's it's not possible to protect the edges and the plywood will be damaged, then we go with a lower-density, less expensive plywood," he says.

The bottom line? Contractors need to be able to reuse the forms many times in order to justify the investment in more expensive plywood, plastic, or metal products.

Construction experts advise contractors to have an open mind when it comes to evaluating what might work best on each individual project. "A lot of contractors tend to use formworks which they've used in the past, and I don't think that's necessarily a good practice," says Treacy. "It's important to think outside the box and reevaluate as time goes on. You have to look at each project individually, looking at time frame, cost, and the sequence in which you need to pour. You can't always go with the lowest-cost alternative."

SURVIVING THE TEST OF TIME

Regardless of construction approach or mix, the most valuable thing about concrete is that even before all the newer technologies and innovations, it was already an appealing building material. Many building owners count on concrete to last for a good part of a century, or even longer. And while concrete does require some maintenance, which will vary based upon geographic location and exposure to the elements, when evaluated through its full life cycle, maintenance comes out to be quite inexpensive, according to Smith.

"This holds true for cast-in-place, tilt-up, and precast concrete systems," he adds. "All have their place in various markets and are affected specifically by labor, equipment, and ready-mix concrete supplier availability."

For example, tilt-up can be cost-effective with large, single-story retail or warehouse projects, as all the pre-assembled, load-bearing reinforced concrete wall panels are cast horizontally and then tilted up into vertical position, making for an efficient, speedy process.

On the other hand, cast-in-place is the strategy of choice for the high-rise market and is very adaptable to just about any construction requirements. Meanwhile, precast concrete eliminates the need for forms and reinforcement, and skips the whole process of pouring and curing the concrete, as the panels come fully ready to install.

Touching briefly on insulating concrete forms (ICFs), while some feel it will take time for the technology to prove itself, others see it as already gaining momentum, thanks to its impressive energy savings. "The economic implications of all these systems vary with the program and context in which they are used," explains Brownell. "In general, thoughtful design that accounts for programmatic flexibility over the life of a building—in addition to its eventual disassembly—may likely return the most value, regardless of which system is initially employed."

Overall, Treacy sees concrete as coming a very long way in the past few decades. In the past, concrete was limited when it came to high-rise construction, and comprehensive strengths could only get so strong. But today, that's all changed with the advent of newer construction systems and high-strength concrete. +

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