# Composites and Digital Fabrication:

## Opportunities in Architecture

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# MAKAI SMITH

Makai Smith is director of product management for MicroStation, Bentley's flagship software for infrastructure design which is used globally in the building, civil, transportation, plant, and geospatial disciplines. MicroStation also serves as the underlying platform for the majority of Bentley's desktop BIM and domain-specific applications. He is responsible for MicroStation strategic direction and the interface between go-to-market execution, development, software quality, professional services, and technical support to deliver a market-driven solution that meets the demands of engineers, design firms, and owner-operators.

Smith joined Bentley Systems in 2007 to serve as product manager for Bentley GenerativeComponents, which pioneered the application of associative parametric modeling in architecture, engineering, and construction. In addition to bringing it from the lab into the market, he was also the lead designer of its visual programming language.

Prior to joining Bentley, he was director of digital fabrication for Kreysler & Associates, a custom architectural composites manufacturer, where he oversaw the construction and operation of bespoke large-scale milling and laser-scanning used for pattern-making.

Smith began his career practicing architecture at Venturi Scott Brown and Associates, holding a Master of Architecture from Arizona State University and a B.S. in Design from the University of Florida.

For over a decade, Smith co-organized The Studio and Design Gallery at ACM SIGGRAPH, the world's largest computer graphics conference, and served as chair in 2009 and 2012. He also co-organized the SmartGeometry Conference, an early catalyst for the exploration of parametric and computational design in architecture.


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Composite materials, also known as fiber-reinforced plastics (FRP), have made a significant impact in many industries, such as aerospace and manufacturing. Glass fiber composites have found successful applications in things like windmill blades and boats because of their low weight, reasonable cost, ability to form doubly curved shapes, and resistance to corrosive environments, like salt water. There are also high-performance composite materials using carbon fiber reinforcing that are used in sports equipment, like racing sailboats or pole vaults, and in critical engineering applications like high-pressure vessels. Notably missing from the picture are buildings. The opportunity is enormous because buildings are worth more than 4% of U.S. GDP but are notoriously inefficient to construct and operate. Looking at why composites are not more widely adopted in architecture, engineering, and construction can help open possibilities for change.

Too frequently, buildings are built the way movies are made. One guy knows a guy, he knows another guy, and soon 300 people are working on a project together who have likely never seen each other before; and when they are done, will likely go away and never work with each other again. It is a fragmented industry, subject to varying methods of construction by geography and by politics of local jurisdictions. It is also configured to resist change because municipalities and corporations are inherently risk averse. Such organizational dynamics favor entrenched methods, especially where fire codes are concerned. It changes when contractors and code officials become more familiar with composites in construction. If one is required to plead a case to the city and educate stakeholders on every project, getting architectural applications approved goes slowly. The publication of specifications by the American Composites Manufacturers Association (ACMA) has helped to reduce friction because the guidelines inform building codes and open markets through increased acceptance.

In 2013, global construction ranked last against other sectors for its proportional investment in R&D, as reported by the European Commission. More work needs to be done in basic research and the application of new materials. Broadly, action is needed by such an inefficient industry, which has remained nearly flat while the productivity of all other industrial sectors roughly doubled in the last 25 years, McKinsey

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& Company found.  Meanwhile, the product of the industry is itself inefficient: buildings account for almost half of U.S. energy consumption according to the U.S. Energy Information Administration. Architectural composites can make a larger contribution because they are highly efficient and uniquely suited to solve certain kinds of construction problems.

When compared to other materials, composites stand out for their specific strength, a ratio of ultimate strength to material weight. Glass fiber composites are not as stiff as those reinforced with carbon fiber, but they are significantly less expensive. Conversely, steel is stiff but very heavy. A practical and efficient panel can be created by combining the two in a single assembly – a fiberglass composite panel engineered with integral steel stiffeners.

Resistance to fire is an important consideration in choosing building materials. Fiberglass composites can be made fire resistant and are approved for use in buildings when designed to the ACMA guidelines, but the lack of familiarity by designers and contractors often leads them to choose glass fiber reinforced concrete (GFRC) instead without fully considering alternatives. For example, the San Francisco Museum of Modern Art (SF MOMA), designed by Snohetta, originally specified the façade to be made of GFRC. Working with Webcor, the general contractor, and Kreysler and Associates, a specialty composites fabricator, they redesigned it to utilize FRP panels instead. The lighter weight, versatility of fabrication, and modularity of composite panels turned out to be a huge advantage.

GFRC has a much lower specific strength than FRP, so for the same panel, GFRC is much heavier. It also tends to crack, so a steel backup structure is required. As first conceived, the SF MOMA façade consisted of the weather wall, an air gap, and then a steel sub-structure carrying GFRC panels weighing about 15 pounds per square-foot. Since FRP panels are much lighter, in this case less than two pounds per square foot, and more inherently structural, they did not need a backup support structure. Not only was the cost and construction of the backup steel eliminated – a weight savings of about 1 million pounds – but so was the need to carry the extra weight of both the steel sub-structure and the heavy GFRC though the primary building structure. So, when the building was reevaluated using FRP, the result was significant cost savings on both the façade construction and primary structure.

The change had other significant knock-on benefits as well. With lighter panels, the tower crane could reach farther, so it did not have to be moved during construction. The savings in weight, coupled with the flexibility of FRP fabrication, also allowed the panels to include the interior wall. Installation of the complete assembly was done in a single, continuous operation, which saved time and reduced interference between trades. The stream-lined installation also lessened demand for layout and staging on the museum's congested, downtown site.

Often it is the systemic effects of using a material which gives rise to its efficiency. In some ways, it is more difficult because it is necessary to design holistically – earlier, and without the preconception of familiar methods – but the upside is huge and so is the need for more efficient construction of high-performance buildings.

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