**Smart Structures: If These Walls Could Talk**

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Robert Farrell

*What's the best way to design a better structure? How can you more accurately determine the life expectancy or maintenance schedule of that bridge? Just listen to it. Today "smart structures" are telling civil and structural engineers, designers, and architects everything they need to know about design, safety, and maintenance.*

The idea of collecting and analyzing data to improve products is certainly nothing new. In the 1970s a process known as *customer usage profiling* (CUP) emerged as a way to collect "real-world" data on the product while in the customer's hands. The idea being that systems, sub-systems and components are often subject to conditions outside of which they were designed to operate. Usage profiling allows manufacturers to identify, quantify, and design products for "the real world". This remains a key step in new product development for such industries as: automotive, off highway, lawn and garden, recreational and more. The results are generally improvements in customer satisfaction and costs by ensuring that products are neither under-designed (reduce liability and warranty claims); nor over-designed (unnecessary material, added weight, and cost).

**Structures**

This same approach has found its way into structural and civil engineering. Similarly, data can be collected on buildings, bridges and other structures to measure actual operating conditions. Knowing the exact forces and loads exerted by high wind, extreme temperatures, humidity, railcars rolling across a span, etc. will allow the next generation of structures to be designed, manufactured, and built to be more durable, efficient, and affordable.

Across the country sensors are helping to determine more accurate maintenance cycles on buildings and elevated road structures. In the US alone, trillions of dollars are spent building, maintaining, repairing, and replacing the nation's highway system. Bridges and roadways in cold weather climates are especially susceptible to the de-icing effects of salt eating away at pavement and corroding exposed metal. Now we can monitor pavement and structures to determine the extent of deterioration and schedule maintenance accordingly. At the same time, preventing unneeded maintenance also fosters a safer working environment for hazardous occupations such as bridge inspectors for example. Additionally, sensors are able to detect the presence of potentially hazardous conditions facing commuters. Bridge decks freeze before pavement that is in contact with the ground creating a black ice effect. This is dangerous because it can catch drivers off guard. Sensors can now detect the presence of icing conditions and trigger warnings automatically.

**A Living Structure**

Unlike test data associated with traditional usage profiling, smart buildings are designed to provide information indefinitely. This constant feedback allows data to be collected during rare unanticipated events such as record heat, extremely high winds, overweight cargo, etc. -- all occurrences that structures must be designed to withstand.

Presently Marquette University engineering students are gaining practical hands-on experience directly from the university's five story Engineering Hall. "In essence Marquette has created an interactive learning center," said Tim Carlier, President of Integrated Test & Measurement (ITM). The Milford, Ohio-based company worked alongside Marquette on the program. "Living structures are unique in that they're designed to provide real time visibility into how structures react to any force at any given moment. Knowing exactly how materials supporting structures react to a wide variety of forces and loads allows for better material choices and designs," said Carlier. Using ITM's iTestSystem software platform, a building monitoring system was created to collect data from a weather station together with more than 120 strain gauge sensors installed along beams, braces and columns inside the Engineering Hall at Marquette University. Data is collected by affixing strain gages to beams and other supporting materials within the structure. Such instrumentation is extremely accurate and sensitive allowing everything from earth tremors to pedestrian traffic to be measured. Readings from the equipment are sent to a data storage unit where software transforms raw data into useful information. This information can be downloaded and viewed in report and graphical formats for quick reference or a more thorough analysis. Just as before, the data can be used to determine the impact of various loads on structures.

The system not only measures wind speed on the structure; it can actually “feel” the wind load during gusts and record its impact on the facility. Data is broadcast in real time to anyone plugged into the servers through their mobile device. Observing the data allows students to understand how a building’s systems “share lateral load” during wind events. In addition, instruments along support beams in the Engineering Materials and Structural Testing lab allow students to analyze moving loads as the crane moves around the bay. At the same time floor sensors measure the impact of people moving through the building. This information will impact future building design and potential building code modifications.

“We want to show structural engineering students how to evaluate the structural engineering models used in steel building systems,” explained Dr. Christopher Foley, Professor and Chair of Civil, Construction & Environmental Engineering, Director of the Engineering Materials and Structural Testing Laboratory at Marquette University, and the person responsible for the vision for the building’s instrumentation and use as a teaching tool at Marquette University**.** “We can literally use the floor structural system as a scale. We can also measure a real building’s response to wind events, occupancy loading, and response to crane loads to evaluate engineering models used for predicting building behavior and response. The potential broader impact of the use of this building as a teaching tool in degree programs related to structural engineering and for structural engineers analyzing and designing buildings is immeasurable.”

**Smarter Infrastructure**

Armed with such information, the next generation of structural engineers and those structural engineers currently involved with writing building codes and analysis/design standards have the ability to advance structural engineering practice. At Marquette high wind speeds trigger different data acquisition sensors and protocol. Students can monitor the wind's effect on the building to calculate and predict its reaction. In the short term understand exactly how and where a building, bridge, or any structure for that matter reacts to catastrophic forces such as earthquakes, hurricanes, fires, etc. allows us to concentrate on assessing areas most likely to be under stress. Assessing damage and related safety issues visually can be difficult and time consuming. With the help of sensors the building itself will instantly pinpoint the exact location and extent of damage. In the longer term this information is used to design buildings more likely to withstand nature's most violent forces.

Just as important, sensor technology can have a place in the day-to-day life of a building's occupants. "Sensor technology, and application, is concerned with the overall health of a building starting with structural integrity and can be expanded to the well-being of its occupants," said Foley. "For example, in the future we might monitor the air quality inside a building to evaluate variation resulting from painting, laying of carpet, or poor outside air quality that is being pulled in and circulated. Building owners can use temperature sensors to better understand heat loss and heat gain within their buildings thereby gathering better information to provide improved living and working environments."

**Information is King**

Until recently we've lacked a proven way to communicate directly with structures and dive into their DNA. Today data collection and interpretation bridges this gap by allowing us to listen, understand, and apply actual feedback. "Simply put, better information yields better decisions," said Carlier. "Now, through advancements in data acquisition, we are able to provide more complete and accurate information allowing a wider range of design alternatives to be evaluated. All of this leads to structures that are more durable, efficient, affordable and safe."

At Marquette engineering students ranging from mechanical, structural, civil, electrical, computer and even bio medical are interested in the process and thinking of applications within their related disciplines. “What we are trying to accomplish is somewhat simple,” explained Dave Newman, Director of Operations and Managing Director of the Engineering Materials and Structural Testing Laboratory (EMSTL) for Marquette University. “Our goal is to educate the next generation of engineers as to what is possible today and ask them to advance the process by continually asking where we go from here.”

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Robert Farrell
Farrell MarCom Services, LLC
513-284-2618
www.farrellmarcom.com

Integrated Test & Measurement (ITM)
Tim Carlier
tim.carlier@itestsystem.com
844.837.8797
www.itestsystem.com

Marquette University
Christopher M. Foley, PhD, PE, FASCE
christopher.foley@marquette.edu