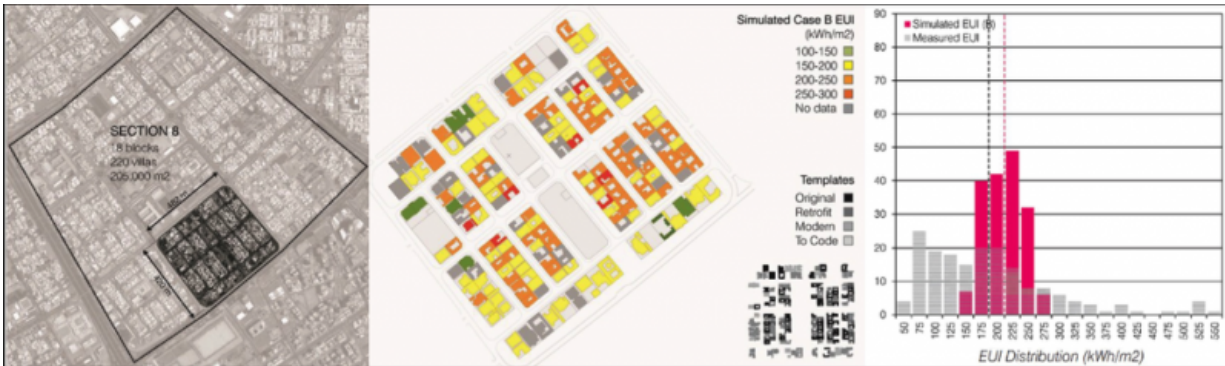


# Sustainability of the built environment

May 8 2015, by Kelsey Damrad



Modeling Al Qadisiyah, Kuwait City (left to right): Aerial view; umi energy model; comparison between measured and simulated energy-use intensity distributions for 200 buildings.

In times of limited resources and continued evidence of significant climate change, sustainability is increasingly regarded as a topic of global importance. Consider areas such as design, energy, and materials: These core concepts associated with sustainability are part of an integrative spectrum of widespread innovation.

"Sustainability is a fashion nowadays," says Oral Buyukozturk, professor of civil and [environmental engineering](#) (CEE) at MIT. "But the concept is often used so loosely that many people are unsure of what it really means."

With a particular focus on mechanics, the durability of [construction](#)

[materials](#), and sound design, Buyukozturk has catalyzed several multidisciplinary ventures in CEE—all with the goal of advancing the science and engineering of quantifiably sustainable designs for infrastructure.

He maintains that science and engineering are the entities that keep skyscrapers erect, materials resilient, and infrastructure intact.

"Physical and civil infrastructures inevitably deteriorate over time," Buyukozturk says. "Construction material deterioration is a global problem, and we are faced with two challenges: How do we rehabilitate and repair existing structures, and how do we build new systems that are more durable under today's conditions?" His work in the sustainability of the built environment strives to provide solutions.

Determined to clarify the concept of sustainability in engineering terms, Buyukozturk launched the Laboratory for Infrastructure Science and Sustainability (LISS) in 2011. Now home to a group of correlating initiatives, LISS aims to contribute to societal and economic development through detailing the sustainability of existing physical infrastructures and enhancing the design of new systems.

LISS encompasses several interrelated initiatives including motion sensing and distributed wireless sensor networks, construction material innovation, infrastructure energy efficiency, as well as new design paradigms in earthquake engineering.

LISS broadly communicates its discoveries and new technologies through the presentation of papers in international conferences on structural health monitoring, earthquake engineering and seismology, as well as publication in journals such as the *Proceedings of the National Academy of Sciences*.

## **LISS tackles the sustainability of Kuwait's built environment**

Among the research initiatives gathered under the LISS umbrella, one of the most ambitious is the Sustainability of Kuwait's Built Environment (SKBE). The mission, coined as the first Kuwait-MIT Signature Project, was announced on March 13, 2013.

Bringing together more than 30 MIT and Kuwaiti researchers, as well as an army of graduate students from every corner of MIT, this team endeavors to generate innovations in building materials, sensing, energy efficiency, resiliency, and urban planning.

Incorporating a myriad of fields, "the overall objective is the development of innovative solutions and methodologies for the sustainability of Kuwait's built environment in extreme conditions," says Buyukozturk, the lead principal investigator of SKBE. The final product will be a blueprint for the future of Kuwait's built environment.

"The project greatly contributes to the energy and life cycle efficiency of materials, buildings, and neighborhoods using a unique multiscale approach to urban planning. It will benefit Kuwait in its future city developments and improve energy utilization of existing buildings and towns with a perspective towards renewable energy concepts," says Ali Hajiah, research scientist at the Energy and Building Research Center of KISR, and co-principal investigator of the Signature Project.

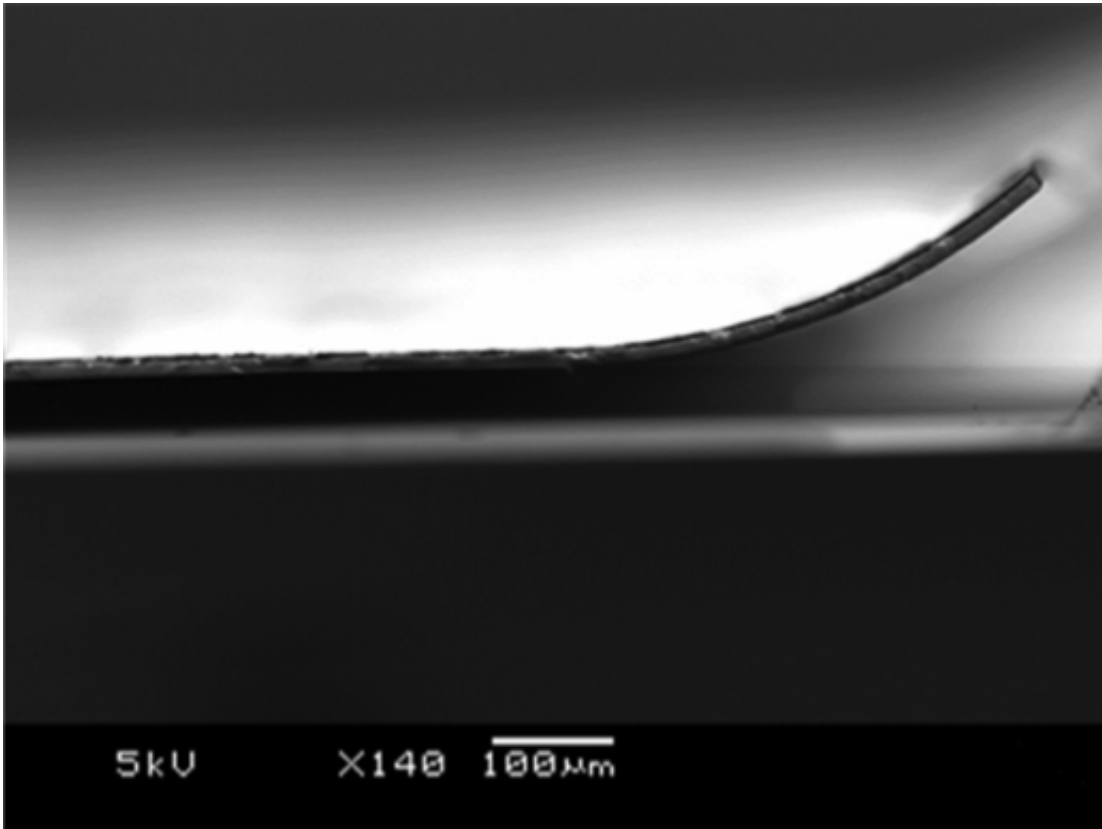
SKBE evolved after years of interaction between MIT and Kuwaiti scientists from the Kuwait Institute for Scientific Research and Kuwait University, and is funded with a \$4.97 million grant through the Kuwait-MIT Center for Natural Resources and the Environment (CNRE) by the Kuwait Foundation for the Advancement of Sciences.

The beauty, says Buyukozturk, is its ensemble of "hot topic" challenges: steep population growth, seismic ground motion, hazardous weather conditions, energy conversion, and future energy depletion. The real-world implementations for the salvage and utilization of an ultimate energy system for Kuwait are vast, he adds.

"To my knowledge, this is a unique program of this scope, dealing with issues of this size," Buyukozturk says. "The challenge is getting everybody working together toward sustainability—not just talking about it, but creating solutions."

In response to the Kuwaiti government's call for an integrated approach to updating its infrastructure, the plan encompasses three research thrusts: nanoengineered construction materials, performance-based engineering and reliability and energy efficiency, and life-cycle performance of construction materials and buildings in Kuwait.

"As several infrastructure projects are to be implemented based on Kuwait's Master plan, this distinctive signature project which is divided into three related thrust areas will provide significant scientific knowledge and benefits to Kuwait for future infrastructure systems, retrofitting existing infrastructures, education, economic, and construction industry," says Hasan Kamal, member of Kuwait Municipal Council, coordinator and a co-PI of the project. "In addition to its benefits to the Gulf region, the outcomes of the project will be used to modify standards, regulations, and codes."



How materials break: Scanning electron microscope image of interfacial debonding. Credit: Oral Buyukozturk

### **SKBE creates durable, construction materials**

One example of the project's success is its development of concrete made to weather the elements with less degradation than that currently used in much of Kuwaiti construction.

"At Kuwait University we have powerful techniques like solid-state 600-NMR, N<sub>2</sub>/H<sub>2</sub>O sorptiometry, Raman spectroscopy, and Nanoindentation. For the first time and through this unique project we are implementing these techniques in cement characterization and optimization," says Professor Ali Bumajdad, vice dean for academic and

graduate studies of Kuwait University, a supervisor of KU's Nanoscopy Science Center, and a co-PI of the project.

Through an iterative process that combines experimentation and the type of multi-scale computational modeling led by Department of Civil and Environmental Engineering head Markus Buehler, the SKBE team is developing a cement paste composition that incorporates volcanic ash—a material found throughout the Persian Gulf region/Arabian peninsula. Concrete made with this composition is less porous and resistant to water penetration and serves the team's sustainability objectives.

"We [in SKBE] incorporate the biological materials studied in Professor Buehler's group into construction and building materials," says Steven Palkovic, CEE graduate student and SKBE collaborator. "This work is innovative because it's one of the first attempts at a multi-scale approach for cement base materials and an ongoing effort to apply lessons from biological materials to one of the most widely used construction building materials in the world."

According to Buyukozturk, this effort will save Kuwait and future missions both money and energy.

"This is a new concept, using locally available material to replace part of the cement to create a material that behaves better, involves less manufacturing costs, and lasts longer," he says.

The vision of the project is to leverage the basic science capabilities of computational materials modeling and simulation in conjunction with current experimental techniques to meet the specific technological challenges of Kuwait.

It is a first step, says Buyukozturk, "of a model for sustainable solutions to materials and for structures."

## **Regulating the infrastructure response to the environment**

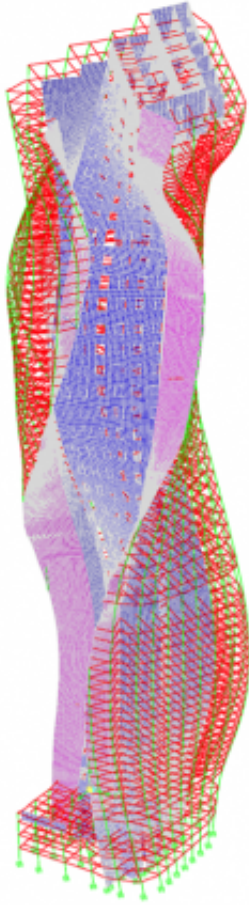
Sensors that detect subtle building behaviors such as twisting, vibrating, and rocking can potentially identify structural damage or weakness before a disaster occurs.

Within the SKBE's scope, sensor networks are being installed on the Al Hamra tower in Kuwait City, the world's tallest sculptured building, to monitor its seismic behavior and any environmental effects. "We build a full-scale finite element model to study the dynamic characteristics of this unique tower and carry out optimal sensor placement analysis before instrumentation," says CEE postdoc Hao Sun. "The objective of optimal sensor placement is to obtain as much information of the structure as possible given a limited number of sensors in practical structural health monitoring."

GPS units and accelerometers have also been placed around Kuwait to measure building movement. "We installed two GPS units in Al Hamra to continuously monitor the motion and displacement of the building," says Tom Herring, a GPS specialist and professor in MIT's Department of Earth, Atmospheric and Planetary Sciences (EAPS). "The GPS is potentially able to monitor the building's dynamic behavior in real time which tells us the seismic and environmental effect on the building and helps us to evaluate the building safety."

A special objective of SKBE is to examine seismic loads applied to tall buildings and superstructures in Kuwait. "Regional earthquakes are important safety-threatening factors to buildings in Kuwait," says Nafi Toksoz, EAPS professor and co-PI. "With the performance-based engineering concepts, we investigate robust methodologies for local ground-motion calculation to provide data for building-response

modeling and performance prediction."



At 412.5 meters, the world's tallest sculptured tower was built as a reinforced concrete structure. The tower's computational model shows (greatly exaggerated) dynamic torsional movements under ambient excitation.

These new technologies, says Buyukozturk, can inform decisions about renovating current infrastructure for safety and reliability and can help with tailoring future building systems to achieve maximum energy efficiencies and sturdiness.

Enhancing the [energy efficiency](#) and life-cycle performance of



infrastructure

Architects are taking the lead on SKBE's third research focus area. One team member, Christoph Reinhart, associate professor in MIT's School of Architecture and Planning, is applying sustainable design simulations and planning models to the large-scale laboratory of Kuwait.

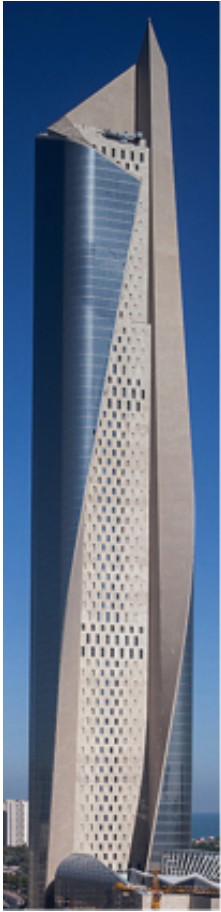
With MIT students and Kuwaiti colleagues, Reinhart is mapping each residence in a typical neighborhood of Kuwait City to determine energy use of occupants as well as each unit's embodied energy use (the energy required to build and maintain a structure over its lifespan). His group is also plotting the "walkability" of city neighborhoods, the proximity and accessibility of stores, parks, and other sites to travelers on foot.

This research will provide planning guidance to the government of Kuwait, which is currently under extreme pressure from a rapidly expanding population and its own commitment to provide affordable housing to Kuwaitis.

"What we're really doing here is creating evidence-based design tools they can use today," Reinhart says. "If we can say that over the next decade, this is how much energy is going to be used in buildings, Kuwaitis can make strategic decisions, such as deciding to retrofit older buildings with photovoltaics or more insulated windows, or deploy new [building materials](#) that keep buildings cooler in the summer."

Reinhart's research reveals tradeoffs that may come into play as Kuwait makes choices about sustainable construction. Well-designed high-rise buildings, which his models suggest are the most energy-efficient and enhance neighborhood walkability, do not prove as amenable to daylighting—a technology that uses natural light from windows to reduce the need for artificial light sources. Increased density of buildings, better for energy savings, may cramp Kuwaitis' desire for

comfortable living spaces.



The Al Hamra Tower

However Kuwait decides to use this work, Reinhart views his neighborhood modeling as "an exciting new energy policy tool that can have a gigantic impact," he says, especially as it gets deployed on larger scales.

In addition, John Ochsendorf, the Class of 1942 Professor in MIT's departments of Civil and Environmental Engineering and Architecture, is working together with Reinhart to quantify the environmental impact

of construction materials in Kuwait. The goal is to identify opportunities for energy savings in both the operation and the construction of buildings. According to Ochsendorf, "this project provides an integrated approach to the planning and design of low-energy cities for the future."

SKBE was originally expected to run for three years, says Buyukozturk. Now in its third year, he hints that the project's natural continuation will extend past the formerly anticipated deadline. "The indications are that with this extension they [Kuwait] would see increased benefits from the intellectual framework and development we have created with this project," he explains. "Particularly, they would like us to continue into the extension of physical implementation of the blueprint we have created."

SKBE represents a first step toward demonstrating the benefits of the alliance synergy, and is an effort to provide a science foundation for a set of technologies addressing the safety and efficiency of Kuwait's built infrastructure.

"As the success of SKBE depends on creating solutions specific to the Kuwait conditions, it also illustrates a principle underlying any science-based transformation of technological enterprises in our society—connecting the push from science advances (global) to the pull from technology demands (local)," says Professor Sidney Yip, a co-investigator of the project in the Department of Nuclear Science and Engineering.

From providing detailed maps of energy usage to the fabrication of durable construction materials for robust infrastructure that withstands the elements, Buyukozturk said Kuwait's quantifiably sustainable designs, along with the other LISS initiatives, "are going to be a very big thing."

**More information:** "A robust nanoscale experimental quantification of fracture energy in a bilayer material system." *PNAS* 2014 111 (33) 11990-11995; published ahead of print August 5, 2014, [DOI: 10.1073/pnas.1402893111](https://doi.org/10.1073/pnas.1402893111)

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