A Vision for Smart Cities based on Current Research

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Smart structures that provide the infrastructure for smart cities should include cutting edge structural engineering design, construction, monitoring, sensing, and should interact with society in smart, sustainable, and resilient ways. This paper discusses a vision based on current research in the Department of Civil, Environmental, and Architectural Engineering at the University of Kansas to improve sustainability and resilience of future smart cities through smart structural systems, the use of smart structural health monitoring sensors, and the interaction of engineering with societal goals.

Structures: Smart structures require construction in smart cities to be adaptable such that new technologies can be implemented without structural system-level replacement. One way to improve the performance of structures is through the use of lightweight modular structures and components that make the most effective use of sensing and analysis of structural health monitoring data. Lightweight structures are beneficial over many conventional structural systems which are heavy and result in large gravity loads and high inertial forces during extreme loading events. In addition, conventional structural systems lend themselves to construction practices that prevent reconfiguration, rapid construction, rapid deconstruction, and are limited by initial assumptions made about the occupancy and usage needs. Modular components and structures that consider integration of non-structural components such as mechanical, electric, plumbing, information technology, and structural health monitoring are vital to the resilient and lightweight structures of the future and can allow for rapid changes to the structure over its lifespan. Lightweight structures will take advantage of rapid and sustainable construction and deconstruction, and reconfiguration to facilitate economical and multi-functional use allowing for variation in the structure's use over time based on the user's need.

Current research is working on lightweight modular two-way steel flooring systems at the University of Kansas as an alternative to conventional steel deck composite floors. This work will allow for more economical steel frames designed for reduced dead loads and seismic forces. Preliminary analysis shows that 30 ft x 40 ft bays with no filler beams are attainable with modular panels. The modularity provides this new flooring system with advantages over traditional steel-concrete composite floors, which have significant construction and curing times. Faster construction and the possibility of deconstruction given future building use changes can reduce long term costs and waste. Additionally, this system lends itself to integrated construction and structural health monitoring which fits within the framework of future smart cities. Modular, lightweight, reconfigurable, rapidly constructible, and rapidly destructible structural systems will be essential for the dynamic nature of future smart cities.

Sensing: Sensors play critical roles in various aspects of smart cities, including structural health monitoring, intelligent transportation systems, environmental monitoring, and indoor monitoring. The goal of infrastructure health monitoring is to inform the current condition of structures by sensing structural responses under external loads and environmental effects to assist with structural maintenance. Current structural inspection practices based on human visual inspections are time-consuming, labor intensive, and prone to error. One tragic example is the collapse of the I-35W highway bridge over the Mississippi River in 2007 which passed a visual inspection a year prior to failure. Structural health monitoring aims to

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assess structural integrity using sensing technology and signal processing approaches, enabling a long-term, continuous monitoring paradigm that can provide a more reliable and economic way of maintenance of civil infrastructure for future smart cities.

Ongoing research at KU for sensing and structural health monitoring includes the following: (1) an autonomous wireless elastomeric skin sensor network for monitoring fatigue damage of steel structures. This innovative capacitance-based skin-type sensor is being integrated with wireless sensor technology to offer reliable monitoring of fatigue cracks on steel bridges. (2) Rapidly deployable self-organizing wireless sensor networks for post-disaster structural monitoring, which are able to be deployed without central base stations for short-term continuous monitoring after disasters such earthquakes. (3) Damage assessment of building structures through indirect interstory drift monitoring enabled by sensor fusion, and (4) long-term structural assessment through a Bayesian-based framework. The capability to closely monitor the integrity of buildings and bridges to aid in informed decision-making is vital to achieving resiliency and sustainability in future smart cities.

Society: The engineering of smart cities will need to include performance goals for the present, and predicted change in, social and economic systems of the city. When discussing the interaction of infrastructure systems in a city, research quickly points to three key concepts - vulnerability, resiliency, and sustainability. Smart cities will have to consider these three concepts in every aspect. Structures can be designed sustainably to reduce vulnerabilities, and increase resiliency, but research shows that these concepts could be enhanced if addressed at the societal level. How can smart cities improve the sustainability, vulnerability and resilience of its people? Current research at KU is exploring multiple ways which address this issue. One research method being explored is optimizing the design level of structures through the built environment's intersectionality with the social, economic, and demographic (SED) characteristics of the city's population. How should a building design differ based on the SED characteristics of the people that use it? Limiting the number of stories in a building which hosts a high percentage of elderly people is one example. This way, elderly people are not required to walk down countless flights of stairs in an emergency situation. Another approach is through public involvement in transportation project planning, and disaster mitigation planning which hypothesizes that civic engagement improves resilience through (1) creating stronger community ties, (2) giving community members a voice, and (3) educating those engaged community members on mitigation techniques to adopt in their own homes, and what to do before, during and after an event. Altogether, stronger community ties, and confidence in local government and non-government agencies, have been shown to speed up the recovery process at the individual household and community level. The capability to improve the resilience of the people which make up the city is imperative to achieving resilience in future smart cities.

Summary: Smart cities use information and communication technologies to enhance quality, performance and interactivity. The previous visions and research summaries give insight to three key components of future smart cities: structural systems, sensing, and society. Future smart cities will incorporate all three of these to develop one integrated smart network of interconnected physical, digital, social, and economic systems.

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