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Grand challenges in sustainable design and construction

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INTRODUCTION

The world has experienced unprecedented urban growth in the last and current centuries. In 1800, only 3% of the world's population lived in urban areas. It increased to 14 and 47% in 1900 and 2000, respectively. Since 2008, for the first time in history, more than half of the world population lives in the urban areas (Laski and Schellekens, 2007). In year 2003, United Nations estimated that by year 2030, up to five billion people will be living in urban areas, accounting for 61% of the world's population. The ongoing migration to urban areas has massive environmental consequences. This condition of unprecedented shift from the countryside to cities has been influencing climate change, where urban areas account for up to 70% of the world greenhouse gas emissions.

Cities are growing toward megacities with higher density urban planning, narrower urban corridors, and more high-rise urban structures. Increasing urbanization causes the deterioration of the urban environment, as the size of housing plots decreases, thus increasing densities and crowding out greeneries (Santamouris et al., 2001). Cities tend to record higher temperatures than their non-urbanized surroundings, a phenomenon known as urban heat island (UHI) (Oke, 1982; Jusuf et al., 2007). Earlier studies show strong relation between urban morphology and increasing air temperature within city centers. Urban structures absorb solar heat during the day and release it during the night. Densely built area tends to trap heat, which is released from urban structures into the urban environment, increasing urban air temperature compared to surrounding rural areas and causes UHI effect. UHI affects street level thermal comfort, health, environment quality, and may increase the urban energy demand.

As the number of buildings and associated infrastructures increases drastically in order to cope with the increasing population in cities, tremendous resources are required for the construction, operation, and maintenance of these buildings. Design of these buildings become very crucial as the resources required in the subsequent operation and maintenance is highly dependent on the quality of such design (Macmillan, 2005). Over the years, there has been tremendous effort put in to design "Green Buildings," with the key objective to make the buildings more sustainable by minimizing the utilization of resources in the construction, operation, and maintenance of buildings. Building systems such as air conditioning and lighting are energy guzzlers, which can consume more than 60% of the energy consumption in a typical commercial building. They can also impact the indoor environmental quality. Thus, energy efficiency of the systems is crucial. Selection of materials, which can minimize the embodied energy and construction waste is also important.

ADVANCES IN THE DESIGN, CONSTRUCTION, OPERATION, AND MAINTENANCE OF THE BUILT ENVIRONMENT

The multifaceted relationship between microclimate and built environment is the key to promote sustainable theme within design and building practice. There is a vast body of knowledge and research studies about this matter, but to understand fully the microclimate impact on built environment is still a very challenging effort. The whole ecology system comprises many systems, which are too complex to be quantified and represented in numbers and models (Yeang, 1995). However, this incomplete and inadequate state of current knowledge about climate–urban relationship should not be the reason to be evasive toward preventive or corrective actions within the design process. Planners and engineers should view design process with a proper understanding on ecological aspects, where the concerns should be laid not just at present time, but also for the future. Over the years, researchers have attempted to develop techniques, models, simulation platforms, etc. for urban planners and architects to understand the impact of their designs on various environmental parameters. One key aspect that has shown tremendous progress is in the study of the urban climate, which deals with issues such as UHI, urban airflow, air pollution, urban noise, daylighting, outdoor thermal comfort, etc. (Kang, 2002; Wong et al., 2003; Compagnon, 2004; Georgakis and Santamouris, 2004; Gulliver and Briggs, 2011; Yang et al., 2013). In recent years, modeling techniques to map out the urban climate (temperature, wind, solar radiation, daylighting) have been developed that help to guide the urban design (Matzarakis et al., 2010; Wong et al., 2011; Tominaga and Stathopoulos, 2013). Various mitigation measures such as the integration of greenery with the urban structures (Wong et al., 2003, 2009; Chen and Wong, 2005), application of cool roof materials (Santamouris et al., 2011; Akbari and Damon Matthews, 2012), improvement of the urban airflow, control of the anthropogenic heat (Sailor, 2010) in urban centers, etc., have been studied to great extent.

At the building level, there has been good progress in the modeling of the performance of buildings and the associate systems such as Energy (Crawley et al., 2008), thermal (Hensen and Lamberts, 2012), lighting (Thanachareonkit et al., 2005), acoustic (Beradi, 2014), indoor air quality (Steeman et al., 2009), etc. with greater precision and certainty. With the advancement of information technology, greater utilization of sensors and control systems have been observed in buildings resulting in better performance and energy efficiency in buildings. At the material level, nanotechnology has been employed to develop building materials that can help to improve the performance of buildings such as improving the thermal and acoustical insulation, allowing more daylighting through glazing systems but reducing the entry of heat. The concept of Life Cycle Analysis (Dixit et al., 2010; Ramesh et al., 2010) has also been introduced that monitors the embodied body of resources utilized throughout the entire building life cycle. This has also resulted in better control of resources utilization during the design, planning, construction, and operation of buildings.

CURRENT CHALLENGES ENCOUNTERED IN SUSTAINABLE DESIGN AND CONSTRUCTION

Despite the advances in the research and development in the built environment as discussed in the earlier section, there are still major challenges encountered. One key challenge is in the integration of such practices in the design process. Most designers still see such tasks as the responsibilities of the environmental consultants rather than part and parcel of their design tasks. Thus, it is essential that more research should be conducted to seamlessly integrate such modeling approaches with the design process. With the advancement of Building Information Modeling (BIM) (Bynum et al., 2013; Volk et al., 2014), this will serve as an excellent platform for such integration to occur. It also allows a better integration of the different simulation models so that a better understanding of the relationship between these simulation models could be obtained. Currently, there is also lack of understanding of the inter-relationship between urban and building systems. Such understanding is crucial as studies have shown that the microclimates, which are very much governed by the urban systems could have major impact on the energy, thermal, and lighting performance of buildings. Currently, there are tremendous research works done at the urban level using Geographical Information System (GIS). The study of such inter-relationship between urban and building systems could be facilitated by a better integration between GIS and BIM.

FUTURE DIRECTIONS

It is envisaged that in the near future, there would be a development of a universal and integrated model that could embedding the entire urban and building models. As such, it allows the seamless integration between these two scales of models. This will also facilitate the development of the boundary conditions generated by the urban model that could be easily utilized by the building model for the simulations. For example, simulations could be conducted to understand the wind and temperature distribution at the urban level and such data could be seamless utilized by the individual building model for the detail simulations of the wind or temperature condition inside the building. Another key development would be the integration of the sensors with the urban model for master planning purpose and for creation of smart cities. Such data at the urban level would then be prorogated to the building level for better understanding of the impact on energy, building performance, etc. At the building level, better integration of sensor data and performance simulations could be achieved and thus results in better energy efficiency and performance of buildings. There should also be more integration of user behavior with the performance simulations.

CONCLUSION

Currently, the research in Sustainable Design and Construction tends to be very fragmented. It is essential that a more holistic approach should be developed to better understand the relationship between urban, building, building systems, and material. It is also essential that such understanding should be propagated throughout the building delivery process from inception to design to construction, operation, and maintenance of the built environment.

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