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Landscape modification for ambient environmental improvement in central business districts – A case from Beijing

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ABSTRACT

Hundreds of large central business district (CBD) developments are in planning or development in China and other developing countries. Poor environmental performance in these large projects is thought to result from a lack of understanding of basic engineering requirements, especially transport-related. Large energy demand and air pollution are the obvious consequences. While many studies have focused on functional, symbolic and aesthetic requirements of these developments, environmental engineering has in general been neglected. In this study, a typical large-scale planned CBD in Beijing was investigated just several years after its completion and occupancy. The current transportation requirements of the development were measured. It was found that the road traffic provision exceeded demand. Redesign of road infrastructure and urban greening were evaluated for their contribution to alleviating heat stress in summer, providing a comfortable walking and living environment. Reducing the under-used road infrastructure, without affecting the traffic flow, would allow more space for urban vegetation. In particular, the thermal environment for pedestrians in the whole area could be substantially improved through the redesign of ground-level space. Using ENVI-met microclimate fluid dynamic model to measure the impact of greater green landscape area, it was found that the median air temperature (T_a) could be reduced by as much as 0.5 °C. The environmental advantages increase with time, as the tree canopies grow. In the micro-scaled simulation (300 × 600 m), the T_a was reduced by 1 °C. That is to say, urban summer T_a mitigation could be achieved if such effective modification schemes were expanded from the micro-scale urban community to the whole city. This research provides support for the use of urban landscape greening as a means to improve environmental conditions and energy demands in large-scale commercial urban development. Reducing redundant road infrastructure and improving the walking environment with urban greening could potentially suppress motorized traffic demand growth and contribute to a more sustainable urban environment.

Introduction

The urban heat island can be observed in large cities all over the world (Kataoka et al., 2009; Streutker, 2003). Rapid urban expansion is accelerating the urban heat island phenomenon, accelerating higher urban energy consumption, lower thermal comfort, and greatly increased risks to human health. In developing countries such as China, mega-project development is favored because it is reasoned large-scale planning reduces inefficiencies and improves functionality. Typical project size starts from 4 ha in area with some reaching 12 km^2 (Zhang and Lv, 2003). Especially in a metropolis such as Beijing, macro-scale developments for residential, business and industrial developments are rapidly replacing the traditional urban landscapes. While these urban development projects often level mountains, divert rivers and displace natural flora, fauna and human settlements (Gellert and Lynch, 2003), the question is whether such approaches produce the often-claimed environmental sustainability. The central business district (CBD) is the high-end functional zone of a city, the focus of much public and private investment and typical of mega-projects. The accommodation of global business and the demands of a highly trained workforce are essential requirements for the successful development of the CBD (Park et al., 1925; Sassen, 2001). Hundreds of CBDs are being developed at very high speed, with high-density buildings and elaborate

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transportation facilities. The open space designs serve as a setting for the architectural project, often using the same space designs as elsewhere in China. Excessively large open spaces and over-provision of traffic infrastructure in the CBD are resulting in high construction costs, traffic volume growth and a degraded urban environment.

At the same time, it is recognized that the built environment plays an important role in determining the urban climate. Green space, buildings, and surface materials affect urban air temperature, air quality and public health. For example, the contribution of green infrastructure to urban climate change mitigation in Greater Manchester, United Kingdom, was demonstrated through a modeling approach. The magnitude of the effect was measured by testing various adaptation strategies (Gill et al., 2007). A simulation study for California's South Coast Air Basin of the US indicated that a reasonable change in the albedo of the city surface material could provide a noticeable decrease in temperature of the downtown area (Taha, 1997). Such urban heat island mitigation also has significant impact on human health. For example, in a five-year follow-up study of older people, it was found that access to walkable green space could increase human life expectancy (Takano et al., 2002). Views of natural settings have been shown to produce significant health benefits in the workplace, home environment and hospitals (Verderber, 1986; Kaplan, 1993, 2001; Ulrich, 2001).

Urban environmental conditions in mega-cities throughout the developing world are rapidly worsening. This is especially the case in Beijing, one of the largest and fastest-growing mega-cities. As a consequence of the urban heat island (UHI), in the first hundred days of 2013, 46 dusty and hazy days were observed, showing 5.5 times that observed in an average year (Beijing.tianqi.com). Morbidities caused by respiratory tract infections, cardiovascular and cerebrovascular diseases are increasing as a consequence of dusty, hazy days (Bai et al., 2006). The estimated economic cost of air pollution on the health of China as a whole was estimated at between 170 and 644 billion RMB in 2004. This is equal to 1% to 6% of China's gross domestic product (Yu et al., 2007). The health consequences caused by dusty, hazy weather is particularly problematic, considering the high population density in the metropolis. Urban environmental governance discussions regarding various aspects of urban environmental concerns are swiftly becoming emergency management tasks.

Urban development largely serves for economic development purposes. Especially in China, large-scale rapid development mostly focuses on the city's operational efficiency, with little attention to the long-term environment after development. This is one of the critical causes of the current serious environmental crisis in China with the problem rapidly expanding to India and other countries of South-East Asia and the Middle East. Numerous studies have focused on urban function planning (Yeh and Li, 2002; Boyce, 2007; Wier et al., 2009) or the detailed impacts on the landscape and on the urban environment (McDonald et al., 2007; Nowak and Dwyer, 2007) but very few have considered links between urban functions and environmental engineering. In this research, we studied Zhongguancun West CBD in Beijing as a typical example of such mega-project development, to (1) investigate the over-planning and under-use of road infrastructure typical of such mega-projects; (2) provide road construction modification schemes to raise the efficiency of road use and promote the pedestrian environment with increased urban vegetation; (3) test the effects of road surface modification and urban vegetation additions in these schemes on UHI reduction using simulation; and (4) discuss the possibility of implementation. This discussion could improve existing urban environments, but also suggest caution in the over-provision of infrastructure in the planning process of mega-projects in all developing countries.

Mega-projects and traffic volume

In order to alleviate road-based traffic congestion, many developing cities favor a dense and high-capacity transportation network. This tendency is especially common in mega-projects. However, vehicle-oriented development will subsequently accelerate vehicle ownership growth, and promote road infrastructure demand (Pianuan et al., 1994). Between 2007 and 2012, with rapid economic growth and large-scale urban development, the annual growth rate of private vehicle ownership in Beijing reached 13.3%, from 3.1 to 5.2 million vehicles (http://www.bjstats.gov.cn/). It is widely assumed that newly planned areas should increase road capacity and car parking provisions to manage such rapid increases in the vehicular fleet.

Similar to China, Great Britain also had rapid economic growth, a building boom and vehicle ownership growth after the Second World War. The ideas of "road hierarchy" and "environmental management" were introduced to reduce traffic volume in local community areas and protect the areas from the danger and environmental destruction of excessive traffic (Buchanan, 1963). This was an influential principle that shaped the development of the urban landscape in the United Kingdom, and it can still be seen in current design guidance and practice (Sinclair Knight Merz (SKM), 2013). While the hierarchy principles were adopted in China, local-scale protection was not.

The controversy about additional road capacity and whether or not it induces more traffic was particularly salient during the 1990s (Prakash et al., 2001; Goodwin and Noland, 2003). It is now commonly agreed that increased road capacity induces traffic directly, with cycles of provision and demand over time (Goodwin, 1996; SACTRA, 1994; ENO Transportation Foundation, 2002; Cervero, 2003; Goodwin and Noland, 2003; Noland, 2001; Noland and Lem, 2002; Mokhtarian et al., 2002; Cairns et al. (1998, 2002);Tam et al., 2000). Limited evidence suggests the shift to public transportation and non-motorized modes may be supported with landscape change (Wey and Chiu, 2013). However, landscape change may precipitate other changes that will help to accelerate the reduction in urban greenhouse gas emissions.

Urban development and urban environment

From 1961 to 1980, the annual air temperature rise was 0.36 °C in the central area of Beijing. However, during the building boom between 1981 and 2000, the annual air temperature rose 0.94 °C (Ren et al., 2007). The correlation coefficient between impervious surface rate and land surface temperature in Beijing reached 0.93 (Xiao et al., 2007). Therefore, the pattern of urbanization, especially in the central city, has a large impact on urban climate change. Spatial variability of UHIs in each city is found to be a function of urban surface properties, which in turn is influenced by land cover, most significantly by vegetation cover and building density (Hung et al., 2006).

In a simulation comparison of high-rise and low-rise building forms in Lujiazui CBD of Shanghai, China, it was seen that wind speed declined 22%, temperature decreased 7%, and O_3 also decreased 9% in the low-rise building form (Zhan et al., 2013). In another research study of the CBD in Toronto, it was observed that the CBD vehicle emission exposure is higher per area than in other districts in the city (Amirjamshidi et al., 2013). Since the CBD is a highly developed zone in the center of the metropolis, a diversity of environmental problems could be expected, but also makes mitigation more urgent.

It is a crucial and demanding task to balance development demands and environmental protection. However, there are certain specific principles of sustainable urban development for facing these difficulties. High development density is required for