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REVIEW ARTICLE

Liang WANG, Xiaolong XUE, Rebecca J. YANG, Xiaowei LUO, Hongying ZHAO

Built environment and management: Exploring grand challenges and management issues in built environment

Abstract Engineering management research objects have gradually been transformed from micro-scale projects to macro-scale built environment. Built environment has driven the advancement of civilization through human history. From the Stone Age to the modern era, built environment, which refers to manmade surroundings, has provided the setting for human activities. Built environment has undergone developments and evolution processes as civilization grew. Today, technological advancements cause influences of built environment to encompass every aspect of life, as material, spatial and cultural products of the human labor force, which combines material factors and energy in a lively way of work and in forms. However, the concept of built environment remains unclear. Built environment faces a major challenge, such as the use of science and technology to solve key national and global issues. Thus, the definitions of built environment were systematically reviewed and summarized from different perspectives and levels to address these issues. The grand challenges of built environment, including climate change and energy consumption, urbanization and infrastructure construction, growth, and innovation, were summarized. Furthermore, the corresponding management issues and future development strategies were proposed to solve identified challenges of built environment.

Keywords built environment, innovation, sustainability, resilience, urbanization, digitalization, infrastructure

1 Introduction

Engineering management research objects have gradually been transformed from micro-scale projects to macro-scale built environment (Philbin, 2015; Shah and Nowocin, 2015). People make substantial contributions to built environment by designing and building their lives through experiences. Based on these experiences, components of built environment are derived from human needs, ideas, and actions. However, irresponsible human behaviors lead to uncomfortable situations, thereby causing adverse effects on the surrounding environment. Moreover, irresponsible human behavior does not adapt to healthy human activities. These adverse effects on the surrounding environment affect us as well.

A clear causal relationship exists between human purpose and creation. The famous historian and former British Prime Minister Winston Churchill stated that "we shape our buildings … thereafter they shape us" (Judd, 2008). Similarly, historian Arthur Cortel said, "tell me the landscape you grew up in and I will tell you about yourself" (Lewis, 1979). Exploring human needs, desires, and the essence of value is essential to understand the relationship between humans and built environment. Psychologist Abraham Maslow formulated the famous hierarchy of human needs that are demonstrated in built environment (Maslow, 1943). Built environment is not

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Liang WANG
School of Architecture and Civil Engineering, Xiamen University, Xiamen 361005, China; School of Management, Harbin Institute of Technology, Harbin 150001, China

Xiaolong XUE (✉)
School of Management, Guangzhou University, Guangzhou 510006, China
E-mails: xlxue@hit.edu.cn; xlxue@gzhu.edu.cn

Rebecca J. YANG, Hongying ZHAO
School of Property, Construction and Project Management, RMIT University, Melbourne 3001, Australia

Xiaowei LUO
Department of Architecture and Civil Engineering, City University of Hong Kong, Hong Kong 999077, China

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only a human attempt to satisfy individual and social needs but also an expression of personal and collective values and aspirations. Thus, each decision will produce value and ethics in built environment's process of formation and reconstruction (Kibert, 1999).

Protecting and restoring the environment are concentrated in a narrow place in the natural system, thereby ignoring the view that the environment where humans interact most directly is the product of human-induced processes (Woodgate and Redclift, 1998). The creation process of these products and people is collectively referred to as built environment. The new term "built environment" is described in one holistic and integrated concept as the creative result of human activities throughout history. The term emerged in the 1980s and was prevalently used in the 1990s (Crowe, 1997).

Built environment has driven the advancement of civilization. They face grand challenges, such as climate change, energy consumption, and urbanization and innovation, which have substantial influence on the development of human society. Thus, we systematically reviewed and summarized definitions of built environment from different perspectives and levels to address these issues. Its grand challenges, including climate change and energy consumption, urbanization and infrastructure construction, and growth and innovation, were also summarized. We also proposed corresponding management issues and future development strategies of built environment to solve these challenges. Figure 1 summarizes the methodological framework of this study.

2 What is built environment?

The early concept of built environment originated from ancient times. Miletus Seahorse, known as the father of urban planning, developed a Greek city from 498 BC to 408 BC (Couch, 2016). These early urban plans were implemented by Daniel Hudson Burnham, a progressive reformist who actively promoted landscape reforms while initiating political changes in the late 19th century to the early 20th century (Wilson, 1994). The effort was a collaboration among those who believed that beautifying American cities would improve the moral compass of citizens and encouraged the upper class to spend their money in cities. This landscaping process included parks and architectural design.

The built environment is certainly pervasive, because it is where people live everyday. However, its term, reach, and implications are surprisingly comprehensive and far-reaching. Generally, built environment can be defined by four interrelated features. First, it provides the background for all human efforts, which are everything that humans have created, modified, constructed, arranged, or

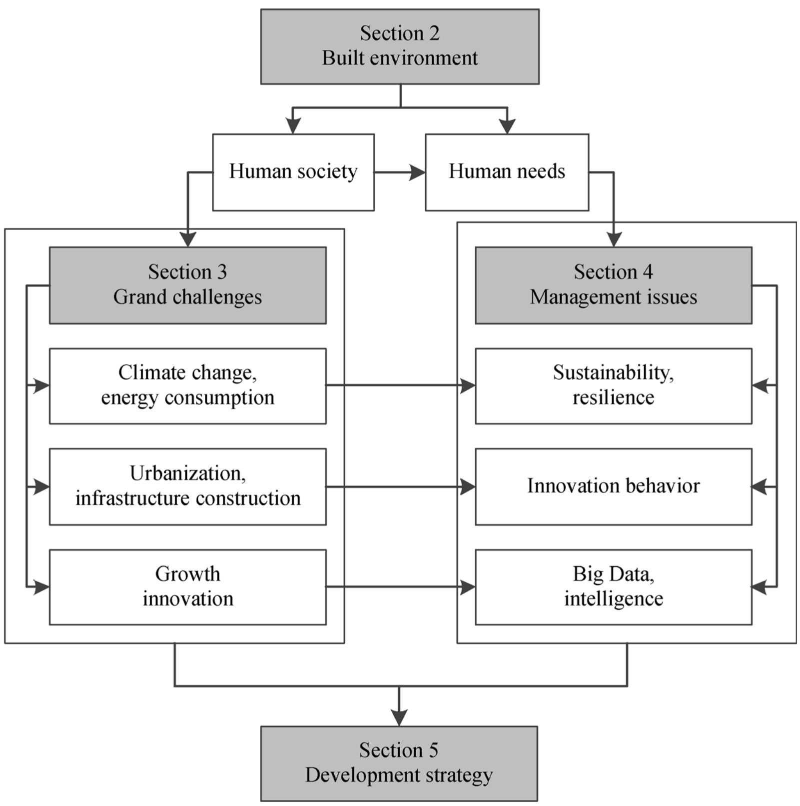

Fig. 1 Methodological framework.

maintained. Second, built environment reflects people's thoughts and goals, which aim to serve human needs, aspirations, and values. Third, built environment is designed to help deal with the overall environment, where we can protect, coordinate, or change the entire environment for comfort and happiness. Finally, an evident but often forgotten characteristic of built environment is that each of its components contributes either positively or negatively to the overall quality of built environment. These local effects are increasingly experienced at the global and universal scales (Habraken and Teicher, 2000).

The term "built environment" refers to manmade surroundings for human activity setting, ranging from buildings, parks or green spaces to neighborhoods and cities, which can often include supporting infrastructures, such as water supply or energy networks. Built environment is the material, spatial, and cultural products of human labor force, which combines material factors and energy in the form of life, work, and entertainment. A constructed environment is defined as "man-made space where people live, work and reproduce every day" (Roof and Oleru, 2008). Built environment is composed of locations and spaces, such as buildings, parks, and transportation systems, that have been created or modified by people. Research on public health has recently expanded the definition of built environment to include healthy food entrances, community gardens, and pedestrian facilities (Lee, 2012).

Built environment is often used to describe interdisciplinary areas and objectives to design, build, manage, and use interrelated artificial environment. This area is not considered a traditional occupation or academic field, such as economics, law, public policy, public health, management, geography, design, technology, and environmental sustainability. For instance, in public health, built environment is defined as an environment that improves community well-being by advancing aesthetics and health, the environment, and lifestyle (Aboelata et al., 2004).

Previous studies imply that an area's formation may affect the physical activity and mental health of its residents (Renalds et al., 2010). Studies show that built environment deliberately designed to improve physical activities is linked to high percentage of physical activities, thereby promoting positive health impact (Carlson et al., 2012). Thus, built environment can meet the development needs of human society.

Figure 2 shows the adaptive cycle relationships among human society, human needs, and built environment. The diversity and scope of built environment, its diverse contents, and its delicate environment are composed of seven interrelated components, namely, products, interiors, structures, landscapes, cities, regions, and earth (McClure and Bartuska, 2011). As important carriers of human needs, these seven interrelated components of built environment satisfy various human needs, such as food, shelter, and community. Human needs, alongside developments in human society, are constantly changing and developing; they have transformed from physiological needs to psychological needs. Moreover, Maslow (1943) suggested that human needs have low- to high-level hierarchies. After meeting physiological needs, psychological needs, such as security, love and belonging, and respect and self-realization, have become increasingly important in modern human society. Similarly, the

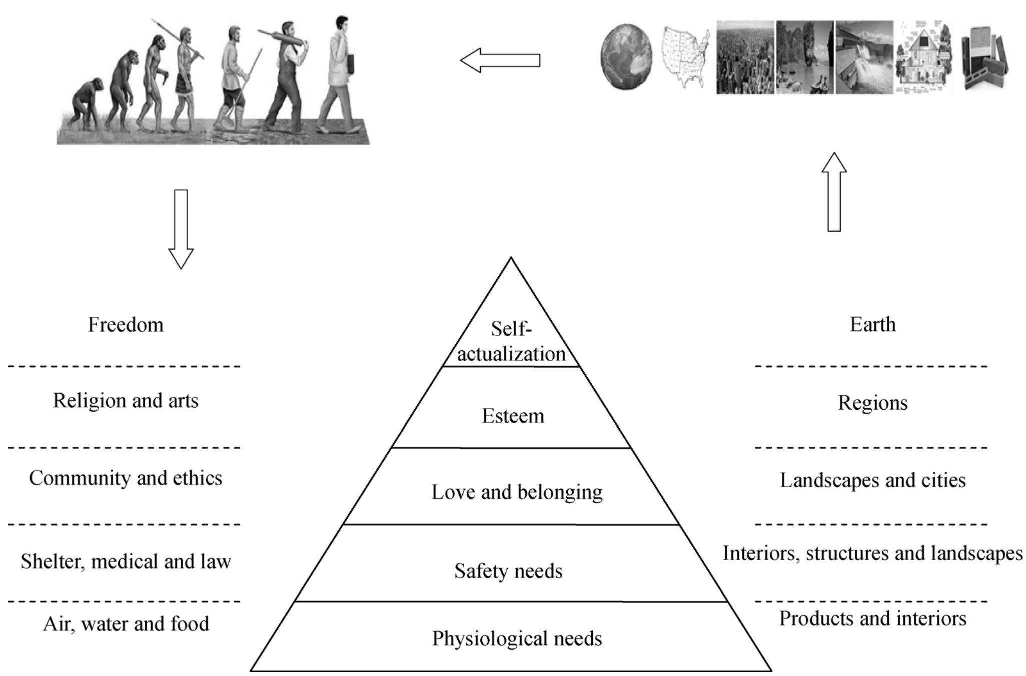

Fig. 2 Relationships between human society, human needs, and built environment.

connotation of built environment continues to evolve and expand from products to earth to adapt to the trends discussed.

3 Grand challenges in built environment

In this section, the grand challenges of built environment were summarized and categorized into three groups, namely, climate change and energy consumption, urbanization and infrastructure construction, and growth and innovation. These challenges revealed problems that can influence management performance in the development of built environment.

3.1 Climate change and energy consumption

Climate change is one of the grand challenges of the 21st century, causing a major impact on human social development (Howard-Grenville et al., 2014). According to Engineering and Physical Sciences Research Council, the average annual temperature is projected to increase by 1 °C to 3 °C by 2050, accompanied by a possible shift to extremely dry summers and wet winters across the country. Other climate change factors, such as solar irradiation, wind, humidity, and evaporation, are also affected, leading to seasonal fluctuations. Rising sea levels may pose problems to coastal area development. This change has inevitably had a major impact on built environment, especially on critical infrastructures such as transportation systems (Lin et al., 2017).

Urbanization has resulted in a decreased ratio of green land coverage. Thus, pressure on urban ecology, including surface temperature, stormwater runoff, carbon accumulation, and biodiversity increases (Pauleit and Duhme, 2000; Whitford et al., 2001). Climate change and urban densification depend partly on lifestyle choices, whereas climate change may facilitate, inhibit, or accentuate lifestyle choices. Therefore, threats from disasters such as flood, droughts, windstorms, and heatwaves tend to increase due to climate change pressures. The “Stern Review” warns about Earth’s bleak future if societies and built environment do not adopt measures to address the implications of climate change and points out that strong preventive measures far outweigh the economic costs of inactivity (Stern et al., 2006).

Consequently, designing buildings, infrastructures, and communities requires a crucial plan to address current and future climate conditions. Experts in environmental construction should consider planning for future climatic conditions as a business opportunity. Appropriately-designed buildings can easily be marketed and command high prices. As a result, real estate companies will have the opportunity to position climate-inspired architecture as a market innovation, gaining new customers and a unique competitive advantage (Bosher et al., 2007).

Similar to climate change issues, research on energy consumption has gained interest from management scholars in different fields, such as social performance (Jones et al., 2014; Zou et al., 2017). The growth of global population has led to increasing difficulty in meeting the rising demand for energy. Energy resources diminish with enormous environmental impact, including ozone depletion, global warming, and climate change (Pérez-Lombard et al., 2008). The US Energy Information Administration has collected data on energy consumption trends from 1980 to 2012. Figure 3 shows that primary energy consumption increased by 85%, whereas carbon dioxide (CO_2) emissions increased by 75%, with an average annual increase of 1.9% and 1.8%, respectively, in the past 33 years (1980–2012) (US Energy Information Administration, 2015; Medjdoub and Chalal, 2017).

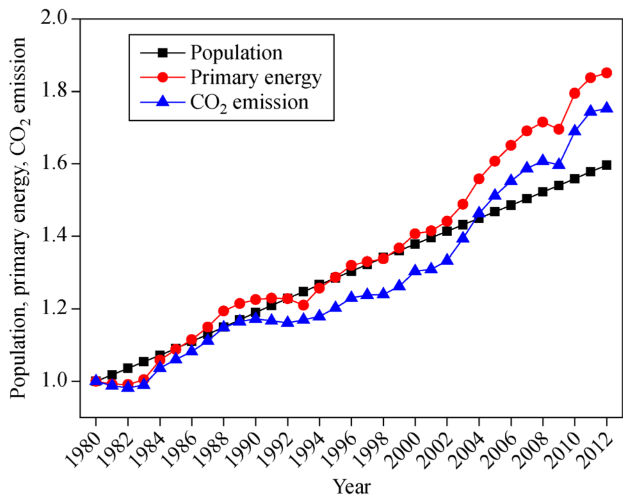

Fig. 3 World population, primary energy consumption, and CO_2 emissions (reference year 1980) (unit: 1).

As shown in Fig. 4, current forecasts show that the growth trend of energy consumption will continue. Energy consumption in emerging countries such as the BRICS countries (Brazil, Russia, India, China, and South Africa) had an average annual growth rate of 4% over the past two decades (1992–2012); This growth rate has exceeded that of developed G7 countries (United States, United Kingdom, France, Germany, Japan, Italy, and Canada) with an average growth rate of only 0.4% in 2011 (US Energy Information Administration, 2015; Wang and Gang, 2017).

Final energy consumption is usually divided into three main sectors, namely, industry, transportation, and “others,” which include final nominated agriculture, service industry, and housing. Therefore, collecting data on energy consumption in buildings is challenging. For instance, energy consumption of non-residential buildings is under shared services in the “others” sector. Given the overall impact of developed countries (buildings account

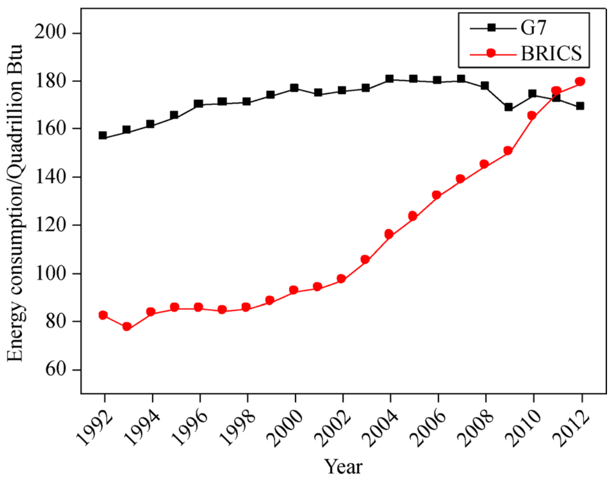

Fig. 4 Energy consumption of G7 and BRICS countries.

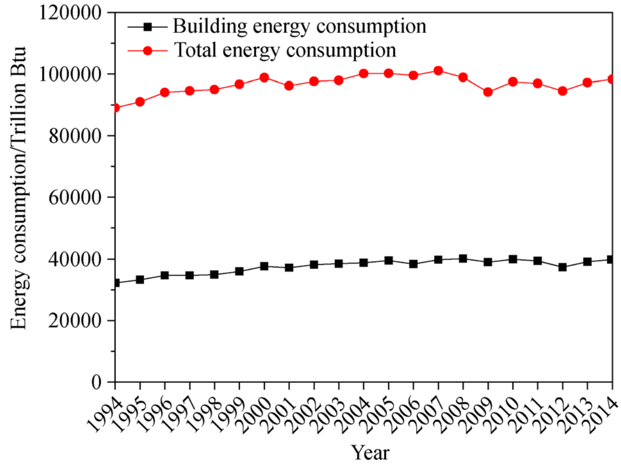

Fig. 6 Total and building energy consumption in the US from 1994 to 2014.

for 20% to 40% of total final energy consumption) in this area, energy consumption in developed countries is calculated separately, at least for residential and commercial buildings (Pérez-Lombard et al., 2008). The energy consumption of buildings increases as population, construction services, expectations of comfort, and buildings' age increase. For instance, the United States (US) is the country with highest energy consumption. Figure 5 shows the percentage of building energy consumption in the US with a rising trend during the last two decades (US Energy Information Administration, 2015; Zhang et al., 2016).

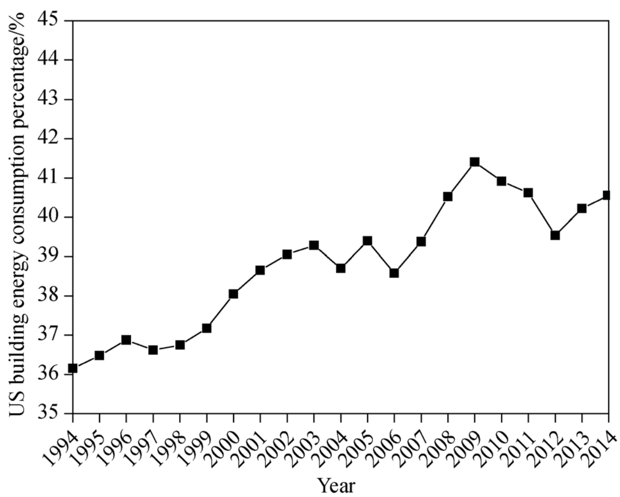

Fig. 5 US building energy consumption percentage.

From 1994 to 2014, the total energy consumption in the US has increased by 10.4%, with an average annual increase of 0.5%. Figure 6 illustrates an upward trend that indicates that building energy consumption in the US has increased by 23.8%, with an average annual growth rate of 1.1%. This rate is higher than the annual growth rate of the total energy consumption (US Energy Information Administration, 2015; Ling, 2016).

Figure 7 presents the US Energy Information Administration's analysis and forecasts of future energy consumption trends in the "*Annual Energy Outlook*" (US Energy Information Administration, 2015). Energy consumption in built environment is expected to grow by 26.9% in the next 27 years at an average rate of 0.9% per year. By 2040, energy consumption in residential and nonresidential sectors will account for approximately 58% and 42%, respectively, of the total energy consumption (US Energy Information Administration, 2015; Ling, 2015).

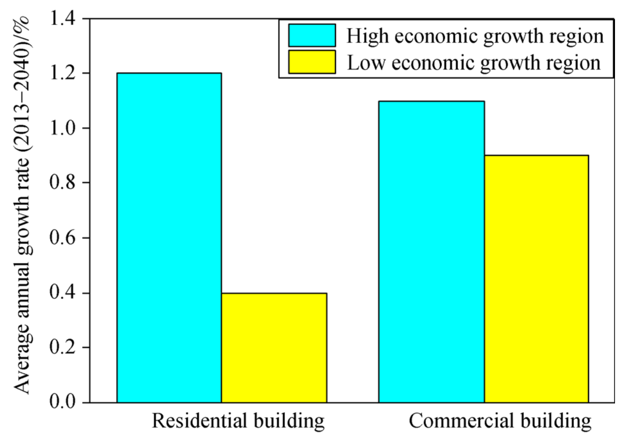

Fig. 7 Global building energy consumption outlook from 2013 to 2040.

3.2 Urbanization and infrastructure construction

Infrastructure refers to fundamental facilities or systems that provide services for economic functions of a country, city, or an area (O'sullivan and Sheffrin, 2003; Mao et al., 2015). Infrastructures are usually characterized by operating structures, such as roads, bridges, tunnels, water supply, sewers, power grids, and telecommunications, which can be defined as "physical components of interrelated systems providing commodities and services essential to enable, sustain, or enhance societal living conditions" (Fulmer, 2009; Zhao et al., 2015).

Global population has exponentially grown since the 20th century, and the wave of urbanization has influenced the world (Bettencourt et al., 2007). Human society is going through an unprecedented historic phenomenon wherein the majority of people live in cities (Crane and Kinzig, 2005). Urbanization increases economic activity and geographical mobility, thereby causing competition between urban and rural areas (Barkema et al., 2015).

Population growth and urbanization bring about high demand for food, energy, transportation, and other necessities, leading to problems such as food shortage, traffic congestion, and energy supply shortage (Crane and Kinzig, 2005; Atack et al., 2010; Liddle, 2014). These findings imply that humans construct a series of infrastructures to meet growing demands and solve problems caused by urbanization (Gandy, 2005). As a vital part of built environment, infrastructures play an increasingly important role in human society.

As global population continues to grow, an increasing number of people move into cities to gain resources and opportunities. The World Bank (2015) stated that in the past 54 years (1960–2013), global population has increased by 2.35 times with an average annual increase of 1.6%. In addition, urban population grew by 3.71 times with an average annual increase of 2.5% (The World Bank, 2015). Figure 8 shows the population growth ratio and percentage of urban population from 1960 to 2013.

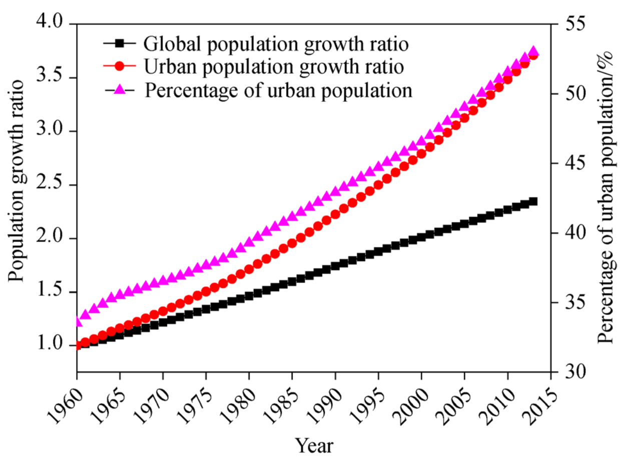

Fig. 8 Population growth ratio and percentage of urban population (reference year 1960).

Extensive infrastructures, such as railways, highways, and air transportation, have been built to meet the needs of urban residents. However, the construction of transport infrastructures brings about major technological and management challenges (Marquis and Huang, 2010; Wyrick and Myers, 2016). Figure 9 shows the US' and China's total length of rail line routes and change ratio from 1980 to 2012 (The World Bank, 2015). The US, as the largest developed country, has reached complete urbanization, wherein the total length of rail line routes shows a declining trend since the 1980s. In contrast, as the biggest developing country, China's total length of rail line routes has increased by 1.33 times at an average growth rate of 0.9% between 1980 and 2012. However, the total route in China accounts for only 29% of that in the US.

Given that developed countries are almost completely urbanized and infrastructures are deteriorating, finances allocated for repair and replacement of existing infrastructures are insufficient. Meanwhile, a number of infrastructure constructions are underway in the urbanization process; thus, infrastructure deterioration will become a key issue in the future. Built environment in the 21st century needs to support the modernization of basic structures of civilization (Doyle et al., 2008).

This challenge is particularly crucial in urban areas where the growing population emphasizes social support systems, natural disasters, accidents, and terrorist attacks that threaten the safety and security of infrastructures. Aging infrastructures in urban areas are not only a problem for developed countries but also for developing countries. The problem of megacities with a population of more than 10 million is evident in developing Asian countries. However, meeting the basic needs of infrastructure in many parts of the world is still a problem. Engineers are required to provide extensive and economical services (Brown and Willis, 2006). Therefore, sustainable infrastructures should be promoted to solve these problems while taking into consideration environmental effects and aesthetic factors that help improve the quality of life.

A number of existing infrastructures are aging, and issues on maintenance and upgrades emerge. For instance, the records of underground pipes and cables are often unavailable or incomplete, causing serious inconvenience during repair. Hence, establishing a method to map and mark embedded infrastructures to facilitate the maintenance and upgrades of buried infrastructure and avoid invisible damages is an important task that needs to be undertaken.

Roads in the 21st century, which are important components of infrastructures, have increased dramatically in number and scope. By 2050, at least 25 million kilometers of new roads worldwide are estimated to be constructed. The total road length will increase by 60% from the total length in 2010, and one-ninth of all road constructions are estimated to be built in developing countries (Dulac, 2013; Laurance et al., 2014).

Traffic, which is one of the basic road functions, is also a major problem in built environment. The maintenance and improvement of traffic remain important issues because

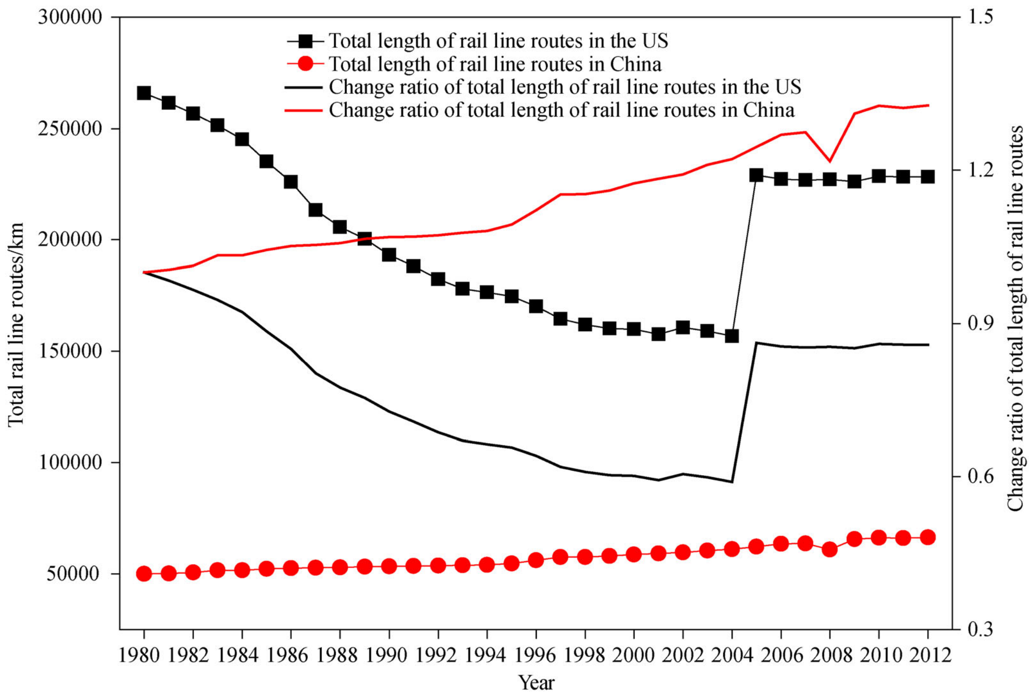

Fig. 9 Total length of rail line routes and change ratio of the US and China (reference year 1980).

roads and highways are key transportation routes. However, designing an integrated transportation system that simplifies and optimizes individual sports vehicles, public transportation, cycling, and walking is the biggest challenge. Moreover, the demand for improving public access to elderly and disabled travelers is an increasingly important consideration (Perry et al., 2008).

Cities worldwide are developing integrated approaches for transportation infrastructure. In certain urban areas, an integrated approach to incorporate energy, water, and waste into a "neighborhood" system can be envisaged. This approach can increase the sustainability of cities through urban-scale infrastructures that meet the needs of all citizens. Such approaches can support the demands of growing urban populations (Zielinski, 2007). Furthermore, new types of infrastructure (e.g., information technology infrastructure) bring organizational and cultural challenges. Considerable differences emerge in research methods and issues that compare new and traditional infrastructures (Huy et al., 2014).

3.3 Growth and innovation

Growth refers to positive changes in size and is often modified over time. Growth can occur as a mature stage or as a process of filling or realizing. Growth can also perpetuate endlessly, for example, as detailed by theories of the ultimate fate of the universe. Researchers and managers should predict how performance and size goals jointly affect growth (Greve, 2008). As the key carrier of human social development, built environment's growth involves population growth, economic growth, and growth at city and regional scale. Human society has experienced a rapid development period since the 1960s. Figure 10 reflects the growth trends of world population and gross domestic product (GDP) from 1980 to 2013 (The World Bank, 2015).

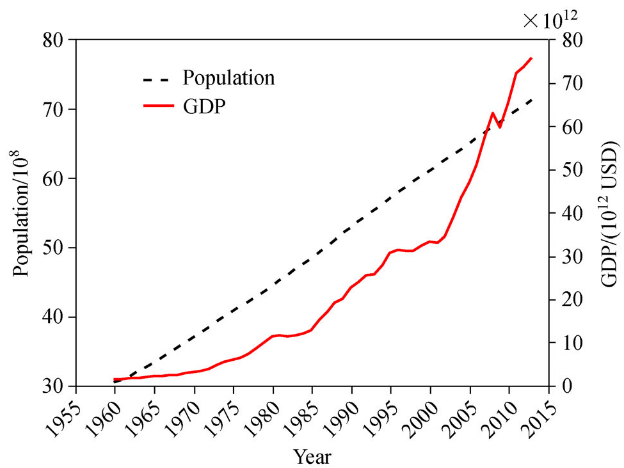

Fig. 10 World population and GDP growth.

Human society has presented different growth models in different periods of development (Penrose, 1959). Smith growth model was the principal development model. Smith thought that wealth was the product of labor. He investigated economic growth from the production and supplement perspectives. Moreover, Smith believed that

(1) population growth leads to increase in labor, which can substantially facilitate the division of labor, improvement of labor productivity, and promotion of economic growth; (2) population growth will expand the market and promote the expansion of production scale and the development of labor division (Ekelund and Hébert, 2013; Chen et al., 2015). Humans increase the inputs of production factor to meet the growing demands based on Smith growth theory. However, Smith growth theory neglects the role of demand, human subjective capacity, and intangible products, which present serious limitations (Spiegel, 1991; Kwon and Adler, 2014).

Resources such as labor, land, and capital are scarce from the economic perspective. As human society develops, the scarcity of resources becomes increasingly serious. The growth model has not been applied to the current situation that relies on the increase of resource input. Moreover, innovation has become the main driving force of economic development (Cannella et al., 2015; Yang et al., 2015). Schumpeter (1982) first proposed the concept of innovation which was the root of economic development. Schumpeter growth is characterized by endogenous research development and innovation which are the decisive factors in promoting technological progress and economic growth (Acemoglu, 2008; Wang et al., 2014).

Innovative research (including technological and organizational changes) has become the mainstream in economics, industrial history, and business administration. It is not merely about competition, market development, and economic growth because customer choice, social and environmental sustainability, and quality of life issues are equally important (Reinecke and Ansari, 2015). These issues are highlighted in the production and use of built environment that provides the required and fixed capital base for modern society. Therefore, increasing innovative activities is a major concern for companies, governments, and research departments. Extensive research has discovered the nature, origin, and process of innovation from a wide range of disciplines, such as management, engineering, economics, political economy, geography, and public policy (Gann, 2003; Chen et al., 2018).

Owing to competition-related costs, science, technology, and innovation in a globalized market are increasing, whereas numerous factors, including efficiency search, are changing. The role of customers and users as co-developers in the innovation process progressively becomes important (von Hippel and Katz, 2002). Customers place strict requirements on producers who often seek service solutions rather than physical artefacts (Davies et al., 2001). Similarly, regulatory factors have changed the requirements of engineers and technicians, such as changes in government policies in intellectual property law, new product approval procedures, environmental issues, sustainability issues, infrastructure development, and capacity building (Gann et al., 1998). Companies and research institutions seek efficient ways to improve economic efficiency and develop new products and services (Dodgson et al., 2002). Traditional research and development, design, and engineering practices are challenged by new ways in which information and communication technology play a central role.

4 Management issues in built environment

In this section, we proposed corresponding management issues to solve the grand challenges summarized in Section 3. These management issues include sustainability and resilience, innovation behavior, and Big Data and intelligence, which play important roles in improving management performance of built environment.

4.1 Sustainability and resilience

Recent natural and human disasters have highlighted vulnerabilities to storms, floods, earthquakes, and terrorism. Although most disasters are not entirely unexpected, some advanced actions can play a sufficiently proactive role in the mitigation of such events. Sustainable and resilient built environment is necessary and must accept substantial investments from stakeholders who are responsible for the planning, design, construction and operation of built environment (Bosher et al., 2007; Avetisyan et al., 2017).

Sustainable development, as introduced by the Brundtland Commission, can be marked as the starting point of a third upsurge of environmental awareness (Brundtland, 1987). The concept of sustainability in built environment was first used to assess the sustainability of buildings in the 1990s, and the Building Research Establishment Environmental Assessment Method served as the building sustainability assessment system (Lee, 2012). The first generation evaluation system focuses on the environment and clearly defines the sustainability of the embedded design (Berardi, 2012). Compared with the first generation evaluation system, the recent system, such as the German Sustainable Building Council, attempts to achieve a more comprehensive view and not just environmental aspects (Hamedani and Huber, 2012).

Infrastructure has become an important part of built environment in the urbanization process, and researchers gradually conduct research on infrastructure sustainability. From the economic, health, and safety perspectives, research on infrastructure sustainability employs the extended evaluation criteria to evaluate the sustainability of different plans with emphasis on the application of quantitative methods and consideration of the long-term effects of different plans (Baetz and Korol, 1995; Wang, 2016). Considering the important role of infrastructures in urban management, a theoretical framework has been developed to measure and improve the sustainability of infrastructures in the life cycle and develop infrastructure and surrounding environment, economic and social systems (Sahely et al., 2005). The development trend of modern engineering practice implies that critical infrastructures are becoming common, which demonstrate globalization, technological integration, and long life cycle characteristics. Modern critical infrastructures should take into account the economic, environmental, and social impacts; thus, the sustainability of critical infrastructure emerged (Levitt, 2007).

The resilience of the ecological field originated in 1973. Holling (1973) defined resiliency as the ability to design systems that can inadvertently absorb and adapt to future events. In built environment, early resilience studies focused on the areas of disaster prevention and reduction, as well as the impact of disasters to engineering from the technological perspective (Chang and Shinozuka, 2004; Bruneau and Reinhorn, 2007). Resilience is commonly studied in the following four aspects: (1) technical, which includes all aspects related to construction; (2) organizational, which deals with management plans, maintenance, and response to emergencies; (3) social, which involves the impact to society and its mitigation; and (4) economic, which addresses indirect and direct economic costs related to social and infrastructural degradation and restoration (Bruneau et al., 2003).

As an important component of built environment, infrastructure resilience is emphasized in various aspects. For instance, infrastructure resilience is evaluated from the unified perspective of management and governance (Heinimann and Hatfield, 2017). For critical infrastructure resilience, a resilience-oriented approach is developed for quantitatively assessing recurrentspatial-temporal congestion on urban roads (Tang and Heinimann, 2018). To measure resilience in infrastructural projects, the importance of resilience has been well acknowledged in terms of managing adversity in engineering projects (Sawalha, 2015). For resilience thinking in built environment, professional education is mainstreamed for a resilient construction process (Amaratunga et al., 2017).

Currently, certain research directions in the resilience of built environment emerge. The development of a resilience framework can reduce inconsistencies and confusions in definitions, methods, and results (Huang et al., 2017). At the same time, the nature of this research consistently means a considerable difference between methods and expectations. Academic research experiments should be accompanied by experimental planning and management in the real world. However, quality standards are lacking in this collaborative research. Therefore, results must be evaluated through an underdeveloped process. The development of design rules (heuristics) should be strengthened. Resilience is expected to lead to templates and case studies that can be relocated and discussed in different institutions and scales. The epistemological significance of resilience research should face the methods and concepts of natural sciences, social sciences, and space sciences. Furthermore, heuristic development should not be limited to current planning and management forms. The heuristic approach must go beyond predicting and reducing the scope of vulnerability (Hassler and Kohler, 2014).

4.2 Innovation behavior

Research on technological innovation and organizational change has become mainstream in economics, industrial history, and business management. Since the late 1960s, innovation research has been the focus of academic research. Most of the knowledge generated include concepts, theoretical models, departmental studies, corporate case studies, business strategies, technological toolkits, government, and industrial policies (Gann, 2003; Ding and Xu, 2017).

Marian Bowley is one of the pioneers in the innovation of built environment and contributed to introducing innovation in built environment (Bowley, 1960; 1966; Zhao et al., 2015). Innovation has remained an important research topic. What is the role of innovation behavior in built environment? How can innovation behavior influence management in built environment? These questions are critical for the process of managing buildings and infrastructure throughout their life cycle in response to social orientation and climate change, population growth, financial constraints, aging infrastructure, thereby posing great importance due to the pressure for a radical transformation.

Research about innovative behaviors in built environment includes work traditions in organizational theory, technical sociology (Pinch and Bijker, 1984; Bijker, 1997), consumption (Shipworth et al., 2010), diffusion of innovation (Rogers, 2010), institutional innovation (March, 1991; Hargadon and Sutton, 1997), and historical use of technology (Hughes, 2005). The development of technological and economic aspects yields to several emerging research areas on innovation behavior in built environment, including (1) user involvement in complex innovation; (2) collective action for new developments in institutional innovation; (3) distributed innovation, which is the project-based edge and distributed innovation networks; and (4) multi-level innovation transformation management (Whyte and Sexton, 2011). These emerging research issues indicate new areas and directions for research with regard to the challenges, thereby transforming the growth model and bringing about complex multi-stakeholder organizational environment.

Current research priorities of innovation behaviors shift from macro- and firm-level to meso-level. However, some areas need further investigation, such as (1) how innovative behaviors absorb, adopt, and diffuse in built environment; (2) what the new features of innovation behaviors of built environment in network situations are; (3) how innovation behaviors influence economic and management production efficiency in built environment; and (4) what the interaction mechanism of technological and organizational innovation is in built environment. However, innovative behavior in built environment is fluid and structured as an ever-evolving combination of social and technical elements experienced in practice. The importance of understanding theories is becoming important for recognizing the all-encompassing value of innovation of multiple stakeholders, not the value of shareholders nor the value of the short-term intellectual property (Whyte and Sexton, 2011).

4.3 Big Data and intelligence

Engineering management research issues, which are important aspects of built environment research, have been changing in the past 50 years. Levitt (2007) reviewed the development path of engineering management research in the 50th anniversary issue of the *Journal of Construction Engineering and Management*. Levitt divided engineering management research into three stages between 1955 to 2005, and the main contents of each stage are as follows: (1) the first two decades (1955–1975) include schedule control, operations analysis, database management systems, and application of social science theories; (2) the second two decades (1975–1995) focus on risk analysis, lean construction, artificial intelligence, and visualization; and (3) the fifth decade (1995–2005) includes collaborative management based on computer and communication networks, applications of GPS, RFID and sensor networks, optimization and automation of work processes based on VDC, and 4D CAD.

Engineering management research issues focused on construction management before the 2000s and shifted into construction engineering and management during 2000s and 2010s. After 2010, engineering management research integrated a number of disciplines, such as system science, management science, economics, psychology, social science, and information technology, which were conducted on an urban scale. From the perspective of urban studies, engineering management can be defined as the management of built environment. Thus, digitalization, including digital twins, digitalization in urban studies, digital cities, and urban planning, is an important process in big data and intelligence in the context of built environment (Townsend, 2013). The current management of built environment has two important research issues: (1) with the rapid development of IT, Big Data has become an important research issue in built environment; (2) an intelligent built environment is an important management task needed in improving the quality of life of residents and meeting their needs (Shi et al., 2017; Zou et al., 2017).

The biggest problem of Big Data is its source from built environment. This issue has been solved by increasing the number of sensor networks in buildings. Data streams can be obtained through the ever-growing sensor networks, with the amount of data beyond anticipation. However, a large number of collected raw data sets needs to be summarized and visualized so that they can be used to present important data processing, information visualization, and interaction challenges (Khan and Hornbæk, 2011). When using occupant-centric sensor network design methods, typical computer science problems will be identified. To solve this problem, sensor networks should be optimized and a new computer algorithm should be initiated. Such job involves numerous stakeholders, and collaborative innovation should be adopted among them. Different disciplines should be integrated to develop technological advancements in big data collection. Progress has actually been made in this field. For instance, environmental scanning, which obtains spatial and architectural point cloud data, is a useful tool in placing sensor data streams in a physical environment (Attar et al., 2010). In addition to substantial data collection, data analysis, result visualization, and decision-making based on large amounts of data from built environment are important aspects of the practicality of streaming and historical data is the presence of sensors. Existing studies have investigated the visualization efficiency and effectiveness of a small number of data points (Cawthon and Moere, 2007). Visualization of a large dataset has also been developed, especially environmental data (Shneiderman, 2008; Wu et al., 2009). To address multi-domain problems, a multi-paradigm visual decision framework should be developed to handle complex spatial-temporal multidimensional data and taking into account the decision-making process in visual technology assessment.

Using smart devices and robots to build smart built environment is necessary to improve the quality of life of residents and to meet their needs. The use of smart devices and robots can transform built environment (Kaklauskas et al., 2010). As various stakeholders participate in built environment, projects and buildings provide different alternatives, and the living environment and economic benefits change in various micro and macro environment. Properly defining the intelligent environment is deemed essential. Researchers have made profound progress in all areas of intelligent built environment, which are (1) physical fields, involving structure and materials, intelligent teaching system, and multimedia service system (de Vries, 1997; Kaklauskas et al., 2006) and (2) virtual site, including multiple assessments of reference life cycle energy efficiency, overall sustainability of built environment, intelligent building evaluation based on the level of service system integration, and standard communication infrastructure (Bushby, 1997; Arkin and Paciuk, 1997; Kua and Lee, 2002; Chen et al., 2006). To address these problems in the field of intelligent buildings, passive design strategies under climate change were studied in the above-mentioned fields, such as multi-reference judgment models for the evaluation of life efficiency of smart buildings, renewable building energy systems, and passive human comfort solutions (Chen et al., 2006; Ochoa and Capeluto, 2008; Omer, 2008). Obstacles to the promotion, acceptance, and practice of smart buildings exist. These barriers demonstrate the lack of information produced by intelligent technologies. To overcome these obstacles, creating various types of information to be shared among stakeholders is necessary (Kua and Lee, 2002). Currently, only a few comprehensive studies on intelligent built environment are available. Key intelligence indicators serve as comprehensive tools to evaluate the components proposed in the design concept for stakeholders (Kaklauskas et al., 2010). Wong and Wang (2005) summarized four areas of research, namely, intelligent building research, advanced/innovative technologies, performance evaluation methods, and investment assessment analysis. However, a lack of universally accepted tools to support intellectual property investment decisions remains a challenge. Current methods and models cannot analyze various stakeholders, whereas only separate elements are analyzed and evaluated in intelligent built environment. To compensate for these deficiencies, multiple criteria of intelligent built environment must be analyzed from different innovation aspects, and complex analysis model should be proposed in intelligent built environment.

5 Conclusions

The research objects of engineering management have been gradually transformed from micro-scale projects to macro-scale built environment. Built environment is material, spatial, and cultural products of human labor that combine physical elements and energy in the forms for living, working, and playing. Built environment is typically used to describe the interdisciplinary field that addresses the design, construction, management, and use of these manmade surroundings as well as their relationship to human activities. With the continuous development of human society, human needs have transformed from subsistence to self-realization. Thus, built environment does not only fulfill personal and social subsistence, but also enable the self-realization of personal and collective values and aspirations and human values. Built environment faces grand challenges, such as global climate change, energy shortage, urbanization, aging infrastructure, and change of growth model. Given that challenges are considered opportunities, built environment has major opportunities in technical, economic, and organizational dimensions. From a global perspective, we are at a critical turning point. Management scholars have an obligation to participate in research about built environment to help stakeholders (policymakers, enterprises, and individuals) make better decisions and practices in this field. Grand challenges in built environment provide opportunities to create better built environment from a systematic perspective.

Figure 11 illustrates this study's design of a future development strategy for built environment. This strategy takes sustainability and resilience as strategic goals, innovative behavior as the strategic guarantee, and Big Data and intelligence as strategic paths, thereby providing a theoretical reference for the creation of built environment. The future development strategy of built environment is described in detail as follows. First, sustainable and resilient built environment should accept substantial investments from stakeholders who are responsible for planning, designing, constructing, and operating built environment. Second, innovative behaviors of management teams determine the achievement of the goals of built environment, and team innovation behaviors can form normative guidance, methods, and tools for driving the management process of built environment. Lastly, the development of information technology has changed the manner of communication and relationship among stakeholders in built environment. These changes enable sharing, equality, openness, and synergy on a global scale. Moreover, intelligence is the strategic path for the implementation of built environment. The application of Big Data-related technologies provides innovative ideas for the transformation of built environment management.

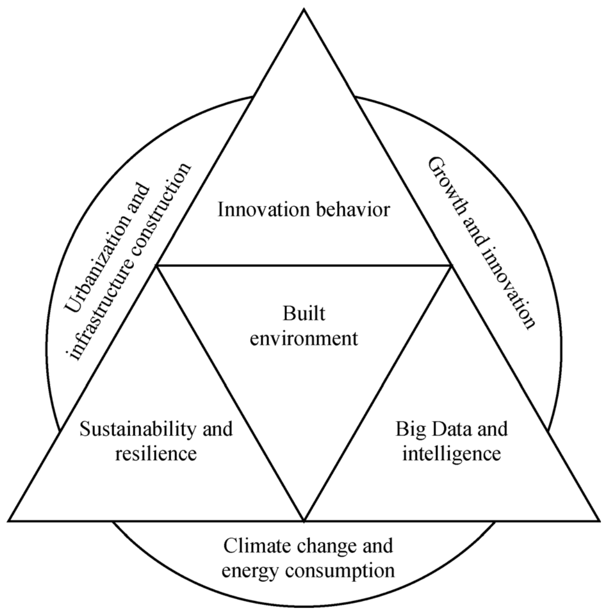

Fig. 11 Future development strategy of built environment.

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