Integration of Low-Carbon Eco-City, Green Campus and Green Building in China

Bao-Jie He, Dong-Xue Zhao and Zhonghua Gou

Abstract Sustainable development has been a consensus of our world, where low-carbon eco-city, green campus and green building are three significant concepts, corresponding to urban, community and building scales. However, many issues and challenges delay the process to effectively implement above three concepts. Considering their co-aims and inner relationships in urban scope, this chapter is designed to examine how these initiatives can be integrated so as to holistically accelerate sustainable development. To meet this end, primary work of present study focuses on interpretation of sustainability at different scales, development of sustainable projects in China and integration of low-carbon eco-city, green campus and green building. Through the analysis, following conclusions can be drawn: (i) green building receives its best development among three sustainable concepts; it can be a micro-driver to promote low-carbon eco-city and green campus development, while much work is needed to understand how they can be linked; (ii) developments of low-carbon eco-city and green campus are still restricted, and their assessment tools require further definitions, revisions and localizations; (iii) there are many similarities in terms of resource, environment, economy and society, and an emphasis of common points in constructing sustainable projects should be a cost-effective way to realize the whole sustainability goal; (iv) low-carbon eco-city, green campus and green building can experience their co-development and developing interrelated projects can help promote our society towards sustainability much easier.

Keywords Sustainable development · Low-carbon eco-city · Green campus · Green building · Urban scale · Similarities and differences

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1 Introduction

The current world is confronting the rapid urbanization, meaning a large population of people are migrating into urban areas. This requires more infrastructures, resources, services and space to maintain human life, safety and development. However, the dilemma is that the shortage of resources and energy cannot accommodate all human beings over several generations. It is estimated that fossil resources like oil will be used up in 40 years, and 67 and 164 years for natural gas and coal, respectively. Only from the energy supply aspect, it has been a worldwide energy crisis issue. More severely, rapid urbanization has also aggravated the environmental problems. For instance, anthropogenic activities such as energy supply for electricity generation, transport, residential and commercial buildings, industry, waste, agriculture, land-use and forestry change, have increased the emission of greenhouse gas (GHG) [1].

At the same time, accompanied with the urbanization and industrialization, the earth has undergone constant temperature increase and higher frequency of extreme weathers in the past 200 years. It is reported by Intergovernmental Panel on Climate Change (IPCC) that during the period from 1905 to 2005, the temperature worldwide had increased by 0.74 ± 0.18 °C [2]. Alarmingly, the speed of temperature increase has accelerated in recent decades. The climate change has obviously led to a series of disasters such as storms, blizzard, hurricanes, floods and drought, and some other potential threats and crisis, e.g. glaciers melting, sea-level rising, animal extinction, vegetation damage, agricultural disasters and other unpalatable impacts. Statement from United Nations Human Settlements Programme mentioned that the above two issues, urbanization and climate change, are working in a combining way, posing severer threats to the environmental, economic and social stability of the world [1].

Considering the unprecedented deterioration in energy and resource crisis, environmental pollution, higher frequency of natural disasters and social inequity, the term of "sustainable development" has been repeatedly underlined in almost all professions and countries. "Sustainable development" was initially defined in Our Common Future (Brundtland Report) by United Nations World Commission on Environment and Development (WCED) in 1987, to meet *the needs of the present without compromising the ability of future generations to meet their own needs* [3]. It is recommended that "sustainable development" could be a holistic method and temporal process that guides human being to achieve the final goal of sustainability [4].

China is one of the developing countries that undergo rapid urbanization and suffer from climate change. According to the National Bureau Statistics of China, the urban population reached 771 million, constituting 56.1% of the total population [5]. Because of the unsustainable developing pattern, the current urban population is confronting many environmental problems, such as unbreathable air ($PM_{2.5}$ and PM_{10}), polluted and undrinkable water, soil loss, heavy metal commination, apart from GHG emissions [6]. Meanwhile, the increasing number of urban inhabitants requires more buildings to accommodate and need more energy to serve the basic living quality. Until 2013, the total building area had surpassed 40 billion m^2, and now it is still rising at a yearly rate of 2 billion m^2. This consumes a large amount

of raw materials like concrete, cement and steel. Meanwhile, energy consumption in building sector accounts for more than 30% of total energy usage; even it takes up above 46.7% of total energy use if embodied energy use is considered in the building lifecycle [7, 8]. In addition, China generates approximately 28% of the global GHG emission, and buildings should be responsible for 30–40% of the total GHG emissions [9, 10]. Therefore, it is imageable that if remaining 603 million rural residents moved into urban areas, urban system would deteriorate [11].

To deal with varieties of complex issues and some future uncertainties during process of enabling such large population to move into urban areas, the central, regional, provincial and city governments at all levels have realized the significance to promote "green" urban development [6, 12, 13]. In practice, innovative approaches such as low-carbon eco-city, green campus and green building that take future sustainability as future development model have been proposed to cope with great challenges in city, neighbourhood and building context, respectively. Considering relationships between city, neighbourhood and building at different urban scales, the authors of this chapter present that how these initiatives can be integrated to accelerate holistically the sustainable development in China, so as to enhance the social, economic and environmental conditions for present and future generations. This chapter, therefore, conducts critical literature reviews of the performance of the three concepts and approaches. Afterwards, the development, definition, utilization and implementation of these concepts in China have been investigated. It is obvious that the sustainable development cannot be achieved in a short term, and these projects are difficult to implement effectively [11, 14, 15]. Because of the collaborative goals of sustainability, the integration in practical projects of low-carbon eco-cities, green campuses and green buildings is analysed to present a better understanding of sustainable theories for sustainable development. Ultimately, some implications for the future development of low-carbon eco-city, green campus and green building are proposed within the context of China.

2 Sustainability at Different Scales

2.1 City Scale: Low-Carbon Eco-Cities and Sustainability

To enhance the contractiveness and competitiveness of urban conditions in terms of society, economy and environment, a large number of cities all over the world have commenced various initiatives, such as sustainable cities, green cities, liveable cities, garden cities, digital cities, smart cities, knowledge cities, information cities, intelligent cities, ubiquitous eco-cities and low-carbon eco-cities [16–21]. Although these ideas have been suggested capturing and conceptualizing the key aspects of sustainability, some differences of primary contents in these concepts can be noted when making closer examination [18]. Meanwhile, Liu et al. [17] comparatively investigated the definition, strategies, indicators and targets of sustainable cities within

the context of China and found different concepts covered distinct contents. Only the terms of low-carbon eco-city could include all contents in social, economic and environmental aspects.

The generation of eco-city can date back to the foundation of urban ecology in 1975, which aims to balance the relationship between cities and nature, and particularly eco-cities are required to minimize the resource consumption in Eco-city Berkeley [16]. Afterwards, in more than 20 years' development, researchers and scholars had enriched the contents of eco-city theory, covering four aspects of environmental protection, energy efficiency, economic growth and social aspects [17]. Specifically, it includes ten principles as follows: building multi-purpose and mixed-use communities; creating non-fossil consumption and convenient transportation; rehabilitating damaged urban environments especially water system; creating affordable and mixed housing; ensuring social equity and opportunities; sustaining local agriculture, greening and gardening; promoting technologies to reduce pollutants and hazards; supporting ecological industrial activities; encouraging simple lifestyle to avoid excessive consumption; and increasing public awareness of ecological sustainability [22]. Later the connotation of eco-city was extended and clarified to cut down the consumption of energy, water and other resources while reducing the emission of wastes and pollutants [23]. Furthermore, eco-city is considered as a rural–urban transition process, to develop an integral system and concern about social, economic and environmental aspects. Rural issues should be also taken into account during this process, so as to improve the harmony and fairness among rural and urban residents [11, 24].

The proposition of low-carbon city is derived from the idea of low-carbon economy, issued in the British Government published the "Energy White Paper" entitled "Our Future Energy: Creating a Low-Carbon Economy" [25]. It emphasizes the transformation of production models and the enormous business opportunities of innovative technologies [26]. Four years later, the Japanese government launched the project of "low-carbon society", aiming at altering inhabitants' consumption habits and lifestyle, and then adopting low-carbon technologies to lower carbon emissions [20, 27]. The concept of low-carbon city combines advantages of low-carbon economy and low-carbon society to balance low-carbon production and consumption, as well as maintain sustainability and ecology in urban areas [26]. This concept is mainly adopted to guide the research in the field of future energy consumption and carbon emissions, especially in developing countries with rapid urbanization [28–31].

Low-carbon eco-city combines both concepts by featuring energy-saving and environmentally friendly city symbolizing low energy consumption and low environmental impact [32], mainly consisting of carbon-efficient economy, environmental protection, energy efficiency, economic growth and social aspects [17]. Through the ELITE (eco and low-carbon indicator tool for evaluating cities), it is noted that the functions of low-carbon eco-city lie in energy and climate, water quality, availability and treatment, air quality, waste, transportation, economic health, land use and urban form, and demographics and social health [33].

However, the development of low-carbon eco-cities is still at the beginning stage, since many problems have been observed during its implementation. Especially when social and economic issues are included, cases and scenarios turn to be more complex. Many efforts have been made to technological and economic development rather than allowing community engagements [11]. For example, the upgradation of services and urban infrastructures of Sino-Singapore Tianjin Eco-city are mainly constructed by migrant labours, but these low-paid workers may never be able to afford to live themselves [34]. The dilemma depends on the fact that low-carbon eco-cities are a sustainable place to live in and many opportunities to work, while how to consider the social equity [35]. Likewise, through the analysis of eco-towns in Northern European countries, Netherlands, Sweden and Germany, Bayulken and Huisingh [15] pointed out that collective action with bottom-up participation and top-down commitment should be taken to create integrated eco-towns where citizens can experience, learn, participate and enjoy. However, to solve various problems, much more time is required to explore patterns to promote the holistic development of low-carbon eco-city [11, 15].

2.2 Community Scale: Green Campus and Sustainability

Schools and universities have been considered a kind of communities, not only to offer students and teachers places to study and work, but also to impart students and teachers with basic understandings of advanced ideas and trends [36, 37]. The concept of sustainability has been already incorporated into students' education, for the goal of improving their awareness of environmental protection and energy conversation [38, 39]. Meanwhile, many schools and universities have launched campaigns to create green campuses, so that all people in relation to education will be involved into real context of sustainable development [37, 40, 41]. Having been affected by a range of factors in school environments, from daily curricula to sustainable behaviours and living environments, students are more likely to enhance their consciousness of sustainable development. After their graduations, the long-term assimilation will make them be the main sector of behaving sustainably [42].

The quest of starting environmental protection education can be dated back to 1972, when a conference on human environment was held in Stockholm, Sweden [40]. Later, because of inequitable production and unsustainable consuming manners, all regions of the world underwent environmental changes in air pollution, natural resources depletion, energy shortage and greenhouse gas emissions, having the potential to further aggravate poverty. With these pressures, presidents from 20 universities signed the Talloires Declaration for the development of sustainability, in which there were ten points in how to practically incorporate sustainability and environmental literacy in teaching, research, operation and outreach at colleges and universities presented [43]. Until 2016, it is estimated that approximately 500 universities from 55 countries on five continents have signed the declaration to act their role as leaders in developing, creating, supporting and maintaining sustainability

[44]. The ideology of green campus was then put forward in an Ecological School Plan based on The Found of European Environmental Education (FEEE) in 1994, which aimed at enabling the disclosure of environmental education among primary and secondary schools via daily curricula [36].

In recent years, the campaign of green campus has been launched by almost all universities and schools around world. Many terminologies on green campus have been put forward and presented in previous literatures, such as green university, sustainable university, sustainable university campus, green campus, green school. Nevertheless, most of them have included the same meaning to enable our society to make the transition to sustainable lifestyle [45].

Moreover, previous studies have consistently indicated that all these activities at community level suggest the significant benefits in environmental, economic, societal and health aspects [46]. Concerning the health benefits of green campus, it is firstly reflected by widespread characteristics of green campus design. For instance, USGBC has launched assessment tools to support green schools for the young generation and has highlighted the importance in several perspectives, such as the improvement of indoor air quality, the removal of toxic materials from places where children learn and play, the improvement of classroom acoustics, the encouragement of waste management, etc. [36]. Additionally, BREEAM has tailored green campus evaluation system for pre-schools, general schools, colleges and universities, vocational colleges and institutions, and other facilities, in which health and well-being has been listed as an evidential requirement. In this item, visual comfort, indoor air quality, safe containment in laboratories, thermal comfort, acoustic performance, safety and security are required [47]. These have provided students and teachers with a cleaner and comfortable physical environment, which can enhance the levels of their health conditions and well-being.

The operation of green campus includes every sector in a university, such as classrooms and laboratories, accommodation, transportation and other facilities. Therefore, economic advantages of green campus could be firstly shown by its characteristics of energy-saving, water efficiency and natural resources [36, 37], especially when energy and water consumption intensities of universities are much higher than those of residential communities. Meanwhile, the economic quality has been set as a significant item in various green campus assessment systems [36]. Furthermore, its macro-effects on economic growth lie in social justness and increased efficiency in natural resources usage [46]. As for environmental benefits, all universities concern about their impacts on energy efficiency, water efficiency, greenhouse gas emission, the utilization of renewable energy, etc., through the upgradation of school or university facilities [37]. The green campus activities generate social benefits which not only promote students and teachers to form the habitats of environmental protection, but also strengthen creation of sustainable society in the long run. Additionally, it is an approach to eliminate poverty and inhabitants' deprivation, to improve societal fairness and to broaden the sustainable development concept to the whole society [48].

It is pointed out that local schools and universities can play many roles in promoting a society to move towards an eco-city [37]. However, how to practise the green

campus remains questionable in many countries, although many educational institutions have attended some alliances of green campus. For instance, some universities are famous for its discipline of architecture and urban planning has witnessed the significance of green campus [40]. Meanwhile, many of them are currently exploring a reasonable green campus assessment system, and how to manage campus activities in relation to sustainability [49–51]. Therefore, how to link the development of eco-city and green campus are still blurring. It is therefore essential to examine the relationships between eco-city and green campus, for an integrative model on their future co-development.

2.3 Building Scale: Green Building and Sustainability

As a building is the minimum physical unit of a city, its construction, operation and maintenance seem to be a process of socioeconomic metabolism: consuming energy, water and materials, and then consequently producing a series of solid, liquid and gaseous wastes. In parallel, buildings are the most important sector to accommodate the rapid growing population, as well as to meet their rising living demands. In developed countries, it is estimated that building sector consumes about 30% of the national energy and exhausts about 40% of total GHG [52]. The percentages of both energy consumption and GHG emissions are much higher in developing countries [53]. In addition, it is pointed out the process of building construction, renovation, refurbishment and retrofitting causes a wide range of negative impacts, like noise, dust, traffic congestion and water pollution [54]. Confronted with the issues of environmental degradation and energy depletion, people proposed, developed and popularized the concept of green building for the pursuit of energy efficiency, ecology and sustainability [53].

The initial consideration of building as an approach to achieve sustainable develop was mentioned in Silent Spring published in 1962 [55]. Later, the terminology, Arcology, a combining form of architecture and ecology, that implied the emergency of green building was put forward by Soleri [56]. After about two decades, the topic of 'green building' was formally presented on the United Nations Conference on Environment and Development held in Rio de Janeiro in 1992 [57]. Generally, green building is firstly expected to provide human beings with healthy, comfortable and safe living, working and activity space, for realizing environmentally responsible and resource-efficient process throughout a building's lifecycle [15]. It is pointed out that four aspects have been included in its definition, such as improving occupants' health conditions, minimizing buildings' impacts on environment, improving returns to developers and local community, and the life-cycle consideration [58]. Green building witnessed its dramatic development after the proposition of green building rating system, such as Building Research Establishment Environmental Assessment Method (BREEAM) in UK and Leadership in Energy and Environmental Design (LEED) system in USA. In recent years, many countries around the world have issued their own green building rating system in accordance with the geograph-

ical, economic and societal features [53]. In general, green building has been widely acknowledged by architects, engineers, developers, policy makers, etc.

There are many terminologies on using buildings to achieve the sustainable development of the society, such as energy-efficient building, low-carbon building, green building, ecological building, sustainable building, low-energy building, zero-energy building and even regenerative building. Energy-efficient building is a holistic concept, including all other concepts, aims to design low energy consumption buildings based on the climatic conditions and energy-saving techniques. Low-energy building, ultra-low-energy building and zero-energy building are a gradual improvement in energy performance. Meanwhile, the extra energy required should be covered by renewable sources produced on site and nearby [59]. Low-carbon building and zero-carbon building highlight the reduction in fossil fuel usage, the improvement of energy efficiency and the reduction on carbon dioxide throughout the lifecycle of building materials and equipment manufacturing, construction and building operation. Ecological building pays more attention to making use of local environment and natural conditions, so as to protect ecology and avoid destroying local environment. The concept of sustainable building is closely attached to sustainable development, where Berardi [52] summarized it *as a healthy facility designed and built in a cradle-to-grave resource-efficient manner, using ecological principles, social equity and lifecycle quality value, and which promotes a sense of sustainable community*. Nevertheless, green building is the most popular concept in both research and real practice.

The relationships between sustainability and green building lie in three pillars, including social, environmental and economic benefits, namely the triple bottom lines. For the environmental stewardship, green building can conserve natural resources, such as water, fossil fuel, as well as maintain and improve the quality of water, air, land, etc., reserving a better earth for the future generations. For example, the statistical data from USGBC has shown that LEED-labelled buildings witness 25% of energy reduction, 11% of water conservation and 34% of GHG reduction, when comparing to conventional buildings [60]. Moreover, it is projected that due 2030, LEED-labelled building can reduce 4.92% of the total GHG emission of American society. When it comes to the social sustainability, its scope mainly covers living quality, occupant health and safety, and future professional development opportunities, as indicated by Zuo and Zhao [54]. In office building, for instance, there are three kinds of illnesses disturbing workers' attendance, including sick building syndrome, asthma and allergies, and communicable and respiratory diseases [61]. A 35% higher in attendance rate has been evidenced when providing sufficient ventilation in offices (24L/s per person) when comparing to 12L/s per person [62]. Meanwhile, a higher hospital admission will be found in extreme weather conditions. The economic benefits could be reflected by reduced resource consumption and the lowered cost in dealing with air pollution. Meanwhile, the improved working attendance and productivity can benefit both occupants and owners.

Green building has been widely accepted by many professions of the society. Moreover, after several years' development, a large amount of experience in realizing green building has been achieved. The further development of green building could

be the small unit to promote low-carbon eco-city development. To some extent, the creation of green building has been embraced by the development of low-carbon eco-city; in other words, green buildings are the one of the prerequisites of low-carbon eco-city [63]. However, few studies have been conducted to connect green building and low-carbon eco-city. Meanwhile, schools are physically composed by buildings. Therefore, the improvement in building resource efficiency and reduction in pollutions and wastes also means promoting the sustainability of schools and universities.

3 Projects for Sustainable Development in China

3.1 Low-Carbon Eco-Cities

Development of low-carbon eco-cities in China accompanies with the steady economic growth and rapid process of urbanization [17]. Since the adoption of Reform and Opening-up Policy in 1978, China has witnessed a dramatic increase in urbanization ratio, from just 17.92% in 1978 to 56.10% in 2015 (Fig. 1). In 2015, there were 771 million people living in urban areas. On the one hand, this society therefore requires more cities to accommodate the increasing urban population. It is illustrated that number of cities in China is 658 in 2013, which is approximately three times of the 193 in 1978. Although cities in China enter a relatively stable state in number [20], essential conditions, e.g. energy, water, houses, living space, to support citizens' daily life have generated significant burdens to the urban systems. The direct environmental degradation and its indirect impacts on economic and social development call for reasonable upgradation in urban management, for making cities more sustainable.

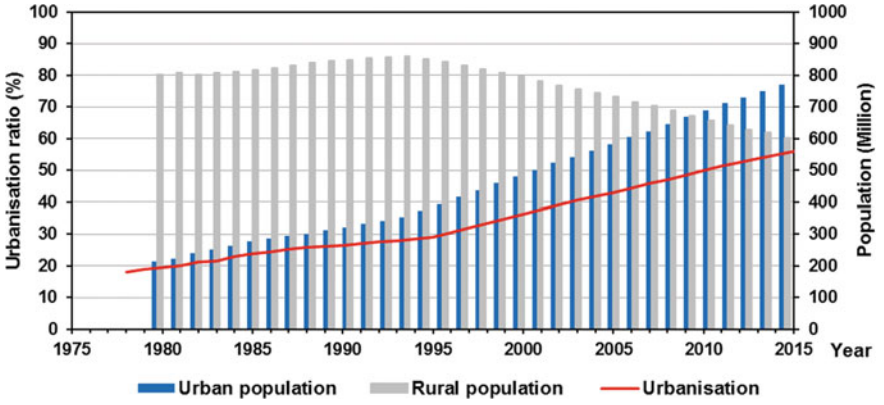

Fig. 1 Urbanization ratio, urban population and rural population in China from 1978 to 2015

In the context of Chinese traditional culture and custom, the concept of low-carbon eco-city has been proposed in the form of "building to unify heaven and humanity". Focusing on the harmony between the city and surrounding environment, this concept has affected the urban design and built environment for several thousand years [64]. In the modern world, the philosophy of low-carbon eco-city evolved after the proposition of eco-city by United Nations Educational, Scientific and Cultural Organization (UNESCO) in 1971. The issue of urban ecological environment was formally included in the Long-Term Plan for the Development of Science and Technology in 1978. Later, the urban issue and urban science had been emphasized. In 1982, National Sixth Five-Year Plan Key Scientific and Technological Projects included Beijing and Tianjin as two pilots to start investigating issues on urban ecosystems.

Given the increasing attention on urban environmental system, Yichun City in Jiangxi Province determined the goal of building an ecological city in 1986, which was implemented after two years. Afterwards, many concepts at city level were proposed. National Garden City was proposed in 1992 by Ministry of Housing and Urban-Rural Development (MOHURD), which was sustained by a series of standards in construction, evaluation and promotion [17]. During the period of National Ninth Five-Year Plan, the concept of National Environmental Protection Exemplary City was developed, aiming to establish healthy urban system from a variety of aspects, such as social, economic, environment, urban construction, health and garden. In 2003, the Ministry of Environmental Protection launched the indicators for eco-county, city and province construction, meaning the top-bottom promotion of this project. Later, the approaches that can encourage urban sustainability were considered as a national policy. For instance, Harmonious Society was proposed in the Fourth Plenary Session of the 16th Chinese Communist Party Central Committee in 2004. The eco-civilization was highlighted in the 17th National Chinese Communist Party, which promoted the proposition of Low-carbon eco-city by MOHURD in 2009 [65]. Although other concepts like national ecological garden city and new urbanization construction have also been put forward, the philosophy of low-carbon eco-city has been the most popular in China.

Before Singapore Prime Minister Lee Hsien Loong and Chinese Premier Wen Jiabao determined a framework agreement for Singapore and China to jointly develop Sino-Singapore Tianjin Eco-city in 2007, the development of low-carbon eco-city was in a state of slow development. However, after this milestone, many cities commenced on developing low-carbon eco-city in the form of MOHURD-province cooperation, MOHURD–city cooperation, and MOHURD pilot low-carbon eco-city [66]. According to the statistics by Chinese Society of Urban Studies (2016), there are 284 prefectural cities creating eco-cities. Around 79% of these ecological cities are in a healthy or very healthy condition, as indicated by ecological cities health index (Chinese Society of Urban Studies 2016). Meanwhile, National Development and Reform Commission of the People's Republic of China (NDRC) has listed 78 prefectural cities and five provinces as the low-carbon city pilots since 2010. It is also found that about 97% of the prefectural cities have expressed their intentions to build low-carbon city or ecological city, showing a great promise in China [11]. However,

the national assessment system for low-carbon eco-city is still in a premature status, which should be further developed in the next few years.

3.2 Green Campus

Accompanied with large population of China, people who are educated in kindergarten, primary and secondary schools, and universities account for a dramatic proportion. According to report from Ministry of Education (MOE), school students at all levels reach 26 million, and students who are receiving higher education exceed 36 million [67]. Although teachers and students in colleges and universities have been well-educated with the significance of resource-saving and situations of resource shortage, still energy-use and water-use intensities of colleges and universities are much higher than those of residential communities. It is shown that energy and water consumption in universities were 17.9 million tons of standard coal and 3.32 billion m^3, accounting for 0.8 and 6.6% of national energy consumption and water supply in 2005. These digits are increasing rapidly due to increase in student number and living quality [68]. If energy- and water-use intensities could be reduced by 20%, a large city with 7.6 million citizens would survive. All these indicate the significant environmental benefits and economic benefits of sustainable university construction [68].

The concept of green university was introduced into China in 1996, aiming to integrate philosophy of sustainable development into teaching and curricula and to cultural atmosphere for comprehensively improving environmental awareness of teachers and students. At the very beginning, development of green university was promoted by a mix of national government, provincial and local governments, city council and universities themselves. In 1998, Tsinghua University was approved as the first green university pilot project by MOE, Ministry of Science and Technology (MOST) and Ministry of Environmental Protection (MEP), formally introducing the concept of green campus into the Chinese universities. In 2001, Shanxi Agricultural University was named green university by Shanxi Provincial Education Department. In 2002, Wuhan Municipal Environmental Protection Bureau and Wuhan Education Bureau collectively developed and Assessment Standard for Wuhan Green University, and Jianghan University was selected as the pilot university. Additionally, many universities spontaneously constructed green university, like Tongji University and Peking University.

In 2007, Tongji University built the first national conservation-oriented campus demonstration project. To promote the exchange and cooperation of colleges and universities in green campus construction, ten universities and academic institutions including Tongji University, Zhejiang University, South China University of Technology, Jiangnan University, Tianjin University, Chongqing University, Shandong Jianzhu University, Hong Kong Polytechnic University, China Architectural Design and Research Institute and Shenzhen Institute of Building Science co-sponsored China Green University Network (CGUN) in 2011. It is shown that this network

has well achieved their goal in forming a platform of experience sharing and complementary resources for leading and promoting sustainable development of green university construction of in China. Many other institutions later applied for enrolment of CGUN.

Green university experiences a process of bottom-up development. In 2008, MOHURD and MOE emphasized the importance of university energy-saving and water-saving, and issued *Promoting the construction of economical campus in colleges and universities: Suggestions on strengthening the aim of energy-saving and water-saving*. It concretely pointed out that both energy consumption and water usage should be reduced by 15% until 2012, compared with situations of 2005. Many regulations were established by MOHURD and MOE in aspects of energy monitoring system, operation management, energy consumption audit and assessment indicators. At the same time, Ministry of Finance (MOF) launched special funds for energy-saving of office buildings and large public buildings to support green university construction. During promoting the energy efficiency of national office building and large public buildings, MOHURD issued *Twelfth five-year plan for building energy conservation*, in which 72 colleges and universities were selected as conservation-oriented campus demonstration projects. Therefore, green university construction was disclosed and spread to provincial and city levels through three stages. On this basis, to provide scientific evaluation standard for green university, MOHURD promulgated and implemented *Evaluation standard for green campus* (CSUS/GBC 04-2013) [69]. It is reported that more than 200 colleges and universities have been certified as green universities (Fig. 2).

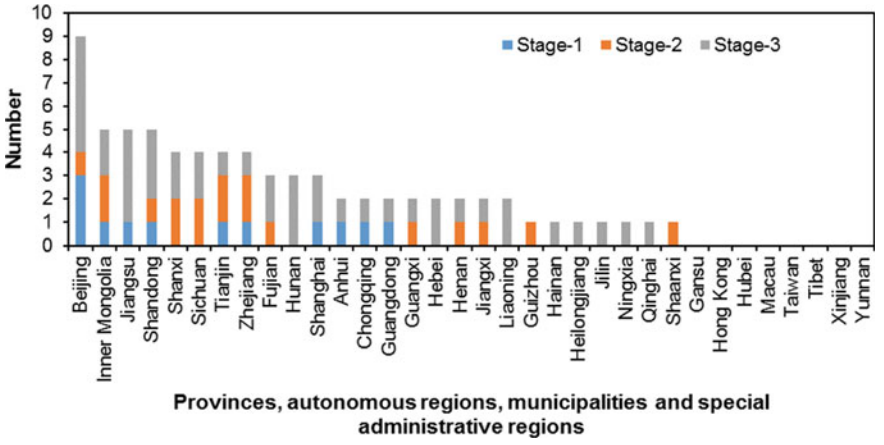

Fig. 2 Provincial distribution of conservation-oriented campus demonstration projects

3.3 Green Building

After the Reform and Opening in 1978, national population and economy of China have witnessed dramatic development, which is backed up by large energy demand. As indicated in Fig. 3, national energy demand increased from just 571 million tons of standard coal in 1978 to 4.3 billion tons standard coal. Moreover, a prodigious number of buildings are required to accommodate the large amount of national population. From 2001, yearly completed building area all exceeded 1 billion m^3, and increased to 4 billion m^3 per years between 2013 and 2015, as presented in Fig. 3. With improvements of living quality, energy consumption of building sector has kept increasing in the past decades, accounting for 27.8% of the national energy consumption in 2008 from only 10% in 1980 [70]. The large amount building energy consumption has encouraged all aspects of building-related staff to find effective approaches to reduce energy consumption.

Before the proposition of green building in 2004, China underwent more than 20 years' development in energy efficiency of buildings. This process was divided into three stages by Shui and Li [71] according to the release of energy-saving policies. Before 1986, energy situations of civil buildings were emphatically studied, and energy conservation design standard for new heating residential buildings (JGJ-95) was released to achieve 30% of reduction in energy consumption. Between 1987 and 1992, Ministry of Construction, State Building Materials Industry Bureau, Ministry of Agriculture, and Ministry of Land and Resources collaborated to promote energy efficiency through wall material innovation, after which Harbin in Heilongjiang Province and Chengdu in Sichuan Provinces were determined as piloting cities to provide guidance for provincial building energy efficiency development. Next stage from 1993 to 2005, standards, regulations and policies were established, providing political and legal supports. More importantly, energy-saving standards and energy-saving targets over different climatic zones and building types were determined, i.e.

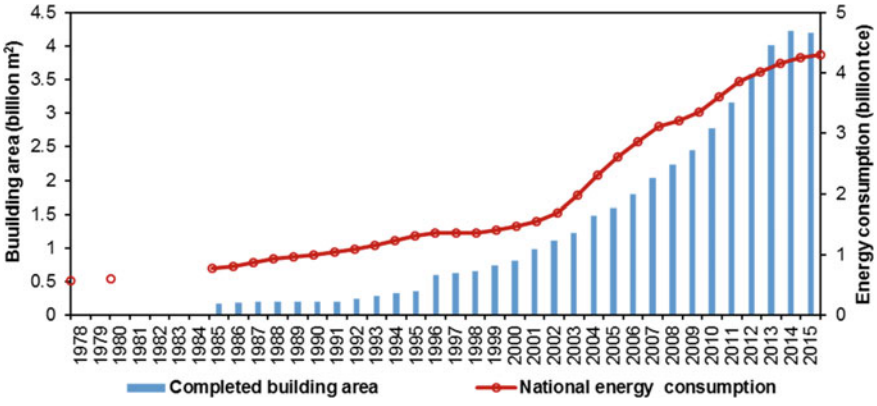

Fig. 3 Trend of China's building area increase and energy consumption between 1978 and 2015 (Summarized from: National Bureau of Statistics of China)

design standard for energy efficiency of residential buildings in hot summer and cold winter zone (JGJ 134-2001), design standard for energy efficiency of residential buildings in hot summer and warm winter zone (JGJ 75-2003). After these stages, people's awareness of energy efficiency has been improved, and governments at all levels have accumulated experience from technical, political and economic aspects.

Green building was formally introduced into China in the form of LEED green building in 2004, in which year only three buildings were registered for LEED. In the same year, the MOHURD released *National green building innovation award management measures* to encourage developers to voluntarily construct green buildings. In 2006, the first national green building standard titled "*Assessment Standard for Green Building*" (GB/T50378-2006) was announced by MOHURD, providing the green building construction with technical supports, although it was not mature and revised in 2014 as GB/T50378-2014 [72]. In progress, a series of technical and management regulations were issued. From 2005 to 2011, certified green building cases increased from only two cases in 2005 to 226 cases in 2010. In 2012, with the collaboration of MOF and MOHURD, economic incentive policies were implemented to upgrade quality of green buildings, where 45 and 80 Yuan RMB per square metre would be subsided to two-star or three-star green buildings. This promoted the application of national green building standard rather LEED, making it better follow current economic, social and technological situations of China. Since 2011, the number of certified Green building-labelled (GBL) green buildings has been more than that of LEED-certified green buildings. The GBL-certified green buildings reached 4515 cases due September 2016, as shown in Fig. 4.

In addition, based on the national technical and economic supports, many provinces and local cities established local standards and regulations for establishing local green buildings. It is shown that Zhejiang, Jiangsu, Beijing, Shanghai, Tianjin, Jiangxi, Hebei, Hunan, etc., have launched provincial green building assessment standards, and 25 provinces, municipal cities, autonomous regions have announced extra economic incentive policies on basis of national policies.

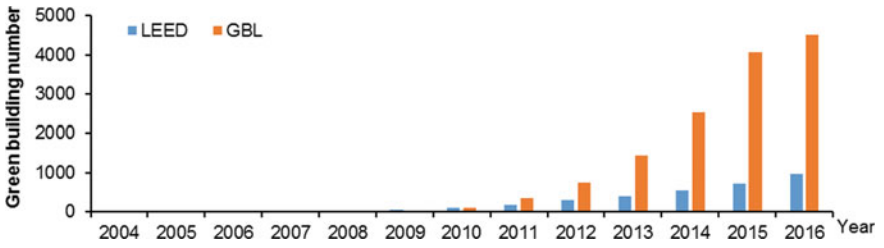

Fig. 4 Number of GBL-certified and LEED-certified green building projects in China (Due September 2016). *Note* The GBL-certified green buildings are mainly distributed in the mainland of China, because Hong Kong, Macau and Taiwan have already established, respectively, local green building evaluation systems, including EEWH (Ecology, Energy-saving, Waste reduction, and Health, Taiwan) and HK-BEAM (The Hong Kong Building Environmental Assessment Method, Hong Kong) [73, 74]

4 Integration of Low-Carbon Eco-City, Green Campus and Green Building

Under the background of sustainable development, various concepts like low-carbon eco-city, green campus and green building were introduced into China in 1980s. All of them underwent a long time of evolution and received great attentions around the year of 2010. Assessment standards for practically creating low-carbon eco-city, green campus and green buildings have also be issued and adopted. All levels of governments from national to local governments show their great activeness to the low-carbon eco-city, green campus and green building. Many departments such as MOHURD, MOE, MOF and MOST have provided technical, management and financial supports for building them. Meanwhile, many projects have been widely developed around the whole country; even many cities are developing low-carbon eco-city, green campus and green buildings with local characteristics. Nevertheless, construction of sustainable city, campus and building has been still independent with each other, while their inner connections in prompting sustainable development have been mostly neglected. The following section then examines the connections existing among low-carbon eco-city, green campus and green building.

4.1 Urban Sustainability

According to the constitution of urban form, development of urban sustainability should be achieved in three scales, namely city scale, community scale and building scale. Their relationship has been presented in Fig. 5, in which sustainable city stands at the highest position in the hierarchy, while sustainable building is the unit, standing at the lowest position. In the scenario of bottom-up pattern, functions and performances should be dominant, determining developments of green campus and low-carbon eco-city. On the contrary, achievements of both low-carbon eco-

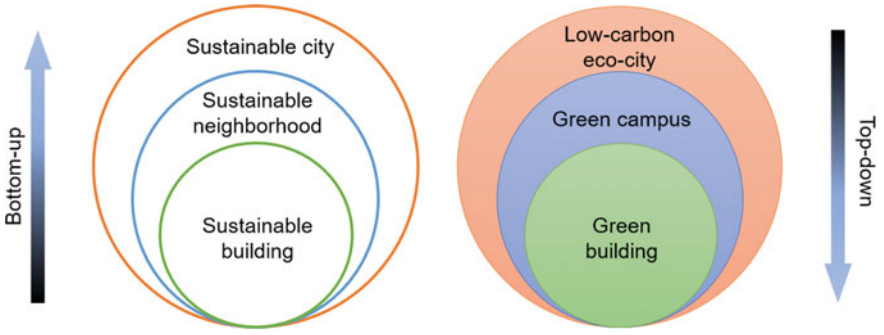

Fig. 5 Hierarchy of urban sustainability

city and green campus construction affect green building development in the top-down pattern [75]. The current context of sustainable development of China follows the bottom-up pattern, where low-carbon eco-city and green campus are developed based on energy-saving, water-saving and environmental protection, while green building that is mainly characterized energy-, material-, land- and water-saving, and environmental protection promotes developments of low-carbon eco-city and green campus in practice.

Although all three concepts are expected to promote resource-saving and environmental protection, there are some differences of roles they play. During realizing urban sustainability, low-carbon eco-city should guide and direct developments of green campus and green building. To start with, low-carbon eco-city does not only include environmental impacts and energy efficiency, but also consider economic development and societal harmony. Next, a master plan and management vision has the effects of connecting intrinsic elements. A low-carbon eco-city is a mix of artificial elements, such as commercial, institutional, educational uses as well as housing styles, sizes and prices, and natural elements like air, water, energy, land, etc. Community is the unit to serve citizens' basic living requirements, through a series of functions like dwelling, industry, entertainment, health care, culture, etc. Compared with low-carbon eco-city, it primarily highlights environmental, societal and healthy aspects rather than economic effects. Sustainable and liveable communities protect historic, cultural and environmental resources, while economic effects are embodied, in indirect relation to advantages of water-, energy-, land- and material-saving and carbon emissions. Green campus is one of several components of urban system, bridging green building and low-carbon eco-city. At the bottom of the hierarchy, building is the smallest unit. It achieves its main goals of environmental protection and resource-saving via technical approaches. However, the social and economic benefits are realized indirectly.

4.2 Connections Between Their Assessment Criterions

To develop low-carbon eco-city, MOHURD and MOF collectively launched a project of *Demonstrating Green Ecological Urban Built-up Areas* in 2012. It is indicated that *Sino-Singapore Tianjin Eco-City* should be the best one among all eight cases [11, 66]. To implement new its philosophy of ecological economy, ecological society, ecological environment, ecological culture, an indicator system consisting of 22 control indicators and four guiding indicators was proposed, based on national sustainable requirements of two countries, international and local Tianjin situations [76]. Meanwhile, to promote development of green campus and green buildings, two national standards denoted as CSUS/GBC 04-2013 and GB/T 50378-2014 were issued, respectively [69, 72]. In this section, the assessment criterions of low-carbon eco-city, green campus and green building are compared to examine their similarities and differences. Note that green campus standard CSUS/GBC 04-2013 includes assessment criterions for primary and secondary schools, and colleges and univer-

sities [69]. Hereafter, the colleges and universities version are adopted. According to possible benefits of three concepts, the comparison is carried out in four aspects: resources, environment, economy and society.

4.2.1 Similarities and Differences in Resource

Comparison of resource criterions was conducted in four aspects: water, land use, energy and material, as presented in Table 1.

Water: All three concepts have highlighted utilization of non-traditional water sources, where reclaimed water and rain water should be employed, while technology of seawater desalination is used to provide water source to the city when developing the low-carbon eco-city. Daily life on campus is appropriately served by municipal water, and non-municipal water is used for campus landscape. Distinctively, non-municipal water has been set as a compulsory indicator in residential, office, commercial and hotel green buildings, despite of differences in utilization rates. At campus and building levels, water-saving appliance and equipment, and water-saving design are required, indicating that green building and green campus construction more underline techniques. The water cooling technology is suggested to recycle water generated by air-conditioners, etc., in buildings. Embodied water for constructing buildings is also included in green building criterion. Low-carbon eco-city and green building formulated average daily water consumption, while green campus did not, which is a leak for water-saving.

Land use: Public green land for people's daily life is a common criterion in all three concepts, where green area per capita should exceed 12 m^3 in low-carbon eco-city and green university sets thresholds for greening rate. Green building combines green area per capita and greening rate as criterions for green land. On land use, the largest difference among them is that newly constructed buildings should be all green buildings in low-carbon eco-city. In order to save land, limits of plot ratio have been both provided in projects of green university and green building, respectively, while living area per capita should firstly meet requirements. During constructing green university and green building, the utilization of underground space has been regarded as an effective way to provide car parking space, saving over-ground space for other usage. Meanwhile, wasteland in campus and green building zones should be redeveloped and restored, and building's site should be reasonably designed for water collection. To protect urban ecology, land protection is a compulsory rule in creating low-carbon eco-city, green university and green building. In low-carbon eco-city, wetland that must be exploited for other use should be compensated via recovery and developing other lands, to maintain net loss of natural wetland zero. More strictly, universities and buildings cannot be developed over natural water bodies, wetlands, agricultural lands, forests and other reserves.

Energy: To cope with global climate change, China determined a goal that due 2020 renewable energy should supply 15% of national energy demand of China on *United Nations Climate Change Conference* in 2009. Therefore, the rate of renewable energy utilization should be higher than 15 percentiles in low-carbon eco-city area,

Table 1 Comparison of similarities and differences in resource criteria

Criterion	Similarities			Differences		
	Low-carbon eco-city	Green campus	Green building	Low-carbon eco-city	Green campus	Green building
Water	Non-traditional	Non-traditional	Non-traditional water	Seawater	Municipal water	Non-municipal water
		Appliance and equipment	Appliance and equipment			Water cooling technology
		Water-saving system	Water-saving system			Construction management
	Daily water usage		Daily water usage			
Land use	Public green land	Green land ratio	Green land	Green building		
		Plot ratio	Plot ratio			
		Underground space	Underground space		Wasteland redevelop-ment	Rainwater collection; Ecological compensation
	Land protection	Land protection	Land protection	Wetland	Water bodies, agricultural land, wetland, forests and reserves	Reserves
Energy	Renewable energy	Renewable energy	Renewable energy	Low-carbon opera-tion; Carbon emission		
		Building and envelope	Building and envelope		Natural ventilation	Natural ventilation
		HVAC	HVAC			
		Lighting and appliance	Lighting and appliance			
		Energy recovery	Energy recovery			
Material		Material-saving design	Material-saving design			
		Material selection	Material selection			Local materials

and renewable energy use is recommended in campus and building scales, where different utilization ratio decides scores buildings can obtain. Generally, low-carbon eco-city is operated under low-carbon situations. More concretely, the construction of green university and green building is based on building and envelope design, HVAC, lighting and appliance and energy recovery techniques. In campus, buildings are required to be well-arranged to avoid winter prevailing wind and beneficial to the formation of outdoor natural ventilation. For green buildings, they should adopt natural ventilation to reduce energy consumption of HVAC system by settings of doors and windows.

Material: For low-carbon eco-city construction, although material-saving has not been proposed as an independent indicator, it is reflected by reduction of carbon emission, which synthetically considers effects of energy structure transition, green transportation and green material. For green university and green building, material-saving design and material selection have been especially listed as two individual items, where local materials should be reasonably employed when constructing green buildings.

4.2.2 Similarities and Differences in Environment

Urban environment covers a wide range of criterions, from quality of water, light, air and sound to waste produced due to anthropogenic activities, wind environment, infrastructures that support people's basic living quality, and local biodiversity, as summarized in Table 2.

Water: Quality and security of water affect directly healthy conditions of citizens. Considering current conditions of water pollution and water shortage in China, low-carbon eco-city, green university and green campus have all agreed that water quality should be a compulsory criterion. In addition, low-carbon eco-city commits to upgrading urban water environment from quality of surface water and centralized drinking water. Non-traditional water adopted in green campus should be monitored, avoiding generating adverse impacts on human health and surrounding environments. Water quality of rainwater collected should be maintained by ecological water treatment technology, in case of runoff pollution to landscape water.

Light: Urban construction has not yet clearly defined light environment, while campuses and buildings are required to create good indoor lighting environment. Light pollution in campus should be avoided, while outdoor vision should be unobscured.

Air: Air pollutants should be controlled in both in indoor and outdoor environments. For low-carbon eco-city, it is an approach to counterbalance the situation of atmospheric pollutions in most industrial cities where SO_2 and NO_X shall be strictly controlled. Outdoor natural ventilation is regarded to improve campus air quality, and dust reduction measures are required when constructing green buildings. Human thermal comfort is another important indicator of air quality, where relative humidity should be regulated by adjustable shading measures, while outside shades should be formed by building arrangement and shading devices installation,

Table 2 Comparison of similarities and differences in environment criteria

Criterion	Similarities			Differences		
	Low-carbon eco-city	Green campus	Green building	Low-carbon eco-city	Green campus	Green building
Water	Quality	Security	Quality	Drinking water; surface water	Non-traditional water	Runoff pollution control
Light		Indoor lighting	Indoor lighting		Lighting pollution	Outdoor vision
Air	Pollutants control	Pollutants control	Pollutants control		Natural ventilation	Construction management
		Thermal comfort	Thermal comfort			Relative humidity
		Urban heat island	Urban heat island		Landscape construction	Tree and cool material
Solid waste	Recycling	Recycling	Recycling	Garbage collection	Construction waste	Construction waste
	Waste control	Waste control	Waste control	Garbage production per person; waste disposal	Away from waste sources	Construction management
Noise	Noise control	Noise control	Noise control	City level	City and indoor level	City and indoor level
Wind		Natural ventilation	Natural ventilation			Comfort
Community	Public service	Public service	Public service	Available in 500 m radius;	University-communities' cooperation	Educational and industrial resources
Biodiversity				Local vegetation coverage		

to improve outdoor thermal comfort sustainably. Urban heat island that has not been mentioned in low-carbon eco-city concept, while campus and building construction should respond to UHI effects, through landscape construction, and greenery and cool material utilization respectively.

Solid waste: The solid waste generated in urban, campus and building operation are expected to be dealt with in a recycling way. To start with, citizens in low-carbon eco-city are encouraged to reduce garbage generation in their daily life. In low-carbon eco-city, solid waste recycled, including resource processing, should account for more than 60% of the totally urban waste, while only waste produced during construction period is considered by green university and green building. In order to provide people with healthy environment, hazardous waste and domestic waste should undergo harmless treatment. However, green campus selects to adaptively stay away from waste source and green building only focuses on reducing solid wastes produced by construction.

Noise: Noise at both urban, community and building level must be controlled, and the only difference between them is in relation to indoor or outdoor noise control.

Wind: At university and building level, natural ventilation has been an effective and low-carbon strategy to improve indoor and indoor air quality. Meanwhile, wind around buildings should be moderate to ensure pedestrian wind comfort.

Community: As a significant part of people's living, public services for entertainable, cultural, health care, etc., use and accessibility facilities should be offered in all three concepts. Low-carbon eco-city defines the service range of 500 m, and universities would like to share public infrastructures with citizens living in surrounding communities. Green building being a sustainable model aims to educate people with sustainable awareness.

Biodiversity: Low-carbon eco-city respects the local natural ecosystem, by keeping local vegetation coverage exceeding 70%.

4.2.3 Similarities and Differences in Economy

The economy pillar of urban sustainability has been analysed in employment, research and development and environmental impacts, as shown in Table 3. The environmental impacts have mainly caused indirect effects on economic development.

Employment: Low-carbon eco-city does not only consider the resource and environmental impacts, but also keeps economy development as its core. Providing citizens with sufficient job opportunity is an important criterion.

Research and development: Developments of a society are driven by technological development. Low-carbon eco-city through upgrading proportion of scientists and engineers promotes knowledge and innovations. Green campus draws on students' advantages to conduct research for utilization of green technology, while green building is the main part to utilize advanced technologies.

Environmental impacts: Low-carbon eco-city pays attentions to low-carbon operation through controlling carbon emission per GDP unit. Meanwhile, it pursues

Table 3 Comparison of similarities and differences in economy criteria

Criterion	Similarities			Differences		
	Low-carbon eco-city	Green campus	Green building	Low-carbon eco-city	Green campus	Green building
Employment	Employment			Workers		
Research and development	Sustainable technology	Green technology	Performance improvement and innovation	Scientists and Engineers	Students	
Environmental impacts	Carbon auditing		Carbon analysis	Carbon emission per GDP unit		Carbon emission intensity
	Circular economy		Economic analysis	Economic development of adjacent areas		Energy efficiency and building performance

circular economy, contributing to spur economic development of surrounding areas. Carbon emission intensity is required to be reduced in building operation, where carbon analysis is compulsory. Energy efficiency and building performance should be analysed to improve economic operation of green buildings.

4.2.4 Similarities and Differences in Society

The requirements of society highlight many aspects, such as transport, housing quality, culture, and their possible social influences, as shown in Table 4.

Transport: Sustainable construction at city, community and building scales all considers significance of public transport, where cycling is especially encouraged by low-carbon eco-city and green building concepts. It is provided that proportion of green transport in low-carbon eco-city should exceed 90%. Green campus and green building, however, mainly draw on reasonably selecting location of entrance and parking, connecting public transport and the places where people study or live.

Housing quality: Low-carbon eco-city has firstly considered providing people with place of residence; therefore, affordable housing ratio has been set as an independent criterion. Meanwhile, housing and income balance has been included. Green campus and green building emphasize the quality people live by regulations of land-use area per capita.

Culture: The item that urban development cannot be the price of destroying historical and cultural heritage is common considered by low-carbon eco-city, green university and green building.

Table 4 Comparison of similarities and differences in society criterions

Criterion	Similarities			Differences		
	Low-carbon eco-city	Green campus	Green building	Low-carbon eco-city	Green campus	Green building
Transport	Public transport, cycling	Public transport	Public transport, cycling	Public participation	Campus and gate location	Gate and parking location
Housing quality		Land-use area per capita	Land-use area per capita			
				Affordable housing ratio Housing and income balance		
Culture	Historical and cultural heritage	Historical and cultural heritage	Historical and cultural heritage			
Social influence				Surrounding area environment	Surrounding community	

Social influence: As sustainable models, low-carbon eco-city and green campus both exert their potentials to influence other areas, where the former one emphasizes surrounding regions and the latter one focuses on surrounding community.

5 Co-development of Green Building, Green Campus and Low-Carbon Eco-City

In previous several years, the eight-pilot low-carbon eco-cities have achieved many experiences that current sustainable city construction can draw on. One of them is the development of green building. It is indicated that green building has received its attentions, especially Sino-Singapore Tianjin Eco-city (SSTEC). The proportion of green buildings has to reach 100%, and the requirements of renewable energy usage, waste disposal and recycling, water-saving and carbon emission are quite strict [6]. Due September 2016, 68 green buildings have achieved their green building label, which accounts for more than one-third of all green building projects in Tianjin. When it comes to the quality of green building, 64 out of 68 are labelled with two-star or three-star. This indicates green building is a part of low-carbon eco-city,

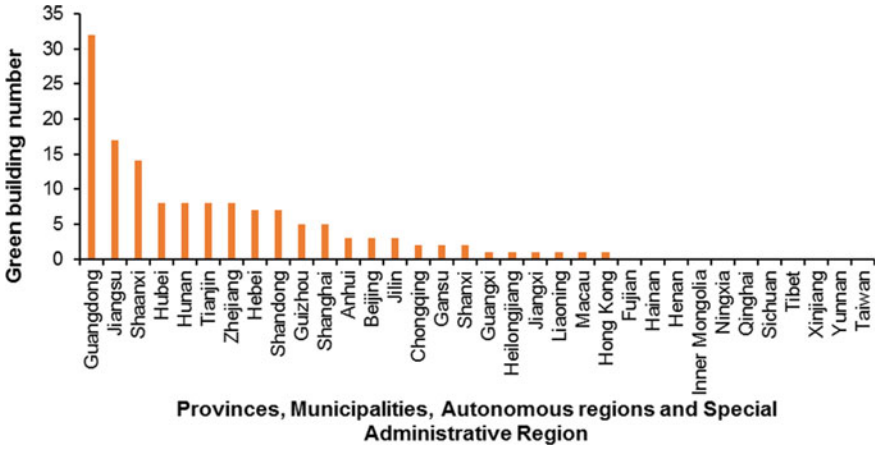

Fig. 6 Provincial distribution of 140 university green buildings in China (Due September 2016)

and construction of low-carbon eco-city is an opportunity that contributes to green building promotion. The benefits in resource, environment, economy and society of low-carbon eco-city and green building are sometimes consistent to promote urban sustainability.

Green buildings can be divided into several categories, such as residential, industrial, public and educated buildings. The green buildings that stand in universities have been studied and presented in Fig. 6. In total, more than 140 buildings have achieved their green building label around China, where universities in 22 provinces have built green buildings. However, compared with 4515 GBL-certified green buildings, university green buildings only account for 3%. Guangdong Province ranks at the first place with 32 green buildings, which accounts for 7.4% of its total green buildings. This high proportion mainly benefits from 15 buildings of Southern University of Science and Technology, which has been built with the concept of green and sustainable campus since 2011. Since many universities are currently retrofitting their old buildings and constructing new buildings, starting from creating green buildings will be an effective to achieve university sustainability.

6 Discussion and Conclusions

To promote sustainable development of present world, concepts such as low-carbon eco-city, green campus and green building have been introduced, corresponding to city, community and building contexts. Although many achievements have been obtained in the past decades, still urban sustainability requires significant efforts of all profession of our society. Based on co-aims and inner urban relationships of low-carbon eco-city, green campus and green building, this chapter settled the aim

of examining how these concepts can be combined as a holistic way to accelerate sustainable development. Through interpretation of sustainability at different scales, development of sustainable projects in China and integration of low-carbon eco-city, green campus and green building, the following conclusions can be drawn.

Initiatives of low-carbon eco-city, green campus and green building date back to the same period of 1970s. Although they have undergone many years' development, many problems can still be found in their implementation. For low-carbon eco-city, it is characterized with carbon-efficient economy, environmental protection, energy efficiency, economic growth and social aspects, while the scope it covers still requires further definition. Low-carbon eco-city is a sustainable place to live in, but economic and social issues make cases and scenarios much complex, because how to realize social equity, i.e. balances of employment and housing of migrating labours, balances of urban–rural relationships, and participations of general public which determines environmental and energy-saving quality, is still in a dilemma situation. Schools and universities are special communities, having potential to propagate sustainable concepts and implement sustainable behaviours by current students after several years. For green campus itself, benefits in environmental, economic, societal and health aspects can be achieved no matter in direct or indirect way. However, campaign of green campus is still questionable, since it is shown that only universities with famous architecture and urban planning disciplines are shock troopers. In addition, green campus assessment system and management of green campus activities are still obscured. Green building receives its best development among three sustainable concepts, because of people's great demands and mature assessment tools around the world. Its benefits in environmental, economic and social aspects have been well-evidenced. As a minimum physical unit of community and city, therefore, green buildings development could be an important driver to promote low-carbon eco-city and green campus, while still much work is needed to understand how they can be linked.

Because of increasing population and rapid urbanization after The Reform and Opening of China in 1978, it is critical to cope with issues of energy shortage and environmental degradation. Low-carbon eco-city, green campus and green building were then introduced into China in 1980s. With a series of political guidance and incentive policies from MOHURD, MOE, MOST and MOF, these projects have been significantly pushed on. After the project of *Demonstrating Green Ecological Urban Built-up Areas*, most cities in China have shown their intentions to construct low-carbon eco-city. Green campus underwent the bottom-up development, after which governments paid attentions to spur its development by a 72 conservation-oriented universities demonstration project. However, development of green university is restricted, for it only accounts for 2.47% of total colleges and universities in China. Green building is well-developed in all provinces, municipalities, autonomous regions and special administrative regions. Currently, assessment systems for low-carbon eco-city, green campus and green building have been established; many provincial green building assessment systems have been developed. National assessment system for low-carbon eco-city and green campus should be further developed to guide local construction.

This study has investigated connections of low-carbon eco-city, green campus and green building from three aspects, namely scales of urban sustainability, similarities and differences of their assessment criterions and co-development of three projects. It is indicated that current development of sustainable projects in China is stipulated by green building, where low-carbon eco-city and green campus are developed on basis of requirements of green building. However, once all concepts are mature, low-carbon eco-city should play its in guidance because of its wide scope of functions, while green campus and green building can perform their roles in partially promoting low-carbon eco-city development.

Assessment criterions of low-carbon eco-city, green campus and green building have been compared in four aspects: resources, environment, economy and society. Generally, low-carbon eco-city assessment criterions set up indicators at a master level, comprehensively considering four aspects, while assessment criterions of green campus and buildings are considered in technical way, mainly in resources and energy aspects. For category of resource, non-traditional water, public green land, land protection and renewable energy have been all considered in low-carbon eco-city, green campus and green building. A series of technical criterions have been provided in green campus and green building assessment systems. For the category of environment, water quality, pollutant control, solid waste recycling, water control, noise control and public service are required by all sustainable projects, while urban heat island and natural ventilation have been only defined by green campus and green building. For low-carbon eco-city, local vegetation coverage is the most characteristic, different from green campus and green building. For scenario of economy, sustainable technologies have been required by all projects, and carbon auditing and economic development have been required by both low-carbon eco-city and green building. Most importantly, low-carbon eco-city emphasizes providing more employment opportunities and scientists and engineers' attendance of research and development. On society scenario, green transport and culture preservation are stipulated by all projects, while low-carbon eco-city more focuses on a target of improving public participation in green transport and green campus and green building technically suggest locations of entrance and parking. Generally, the emphasis of common points in constructing sustainable projects should be a cost-effective way to realize whole urban sustainability.

Low-carbon eco-city, green campus and green building can experience their co-development when other projects are constructing. Since green building itself is characterized by energy efficiency, water-saving, land-saving, material-saving, its development can promote upgradation of low-carbon eco-city. Sino-Singapore Tianjin Eco-city has been a successful case for green building development, since it specifies 100% green building as one of the compulsory rules. Meanwhile, green campuses constructed are also attempting to reduce consumption of water, energy, land and material, and recent built projects account for a higher proportion of the university green buildings. Therefore, a stricter retrofitting or newly constructing requirement for buildings not only helps promote green building development, but also benefits to green campus construction. Since the MOHURD has launched Thirteenth five-year plan for energy efficiency and green building development, in which goals of

constructing green building, green campus and low-carbon eco-city have been set, respectively. Therefore, developing green building, green campus and low-carbon eco-city can help achieve goals much easier, considering the hardship in promoting our society towards sustainability.

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