The importance of green infrastructure in spatial arrangement of big cities: lessons learnt from Beijing, Shanghai and Shenzhen

Summary
The concept of *Green Infrastructure* is one of key tools allowing for sustainable development of urban areas, it being a strategic activity with goals defined for up to several decades. Among the most important assumptions that accompany designing the *GI* system is the formation of multi-functional spaces where the course of natural processes is preserved, while also serving social and economic functions. The key role is played by the sustainability of the system, whose operation is programmed with an eye towards future generations, not only current needs. The desirability of implementing the concept of *Green Infrastructure* is illustrated by numerous examples in the US and Europe. They include operations of varied scale, contributing to the improvement of man–nature relations. The article presents *GI* activities in Chinese cities: Beijing, Shanghai and Shenzhen. A critical analysis of the implementation of the *GI* concept in individual cities is also presented.
Key words: *Green Infrastructure*, China, sustainable urban development

Introduction
At a global level, the dynamic development of urban areas leads to a growing imbalance between natural ecosystems and invested areas. More and more often the natural elements are violently entering city areas, leaving many dead or injured, also causing huge material losses. One of the fastest growing regions of the world is currently China, where the process of urbanization has reached unprecedented proportions. Since 1978, when Special Economic Zones (Shantou, Shenzhen, Zhuai, Xiamen, Hainan) were first created, and despite legal restrictions on migration from rural to urban areas, urban population has increased from 170 to 670 million in 1978–2010 (Liauw 2008; Weiwen 2008; Chen, Jia, Lau 2008; Chen, Liu, Tao 2013).[1] The cities are now inhabited by 50% of China's population, simulations indicating that by 2025 the number of urban dwellers will have reached 1 billion, living in – among other – eight mega-cities with a population exceeding 10 million (Liu et al. 2014). The process of mass migration involves mainly the areas of the southern and eastern coasts of China, which are at the same time characterized by the largest number of natural, climate-meteorological disasters. Only in 2013 the area was hit by five typhoons, of which three (Haiyan, Utor and Usagi) were classified as the strongest Fifth Category. Heavy rain associated with a series of cyclones affected many urban areas, including Beijing, Shanghai, Hong Kong and Shenzhen, leading to huge financial losses. The value of the damage caused by only one Super Typhoon (Usagi) amounted to 3.8 billion US dollars. At the same time, the central and eastern parts of the country experienced a record-breaking summer heat and a resulting drought, which produced economic losses of up to 10 billion US dollars. (*Impact Forecasting. September...* 2013*; Impact Forecasting. Annual...* 2013; Zhang et al. 2015) The increasing air pollution is another climactic phenomenon occurring in Chinese agglomerations that is extremely dangerous to the health of the inhabitants of megacities. As shown in many studies, 16 out of

[1] Individual authors refer to different time periods in the reporting period. The values given are the summary of the data contained in the cited publications.

20 most polluted cities in the world are located in China (Liauw 2008; Liu 2014). Over a number of days each year, both the particulate (PM_{10}, $PM_{2,5}$) and ozone (O_3) levels substantially exceed norms (Streets D. et al. 2007). Other dangerous factors affecting Chinese cities, especially the northern, arid part of the country, include air pollution as a result of aeolian erosion. This phenomenon can be observed in about 9% of the country, affecting significantly the quality of the atmosphere in the cities, including Beijing (Guo 2014). The situation in terms of supply of urban drinking water from both surface reservoirs and groundwater is also critical. The systematic lowering of the water table due to over-exploitation, as well as pollution and silting of reservoirs, cause constraints in the supply of drinking water (Chang 1998). The cities located in the monsoon area of the eastern and southern coasts are also threatened by floods caused by both heavy rain and backflow of sea water (Yin et al. 2015). One of the tools that can be used to alleviate the growing social and climactic problems is the *Green Infrastructure*, understood as a network of natural, quasi-natural and man-made green areas, forming a coherent system whose resources are used for both the needs of local communities and the functioning of ecosystems.

Aim

The aim of the study is to assess the application of the concept of *Green Infrastructure* as an effective and economical tool for sustainable development in the context of the dynamic development of big cities as illustrated by selected agglomerations of mainland China, and applying their experience to European conditions.

Material and Methods

An analysis of literature on mainland Chinese megacities[2] has shown a noticeable lack of a precisely defined study area in the cited publications. Data are often given for the entire agglomeration area, and in other cases – only the very centre. Review papers, especially those published by Chinese authors, often disregard the territory of Hong Kong, which in 1997 formally became part of China, and are guided by the principle: one country, two systems. It is therefore impossible to make a direct comparison between individual values for mainland cities and island territories, such as Macau and Hong Kong. Noticeable are also contradictions in the data given by various authors, in particular on the dynamics of changes in the size of green areas (e.g. Zhao et al. 2013 vs. Liu, Holst, Yu 2014).

China is an interesting area of research due to the fact that while in the second half of the 20th century in most countries of the world the number of cities was stable, in China it grew significantly because of the official policy of boosting the pace of urbanization promoted by the central government. In 1982–1997 the number of cities increased from about 250 to more than 650 (Liu et al., 2014; Huang et al. 2015). China is currently the most populous country in the world, its population estimated at 1.4 billion people[3], its territory being proportionally

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[2] In the literature presented the term "megacities" refers to centres with a population of over 1 million inhabitants.

[3] http://www.worldometers.info/world-population/china-population/, accessed on 30th September 2015

small in relation to the number, resulting in a significant reduction in available space. For example, the area of arable land per capita is only a third of the world average, and the size of green areas per city dweller is only 10% of the number recommended by the United Nations, amounting to 6.83 m^2. Therefore, Chinese cities are formed in a compact way, spanning as little area as possible and with a high population density. The consequence of this approach is, *inter alia*, excessive loading of available green areas, as well as the need to incorporate them for construction (Chen, Jia Lau 2008).

It is worth noting that the issues of development and shaping of cities in China go beyond the scales considered in European and American theoretical studies, mainly due to large populations living in the agglomerations, but also the area covered (Chen, Jia, Lau 2008; Vogel et al. 2010; Chen, Liu, Tao 2014). In 1992–2008 the total area of cities in mainland China (excluding Hong Kong, among other) increased from 27,500 km^2 to approximately 73,000 km^2, reaching the average yearly growth rate of 2,679 km^2. A rapid growth of city areas was reported in 2000–2003. The main areas of dynamic urban development in China are the deltas of large rivers – the Pearl and the Yangtze, and the Beijing-Tianjin agglomeration (Huang et al. 2015). With the launch of the development program of Special Economic Zones (SEZ) in 1978, separate zones were created in almost every region of China. Initially, the program included 14 cities on the eastern and southern coasts of the country, and then the neighbouring cities, the so-called second tier. It was only after the year 2000 that the program included the cities in the interior of China, including the politically and socially unstable western part of the country. The guidelines were aimed at the development of economic and political aspects, excluding the issues of sustainable (Wei, Yu 2006; Weiwen 2008) and social development. Urban centres became communities of workers coming from rural areas who – lacking the status of "townspeople" – did not identify themselves with their new place of residence (Weiwen 2008). Central planning, together with the decentralization of economic centres, led to improper disposal of existing environmental and spatial resources. Different regions, competing to attract investments, began to create separate financial, industrial and service centres in an uncoordinated fashion, contending for available areas and financial, energy and human resources. One example of such activities is the area of the Pearl River Delta, where five independent large airports were situated in neighbouring cities, and cannot be fully utilized because of the limited air traffic organization. The pursuit of potential profits has also led to uncontrolled spatial development. Despite the under-utilization of existing projects (office buildings, business and industrial centres etc.), new investments are being implemented. These, though realized under different slogans of sustainable development, promoted by state authorities since the early 1990s (including the so-called Ecocities, Garden Cities, Low-Carbon Cities), are ordinary real estate projects. In recent years (i.e. after 2000) many adverse social changes have been observed, which resulted in the authorities directing their efforts towards a more sustainable social development, including communal housing, social services and transport (Jie 2008; Vogel et al., 2010; Liu et al . 2014). This also includes an improvement in the availability of green areas in urban areas as well as maintenance and development of new sites offering diverse ecosystem benefits (Chen 2015). It is noteworthy that in 1989–2009 the rate of average size of green areas in mainland Chinese cities increased from 17 to 37.3%[4], bearing in mind, though, that the cities with the highest percentage of these areas also had planned extensive gardens (Zhao et al. 2013).

Principles of *Green Infrastructure (GI)*

The concept of *Green Infrastructure* is used in a variety of scales, from small-scale local projects that cover the urban quarter, through medium-scale regional activities, to large-scale initiatives covering the entire continent (Benedict, McMahon 2006; *Towards...* 2010; Estreguil, Caudullo, Miguel 2013). In the scale of the city, *GI* is defined as a network of designed and non-designed green areas, constituting both public and private properties, and managed as an integrated system that brings a variety of benefits both for society and the environment. It includes remains of natural greenery, as well as arranged green areas and those created using various technologies, such as green roofs, reservoirs, green walls (Norton et al. 2015). These elements form a system which consists of core areas (large areas with maximum biodiversity), and a network of ecological corridors that link them, built along water courses and other types of linear greenery and surface waters. An integral component of the *GI* structure are also the so-called "spots", or isolated patches of greenery and open water, indirectly connected to the system by means of ecological corridors, but located at a distance that allows a free migration of animals and plants (Benedict, McMahon 2006).

Creating *Green Infrastructure* systems is based on a number of principles, which together enable a sustainable use of natural resources while maintaining mutual benefits for both the environment and local communities. Out of the decalogue of principles guiding the planning of *Green Infrastructure* projects (Benedict, McMahon 2006; Kowalski 2011), those currently in the foreground are aspects of using ecosystem benefits (services) for multifunctional land use, taking into account the aesthetic qualities of the area.

Benefits of implementing the *Green Infrastructure* concept

In all its forms, *Green Infrastructure (GI)* is essential for the formation of the climate of the city. Both in cities located in hot and moderate climates it helps to reduce the effect of the urban heat island, thanks to all kinds of technical solutions, such as green roofs, permeable pavements, or tree planting. For example, increasing urban green areas by 10% contributes to a decrease in the maximum temperature by 1° C (Kowalski 2014; Emmanuel, Loconsole 2015; Norton et al. 2015).[5] *GI* systems play a significant role in the retention and purification of rainwater (Pellegrino, Ahern, Becker 2015; Zhang et al. 2015; Zhao et al. 2015). Green areas contribute to the reduction of particulate and gaseous pollutants, the efficiency of the purifying performance , however, is closely associated with age (size) and the condition of the stand as well as the length of the vegetation period (Yang et al., 2005; Chen 2015). The

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[4] More specifically, the proportion of green areas in cities was in the range of 2.8% to 69.9%. The area of green areas in 59.7% of Chinese cities exceeded 37.3%, as of 2009 (Zhao et al. 2013).

[5] Also numerous reports presenting results of applying the *Green Infrastructure* strategy show a wide range of environmental, economic and social benefits of a project that is properly prepared and carried out, e.g. *Banking on Green: A Look AT How Green Infrastructure Can Save Municipalities Money and Provide Economic Benefits Community-wide. A Joint Report by American Rivers, the Water Environment Federation, the American Society of Landscape Architects and ECONorthwest*, 2012; *Kansas City*

functioning of the *Green Infrastructure* also brings visible economic benefits in the form of restricting expenditures necessarily associated with the construction and maintenance of systems of sewage and rainwater purification, as well as with an increase in property values. A positive correlation between the size of green areas and GDP is also pointed out (Benedict, McMahon 2006). Greenery also reportedly improves health and well-being of inhabitants. To achieve good results it is necessary to ensure a minimum ratio of biologically active compounds, which consists of arranged and non-arranged green areas and surface waters. Research shows (Szulczewska et al. 2014) that the minimum rate of biologically active surface should constitute 41–48% of the city, which would allow a thermal comfort of inhabitants and a proper course of hydrological processes. Systems of urban green areas are also an important factor affecting the spatial shape of cities of different sizes (Zachariasz 2006; Kowalski 2014).

Perception and application of the concept of *Green Infrastructure* in China

Green Infrastructure does not currently constitute an institutionalized form of action in China. What is more, bottom-up initiatives to build and maintain the system of *GI* are deprived of state financial support, and structural activities that would allow a simultaneous development of “gray” and “green” infrastructure are not integrated (Chen 2015). One of the factors that could support the development of *Green Infrastructure* is the legal status of land in the cities. According to Chinese law, the land is owned collectively, but so far only in a few cases were the state planning activities aimed at the development of cities in a sustainable manner, ensuring the availability of housing for families with average incomes, while preserving natural resources (Chang 1998; Shiwen 2008).

The application of the *GI* concept to improve the quality of life of Chinese city-dwellers is met with social understanding and acceptance. In some cities (e.g. Hangzhou) *GI* is applied in neglected areas, located under flyovers and along roads. The concept of *Green Infrastructure*, however, is mostly identified with the planting of trees. Greenery in cities is treated in a mono-functional way and is often used as a decorative element, a “pleasure garden”, although the location of green areas is unfavourable taking into account active recreation. An active policy of increasing the size of green areas and improving their availability in the cities (Zhao et al. 2013; Chen, 2015; Byrne, Lo, Jyanjun 2015) is implemented. Currently an increasing importance is given to the role of green areas as a significant factor influencing the climate of the city and water relations. Also important is the role of *GI* systems in the absorption of CO_2 generated in cities. To improve the efficiency of this process, it is proposed that species retaining the most CO_2, adapted to individual climate zones of China, be used. In order to obtain results associated with increased CO_2 levels as quickly as possible, mature trees are generally planted in Chinese cities[6], though most of the trees in cities such as Beijing, Shanghai, and Hangzhou are classified as young, under the age of 25 (Chen 2015). The importance of urban green areas in reducing the size of surface outflow was examined for the Beijing’s 5th Ring Road. The analyses have shown that a reduction in the size of green areas in 2000–2010

[6] In contrast to European and US practices, mature trees are not derived from plant nurseries, but directly from natural habitats. Since the plants are not prepared for replantation, a high percentage of them are rejected and replaced with trees taken from the woods.

reduced the potential of natural retention by 6 percentage points. It was replaced by the development of a stormwater drainage system. This happened despite the available results of research conducted in the Beijing area since the mid-1990s, which proved the effectiveness of green cover in reducing surface runoff and improving the quality of rainwater (Zhang et al. 2015). Similar studies were performed in Shanghai (Zhao et al. 2015).

Method

Research prior to the preparation of this publication was conducted in two ways: (1) a critical evaluation of the literature was completed, focusing on the assessment of urban greenery and the use of existing resources in shaping the system of *Green Infrastructure* in selected cities in China. The literature review included, *inter alia*, a conversion and standardization of space units mentioned in bibliographic references. (2) field studies were performed, which included a verification of the condition of green areas as well as prospects for the sustainability of historical and contemporary green areas. The work covered cities with different cultural and economic dynamics of development in the scale of the country. The choice of research areas was made taking into account the following aspects: (1) the way of forming the city structure up until the 19th century. (2) the development of the city throughout the 19th, 20th and 21st centuries, including the impact of various cultural influences (both domestic and foreign), and the diversification of economic and social functions of the city during that period. An important selection criterion was also whether the city held any important cultural events of international nature, which often become a stimulus for changes in the spatial structure of the city. As a result of a critical analysis of the literature, three big cities were identified, differing significantly in their origins as well as their socio-economic role today and in the past:

1. Beijing – the current capital of China, an important cultural and economic centre, from the 13th century onwards performing essential administrative functions. Up until the mid-19th century it had been insulated from the influence of Western culture, which allowed the preservation of the historical urban layout and greenery of the central part of the city. Until Mao’s Cultural Revolution it had remained a city of politics and culture, after 1949 gaining the status of an industrial city. Despite significant transformations of its greater part, the historically formed green areas accompanying the extensive complex of the Imperial Palace (Forbidden City) (Chang 1998) retained their significance in the spatial structure of central districts. The great event of international importance which marked the beginning of the next phase of city transformation was the Summer Olympic Games in 2008.

2. Shanghai – a port city situated at the mouth of the Yangtze River where it meets the East China Sea, of key economic importance, both historical and contemporary (Walcott, Pannell 2006). The structure of the city was formed as late as the 19th century. Extensive trade relations and opening to Western cultural influences are visible in the spatial arrangement of some districts (Bund). In 1979 it was granted the Special Economic Zone status, the aim of which is to boost economic exchanges with the world. The city is characterized by a very low rate of green areas per capita, even compared to other urban Chinese agglomerations (Gao et al., 2004). In 2010 the city was home to the World Exhibition EXPO, an event of major international importance.

3. Shenzhen – a city with a unique character, established from scratch in 1979 in what was before a fishing village. It was established as a Special Economic Zone, near the border with Hong Kong. Initially, the main focus of its development was placed on the creation of areas attractive for foreign investors. Only after more than 20 years of construction, assumptions were made to find a new, environmentally friendly balance of development. In the system of urban greenery an important role is played by remnants of a tropical forest, scattered on the hills surrounding the central part of the city.

Case study. Analysis of selected cities with regard to the functioning of *Green Infrastructure*

BEIJING

The city has been the capital of China since the 13th century[7]. The central part spans the Imperial Palace – the Forbidden City – whose layout remained nearly unchanged from the 14th to late 19th century. In its structure, in addition to nearly 9,000 buildings, a significant role was played by the vast gardens, connected both with the palace complex, as well as satellite Temples: of the Earth (in the north), the Sun (in the east), the Moon (in the west) and the Heaven (in the south). The transformation of the Forbidden City began in the 1950s, when it became part of the Beijing reconstruction program, and included partial demolition of the walls and buildings of the palace (Chang 1998; Wei, Yu 2006). With the change in development strategy – from a political and cultural centre to an industrial city – a significant inflow of people was recorded, and consequently a sharp increase in city size. Heavy industry, petrochemical, electronics, textile and food companies set up their main offices here. As a result, Beijing became the second biggest industrial city of China after Shanghai. In 1953–2000, the population of metropolitan Beijing quadrupled, increasing from about 3 to almost 14 million inhabitants (Jinshuang, Quanru 2003; Yang et. al. 2005). Currently (as of 2010) the area is inhabited by 17 million people. The built-up area increased from 109 km^2 in 1949 to 1,350 km^2 in 2009 (Zhang et al. 2015). Today the agglomeration of Beijing consists of 16 districts, covering the area of 16,808 km^2, which extend over a distance of 180 km in the north-south axis, and 160 km from east to west. The inner metropolitan area, comprising 8 districts, covers an area of 1,385 km^2, and has a population of 8.5 million inhabitants (Jinshuang, Quanru 2003; Yang et al. 2005). The population density is 95.4 people per hectare (2002) (Chen, Jia, Lau 2008).

[7] Almost continuously. Periodically, Nanjing was the state capital.

Photo 1. Beijing. The green areas of the Olympic Park play mainly a decorative function. Photo taken by the author, August 2014.

Photo 2. Beijing. Greenery in built-up areas is a valued element of interior street composition. Hutong district. Photo taken by the author, August 2014.

Green areas in Beijing cover 626.72 km^2 (Chen 2015); however, a systematic reduction of this value can be noticed. Data show that in 1992–2004 it decreased by 1,857 km^2, including both crop areas, pasture areas and surface waters (Liu, Holst, Yu, 2014),[8] and in 2010 it constituted 14,68% of the city. At the same time, there has been a recorded increase in the park area of inner districts, which in 2000–2010 exceeded 6% per year. As a result of all the transformations, green area in the central area of Beijing decreased from 1,041 km^2 to 842 km^2. There has also been a growing isolation and fragmentation of green areas, which is not conducive to maintaining a system of *Green Infrastructure* (Zhang et al. 2015). Changes in the structure and size of green areas in Beijing are presented in Table 1. Currently the ratio of green areas per capita in Beijing is 88 m^2 (*Asian Green...* 2011).[9] The effect of limiting the *Green Infrastructure* in Beijing is – among other things – reducing rainwater retention, which together with the intensive exploitation of groundwater with more than 40,000 wells, contributed to lowering the groundwater level by 45 m over 40 years, from the 1950s to 1990s. While considering the concept of *Green Infrastructure* it is interesting to point out that in the mid-90s, 62% of water in the area of urban Beijing was consumed by the agricultural sector. The greatest demand for water is associated with the cultivation of rice in the dry climate of Beijing – crops area in 1990 covered more than 32,000 hectares (Chang 1998).

Year	**Type of land cover** **Area covered [km^2]**						
	Forest	Grassland	Crops	Wasteland	Water	Σ Green	Impermeabl

[8] A direct comparison of these data is impossible. The authors probably refer to the central metropolitan area (Chen 2015) and to the entire agglomeration (Liu, Holst, Yu 2014).

[9] The specified value should be interpreted as relating to the size of the whole metropolitan area, not just inner-city districts.

						Infrastruct ure	e surfaces
2000-2005	135,20	91,96	-295,09	2,13	-11,56	-65,80	77,37
2005-2010	-73,40	31,29	-76,34	-14,23	-3,88	-77,28	141,83
2000-2010	61,81	123,25	-371,44	-12,10	-20,71	-198,49	219,19

Table 1 Changes in land cover in 2000–2010 (by Zhang et al. 2015); author´s compilation

Beijing belongs to those Chinese cities where historical gardens associated with the Empire play an important role in the system of urban green infrastructure. Thanks to there being a lot of old trees in urban parks, green areas now store a total of 1.2 million tonnes of CO_2, every year adding to the count another 130 thousand tonnes (Chen 2015). In addition, trees growing in the central park area also accumulate particulate (PM_{10}) and gaseous matter (O_3, SO_2) (Yang et al. 2005). The structure of the stand is dominated by species grown in temperate climates, such as *Platanus* sp., *Populus* spp., *Sophora japonica, Ginkgo biloba, Robinia* spp., *Juniperus* spp., *Ulmus pumila, Acer truncatum, Ailanthus altissima, Fraxinus* spp., *Pinus* spp (Ma, Liu 2003). The phytosanitary condition of Beijing dendroflora is varied. Research by Yang et al. (2005) and the author’s observations (2014) show that most of the trees are in n average, good and very good phytosanitary condition but the condition of almost 30% of them is considered to be bad.

The distribution of *Green Infrastructure* in the central area of Beijing is heterogeneous. It consists of areas of historical parks, creating isolated islands of compact development. The system of connections in the form of ecological corridors is poorly developed and confined mainly to the greenery accompanying sequences of communication. It plays a mostly decorative function, with many streets having a compact group of planned vegetation. It requires systematic care as well as irrigation, which further contributes to the deterioration of the water balance of the city and increases CO_2 emissions. *Green Infrastructure* elements associated with building areas are a highly valued part of the landscape also at the smallest scale, helping to improve the aesthetics of the interior of building blocks and narrow streets. The system of rivers and canals connecting numerous urban waters has not been incorporated into the system of *GI*. In their vicinity, no buffer zones with green areas have been developed that would separate building areas from the water.

Major infrastructure projects are currently underway to improve air condition, reduce the effect of urban heat island, as well as to increase water retention and to ensure adequate supplies of drinking water in the city. These take the form of planting desert areas surrounding the north-western part of the city with herbaceous vegetation and shrubs, and retaining surface waters outside the city limits. As part of the 2008 Olympics, an extensive program of reconstruction was implemented in the central districts of Beijing, which included the creation of new green areas surrounding Olympic buildings. These are mostly governed by aesthetic function, their design and maintenance not being a priority as far as issues related to the use of potential eco-system benefits are concerned.

SHANGHAI

It is one of four autonomous cities, forming an independent administrative unit. In 2009 the population of Shanghai reached 19.21 million of permanent residents, making it the most populous city in China. Population density (2002): 178.88 people per hectare (Chen, Jia, Lau 2008). The Shanghai metropolitan area covers 6,340 km^2, the maximum span on the N-S axis being 120 km, and the E-W axis – 100 km. 570 km^2 of the area are covered by surface waters (Zhang et al. 2004; Zhao et al. 2015) which constitute excellent potential for the development of *Green Infrastructure*. Urban area covers about 800 km^2 (as of 2000, as cited in: Zhang et al. 2004) while green areas in the metropolitan area cover 1,201.48 km^2 (2010). More than 2 million tonnes of CO_2 are stored in this area, and the storage capacity is estimated at 140 thousand tonnes of CO_2 per year. This high value is due to a significant share of mature stand in urban green areas (Chen 2015). In the urban area, the ratio of green areas is 2.4 m^2/ capita. Here, green areas cover only 5% (Gao et al. 2004) to 10% (Zhao et al. 2015) of the total area of the city. To increase this ratio, about 27,000 hectares of forest are planned to be planted in the next few years (Zhao et al. 2015). Among the species that make up the core of the stand in the city are: *Cinnamomum japonicum, Machilus thunbergii, Castanopsis sclerophylla, Schima superba* and *Cyclobalanopsis glauca.* The herbaceous vegetation of the wetlands is shaped mainly by *Phragmites australis, Scirpus mariqueter* and *Spartina alterniflora*. These are species typical of the subtropical climate zone (Zhang et al. 2004).

Photo 3. Shanghai. Green areas arranged at traffic routes. Photo taken by the author, August 2014.

Photo 4. Shanghai. Houtan Park – EXPO 2010. Photo taken by the author, August 2014.

The city is located in the delta of the Yangtze River. The average height of the area is only 4 metres above sea level. This unusual location, coupled with the ongoing subsidence of the land, causes a high risk of flooding. Threat is posed both by tidal waves, storms caused by monsoon winds, as well as fluctuations in the level of the rivers flowing through the city (the Yangtze and Huangpu). In order to protect the city against floods, starting with the 1960s embankments have been constructed and their height gradually increased after successive floods in 1962, 1974, 1981, 1997, and are now said to protect the very centre of the city from the 100-year flood (Yin et al. 2015).

The population of Shanghai is steadily increasing, and therefore significant changes have been observed in land use in the city centre. As a result of rebuilding the city centre, inhabited areas are transformed into commercial zones, which results in a displacement of residents to the suburbs, where, in turn, agricultural land is transformed into urban areas. Consequently there is a continuous perforation of green areas, especially in the suburbs (Walcott, Pannell 2006; Vogel et al. 2010). In order to limit the negative effects of the reduction of green areas, in 1994 it was proposed that a green ring (Greenbelt-u) be created around the outer ring road of the city, which may become an important component of urban *GI* in Shanghai. The planned length of the foundation is 97 km, and its size – 72 km^2. According to the plan, the ring will include woodland, cultivated areas and recreational parks. Until 2005, only 58% of the project had been completed. The greater part of land transformation entails planting areas not yet wooded and the densification of the existing forest. Almost half of the green belt is in the district of Pudong, and is now protected against urban occupation (Wang et al. 2014). This district was established on agricultural land (Walcott, Pannell 2006), in a manner contrary to the principles of forming *Green Infrastructure*. Numerous investments were made on floodplains, reducing the comprehensive benefits of the ecosystem derived from open areas of crops. Another important element contributing to the potential development of the city in accordance with the *GI* is Zhujiajiao – a Shanghai district considered to be a garden city. Located on water in 2008, it received a silver medal in the Liveable Communities competition, in B category (city inhabited by 20–75 thousand inhabitants). The proportions of spatial elements of Zhujiajiao are very similar to the theoretical solutions proposed by E. Howard for the garden city (Yuan et al. 2014).

In connection with the World Exhibition EXPO 2010, an ambitious project to revitalize former shipyard sites located on the banks of the Huangpu River was realized, developed by the Turenscape studio. It perfectly matches the guidelines *Green Infrastructure*. The area of the future 14-hectare park, located in the western part of the district of Pudong, was degraded: a significant pollution of soil and river contamination were demonstrated, which is considered dangerous for swimming and unfit for any other forms of recreation. The implementation of the project, whose value is estimated at 4.2 million, has brought multilateral benefits to economy, environment and society, as well as the landscape. Particularly noteworthy is the innovative use of large-scale natural ability to filter exhibited by wetlands. Cascade-shaped terraces planted with meticulously selected vegetation allow for clearing 2,400 m^3 of Huangpu River water, raising it from the 5th Category (lowest) to 3rd Category[10]. Around the park, however, a system of corridors that would connect with other green areas was not developed; in effect, it constitutes an isolated island surrounded by green areas gradually transformed into construction areas.

In the urban area of Shanghai, *GI* elements are arranged in a non-uniform manner. Central districts, formed from the 19th century onwards, have scattered groups of dense greenery, including historical gardens. As in the case of Beijing, so here, they are not connected using terrestrial or aquatic ecological corridors, thus constituting isolated islands in the city matrix. This issue is dealt differently in the new district of Pudong, where already at the stage of investment preparation care was taken to preserve part of the open areas. As a result, the *GI* system is clear, and contains both water and land. However, what goes against the idea of *GI* is the creation of investments in areas valuable for its nature, thus exposing them to the destructive influence of environmental factors.

[10] http://www.turenscape.com/english/projects/project.php?id=443, accessed on 5th September 2015

SHENZHEN

The city was founded in 1979, and in 1980 it was granted the Special Economic Zone status. The population of the city was initially 314,100 inhabitants (Shi, Yu 2014). Since it was founded, its structure has been shaped in several stages, with different development centres located within the Special Economic Zone (SEZ), as well as a different pace of development and nature of the ongoing construction. The first early stage of urbanization (1979–1985) included areas of what today is the centre of Shenzhen. The second stage – of accelerated urbanization – covered the years 1986–1995, followed by a period of stabilization of urban planning processes, which continues to this day, and subsumes the phase of adjustment (1996–2000) and optimization (2001 onwards). The following stages of city development initially included incorporation of flat terrains located on the Gulf of Shenzhen, gradually extending to the surrounding hills within the SEZ, later also the areas located outside the Zone, in what today are the districts of Bao'an and Longgang (Quing et al. 2013). Since 2005, the city government implemented a program of action for sustainable development, based on the Eco-City strategy. Since 2010 it has been transformed into a formula of shaping China's first Low-carbon Demonstration Eco-City. In this project, special attention is paid to the organization of transport, development of urban green areas, management of water resources and waste (Liu et al. 2014).

The total area of land covered by the agglomeration is now over 1,990 km^2, inhabited by 10.37 million people (as of 2010) (Shi, Yu 2014). This number does not include the area of offshore islands (Quing et al. 2013). Population density (2002): 72.19 people per hectare (Chen, Jia, Lau 2008). The city's green areas consist of more than 800 parks, some created in residual forest areas. Hence the presence of significant amounts of mature trees, which together with other types of greenery have accumulated 1.19 million tonnes of CO_2, and retain a further 290,000 tonnes of CO_2 per year (Chen 2015). The subtropical climate of the city is dominated by evergreen species, mainly classified as *Ficus*. They are characterized by the highest capacity to absorb CO_2, which exceeds 10 t/ha/year (Chen 2015).

By 2030, Shenzhen will have become part of the megacity surrounding the edges of the Pearl River Delta. The 11 cities constituting the conurbation (including Macau and Hong Kong) will be inhabited by a total of 80 million people. It is planned that each section of this organism will be available during an hour's travel using fats urban rail. The merging of 9 mainland cities and 2 subordinate territories (Macau and Hong Kong) will become reality thanks to large infrastructure projects, which include transport, electricity and water supply, and telecommunications. However, they do not include environmental issues (Cooper 2014).

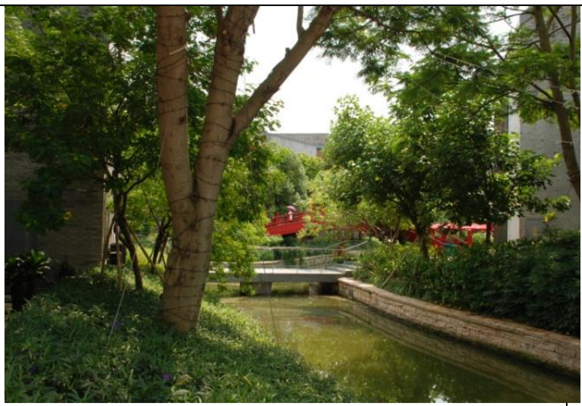

Photo 5. Shenzhen. OCT Park. Man-made greenery over an artificial canal. Photo taken by the author, August 2014.	Photo 6. Shenzhen. OCT Park. City section, view from the Meridian View Centre. Compact construction reduces space for green areas. Photo taken by the author, August 2014.

With the development of the spatial structure of the city, also the character and distribution of green areas were subject to changes. Initially, the area around the new city was agricultural. With the development of buildings and the disappearance of the traditional way of life, part of the arable land was abandoned, consequently becoming a wooded, to later give way to construction and man-made greenery. A steady decline of the size of green areas is observed; however, in relation to the total area of the city, they covered more than 61% (2005). Changes in the spatial proportion of different types of greenery throughout the development of the city are shown in Table 2. The centre the city is dominated by man-made vegetation: arranged squares and parks, also street-adjacent greenery, all characterized by a low rate of naturalness and biodiversity. Natural greenery is almost non-existent, which is confirmed by studies of Quing et al. (2013). The research team equates *Green Infrastructure* with different types of green areas: natural, semi-natural (in this case, crop areas are considered to be semi-natural green areas), and artificial. In addition to the qualitative change observed since the mid-1980s, Shenzhen green areas are also subject to quantitative transformations, by process of disappearance, filling, segmentation, fragmentation and perforation (Quing et al. 2013). The uncontrolled growth of the city has led to the destruction of many natural resources, including limiting natural biodiversity to a few isolated enclaves.

Year	Total area [km^2]	Natural greenery [km^2]	Semi-natural greenery [km^2]	Man-made greenery [km^2]
1985	1,858.08	872.47	982.24	3.37
1990	1,796.05	1,026.99	752.47	16.60
1995	1,464.39	1,044.41	354.07	65.91
2000	1,412.45	985.04	432.29	95.13
2005	1,190.26	600.96	487.20	102.10

Table 2 The changing proportions of different types of green areas in Shenzhen in 1985–2005 (as cited in Quing et al. 2013; author's compilation).

As Shi and Yu's research shows (2014), the areas of the highest natural value, which can act as nodes in the system of Shenzhen'z *Green Infrastructure*, cover an area of 974.5 km^2. They can be connected with more than 615 km of channels that can become the basis for the creation of 10 main ecological corridors.

It should be especially noted that the opportunity was missed to create a balanced city from scratch, in which natural processes and the development of urban structure would be given equal weight. As indicated by author's own observations and research (Quing et al. 2013; Shi, Yu 2014), green areas are treated primarily as a decorative element for the newly implemented investments, not considering their importance for improving the quality of life of residents and the environment, nor its ecosystem benefits. Due to the deteriorating condition of the environment and decreased comfort of living, city authorities are currently working on the implementation of the *GI* concept. A system solution, which aims to strengthen ecosystem benefits while balancing social, economic and ecological aspects, has been welcomed by local authorities and a decision was made to apply it (Shi, Yu 2014).

CONCLUSION

Presented Chinese cities are characterized by dynamics of population growth and expansion of built-up areas that are unparalleled in Europe. However, certain generalizations can be drawn, and they can be used to support the sustainable development of European cities based on the concept of *Green Infrastructure*. Having analyzed the literature, it can be seen that the issue of maintaining and developing the *GI* system in the analyzed cities of mainland China has been neglected. Only after 2010 did this issue gain wider interest. However, what is lacking is a review of the system that would focus on individual cities, instead of giving a general view. Among analyzed agglomerations, only Shenzhen had a developed concept of the *Green Infrastructure* system, which includes its multi-layered structure and a wider range of functions. In Shanghai a wider systemic action can be observed in one district – Pudong – in which a large part of the green tier of the city is located. In Beijing, despite the availability of basic research results regarding the potential development of the *GI* system, no targeted actions are carried out by the authorities.

There has been a qualitative change in the proportions of green areas within the cities analyzed. Natural and semi-natural areas are disappearing, giving way to artificial, man-made systems. Also noticeable is the tendency to reduce the total area of green spaces, as well as their progressive fragmentation and isolation. The development of these cities since the late 1970s is in fact a negation of subsequent urban theories associated with the formation of sustainable centres of residence. This has led to a state of a significant ecological and urban imbalance, which is manifested, among other things, by the susceptibility of the cities analyzed to the influence of environmental factors, and the deterioration of living standards. Measures aimed at limiting the impact of climate change and improving the standard of living through the implementation and development of *Green Infrastructure* are taken too late, which limits their effectiveness and is associated with incurring substantial financial costs.

Conducted field observations have shown a lack of consistency in the development of *Green Infrastructure* elements. While green areas accompanying historical gardens and urban layouts are preserved in good condition, the newly formed parks, gardens and spatial systems are often treated as temporary greenery, which gives way to the emerging construction – contrary to the principle of sustainability, one of the fundamental determinants shaping the *GI* system.

The study indicates that the implementation of the *Green Infrastructure* concept in accordance with its basic assumptions, above all, strategic planning, can bring significant social, environmental and economic benefits. Neglecting only one of the principles of the *GI* philosophy leads to the deterioration of human-nature relations. Repairing the damage is expensive and often impossible.

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