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Conceptual Framework for Environmental City Planning Tool with an Intelligent System based on BIM and GIS Technology

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ABSTRACT

Recently, the rising of the maximum temperature in summertime and air pollution in the winter time have been common issues in the cities of China, especially the large cities. The heat island phenomenon, triggered by urbanization based on the global warming, are caused by different factors. The high density of building development which change the urban typology, leading to the change of traffic volume, vegetation coverage and the urban micro-climate are considered as the important factors. Most of the existing studies to mitigate heat island phenomenon usually weight on introduction of low surface temperature material, reduction of the heat exhaust or vegetation from building-scale viewpoint, or strategies as instruction of large parks, shifting to public transportation systems from district-scale viewpoint.

However, the community-scale environmental friendly planning method are merely to be discussed, such as making effective network of cool spots and the wind path in the community. It is an optimal approach, with synergies among various elements and solutions interactively consider existing community structures, energy systems for different building types, traffic strategies, greenery renovation possibility and city typologies.

In this paper, we propose a system for environmental urban planning tool with Geographic information system (GIS) and Information and Communication Technology (ICT). We firstly introduce the concept and architecture of the tool. The applicability of the resulting model is then examined by applying it to the city of Xi'an, China. Finally, thermal environmental simulation are adopted to figure out the opportunities and challenges for environmental urban development in these target area.

Introduction

Recently, the rising of the maximum temperature in summertime and air pollution in the winter time have been common issues in the cities of China, especially the large cities like Xi'an. From the view of non-industrial field, these environmental problems are mainly resulted from the increasing population, energy consumption and automobile utilization during the rapid urban development. As a solution for both considering the urban environment and construction cost, the researches and the design initiation for environment-friendly planning and its related methodologies that can manage different issues like buildings, greenery and transportation should be comprehensively proceeded from the early stage of construction projects.

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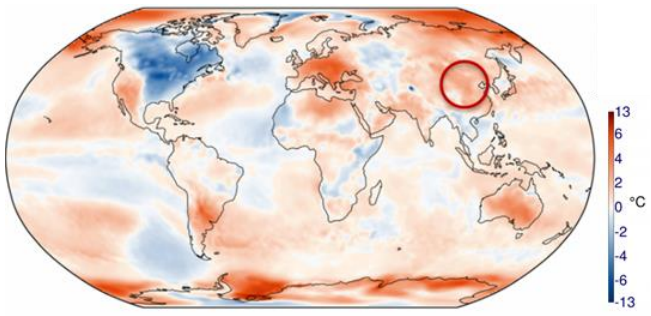
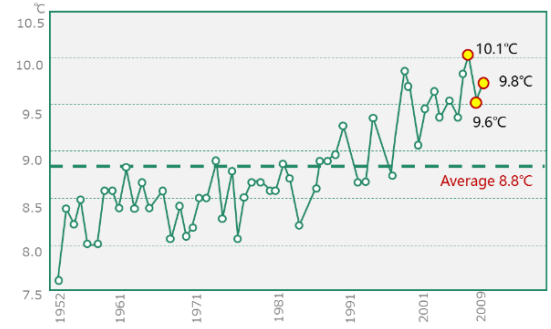
Environmental issues with urbanization

The rapid urban development in the mega cities with urban population growth and land expansion significantly change the urban energy balance, increase energy consumption thereby causes the higher temperature compared to the surrounding area, which is known as a phenomenon of urban heat island effect (UHIE). In recent years, UHIE is widely observed in the worlds developed countries and also effect the inland in China (Figure1a). During the past 100 years, the global average air temperature increased around 0.68℃) while china increased around 2.0 ℃ (Figure1b), especially, during the recent 50 years as the nation level.



(a) Surface air tempreature anomaly for April 2018 relative to 1981 – 2010 (Source:World Meteological Organization HP)



(b)Average temperature increase from 1952 to 2009 in China (Annual report of Japan Meteorological Agency,2011)

Figure1 Global Warming and Urban Climate Change

Opportunities and challenges for environmental planning

Given these environmental issues, especially the UHIE and air pollution, sustainable urban development becomes an important task. Most of existing research for the heat island mitigation has weighed on building oriented issues and evaluate the effect of energy conservation, low surface temperature material and façade design (J,Fox et.al,2018). In addition, from the large-city scale viewpoint, the research about the effect of increasing the uniform greenery rate in whole cities, shifting to the public transportation system, reducing fossil fuel vehicles have been enough referred (X.Li et.al,2019). However, especially for in the central part of the cities, the urbanization patterns has a large impact on urban climate change (T. Hung, et.al, 2006). The spatial variability of urban pattern especially in community scale, includes urban block form, vegetation coverage and building density. Instead of single solution in/around buildings, environmental friendly city planning should be an optimal approach, with considering status of existing community structures and synergies among various elements and solutions that can develop the effective network of the cool spots and window path in community scale with considering both existing community structures and advanced low energy methodologies.

However, there are two main challenges for the offer the comprehensive solution on urban heat island mitigation methods. The first one is observational methodology. There are various methods for observe, analysis and understanding of the urban heat island, as the analysis of Landsat data, simulation and survey. The measurement data and the simulation in the limited scale are difficult to estimate and understand overall thermal condition in an urban area, while the Landsat data analysis is hard to figure out the effect of the factors in the community. The observational methodology that can figure out from the building scale to city scale are limited.

The other challenge is the lack of platform to unify and analyses the existing data from different standpoint of urban sector, such as transportation, city infrastructure and urban information as a base for comprehensive discussion.

As one of the important part of the comprehensive solution, we propose a smart city planning tool in the previous research (Yamamura, 2016), and developed the sub tool for district energy system planning in consideration of current energy consumption, built year, district energy plant and renewable energy introduction. This research, we focus on the urban climate change in the community scale and develop an urban environmental friendly planning tool based on the system we proposed.

Historical development and issues in Xi'an

Xi'an is one of the most representative historical and cultural cities as well as one of the most developed cities in China. It is suggested that until the year 2016, the urbanization rate (percentage of the total population living in urban areas) in Xi'an is around 73%, ranked as top three in China (Shanxi Provincial Bureau of Statistics,2016). It is one of the cities that with highest urbanization speed.

The city is developed during the different time in the different period that it has the different styles and residential building types. As a historical city, it have the characteristic common pattern that have preserved low rise high density buildings in the center of the city and high rise building in the suburban area. Furthermore, the additional large amount of greenery is difficult to be introduced in the historical areas. Therefore, compared with other cities, the environmental plan for Xi'an should pay more attention on the integration of urban typology, available green space and transportation that can creates detailed networks of the cool spots and small/mid -size wind path comprehensively in the community scale.

From the climate aspect, Xi'an is an inland city with averaged low wind speed that is not enough to diffuse the stagnated high temperature air, which is a more sever model for heat island mitigation case study.

To overcome these problems, and studies the special issues of Xi'an. In this paper, we propose a system for environmental urban planning tool based on Geographic information system (GIS), Information and Communication Technology (ICT) and Building Information Modeling (BIM). In the research reported herein, the data of building and community which supported by BIM are unified by a three-dimensional (3D) city model in a GIS which combine the urban information as urban infrastructure and structure. Further, the information of traffic, people flow, environment and energy consumption collected with sensors from various aspect are described in a geometric manner with detailed information.

We firstly introduce the concept and architecture of the tool. The applicability of the resulting model is then examined by applying it to the city of Xian, China. Based on the existing information analysis, one residential blocks with the green space are selected as case studies. Finally, environmental simulation are adopted to figure out the opportunities and challenges for environmental urban development pattern in the target area.

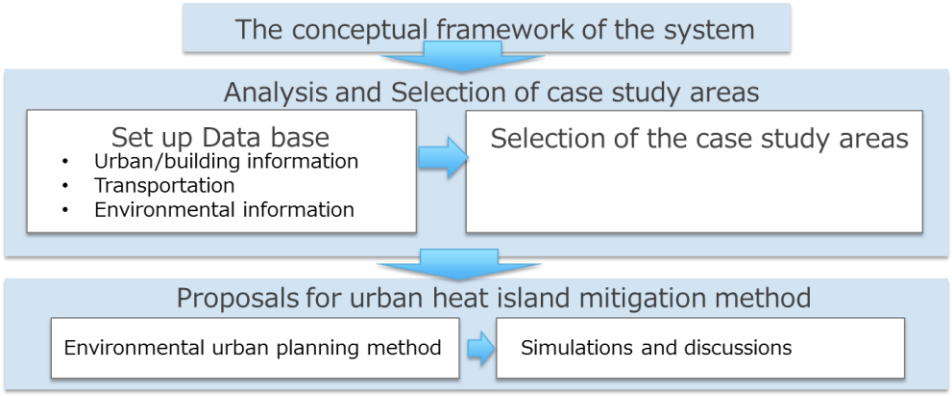


Figure1 Research flow

The conceptual framework of the system

System architecture

As a sub tool for the smart city planning tool that we proposed in the previous studies, it has the same architecture. Figure 2 shows the outline of the system. It constitute with three parts data base, layer integration and the optimal design parts. Database sector and layer integration sector interpret the city information by layered data, including the data related to urban planning, transportation and other various sectors. The two parts are the set based on cyber physical space that built with GIS and ICT technology. The city 3D model is built with the basic urban information from GIS data, while the transportation information, environmental information and energy information are collected with various sensors. These data are plot to the city 3D model built by GIS platform.

Optimal design sector is the simulation and assessment model for optimal thermal environment planning which come from urban heat island mitigation strategies based on the BIM. This tool can comprehensively evaluate the community greenery which are able to be implemented between buildings, energy conservation with building types and age, detailed transportation status in community level. . The result of the simulation is evaluated, feedback and readjust the urban plan until the optimal solution.

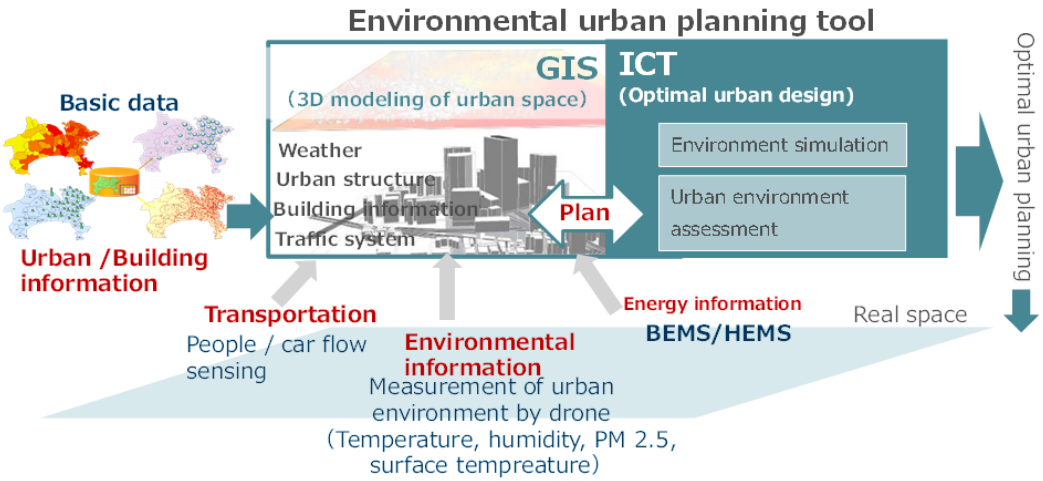


Figure2 Conceptual framework of the system (Environmental planning sub tool)

Datasets for analysis

For comprehensive analysis and planning, various data are adopted in the database. They are as below:

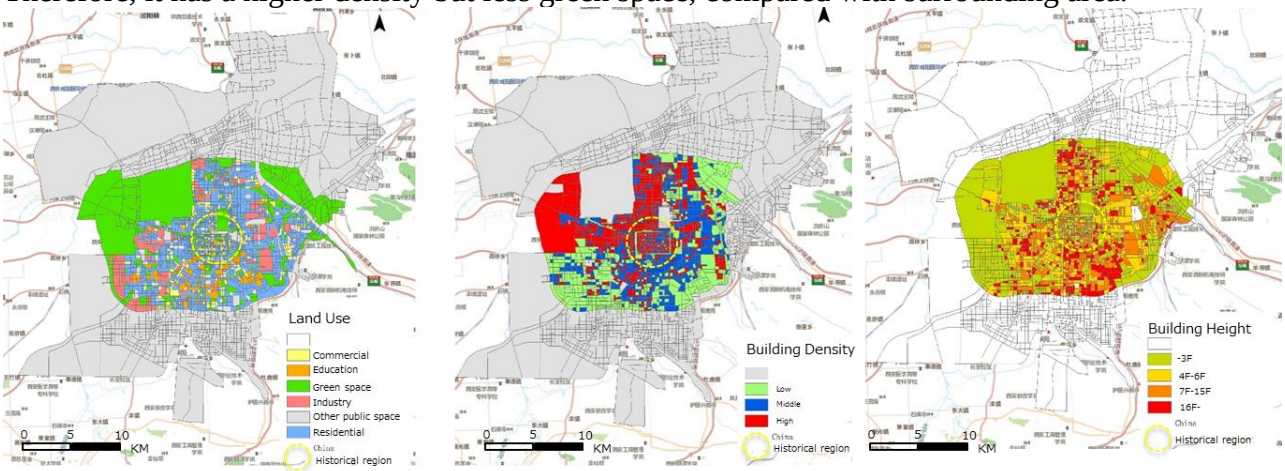
Table1 Datasets

Type	Data
Urban Planning	Land use Building density: Estimated by building area and height Building height
Environment condition	Land surface temperature: analysis data from Landsat (11:29 14th July, 2014) Air temperature data: measurement data from 11th June 2014 to 27th August 2014 Air quality: PM10
Transportation	The measurement on 10th June,2018

Analysis and Selection of case study areas

Urban structure analysis

Firgure3, the land use, building density and building height can figure out the features of urban structure. In the center of the city, the historical area is constitute of low rise residence. Therefore, it has a higher density but less green space, compared with surrounding area.

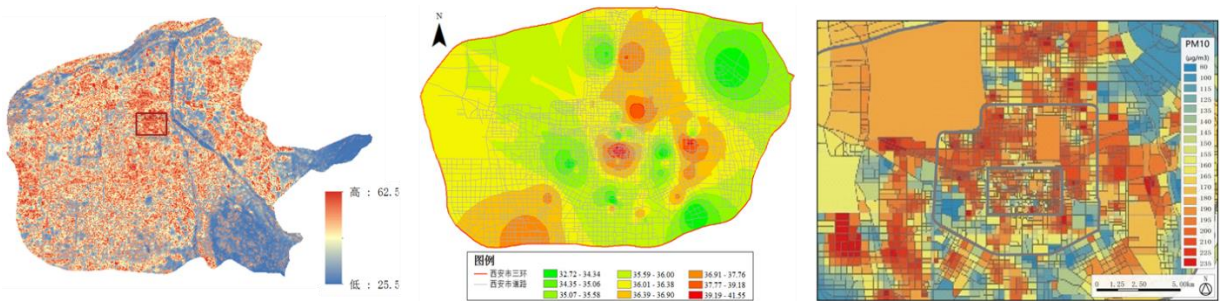


Land use Building density Building hight

Figure3 Analysis of urban structure

Environment condition analysis

Figure4 is the environment condition with land surface temperature, air temperature and air pollution (PM10.0). It suggested that, historical area in the center of the city has the highest surface temperature and air temperature than the surrounding area.



Land surface temperature　　Air temperature　　Air pollution

Figure4 Analysis of urban structure

Selection of the case study areas

As one of the most serious areas under UHIE. This study selects one of the low rise and high density area around a park, Xi'an Revolution Park as case study (Figure5).

Xi'an Revolution Park is located inside Xi'an Circumvallation. As an historical city, the building height in this area is limited no more than 36m and Floor Area Ratio is less than 300%.

By this case study, the research is aim to confirm the effect of the park in residential area and also its environmental effect with the urban typology.

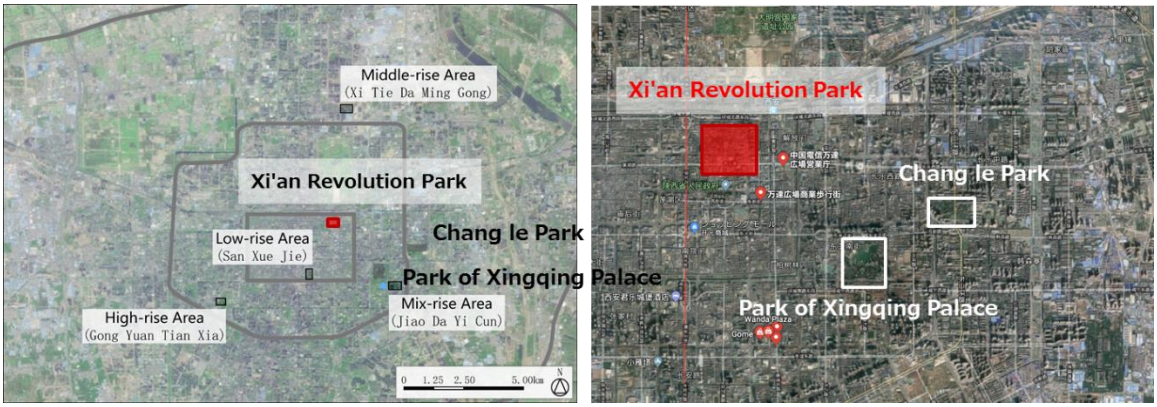


Figure5 Xi'an Revolution Park

Proposals for urban heat island mitigation method

Introduction of cool spots network and the wind path are the usual method for environmental planning. However, in the historical area, the reconstruction and the height of the building is limited, which made the environmental planning difficult.

In this research, we proposed the regeneration method by insert the small green space nearby "Living space" in the building block, the way for revitalize area with the traditional "Courtyard" pattern and introduction of roof greening during the reconstruction of the aged building (Figure6). At the same time, the existing part place is also revitalized by increasing tall trees.

Figure6 Proposed Courtyard pattern for environmental plan

Simulation model

Simulation method

We use 3D thermal radiational environment analysis tool "THERMORender" for simulate the 3D surface temperature and k-εturbulent model "STREAM®" for the average wind distribution and the air temperature distribution.

For the integrated planning, the simulation model we used in this research is a model that can combine the building energy consumption simulation and outdoor thermal environmental simulation (Figure 7). It includes three, modelling parts (input 3D model), solver and output. The modelling parts is the input for simulation, which consists of 3D model and database. Solver is the part of simulation, including thermal environment simulation module, building load simulation module and energy consumption simulation module (Yamamura 2009).

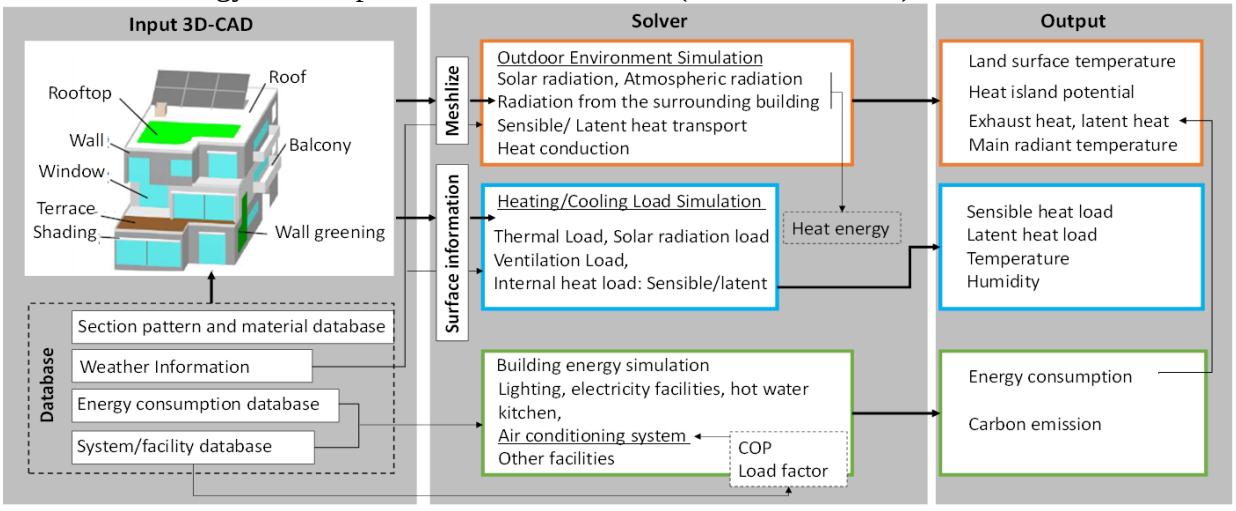


Figure7 Image of Simulation model (S.Yamamura, 2009)

Case setting

In order to find out the effect of the proposed environmental development pattern. Two cases are set for simulation, the existing pattern and the proposed patter (Figure8)

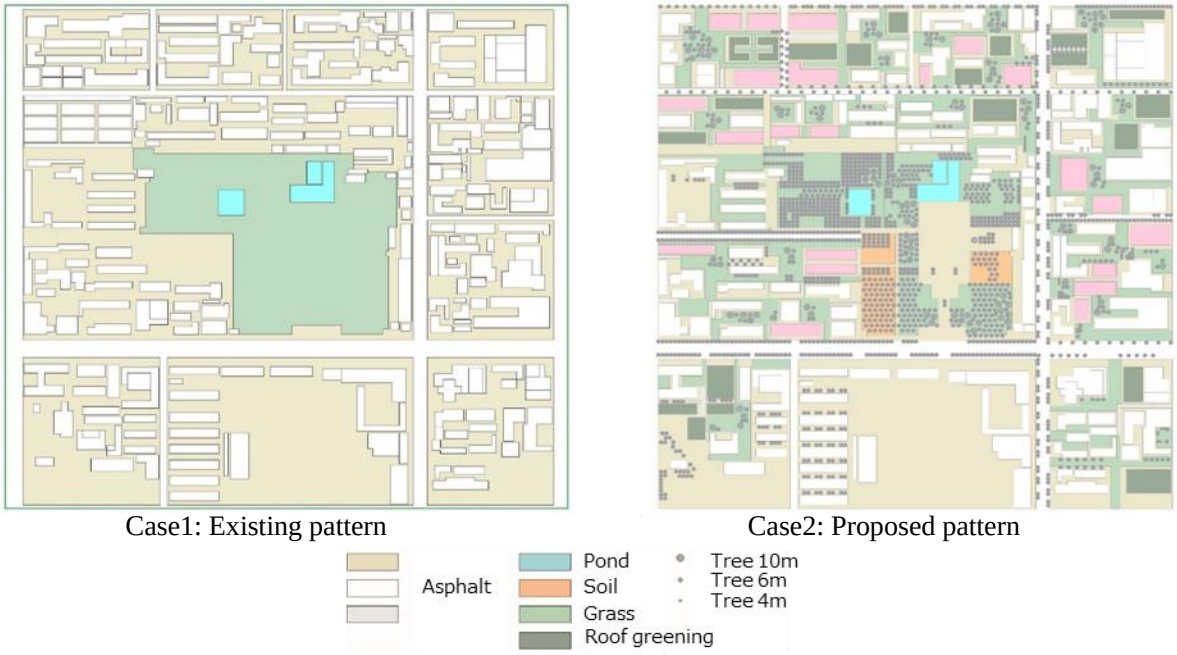


Figure8 Simulation case setting

The setting for simulation are as Table2

Table2 Detail input for simulation

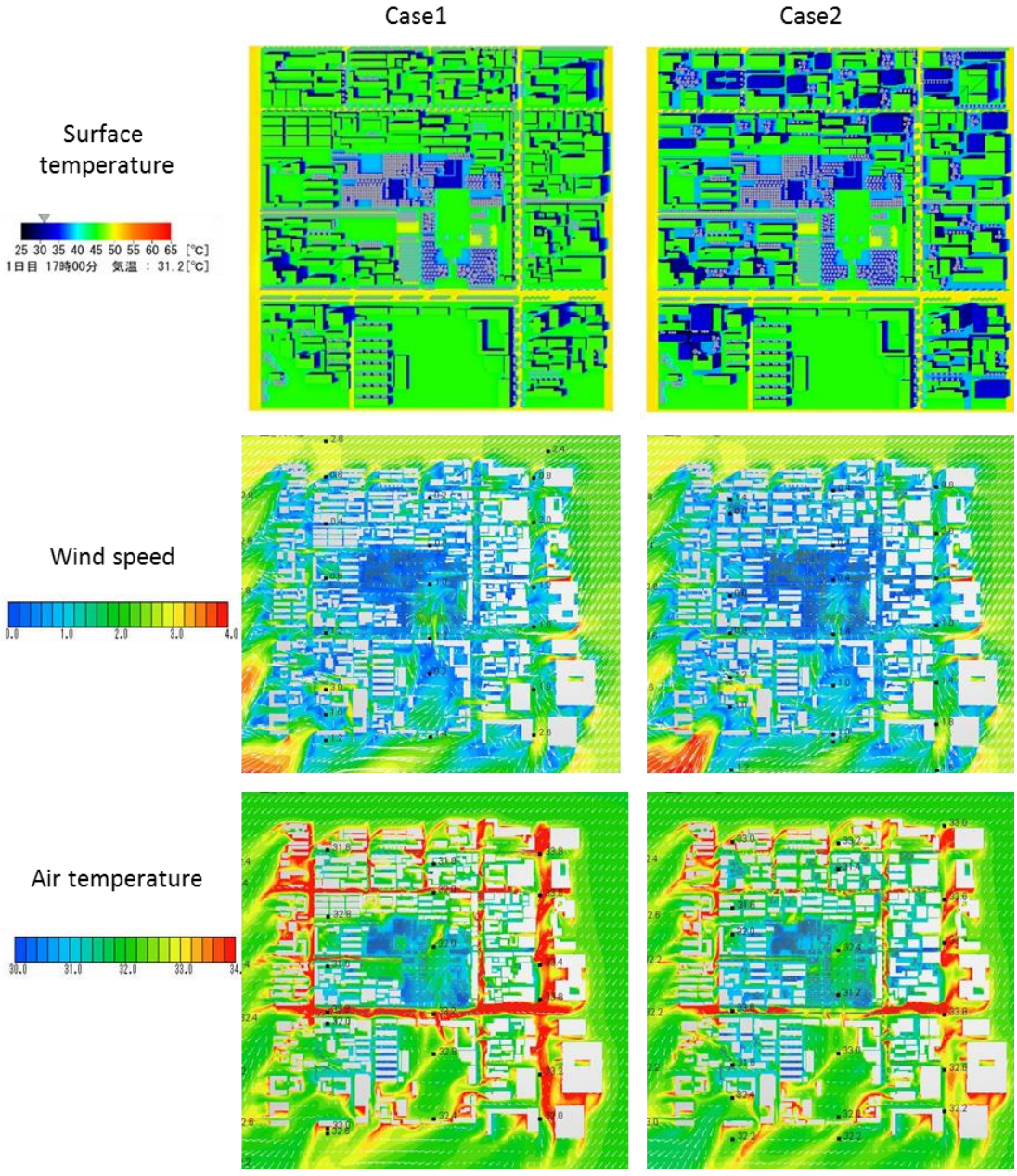
Category	Case1	Case2
Weather data	EnergyPlus™ weather data (August, Typical summer day)	
	Simulation time: 15:00 Wind Speed:2m/s, Northeast Solar radiation: 790 w/m^2 (2.844 MJ/m^2)	
Indoor temperature	Non-residential: 6:00~24:00 26℃ Residential: 19:00~24:00 26℃	
Transportation	Based on the existing survey	50% EV introduction
Energy consumption	Existing energy system	LED and high efficient Air conditioner for 30% energy consumption reduction

Result and Discussion

The surface temperature, Figure9 suggests that the surface temperature of the water remain pavement and the roof greening are 5 ℃ lower than case1. It contributes to spread the lower surface temperature area surrounding buildings in each building block. The wind speed of the two cases can suggest that the introduction of the additional trees in the public space slightly slow down the wind speed. In that case, the cool air that created by the greenery remain in the space and make

the air temperature lower. The air temperature of different building blocks, show in figure10, shows that the maximum temperature of the blocks distributes from around 0.2 to 2.0℃ and averagely decreased 0.63 ℃. The air temperature of the public space, the courtyard, averagely decreased 0.33 ℃. Although the cooling effect is affected by the specific structure in building blocks, it is clarified that introduction of cool spots in every building block and making a network between them leads to create wind paths across the street.

Figure9 Simulation result



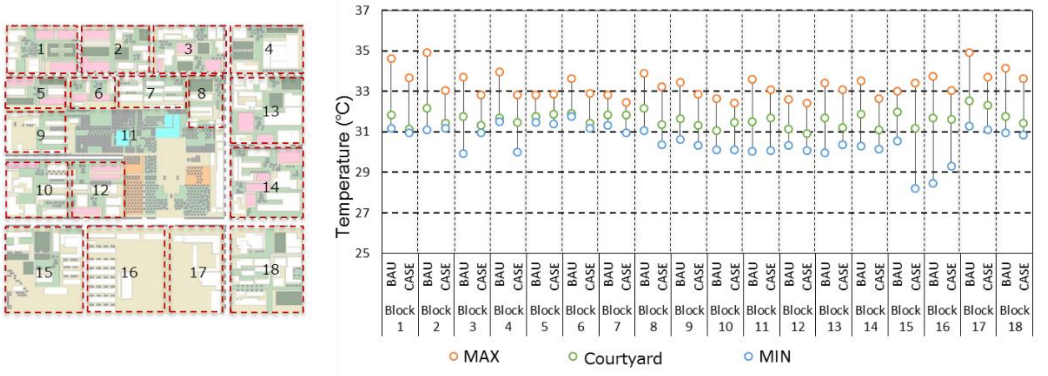


Figure10 Air temperature of different blocks

Conclusions

Based on the concept in the previous research (Yamamura, 2016), we developed a conceptual framework to support environmental friendly planning with integrating BIM and GIS technology in an intelligent system for environmental design. The effectiveness of our proposed system was illustrated by conducting case studies in Xi'an that is traditional and complex urban structure and more difficult to proceed extensive and drastic redevelopment. It is approved that the system can mainly achieve the following:

Combination, analysis, and visualization of the data from urban planning, transportation, and the building information from BIM;

Simulation, analysis, and comparison of the effects of different environmental design patterns, and presented the result through easily understood 3D models.

With the support of the simulation tool, it is proved that the planning method with introduction of small scale cool spot and network of wind path can be a practical urban heat island mitigation method in the historical city as Xi'an. This method considerate existing community structure, development phase, and the practically possibility for environment-friendly planning that can also be used in the similar cities in China and other countries. The tool can be effectively used to confirm various environment-friendly planning strategies and form an action guideline for urban heat island mitigation from community view, instead of building or city view.

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