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Urban Green Space Remote Sensing Retrieval with LIDAR and Multi-Spectral Satellite Data

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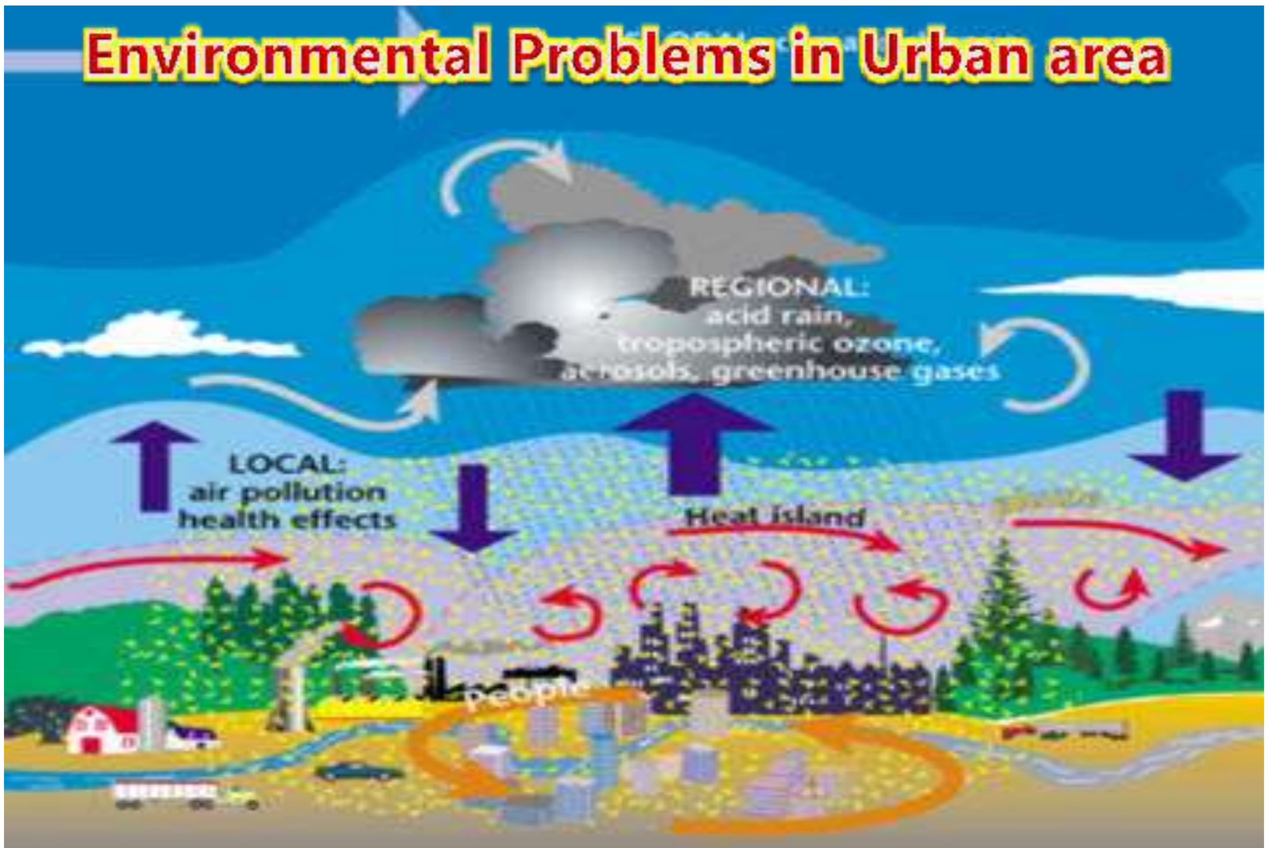
Outline

1. Research Background and Necessity
2. Research Contents
3. Implementation of Research
4. Achievements and Conclusions
5. Application Prospects

1.Research Background and Necessity

Urban Ecosystem

More than 50% of world population lives in urban area which accounts only 4% of terrestrial surface.



Urban Heat Island

Air Pollution

Impervious Suface

1.Research Background and Necessity

Urban Ecosystem

Humanity is increasingly urban, but continues to depend on Nature for its survival !!!

Urban area can be treated as one single ecosystem or as composed of several individual ecosystems.

Bolund and Hunhammar (1999) list seven urban ecosystems: street trees, lawn/parks, urban forest, cultivated land, wetland, lakes/Sea, and streams. All of them can be categorized as green part and blue part.

1.Research Background and Necessity

Uneven Distribution of Green

Figure 1. Urban heterogeneity. False color infrared aerial photo of Baltimore City, MD, taken in 1999 at submeter resolution.

1.Research Background and Necessity

Uneven Distribution of Green

New York

Beijing

1.Research Background and Necessity

Uneven Distribution of Green Per Capita

1.Research Background and Necessity

- **How to estimate green distribution in the city?**
- **How to estimate the probability of resident contacting green and the level of enjoying urban green?**
- **What can remote sensing do?**

1.Research Background and Necessity

What is Urban Green Space?

- **Urban Area covered by Vegetation**

Urban green space (UGS) is a comprehensive concept； it refers to the region covered by vegetation and has certain ecological benefits in the city. It reflects the quality and quantity of green space in the region based on building scale from 3D perspective. It is comprised of urban forest, grassland, gardens and recreation venues, planted trees along streets and or other permeable surface.

- **Evaluation of ecological service of green**

1.Research Background and Necessity

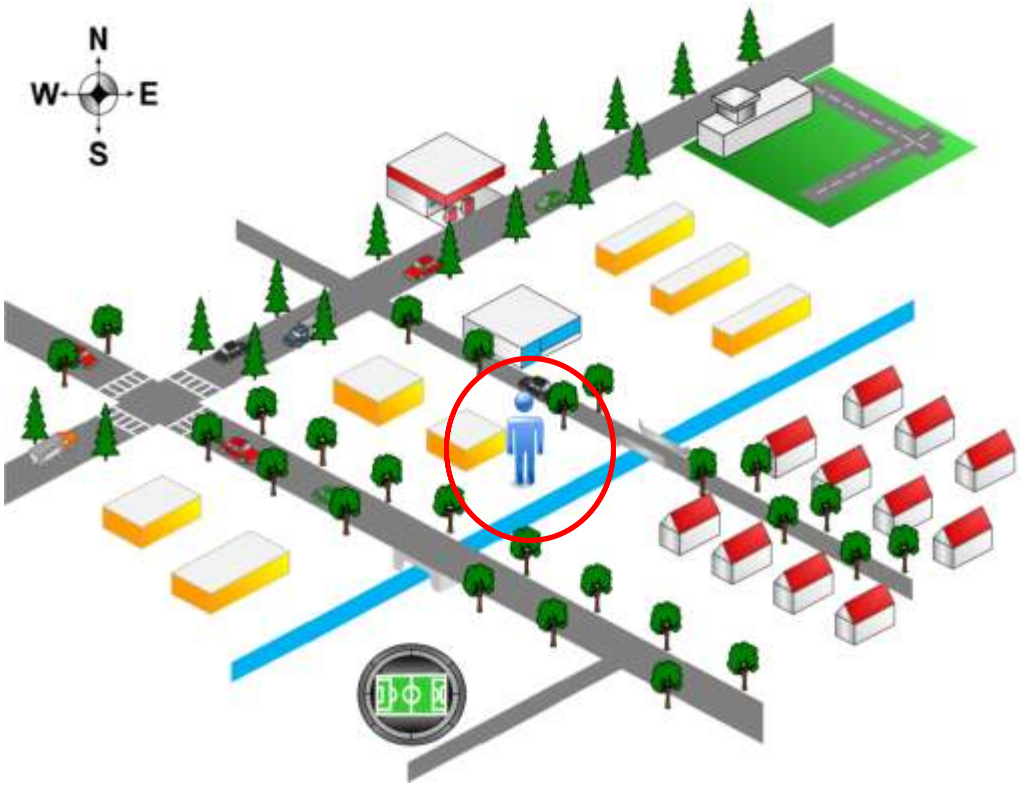
Benefits of Urban Green Space

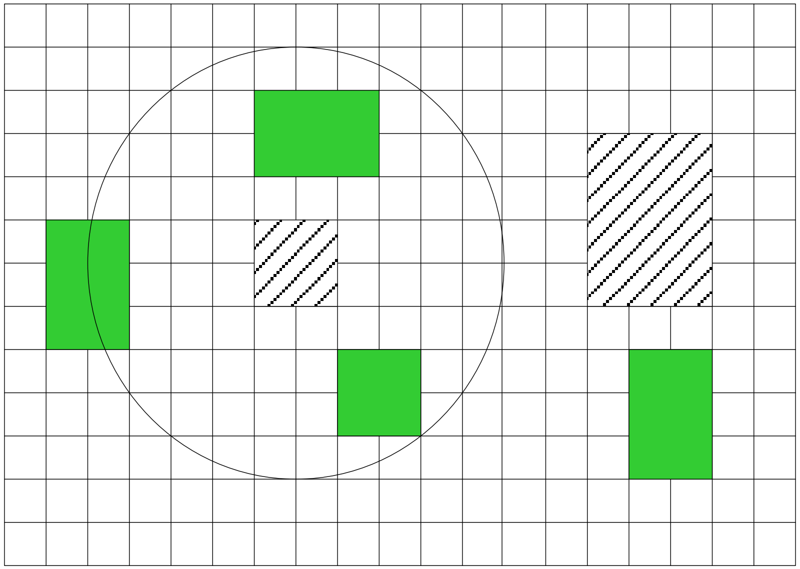
- **UGS can absorb carbon dioxide and release oxygen (Hough, 1984);**
- **UGS can alleviate UHI effect, air pollution, noise pollution, even prospect of floods after heavy rainfall (Chen et al. 2006; Jim and Chen 2008; Onishi et al. 2010; Miller, 1997; Dole, 1989);**
- **Exposure to green space contributes to health (Gidlow et al. 2012; van Dillen et al. 2012; Wendel et al. 2011);**
- **UGS also provide ascetic value to urban citizens, and there is evidence that living in a greener environment makes people feel closer to nature.**

1.Research Background and Necessity

Urban Green Space Index

UGSI is a new index which aims to estimate urban green from spatial perspective based on high resolution remote sensing images and it considers green type, buildings distribution and so on. UGSI can effectively estimate the quality and quantity of urban green space.





1.Research Background and Necessity

Research Status

- **Most of the previous studies analyzed urban green through green distribution and area from two dimensional perspective.**

- **There are few studies on estimating the probability of residents contacting green and its spatial distribution between buildings and green.**

- **There are few studies on validation and adaptability of the urban green space model.**

1.Research Background and Necessity

- **Buildings are the main habitat for urban citizens. The distribution of building can be used to indicate the distribution of residents.**
- **Study on urban green space at building scale can represent human's perception to urban green space and its distribution disparity of ecological benefit of urban green space.**

Outline

1. Research Background and Necessity
2. Research Contents
3. Implementation of Research
4. Achievements and Conclusions
5. Application Prospects

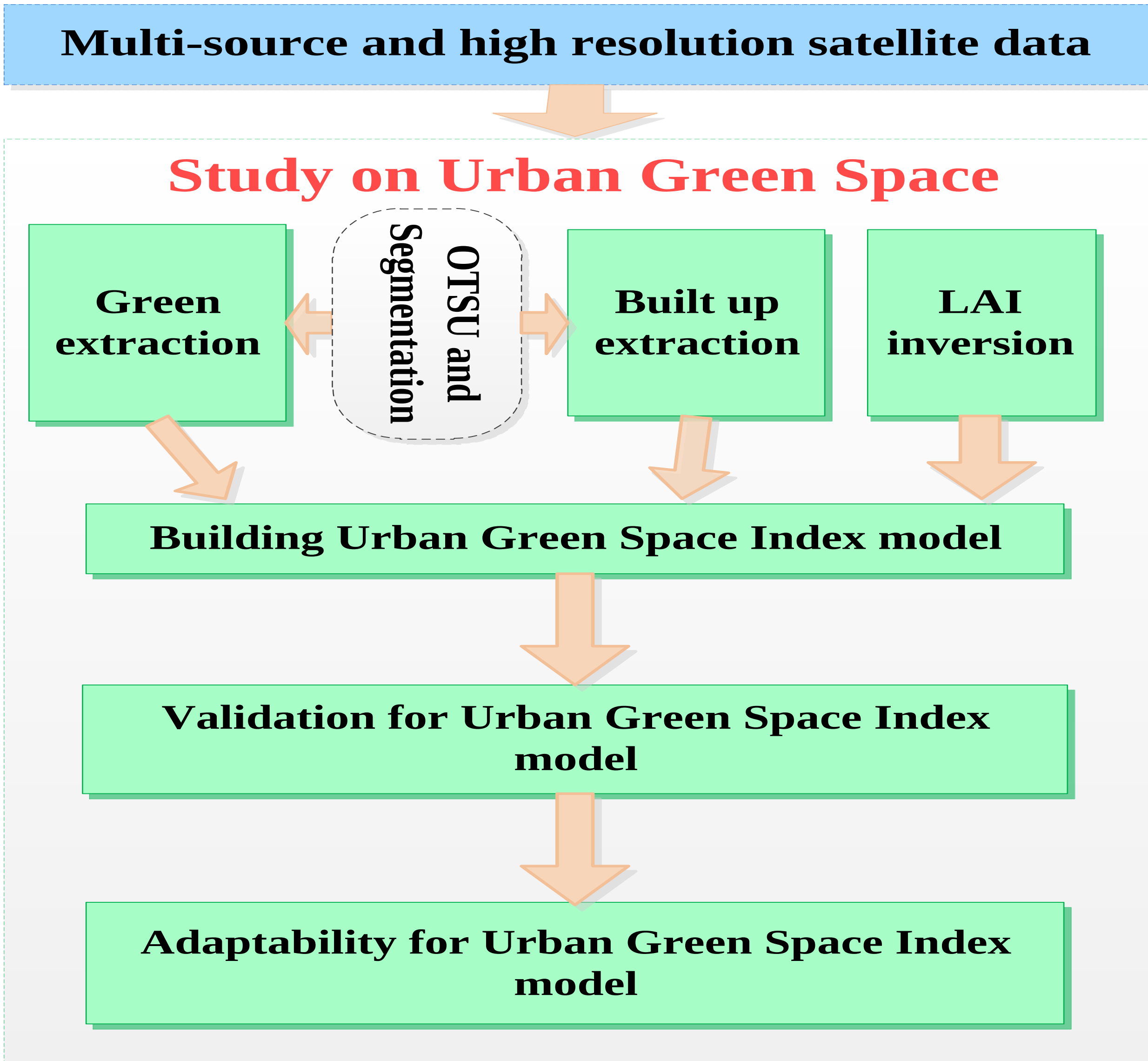
2. Research Contents

Research Objects

Developing a complete set of technical system on urban green space

- **Developing Urban Green Space Index model based on building scale;**
- **Validation study of urban Green Space Index model；**
- **Adaptability study of Urban Green Space Index model in different areas, to promote the practicability and operation of the model.**

2. Research Contents

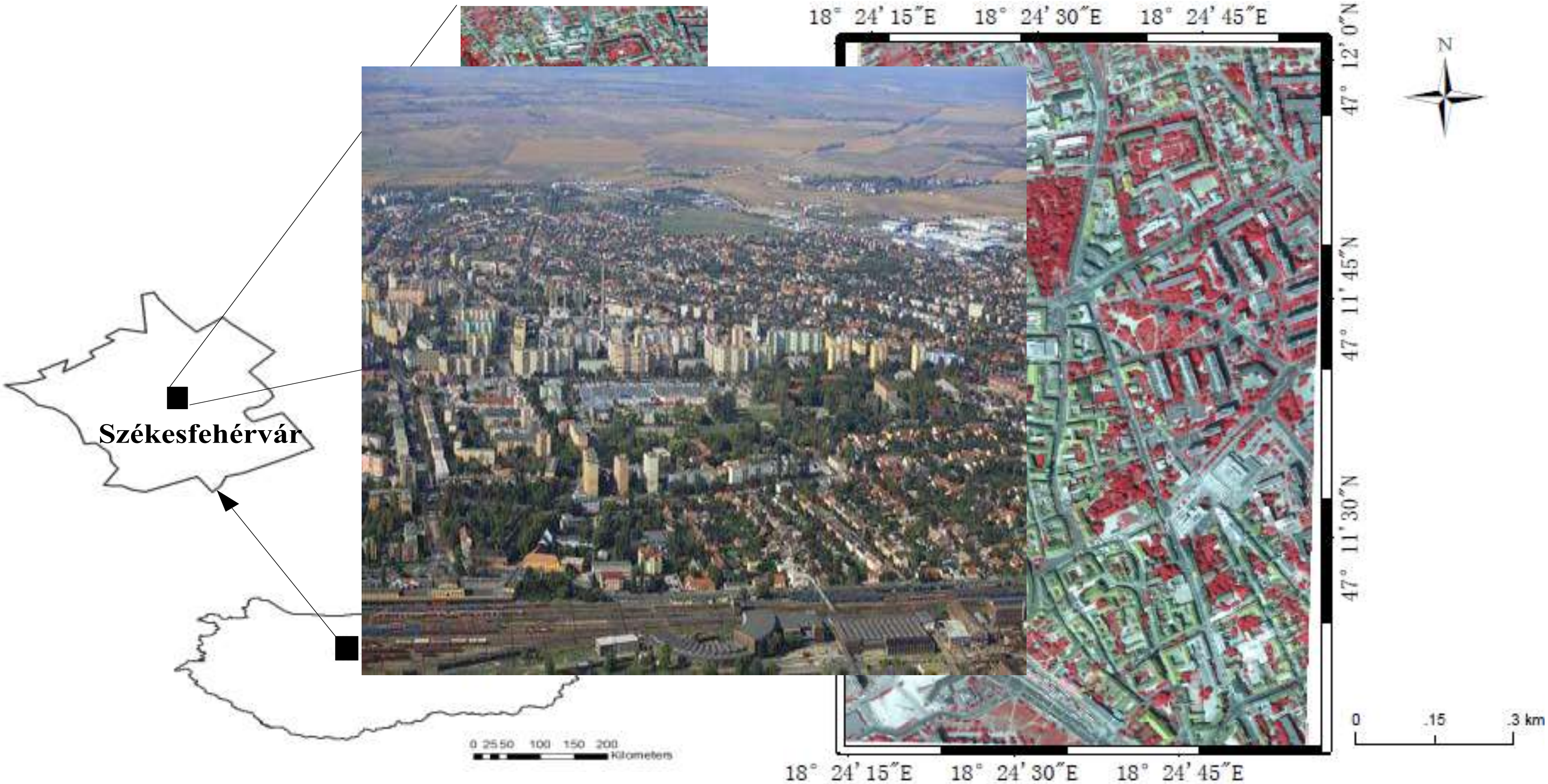


Outline

1. Research Background and Necessity
2. Research Contents
3. Implementation of Research
4. Achievements and Highlights
5. Application Prospects

3. Implementation of Research

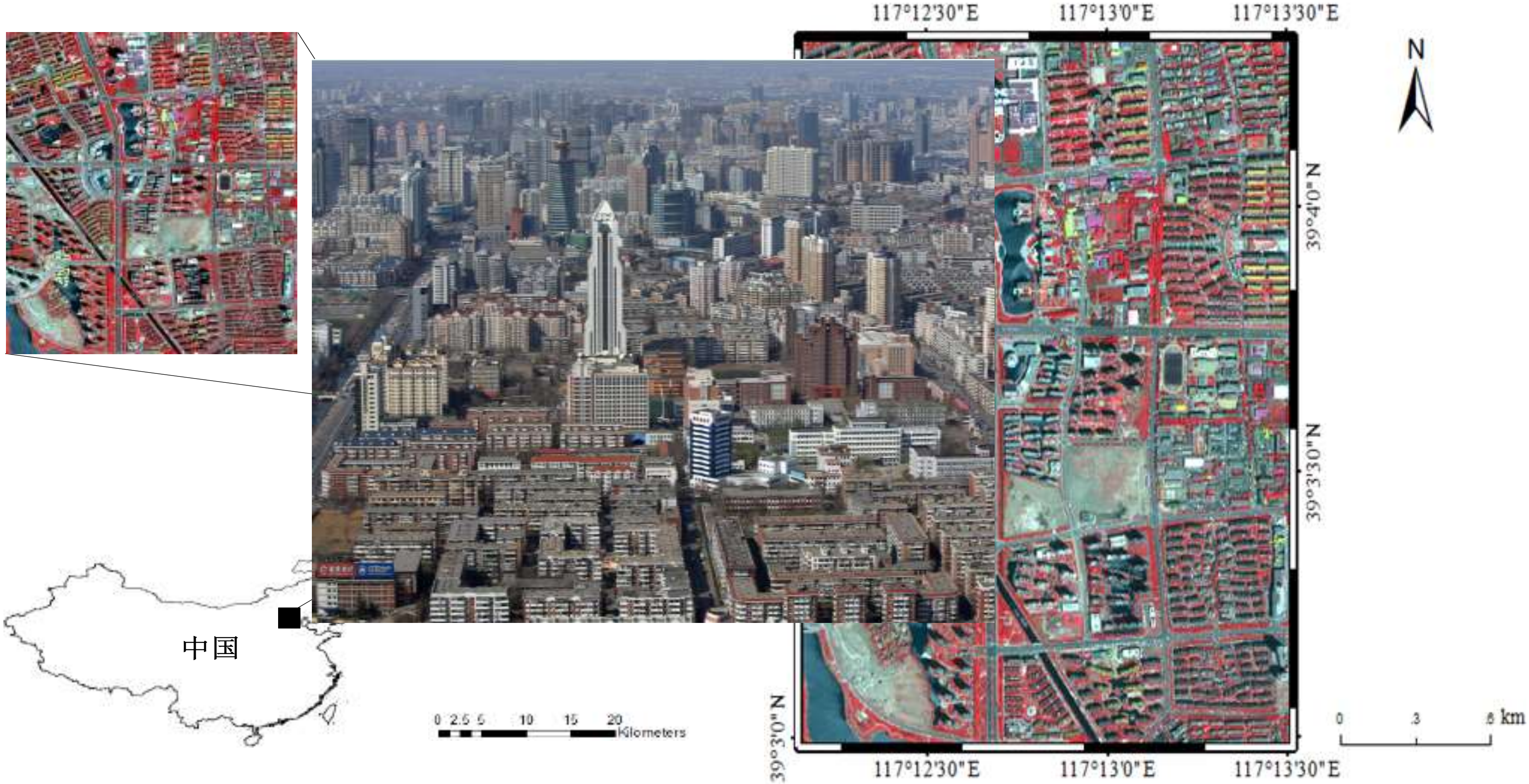
Study area



Székesehérvár

3. Implementation of Research

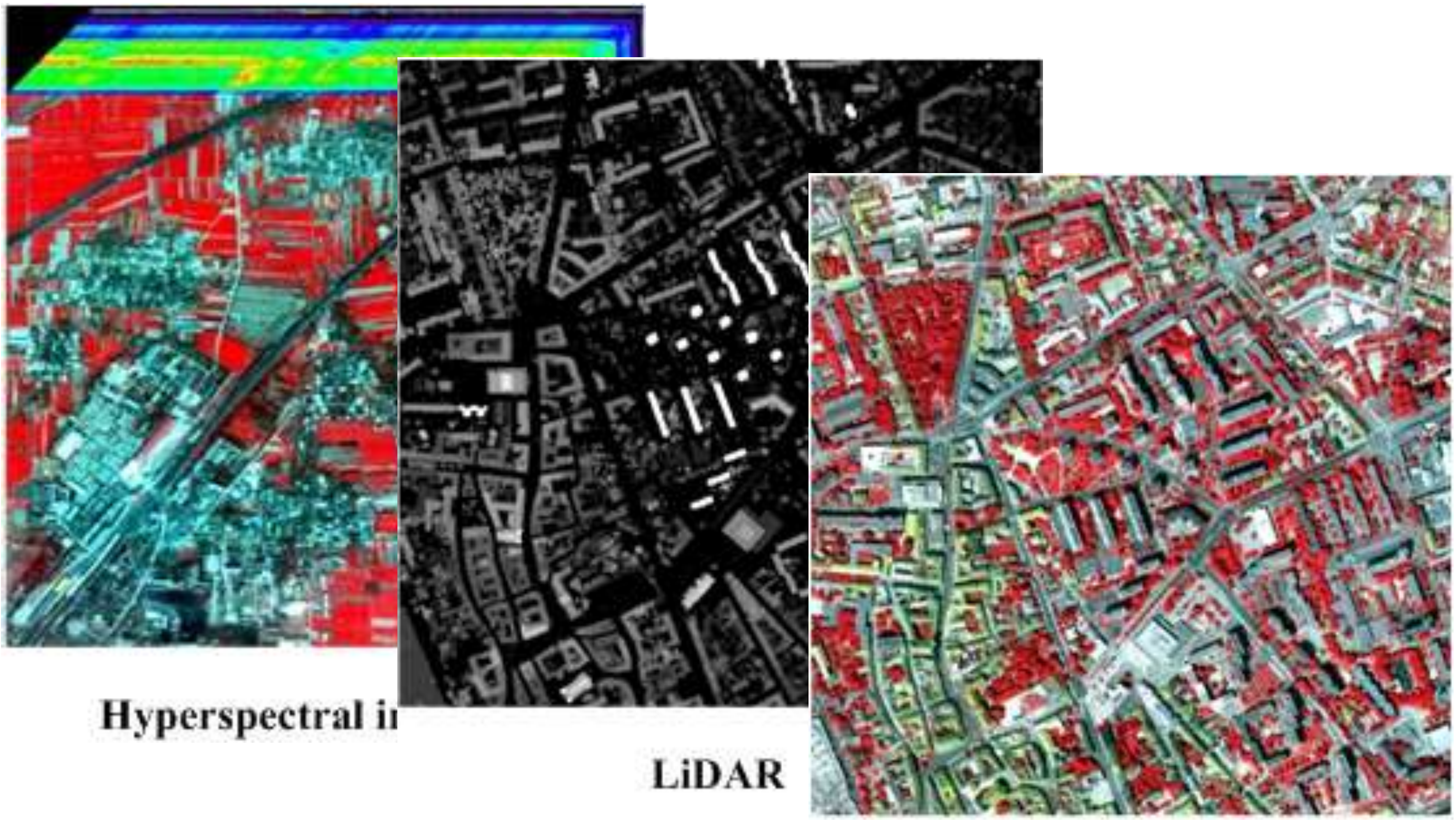
Study area



Tianjin, China

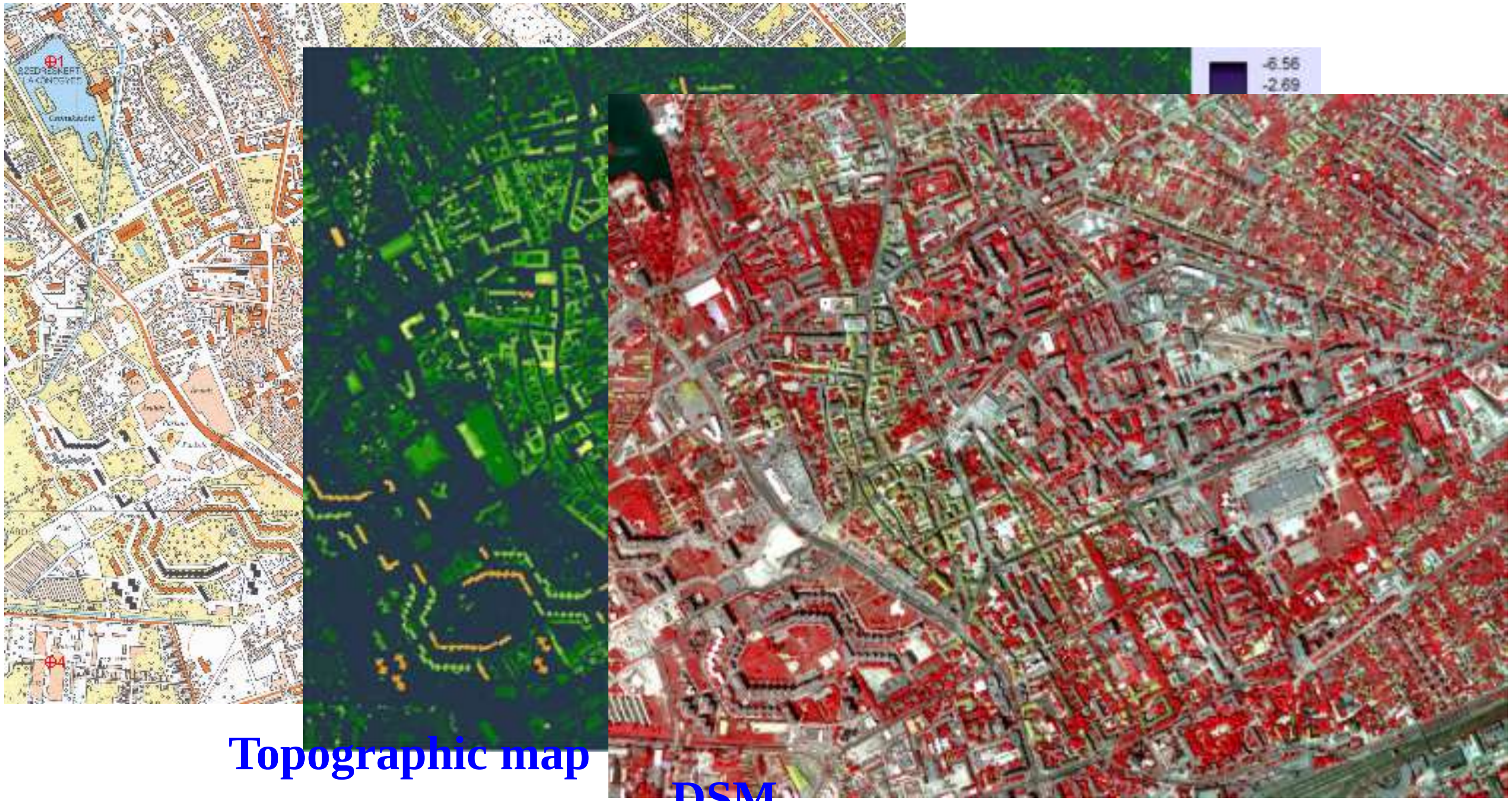
3. Implementation of Research

Data Sources



3. Implementation of Research

Geometric Registration



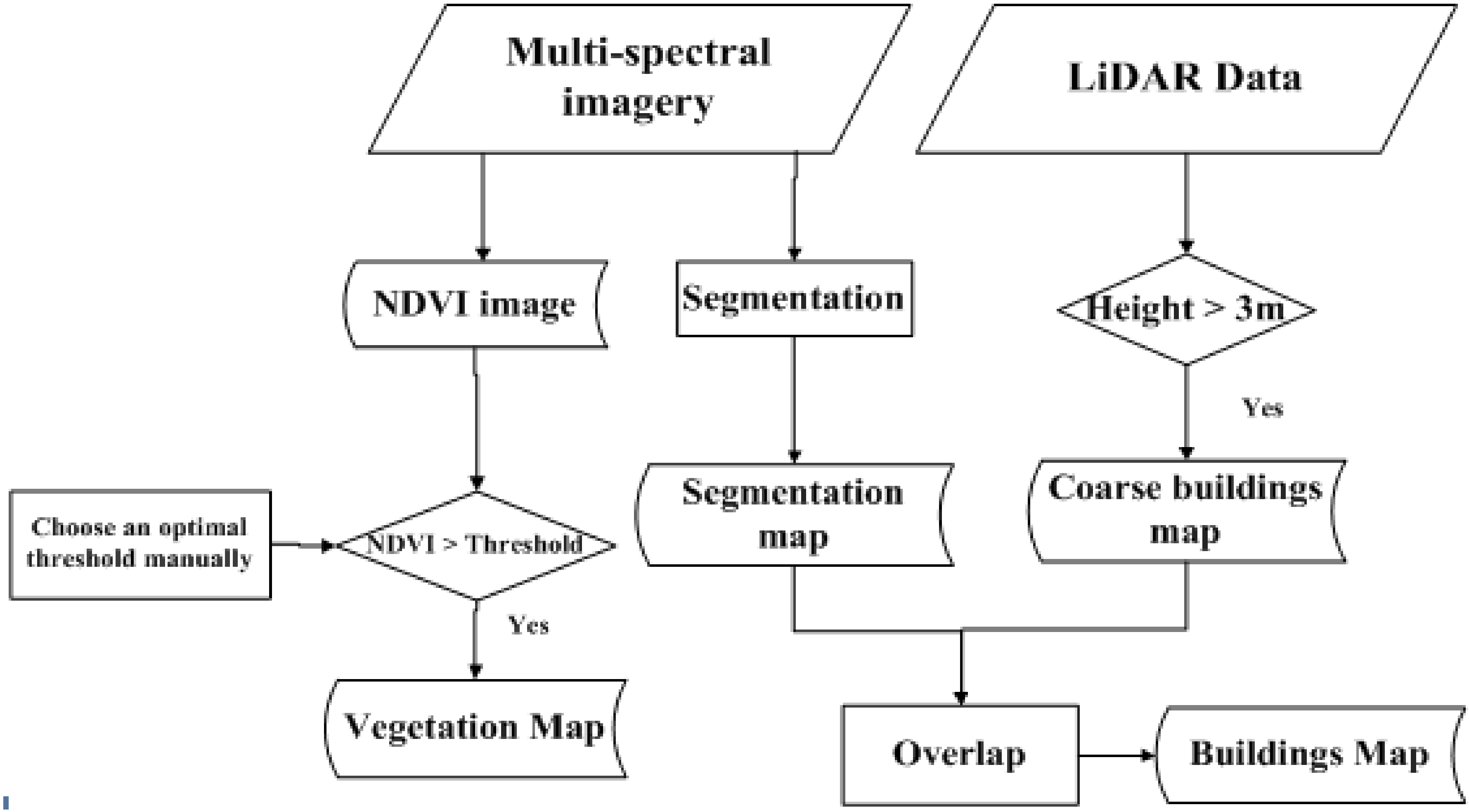
Topographic map

DSM

Multispectral data

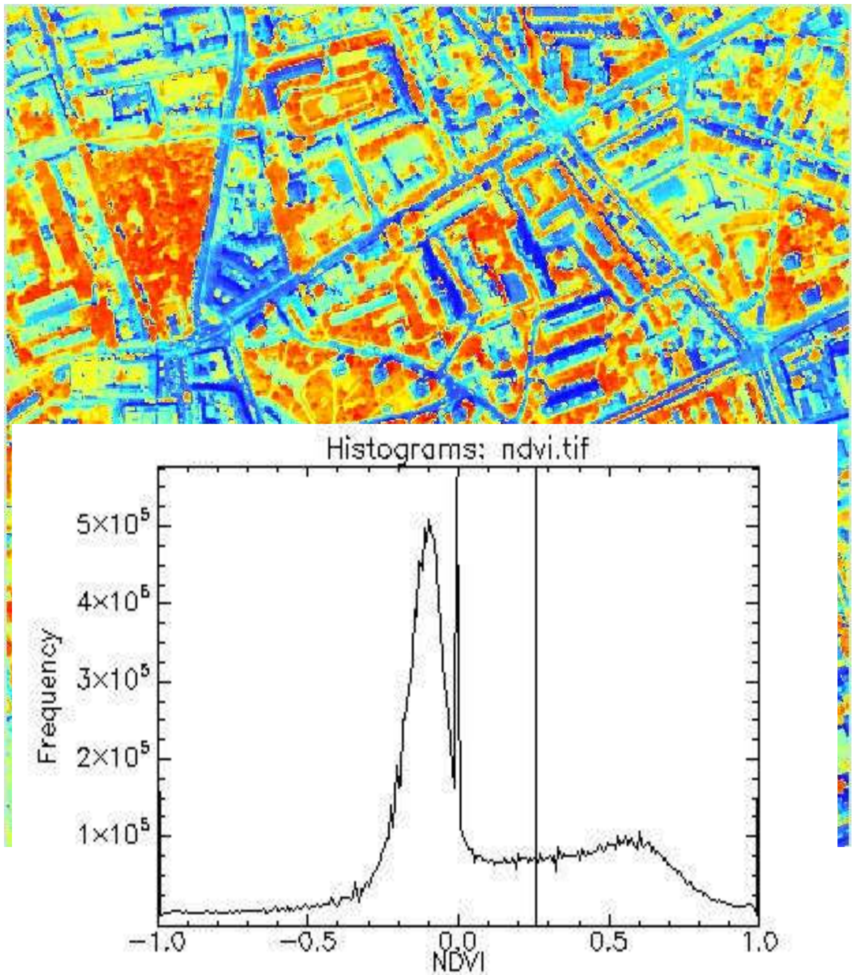
3. Implementation of Research

Retrieval of Vegetation and Buildings



3. Implementation of Research

OTSU Method



$$NDVI = \frac{NIR - RED}{NIR + RED}$$

NIR refers to the reflectance at the near infrared band. RED stand for the reflectance at the red band.

OTSU method is used to screen the threshold automatically. Then, the vegetation can be retrieved without subjective factors' effect.

3. Implementation of Research

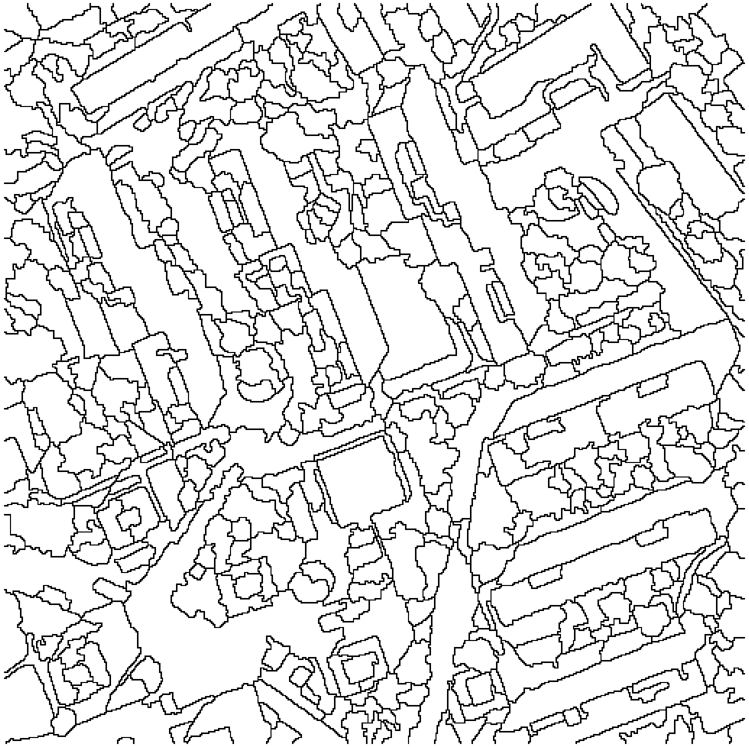
Vegetation Retrieval

False color imagery **Vegetation retrieval result**

3. Implementation of Research

Segmentation

False color image(0.5m)

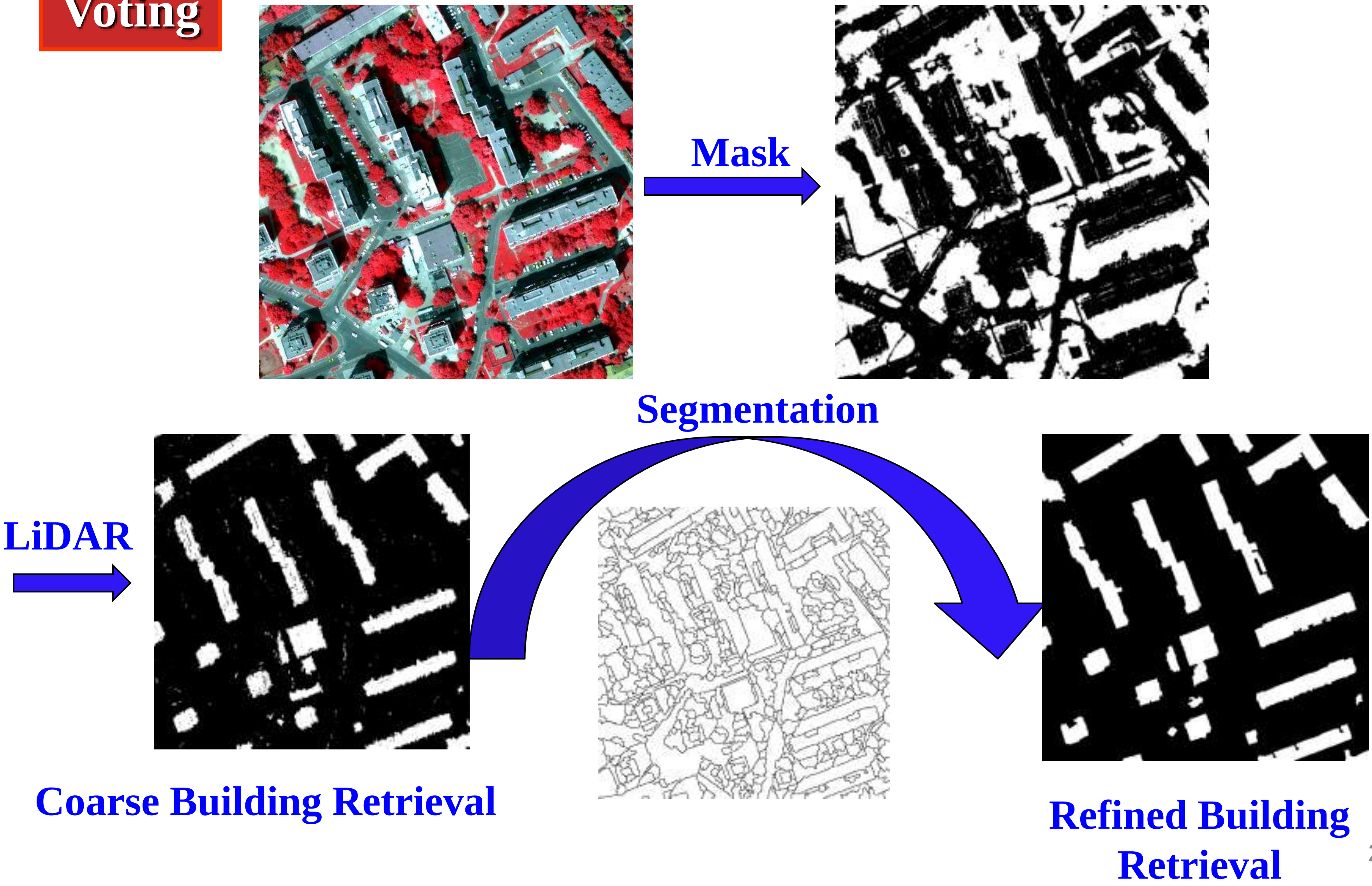


(b) Segmentation result

Segmentation result of the image

3. Implementation of Research

Voting



3. Implementation of Research

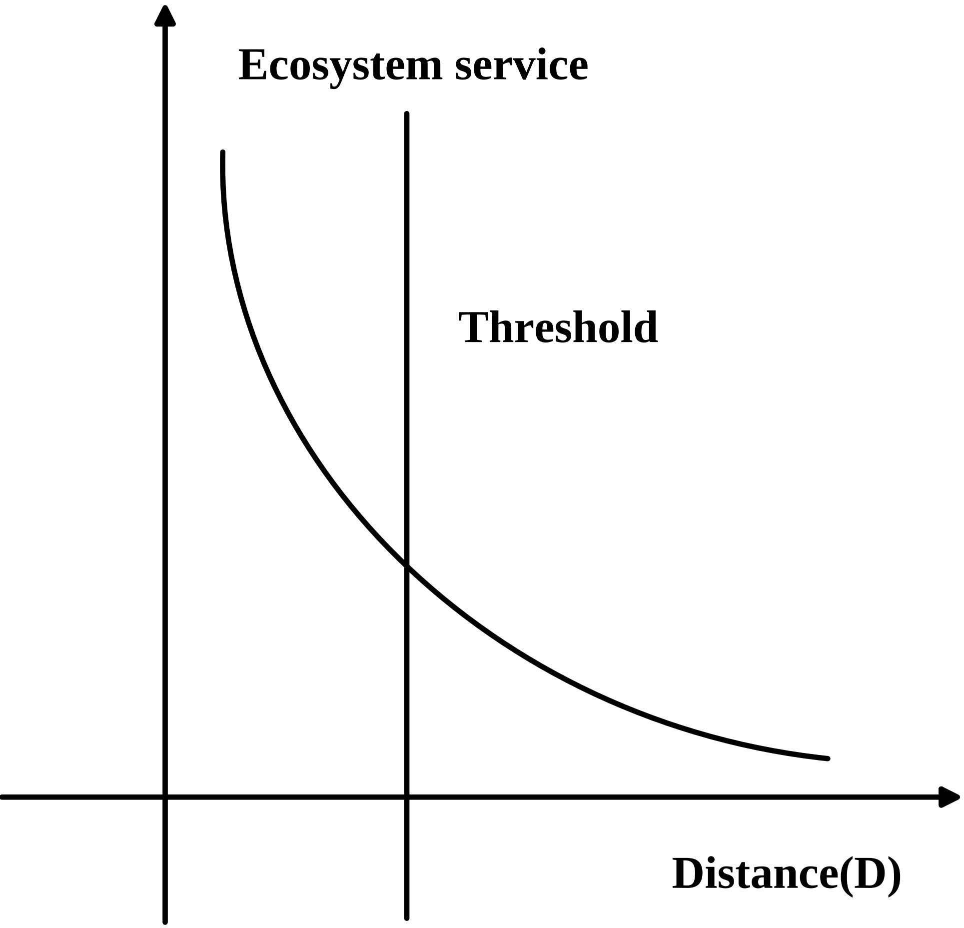
Building Retrieval

False color imagery   Building extraction Result

Building retrieval result of the whole research area

3. Implementation of Research

Building's Accessibility to Green Space Index



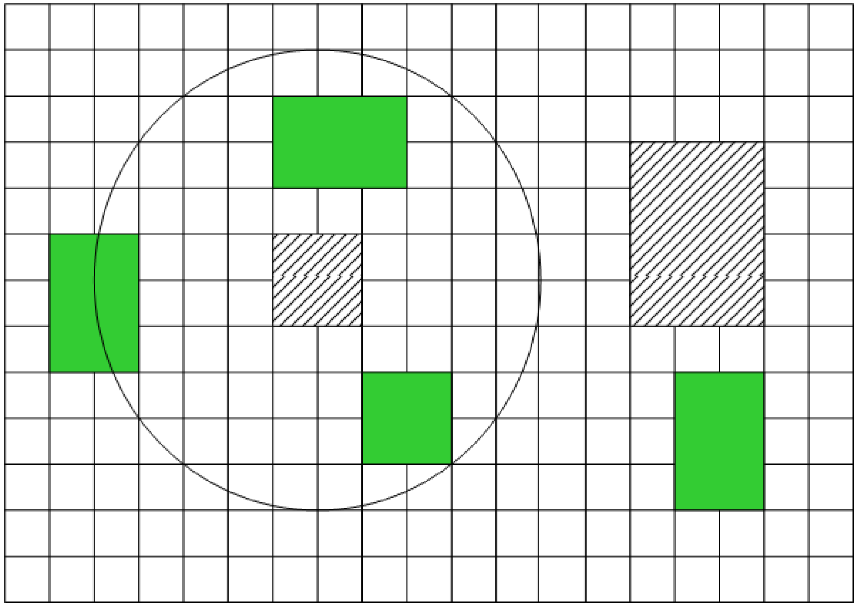
Assumption:

The ecological benefit of green space fits to the general distance decay theory, that is, the farther from the green space, the less of enjoying the ecological service of green space.

3. Implementation of Research

Building's Accessibility to Green Space Index

Spatial configuration relationship between buildings and green space at 2-dimension.



The green refers to urban green space
The shadow grey parts refer to buildings.
The green space in the circle is the contagious vegetation.

3. Implementation of Research

Building's Accessibility to Green Space Index

$$eBAGI_i = \frac{\sum_j par_{ij}}{length_i}, D < 10m$$

$$aBAGI_i = \frac{\sum_j par_{ij}}{area_i}, D < 10m$$

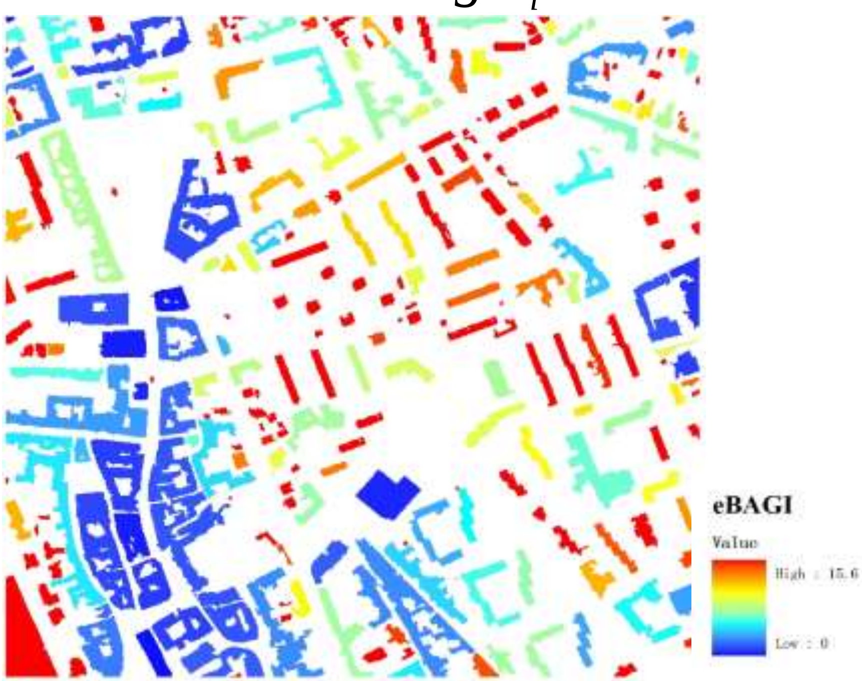
- **par_{ij} refers to the parameters of urban vegetation**
- **$length_i$ refers to the length of the isolated building**
- **$area_i$ refers to the area of the *i*th building**
- ***i* range from 1 to *n*, n is the number of buildings.**

3. Implementation of Research

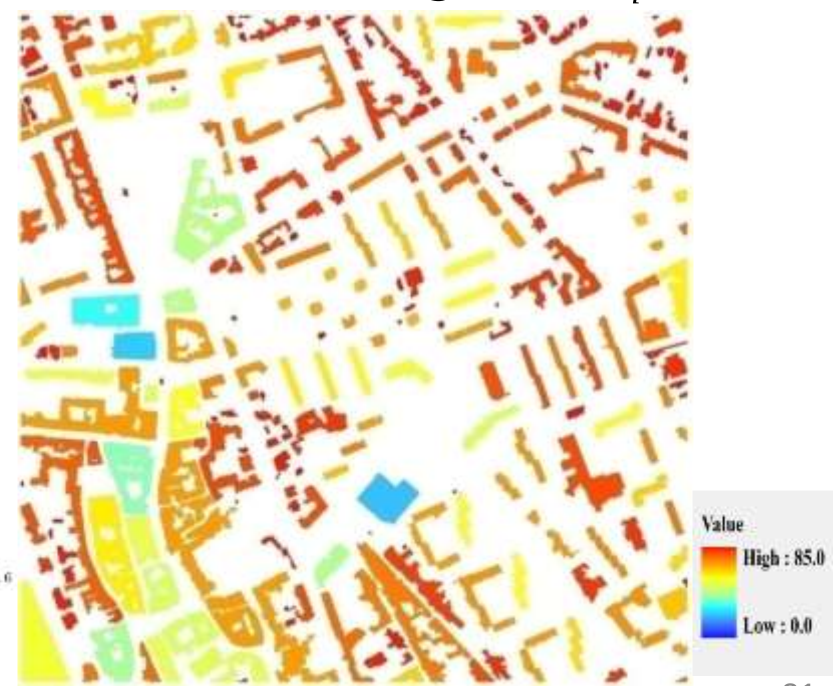
Building's Accessibility to Green Space Index

aBAGI and eBAGI are calculated based on the distributed area of vegetation.

$$eBAGI = \frac{\sum_j area_{ij}}{length_i} \qquad aBAGI = \frac{\sum_j area_{ij}}{building\_area_i}$$



eBAGI



$eBAGI_{LAI}$

3. Implementation of Research

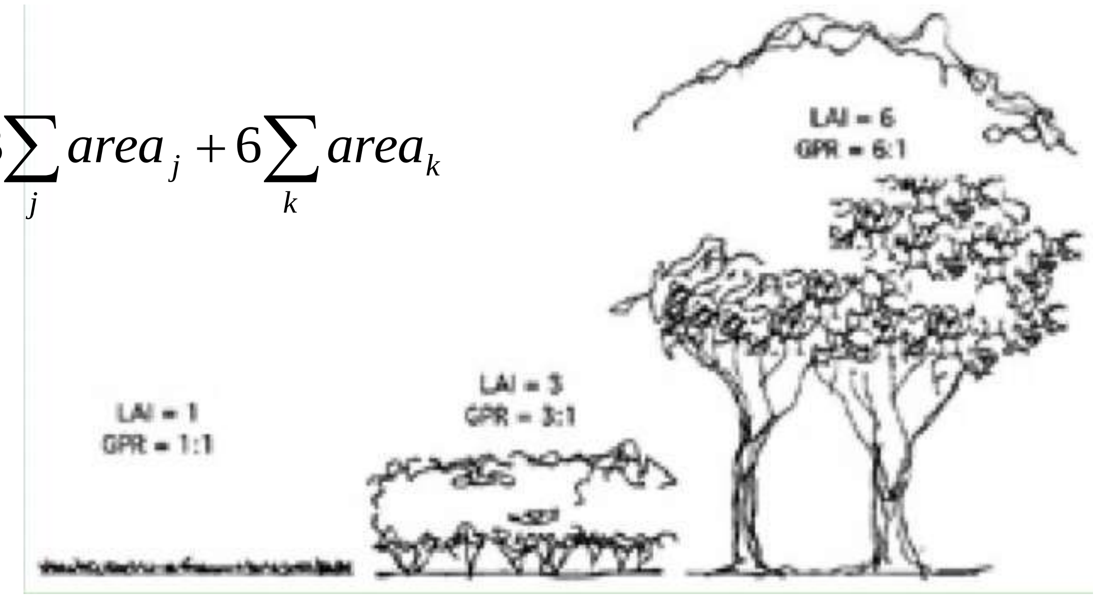
Building's Accessibility to Green Space Index

The ecological benefits of urban green has close relationship with vegetation's bio-physiological processes. The extent to which plants engage in these processes is directly related to the amount of green matter, usually found in the leaves of the plant (Ong, 2003)

$$eBAGI = \frac{\sum_j LAI_{ij}}{length_i} \qquad aBAGI = \frac{\sum_j LAI_{ij}}{building\_area_i}$$

$$G\_LAI_j = \sum_i area_i + 3\sum_j area_j + 6\sum_k area_k$$

- ***$area_i$* is the area of grass,**
- ***$area_j$* is the area of shrub**
- ***$area_k$* is the area of tree**

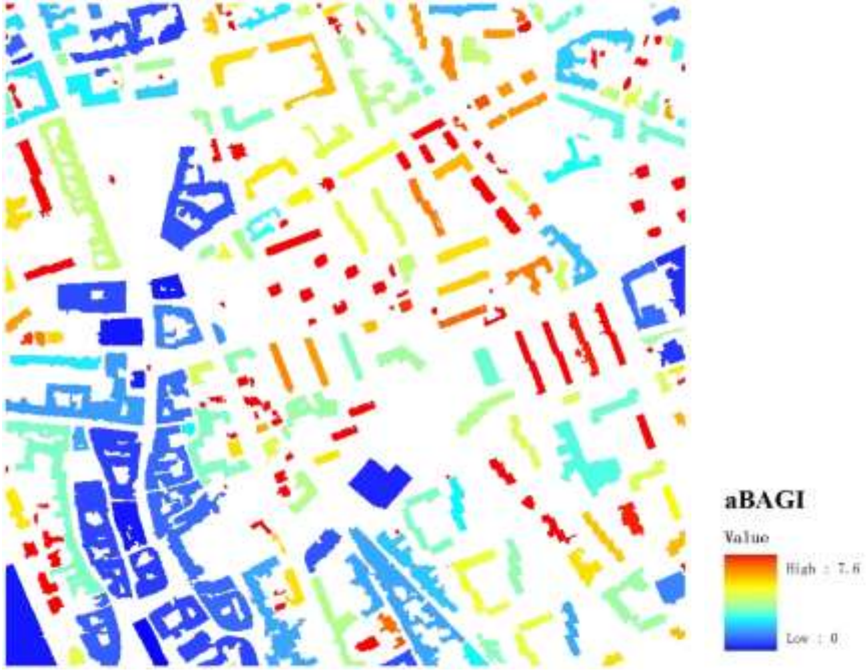


3. Implementation of Research

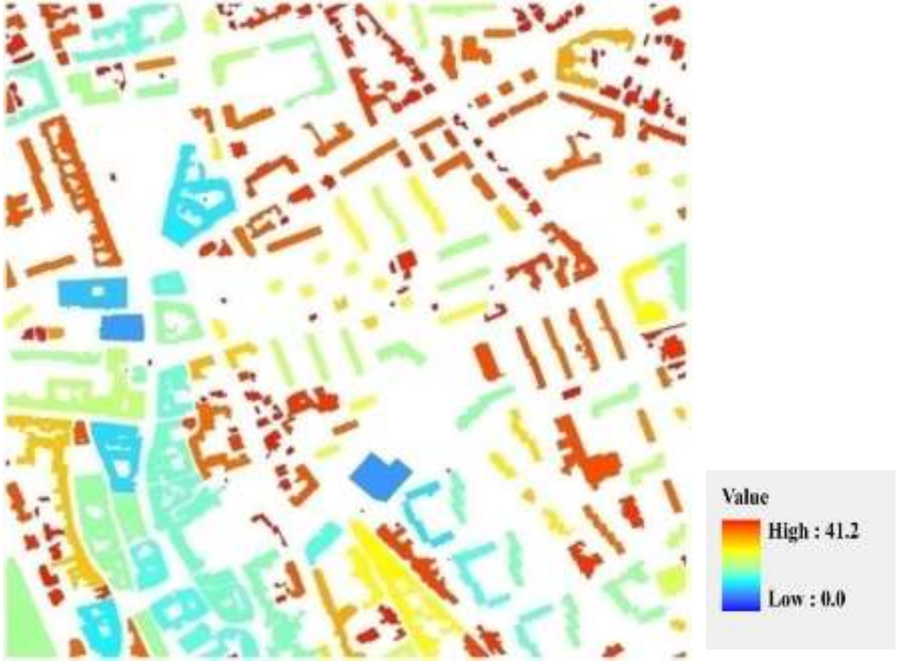
Building's Accessibility to Green Space Index

$$eBAGI_{LAI} = \frac{\sum_i area_i + 3\sum_j area_j + 6\sum_k area_k}{length_i} \qquad aBAGI_{LAI} = \frac{\sum_i area_i + 3\sum_j area_j + 6\sum_k area_k}{building\_area_i}$$

***$area_i$* is the area of grass, *$area_j$* is the area of shrub, *$area_k$* is the area of tree.**



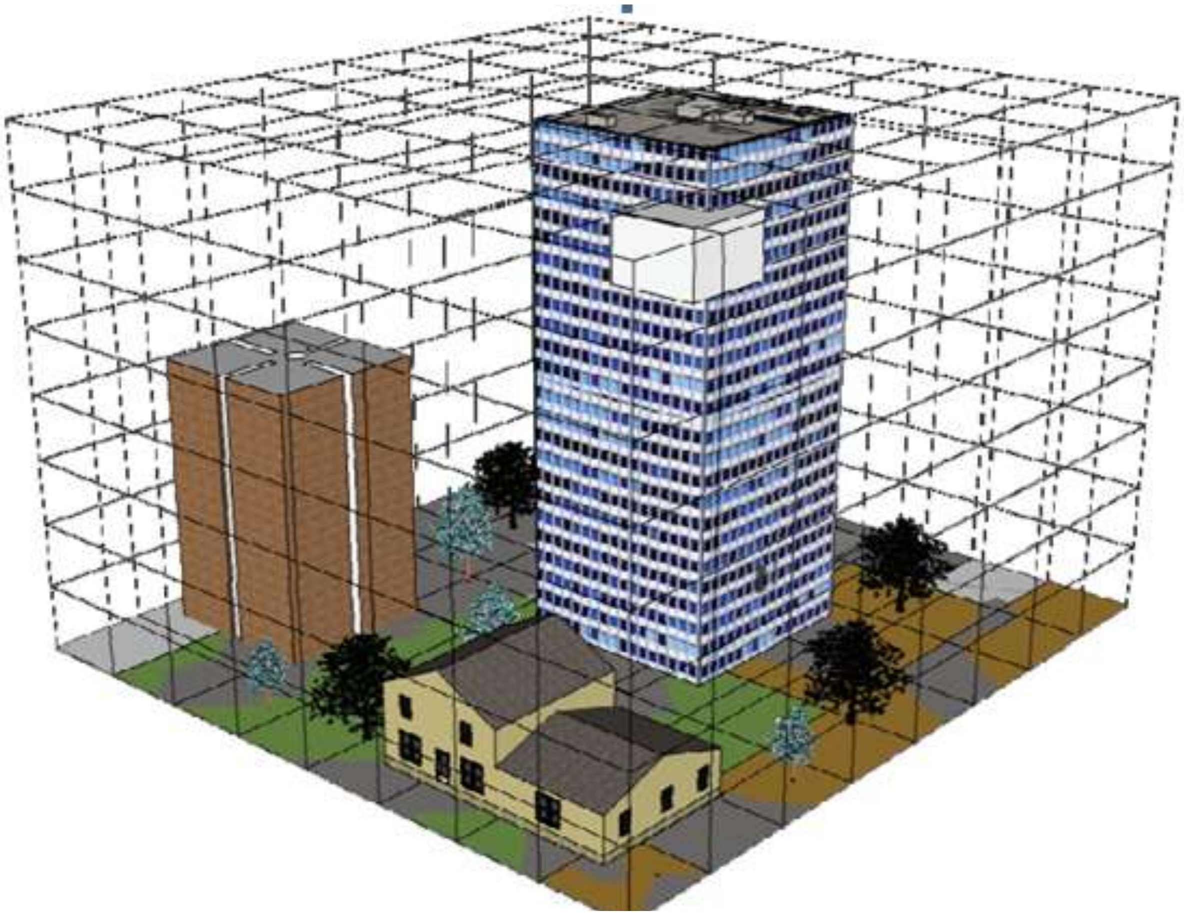
aBAGI



$aBAGI_{LAI}$

3. Implementation of Research

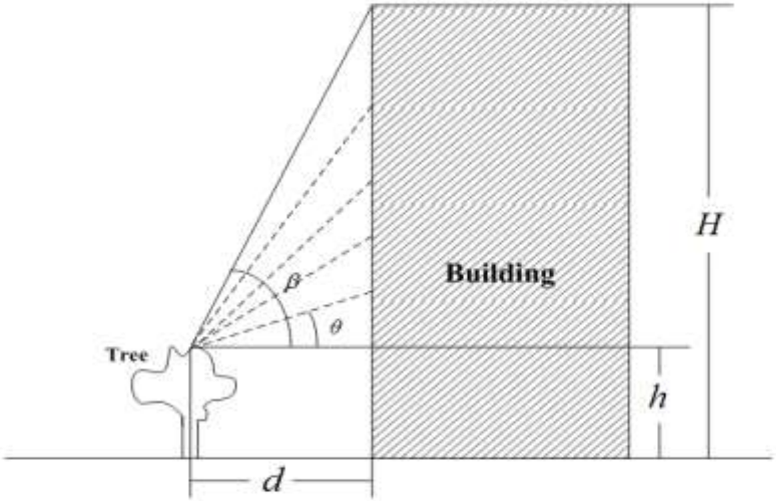
Building's Accessibility to Green Space Index



Spatial configuration between buildings and urban green

3. Implementation of Research

Building's Accessibility to Green Space Index



$$\beta = \arctan\left|\frac{H-h}{d}\right|$$

$$D = \frac{\int_0^\beta \frac{d}{\cos\theta} d\theta}{\beta}$$

$$D = \frac{d}{\beta}\int_0^\beta \frac{1}{\cos\theta} d\theta$$

$$D = \frac{d}{\arctan\left|\frac{H-h}{d}\right|}\ln\frac{|H-h| + \sqrt{(H-h)^2 + d^2}}{d}$$

Proximity model of building and urban green

When assuming the height of grass is zero, equation D can be transformed into

$$D = \frac{d}{\arctan\frac{H}{d}}\ln\frac{H + \sqrt{H^2 + d^2}}{d}$$

3. Implementation of Research

Building's Accessibility to Green Space Index

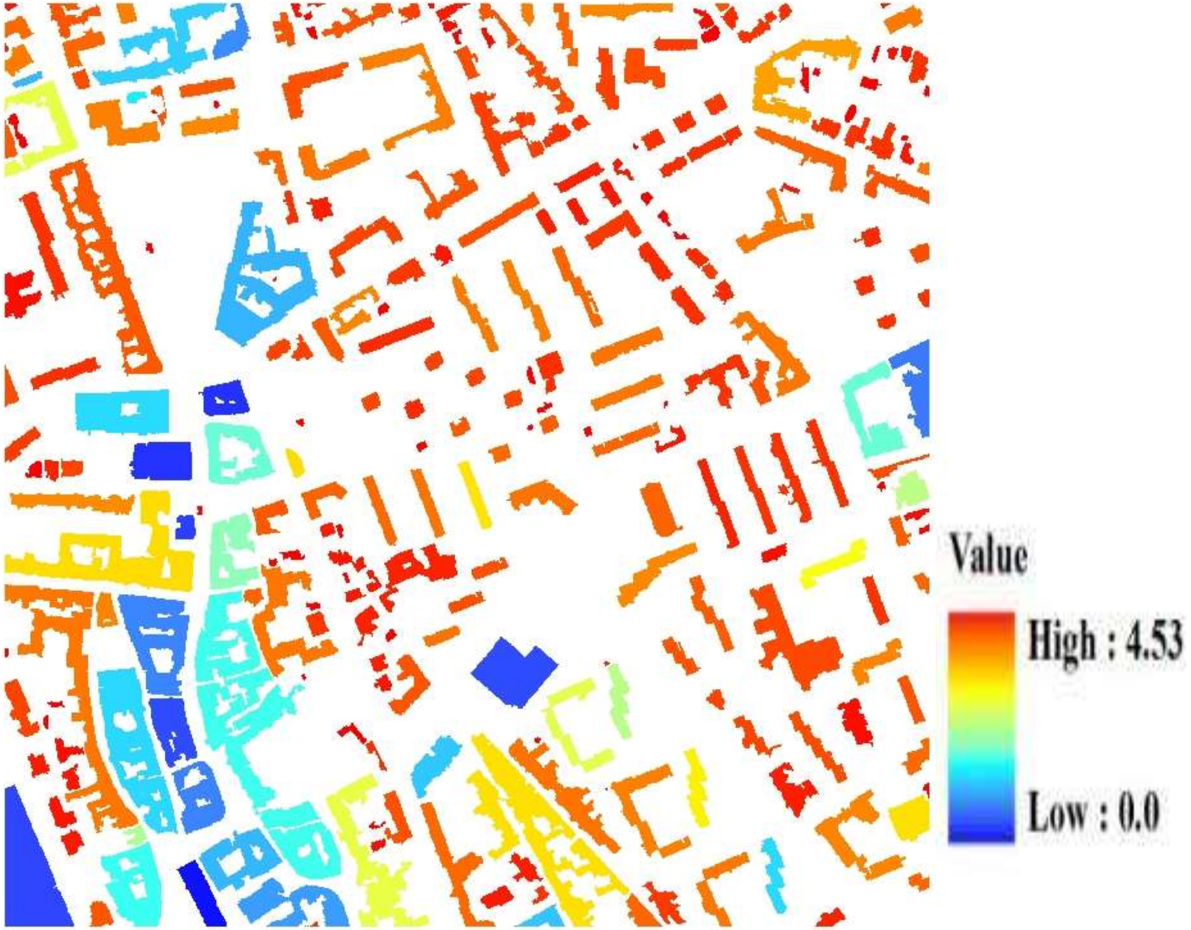
- **D is the modified distance between buildings and their nearby vegetation based on considering height of buildings and vegetation.**
- **Furthermore, it is better to use the lateral area and volume of buildings to describe the possibility of buildings's contacting urban green than using their perimeter and occupied area.**
- **Thus, *3D-BAGSI* , three Dimensional Building's Accessibility to Green Space Index was developed, it can be calculated as the following formula:**

$$3D-BAGSI = \frac{area_i}{Build\_Area_i}$$

3. Implementation of Research

Building's Accessibility to Green Space Index

$$3D-BAGSI = \frac{area_i}{Build\_Area_i}$$



Distribution of *3D-BAGSI*

3. Implementation of Research

Building's Accessibility to Green Space Index

- ***3D-BAGSI*** **is a new quantitative measurement of urban green space and human's accessibility to green space. Different from the traditional percentage method,** ***3D-BAGSI*** **is a human oriented method.**
- ***3D-BAGSI*** **combines the proximity to the vegetation, the spatial configuration at three dimensions between green space and the buildings to measure green space.**

3. Implementation of Research

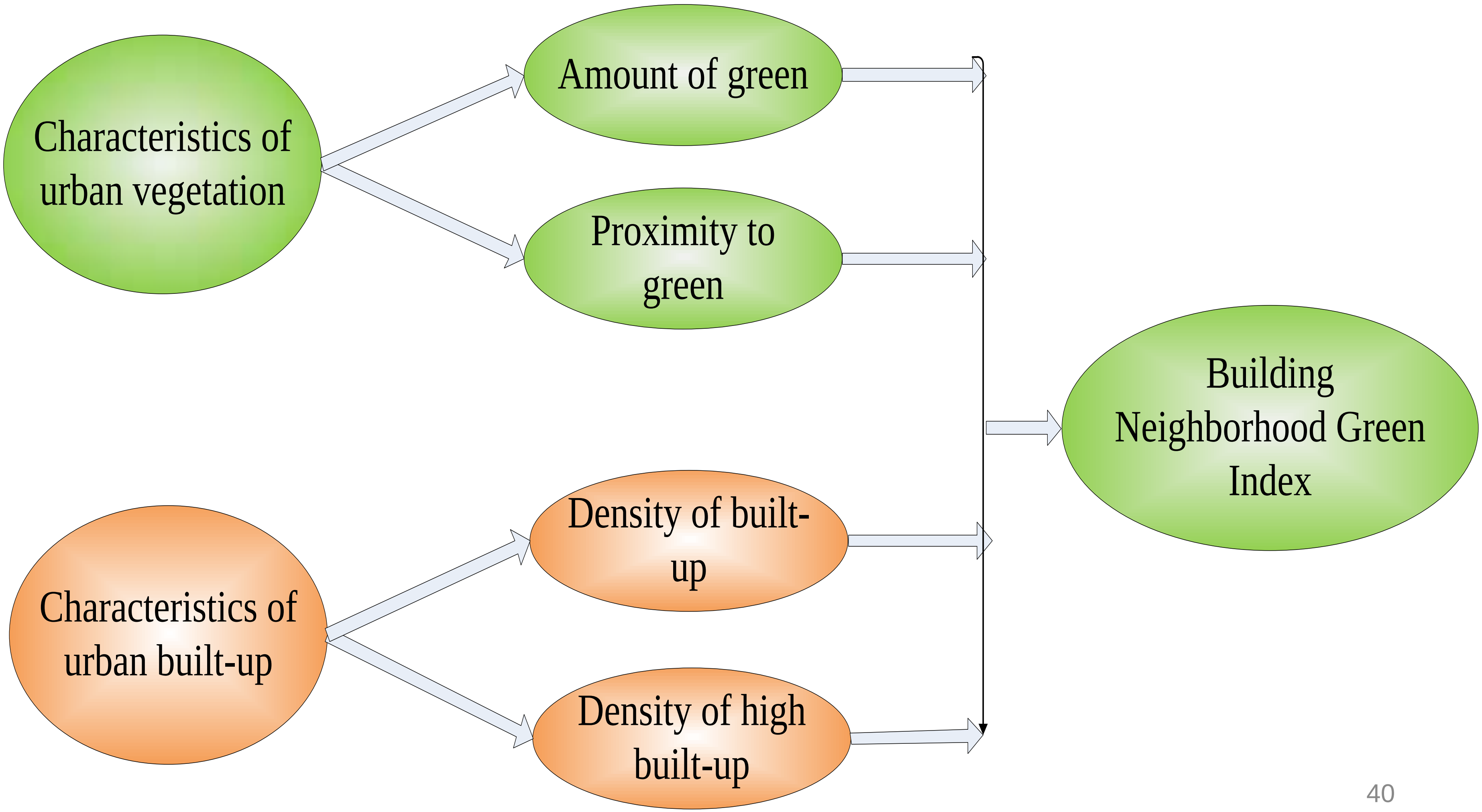
Building Neighborhood Green Index

Building Neighborhood refers to the certain area of homogeneous or same characteristics, whether in terms of ethnicity, housing, type of development , etc. Building Neighborhood Green Index（BNGI） can reflect the degree of resident enjoying the urban green space.

Based on neighborhood level, the urban green can be described with two parameters, amount of green and proximity to green. Similarly, urban buildings neighborhood level can be described also with two parameters, building density and high building density.

3. Implementation of Research

Building Neighborhood Green Index



3. Implementation of Research

Building Neighborhood Green Index---Green Index

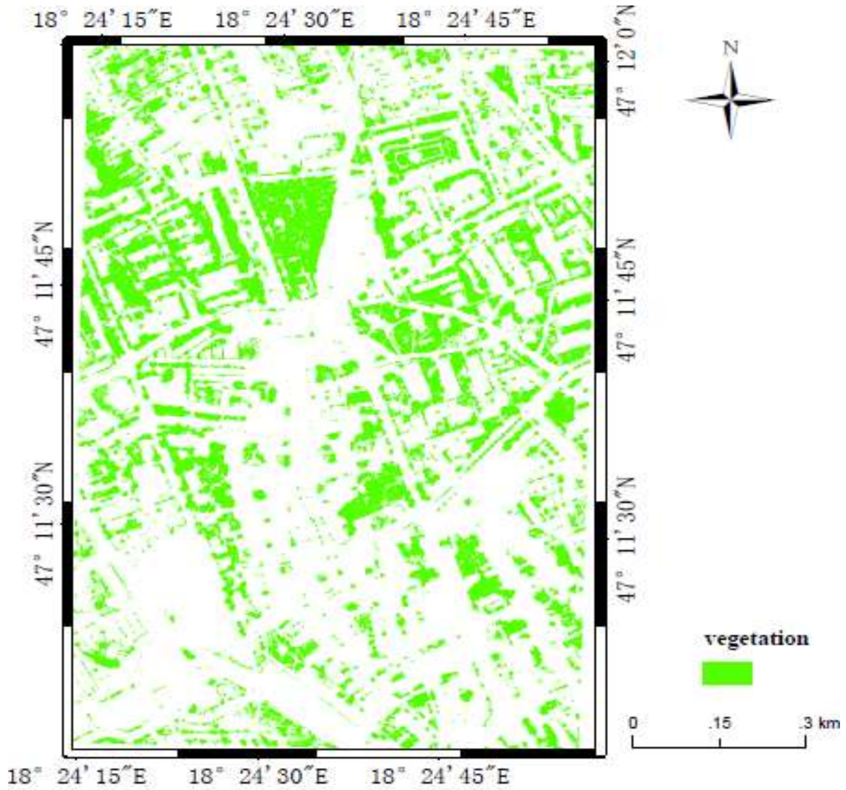
NDVI was retrieved with multispectral images and the vegetation thematic with green information can be achieved further through calculating the threshold by OTSU method.

$$GI=A_{green}/A_{buffer}$$

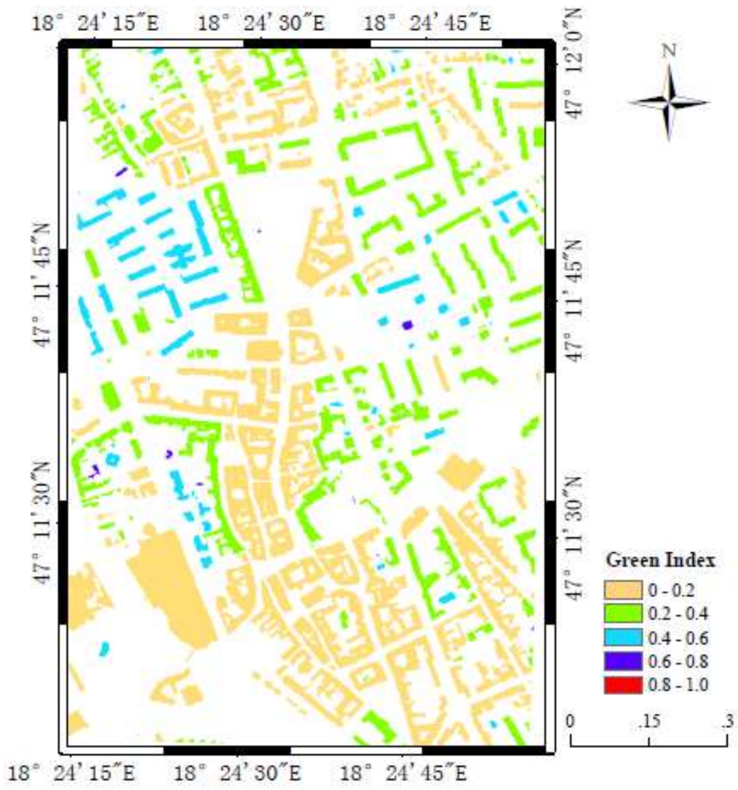
- **A_{green} is green area in the buffer of single building**
- **A_{buffer} is the buffer area of single building (including the area of the building).**

3. Implementation of Research

Building Neighborhood Green Index---Green Index



Green distribution in study area



Green Index distribution in study area

3. Implementation of Research

Building Neighborhood Green Index---False Built –up Density

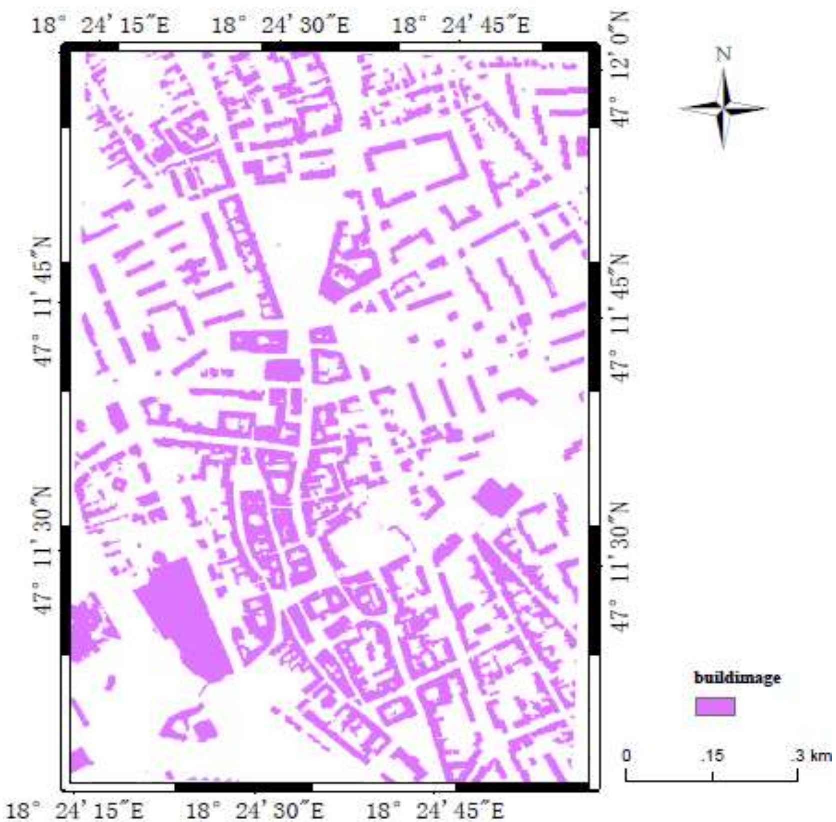
Corse building information was extracted through combining NDVI with Lidar data. Then , the voting method was used to correct the building information combined with segmentation result further. Finally, the building height was calculated through building thematic and DSM.

$$\text{False built-up density} = 1.0 - A_{build} / A_{buffer}$$

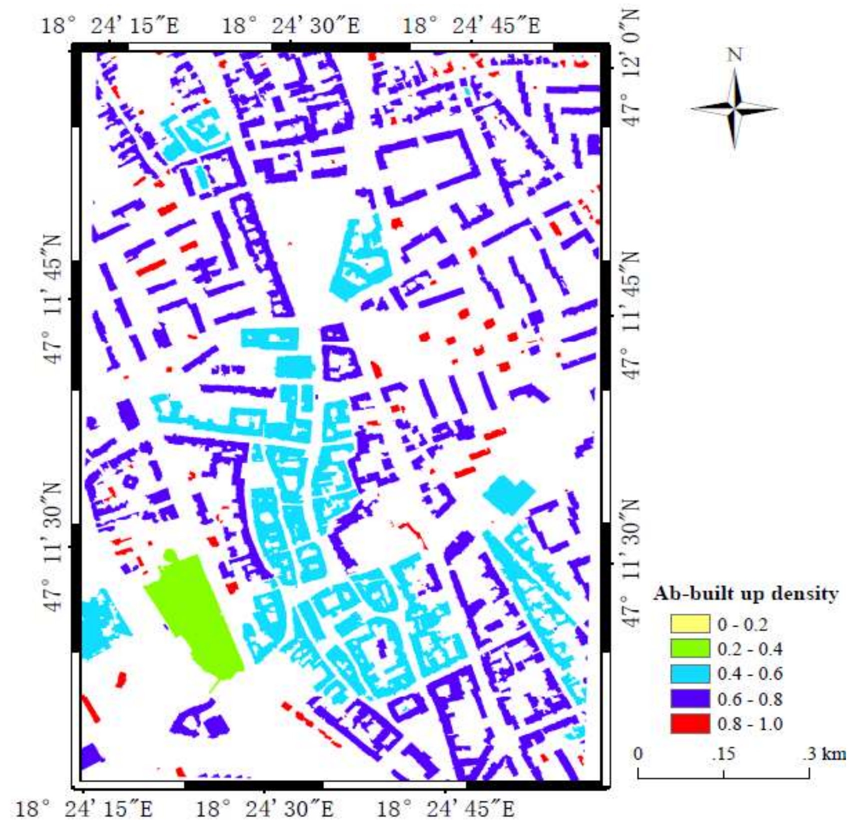
- **A_{build} is building area in the buffer of single building**
- **A_{buffer} is the buffer area of single building(including building area).**

3. Implementation of Research

Building Neighborhood Green Index---False Built –up Density



building distribution in study area



False building density in study area

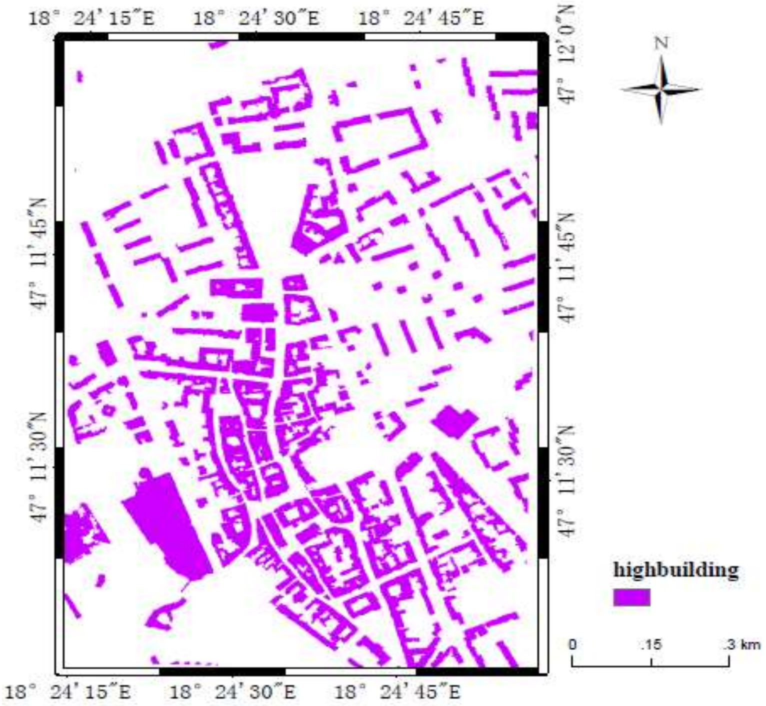
3. Implementation of Research

Building Neighborhood Green Index---False Built –up Density

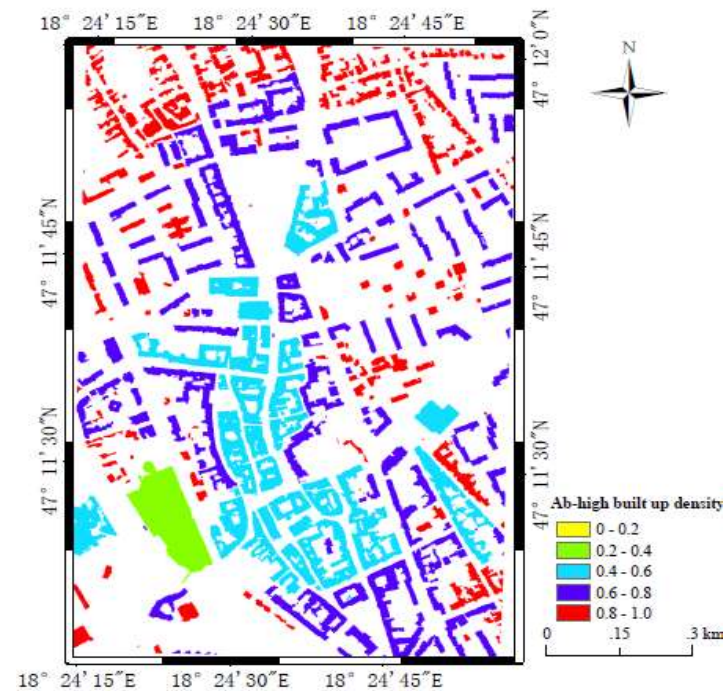
Mean height of building was achieved.

False high built-up density=1.0- $A_{H\text{-}build}/A_{buffer}$

- $A_{H\text{-}build}$ **is high building area in the buffer of single building;**
- A_{buffer} **is the buffer area of single building(including the building area).**



High building distribution in study area

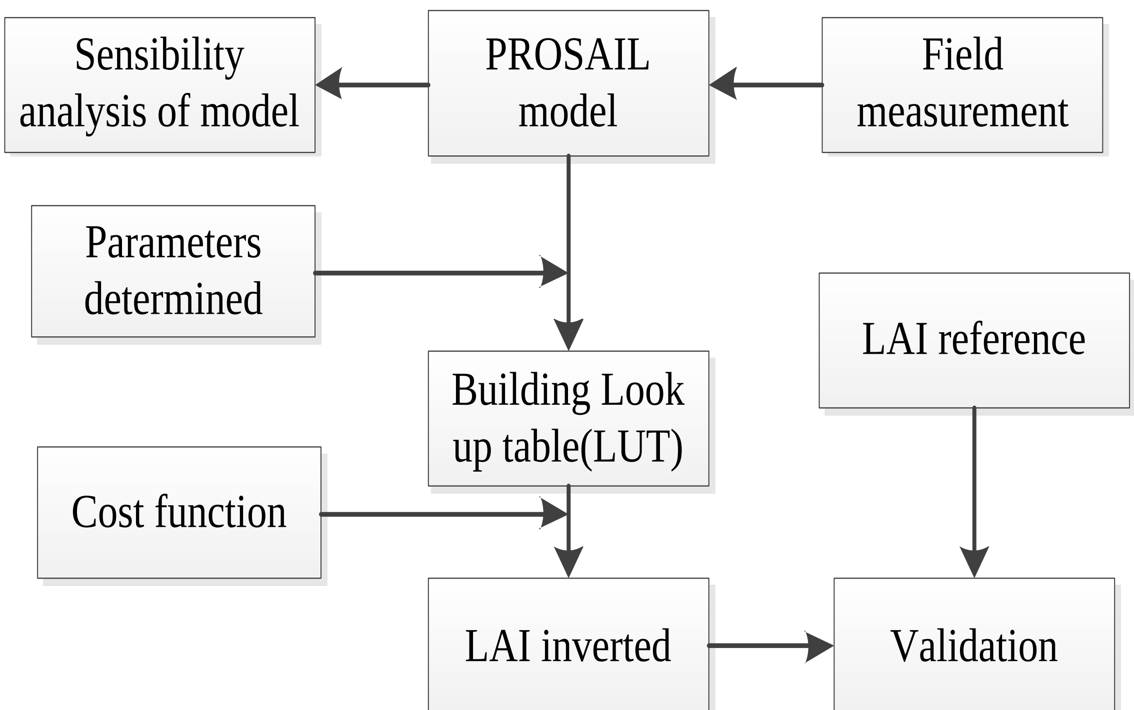


False high building density in study area

3. Implementation of Research

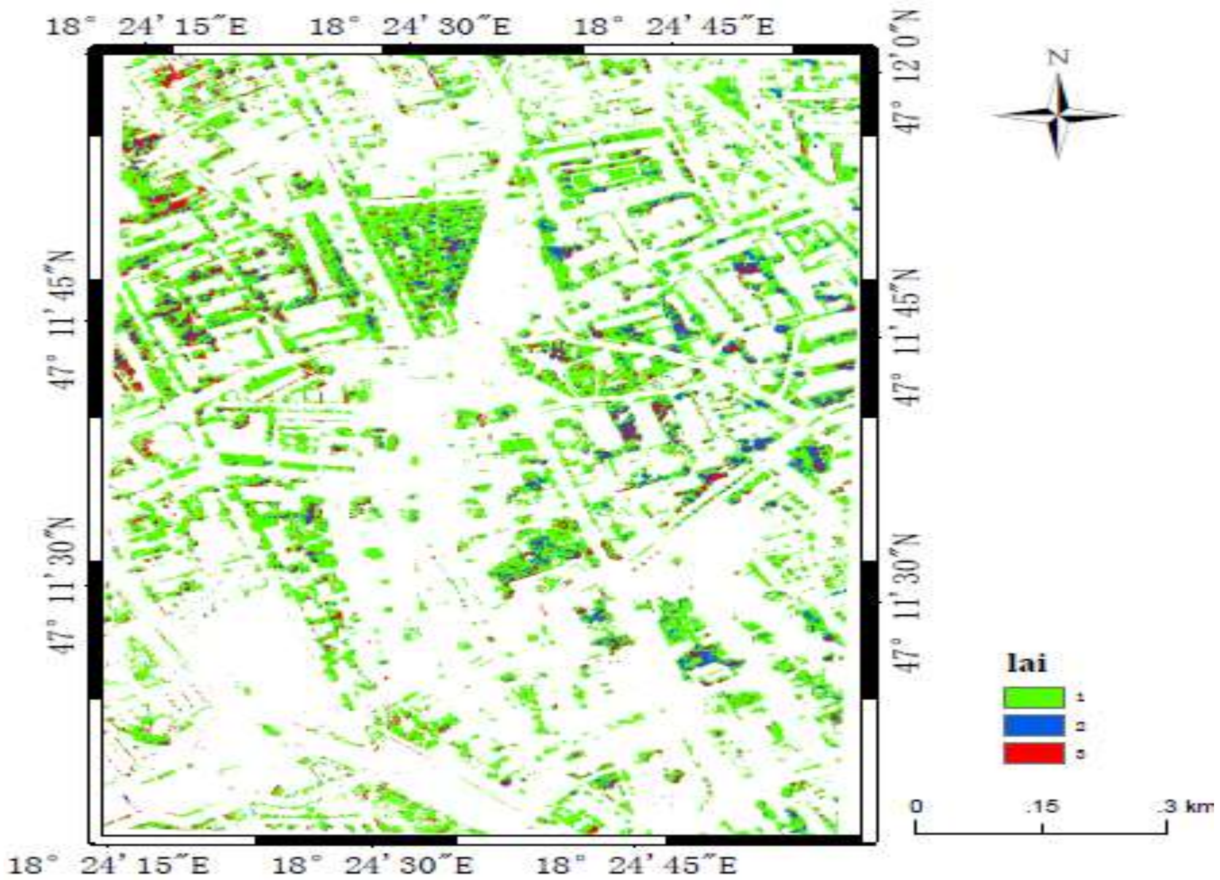
Building Neighborhood Green Index---Leaf Area Index Retrieval

After sensibility analysis of PROSAIL model, and consulting LOPEX'93（Leaf Optical Properties Experiment）data base and knowledge spectrum base of typical surface features, The LUT was built up and LAI was retrieved.



3. Implementation of Research

Building Neighborhood Green Index---Leaf Area Index Retrieval



Leaf Area Index Retrieval Result in study area

3. Implementation of Research

Building Neighborhood Green Index-----Proximity to Green

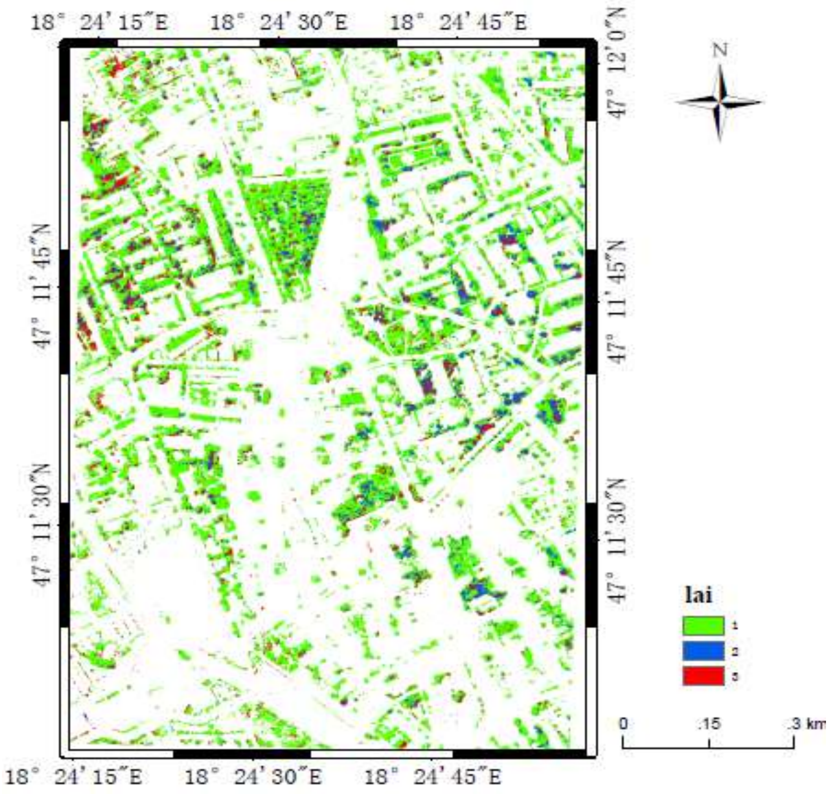
According to the LAI value, the vegetation was classified into different types. And the Degree of ecological Benefit Exposure to Vegetation （DBEV) were defined as the following.

$$\text{DBEV} = \sum_{j=1 \text{ } to \text{ } 3} W_j \times P_j$$

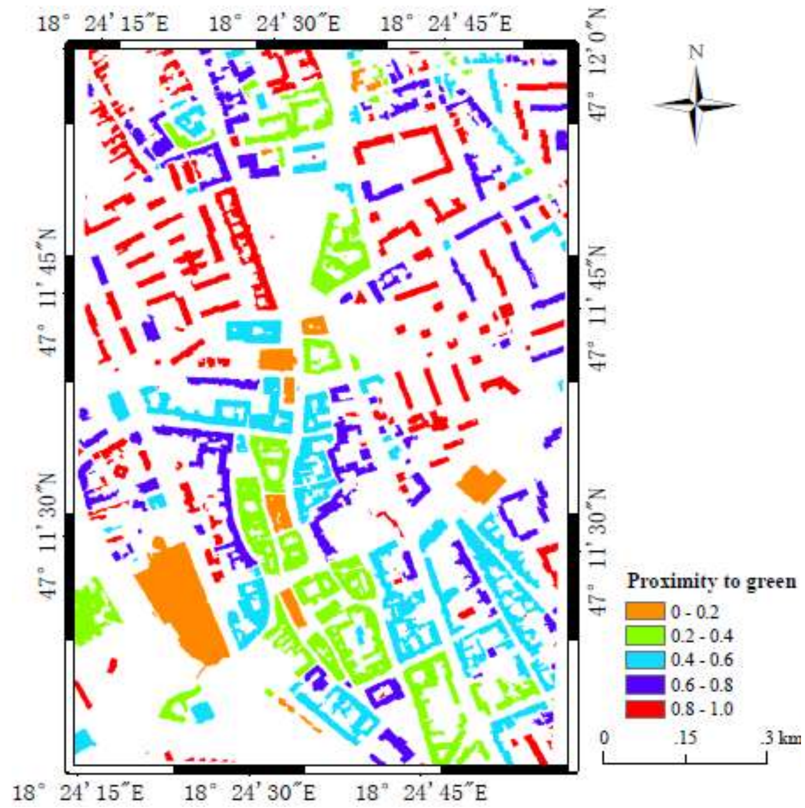
Where, Pj（j=1,2,3）is the ratio between gross area of exposure to different kind of vegetation type and area of buffer of single building. Wj is the weight of Pj.

3. Implementation of Research

Building Neighborhood Green Index



Leaf area index in study area



Proximity to green in study area

3. Implementation of Research

Building Neighborhood Green Index

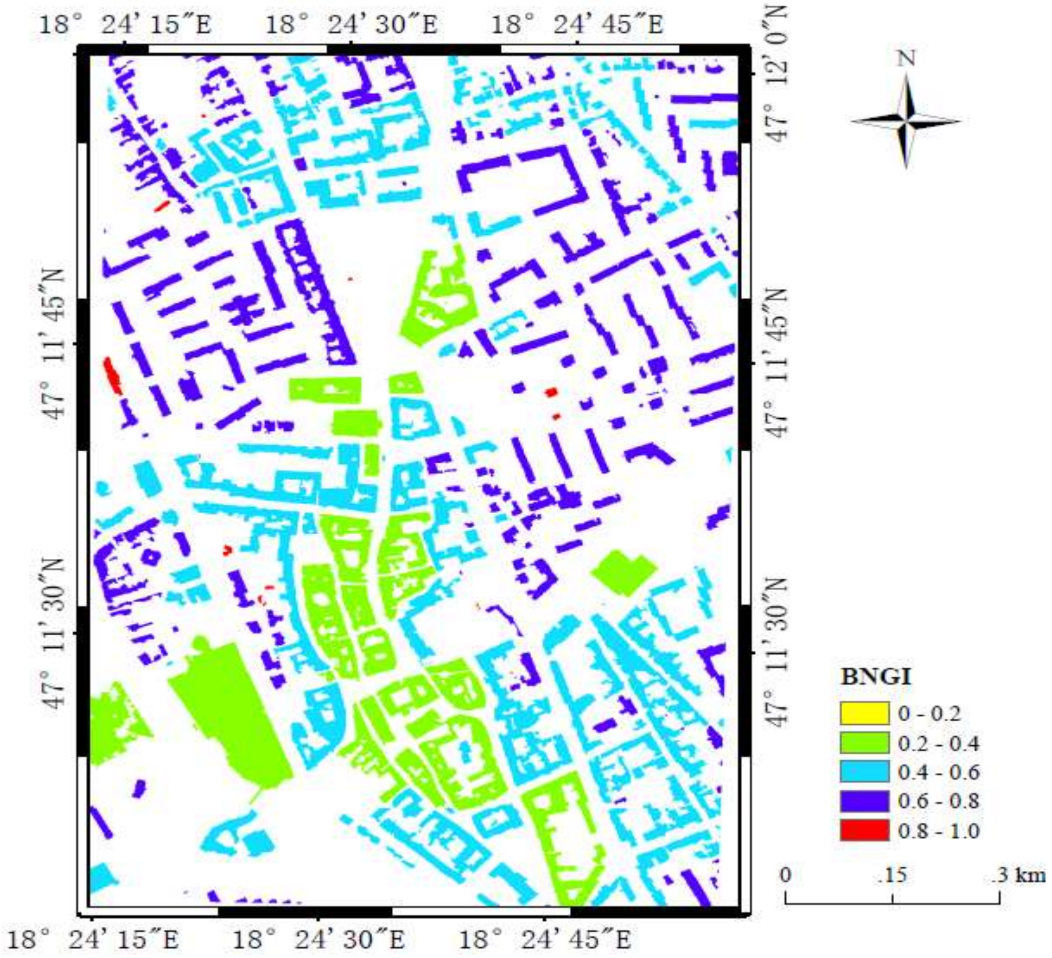
This study mainly considered four factors: green index, proximity to green, building density and high building density. Meanwhile, the weights of four factors are different.

$$BNGI = \sum_{j=1\ to\ 4}^{i=1\ to\ n} W_j \times P_{ij}$$

- **Pij （j=1,2,3）represents the values of green index, proximity to green, building density and high building density respectively.**
- **Wj is the weight of Pij, j represents four factors. i represents the relative single building.**

3. Implementation of Research

Building Neighborhood Green Index



Build Neighborhood Green Index in study area

3. Implementation of Research

Validity of Building Neighborhood Green Index

mixed-use district (test1) **Resident area (test2)** **Downtown (test3)**

Areas with different functions of building

3. Implementation of Research

Validity of Building Neighborhood Green Index

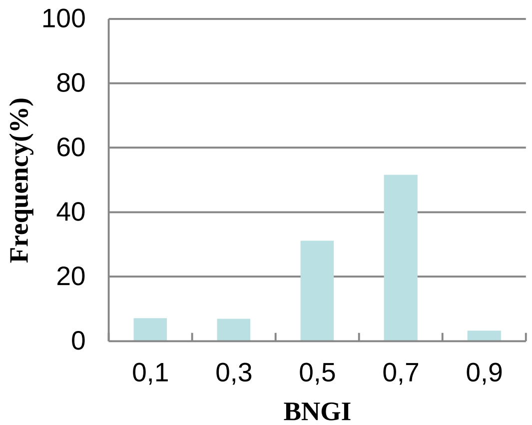
		BNGI	GI
Test1	Mean	0.57	0.24
	SD	0.20	0.17
	Median	0.62	0.24
Test2	Mean	0.65	0.31
	SD	0.15	0.12
	Median	0.67	0.32
Test3	Mean	0.51	0.24
	SD	0.22	0.20
	Median	0.50	0.18

1、The SD value of resident area was lowest and the value of downtown was highest, which showed that the change of BNGI was most stable in resident area while least stable in downtown. It may be because of the uneven distribution of green in the area.

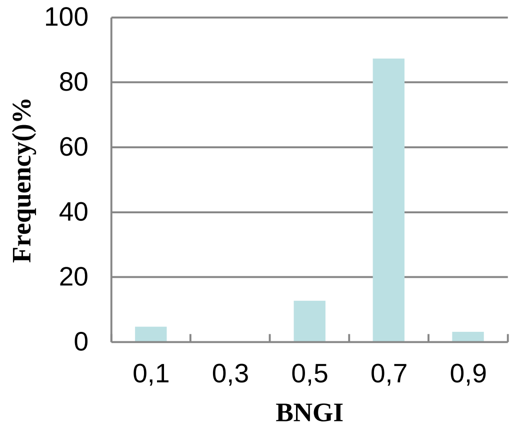
2、The mean value and median value of BNGI in resident area were highest, which implied that people in the area enjoyed more green space and has high green space quality, while in the downtown the mean value and median value of BNGI were lowest.

3. Implementation of Research

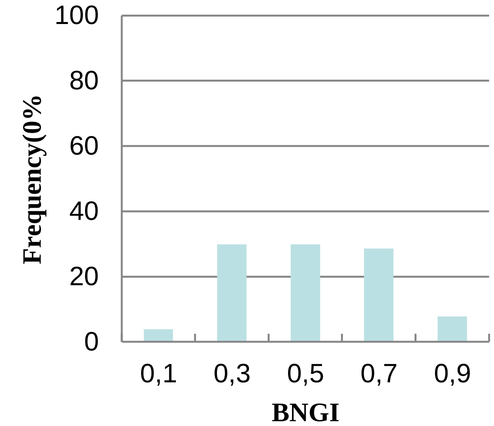
Validity of Building Neighborhood Green Index



(a)BNGI histogram in mixed-use district



(b)BNGI histogram in resident area

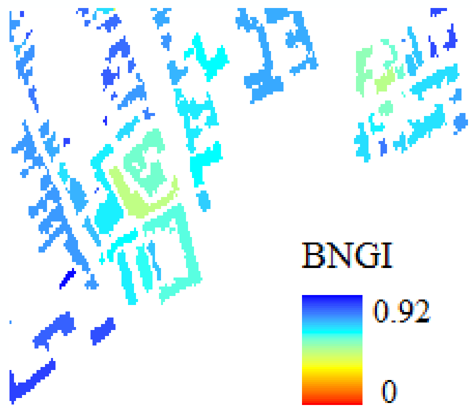


(c)BNGI histogram in downtown

- **It is found that BNGI in mixed-use district mostly are from 0.6 to 0.8 and it counts about 50%. BNGI in resident area are from 0.6 to 0.8 and counts about 85%，while BNGI in downtown mostly varied from 0.2 to 0.8 and counts about 30% respectively in different ranges.**
- **It showed that the BNGI value in resident area is highest, while the BNGI value in downtown least and mixed-use district next to it.**
- **Conclusion can drawn that people in resident area enjoys more urban green space than others.**

3. Implementation of Research

Areas with different traits of building distribution



Study area in Székesfehérvár

High building and high density area test1

Low building and low density area test2

High building low density area test3

3. Implementation of Research

Areas with different traits of building distribution

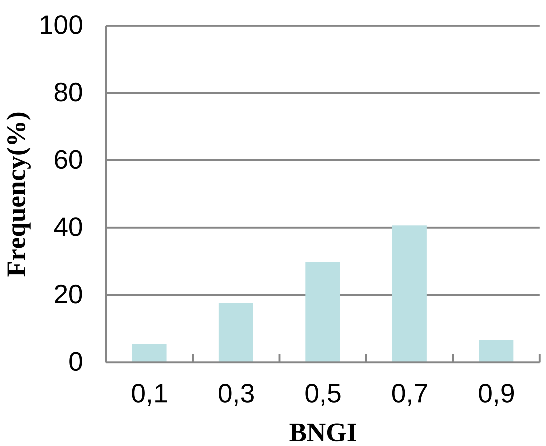
		BNGI	GI
Test1	Mean	0.55	0.25
	SD	0.21	0.19
	Median	0.59	0.23
Test2	Mean	0.63	0.25
	SD	0.15	0.13
	Median	0.66	0.26
Test3	Mean	0.59	0.25
	SD	0.19	0.14
	Median	0.65	0.26

1、In high building high density area (test1), mean value and median value of were lowest, and standard deviation of BNGI was highest , it showed that the resident in the area enjoying least green space;

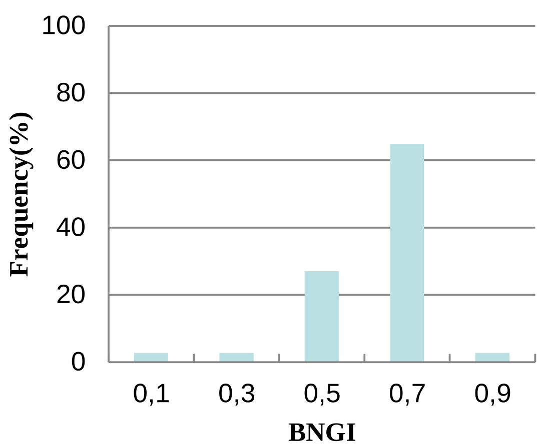
2、In three different areas of city, the value of BNGI is not equal when the value of GI is same, So BNGI showed more practical, which took more factors into account, including green distribution and building distribution.

3. Implementation of Research

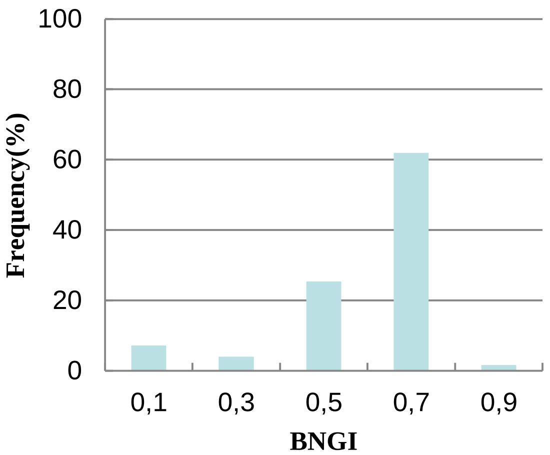
Areas with different traits of building distribution



(a)BNGI in high building high density area



(b)BNGI in low building high density area



(c)BNGI in high building low density area

- Mostly in high building/high density area are from 0.6 to 0.8,and it counts around 40%, and it counts around 20% from 0.2 to 0.4.
- Mostly BNGI in low building/high density and high building/low density area are from 0.6 to 0.8, and count 60% and 60% respectively.
- It showed that the BNGI in high building/high density area was relative low, while the BNGI in low building/high density and high building/low density area were relative high.
- Conclusion can be drawn that people in high building/high density area enjoys less urban green space than others.

3. Implementation of Research

Areas with different distribution of BNGI and GI

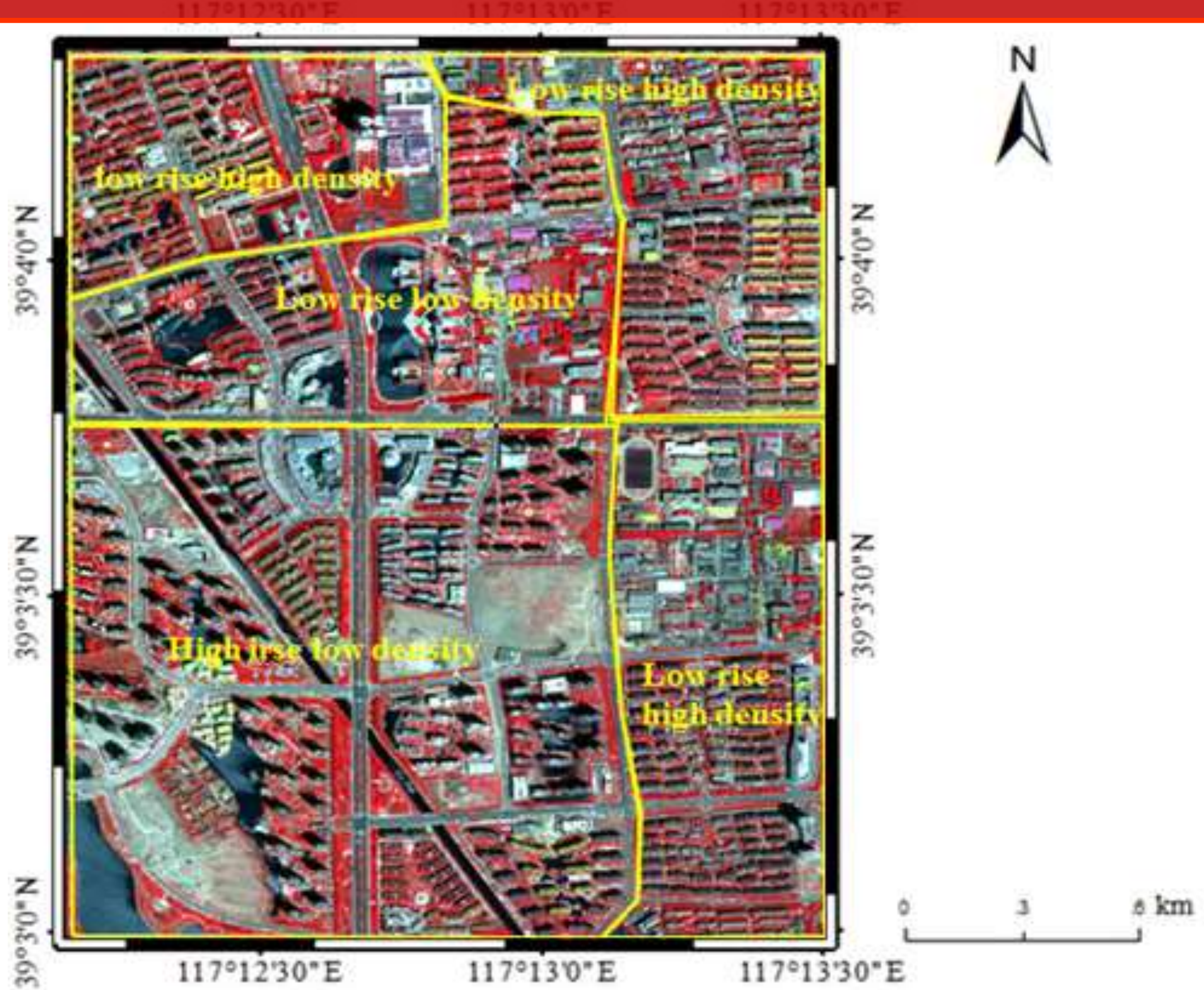
Different statistics in various neighborhoods

Index type	High building low density（n=117）		Low building high density（n=72）		High building high density（n=86）	
	BNGI	GI	BNGI	GI	BNGI	GI
[0,0.25]	0	41.03%	0	44.29%	1.16%	51.16%
(0.25,0.5]	9.40%	55.56%	8.33%	51.43%	29.07%	36.05%
(0.5,0.75]	80.34%	3.42%	73.61%	4.29%	54.65%	11.63%
(0.75,1]	10.26%	0.01%	18.06%	0.01%	15.12%	1.16%
Total	100%	100%	100%	100%	100%	100%

It is found that BNGI was more practical and reliable. Unlike the distribution of BNGI and GI in the high building/low density and low building/ high density area, the gap of the proportion between BNGI and GI in（0, 0.5）decreased obviously. So conclusion can be drawn that BNGI consider more factors including building distribution and was more practical.

3. Implementation of Research

Adaptability of Building Neighborhood Green Index(BNGI) Model



Various area types of different building distribution of Tian jin city

3. Implementation of Research

Adaptability of Building Neighborhood Green Index(BNGI) Model

BNGI Statistics in various kinds of area in Tianjin

Area	GI			BNGI		
	Mean	SD	Median	Mean	SD	Median
High building low density	**0.3072**	0.1320	0.3162	**0.5437**	0.0963	0.5389
Low building low density	0.3680	0.1208	0.3417	0.5847	0.0839	0.5653
Low building high density	**0.3073**	0.1051	0.3156	**0.5094**	0.0526	0.5037

The values of GI were almost same between high building/low density area and low building/high density area, While the values of BNGI were 0.5437 in high building/low density area and 0.5094 in low building/high density area respectively. It showed that BNGI considered more factors including building distribution and proximity to green, and was more practical.

3. Implementation of Research

Adaptability of Building Neighborhood Green Index(BNGI) Model

Different statistics in various kinds of area in Tianjin

Index type	High building low density （n=156）		Low building high density （n=194）		Low building low density （n=244）	
	BNGI	GI	BNGI	GI	BNGI	GI
[0,0.25]	0	34.62%	0	24.23%	0	17.62%
(0.25,0.5]	33.33%	58.33%	47.94%	71.65%	12.3%	64.34%
(0.5,0.75]	64.74%	7.05%	52.06%	4.12%	82.38%	18.04%
(0.75,1]	1.93%	0	0	0	5.32%	0
Total	100%	100%	100%	100%	100%	100%

Unlike the distribution of BNGI and GI in the high building/ low density and low building/high density area, the gap of the proportion between BNGI and GI in （0, 0.5）increased obviously in low building/low density. It proves that the Model is suitable in Tianjin also.

Outline

1. Research Background and Necessity
2. Research Contents
3. Implementation of Research
4. Achievements and Conclusions
5. Application Prospects

4. Achievements and Conclusions

Achievements

（1）Building Urban Green Space Index model

Establishing Urban Green Space Index model based on building scale, which consider distribution of green、proximity to green、distribution of buildings.

（2）Validation for urban green space index model

Validation is carried out by comparing mean value and standard deviation of urban green space index and traditional green index in different study areas and comparing results with measurements in study areas.

（3）Adaptability for Urban Green Space Index model

Urban green space index model was applied to different cities and different areas in the same city. Analyzing the adaptability of the model in different areas with different traits.

4. Achievements and Conclusions

Highlights

- **The developed model not only was carried out based on building scale, but also takes into account the characteristics of urban vegetation and building.**

- **The developed model consider the proximity to green based on LAI inversion result, which makes the model more practical.**

- **Validation for the developed model research was conducted in different areas with different traits of building, which was seldom realized by previous studies.**

The developed index reflects the importance of distribution of green areas in specific neighborhoods and environments. It can account for the proximity and spatial arrangement of green spaces within the areal units besides; it also can address the vertical dimension and density of urban building.

Outline

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5. Application Prospects

- **The developed UGS index provides decision support to evaluate, quantify and compare civilians' living environment in different cities through evaluating the distribution of green spatial structure.**
- **The UGS index can be an input to model and evaluate future scenarios better aligned to principle of sustainable development.**
- **The application of UGS index can help to undertake a range of neighborhood greening strategies and will be a useful input for urban planning.**

Thank you!

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Thanks for your attention