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Article

Recognition and Spatial Distribution of Rural Building in Vietnam

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Abstract: The research on the distribution of rural buildings is one of the fundamental works of urban-rural development in Vietnam. Adopting Mask R-CNN deep learning framework and collecting sub-meter remote sensing images, this research used a remote sensing interpretation model of rural buildings trained based on East Asian characteristics of rural buildings and successfully recognized about 2.87 million rural buildings in 34 Vietnamese provincial administrative districts with a total area of rural buildings of 2,492 million square meters. The reliability of the identification results was verified by manual detection and quantitative statistics, and a multi-scale database of rural buildings in Vietnam based on individual rural buildings was created. Based on the database, this paper analyzes the distribution characteristics of rural buildings and summarizes characteristics of rural buildings distribution at the country, regional, and provincial scales. The identification results lay the foundation for the next study of urban-rural relations in Southeast Asia and the construction of a basic database on villages.

Keywords: rural building; remote sensing interpretation; density; distribution; Vietnam

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1. Introduction

Vietnam's economy has been dominated by smallholder farming for a long time during its economic development [1]. Rural buildings are the core elements of rural settlements in Vietnam, and are deeply embedded in the process of modernization and development, underpinned by a smallholder economy [2]. With the rapid economic growth and urbanization in Vietnam [3], land use and landscape patterns in rural areas have undergone significant changes [4], which can be seen in the evolution of rural settlement patterns. The individual rural building is an important asset for rural families [5,6], and its quantity, type, and quality reflect the level of economic development of the local community [7]. The spatial distribution pattern of rural buildings, as the main living space and activities of the residents, to some extent reflects the population distribution in rural Vietnam [8,9]. Differences in the distribution of population and rural buildings can provide new perspectives for the study of urban-rural population movements [10–12].

Vietnam is a country with a vast rural hinterland and a rich agricultural heritage [13–15]. As a result, there are a large number of rural settlements that are widely dispersed [16]. However, there is a limited amount of data available on rural areas in Vietnam due to the low level of rural informatization [17]. Currently, the available data on rural areas mainly consists of macro-sampling survey statistics conducted by the Vietnamese government [18]. Obtaining small-scale rural data is best done through traditional rural community research [19–22]. Nonetheless, there is a challenge in transitioning from specific to general and local to overall perspectives [23]. For large-scale rural field investigations, significant time and manpower resources are required, and the universality and objectivity of the findings may be subject to scrutiny [24,25]. As such, current studies on rural Vietnam mainly focus on case studies that examine the interplay between regions, villages, rural buildings, population dynamics, and social culture [26–28]. Unfortunately, there has been no comprehensive exploration of the multi-scale spatial distribution pattern of rural buildings in Vietnam.

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Currently, with the rapid advancement of remote sensing technology and the increasing maturity of deep learning techniques [29], it has become feasible to extract large-scale, multi-scale, and high-precision information about rural buildings [30,31]. To acquire extensive individual data on rural buildings, an efficient approach involves utilizing remote sensing and machine learning methods to effectively extract roof information from high-precision satellite images [32]. House roofs possess distinct geometric features, texture structures, and spatial semantic relationships [33], which enable the extraction of specific targets from remote sensing imagery [34]. The application of machine learning techniques for image segmentation and feature extraction of building roofs in high-resolution satellite images provides valuable technical support in identifying human settlements, monitoring land encroachment in rural areas, analyzing spatial evolution patterns, and estimating solar power potential associated with buildings. [35–38]. Instance segmentation is a significant branch within the field of building recognition using machine learning approaches [39]. By employing the Mask R-CNN instance segmentation framework to detect building targets in remote sensing images and selecting/segmenting buildings along with their backgrounds within target frames [40], it becomes possible to obtain outlines for each building thereby achieving spatial localization while also determining their number and area [41]. However, current research efforts primarily focus on urban areas when it comes to building extraction tasks [42]. For instance, Stiller et al., employed a Mask R-CNN model to extract buildings in Santiago (the capital city of Chile) by utilizing augmented fine-tuned models resulting in high accuracy levels [43]. Tiede et al. employed the Mask R-CNN model [44] to extract residential buildings in Khartoum, Sudan from VHR satellite data. While foreign publicly available building datasets such as ISPRS [45], Massachusetts [46], and Inria [47] are predominantly located in urban areas, rural areas have received limited attention for rural building extraction due to their vast area and dispersed distribution [48], resulting in challenges of time-consuming and difficult building extraction.

Vietnam is in the rapid development stage of urbanization [49], and the study of the distribution pattern of rural buildings in Vietnam can provide reliable data support for the development of urbanization and the study of rural urbanization in Vietnam. Therefore, this paper aims to construct a Vietnamese rural buildings database as one of its key objectives. The identification of rural buildings at a granular scale can provide valuable insights into the fundamental patterns of rural settlement development in Vietnam, offering essential data for rural planning and agricultural production. By studying and analyzing rural buildings, it becomes possible to gain a better understanding of the living and production conditions of local rural residents, thereby providing crucial data support for the formulation of policies related to rural social security enhancement and poverty alleviation [50].

2. Methodology

2.1. Study area

Vietnam is a region of study situated on the eastern Indo-China Peninsula. It spans an area of 330,000 sq. km. and is home to nearly 100 million individuals[1]. It is bordered by China, Laos, and Cambodia. The topography of the country is defined by highlands and lowlands, with approximately three-quarters of the land being mountainous. The primary agricultural production areas are the Red River Delta and Mekong River Delta plains. In the northwestern region, the Truong Son Range extends from north to south [51]. (Figure 1)

Vietnam's urbanization rate in 2022 is about 39%, with an urban population of 38.3 million, an increase of 1.009 million from the previous year[2]. The rural population is 60.814 million, accounting for 62.9% of the total population.

Due to the complexity and diversity of topography and landscape in Vietnam, and the large north-south span and wide latitudinal distribution in Vietnam, it is beneficial to test the accuracy and

[1] Data Sources:https://data.worldbank.org/country/viet-nam

[2] Data Sources:https://data.worldbank.org/indicator/SP.URB.TOTL?locations=VN

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reliability of the interpretation model. On the other hand, the development of industrialization and urbanization has significantly changed the rural landscape and the spatial form of the countryside in Vietnam. and the refinement of rural data is important for conducting research on urban and rural development and population flow in Vietnam.

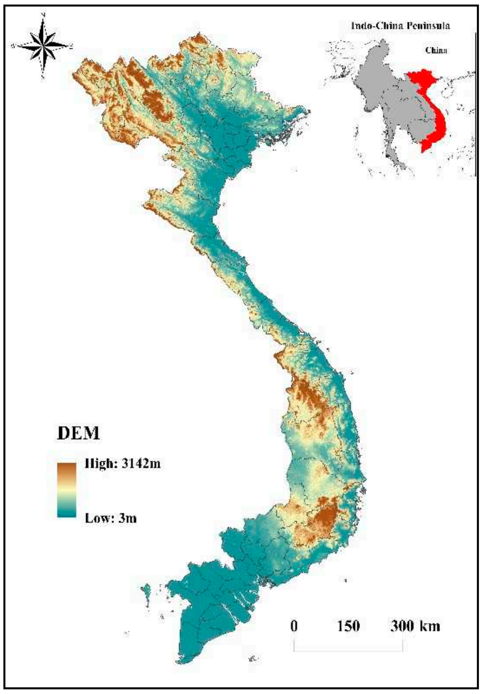

Figure 1. Location map of Vietnam.

2.2. Date sets

Google Earth satellite images are the core data source of this paper, with a resolution of up to 0.25m, which can accurately reflect the roof profile of rural buildings. The comprehensive nature of the Google image database facilitates future data iterations of the Vietnam database.

The core work of this study is to complete the identification and extraction of rural buildings throughout Vietnam. The study uses 0.5m resolution satellite images of the whole area of Vietnam. which can already meet the requirements of building identification. The years of the downloaded satellite images are 2019-2021, so the timeliness can be guaranteed.

Firstly, the study extracted building roof information for the whole of Vietnam, and then used the global urban boundary data mapped based on global impervious surface analysis by Li [52] to extract the rural areas of Vietnam, and identified these buildings within the area as rural buildings.

The rural population data used in the study were obtained from the 2020 and 2021 statistical yearbooks of General Statistics Office of Vietnam[3].

2.3. Method

Mask R-CNN is an instance segmentation framework proposed by He in 2017 [53]. This research is mainly based on the Mask R-CNN instance segmentation framework and uses machine learning and big data analysis to train a remote sensing interpretation model [54] for buildings, remote sensing interpretation of building satellite images (including housing and nonresidential buildings) in 63 provinces and municipalities of Vietnam, and completes vectorization work. To test the accuracy of the model and the results of rural building identification, after selecting rural areas, rural population statistics were used to test the interpreted rural building quantity data by using the Pearson correlation coefficient method, and manual verification was supplemented. Finally, we combined

[3] Data Sources: https://www.gso.gov.vn/en/data-and-statistics/

Gini coefficient, DEM data, and some data from the Vietnam Yearbook 2021 to analyze the distribution characteristics of rural housing in Vietnam.

2.3.1. Image Recognition

Example segmentation by Mask R-CNN model can be mainly divided into the following steps (Figure 2): First, the trained deep-learning model is used for feature extraction. The image is then input into resnet101 to get the feature map. ResNet 101 [55] is a convolutional neural network (CNN) for feature extraction that reduces hyperparameters while increasing their complexity and improving accuracy. After the CNN calculation, the anchor points of different sizes are evenly selected on the feature map. Calculate the size of the area of Interest (ROIs) for each anchor point and link it to the original image. This feature map shows a large number of candidate frame locations (e.g., area of interest or ROI), and it uses Softmax classification to identify the background and foreground of a given frame. The Region Suggestion Network (RPN) is used to screen out the irrelevant bounding boxes (BB) from the ROI and classify them into target labels and background labels. RPNS performs binary classification to identify background and target objects of interest to a certain extent. Then the bounding box regression is used to identify the true outline of the object. The ROIALIGN layer inputs feature maps and residual feature maps to generate fixed-size feature maps. The Roialign operation is a way to improve the efficiency of the ROI pool processing during RCNN feature extraction. It eliminates pixel offsets caused by the quantization process. Finally, it goes through two branches, the first for object classification and the second for frame regression. It uses a full join layer and a full convolutional network (FCN) to generate masks.

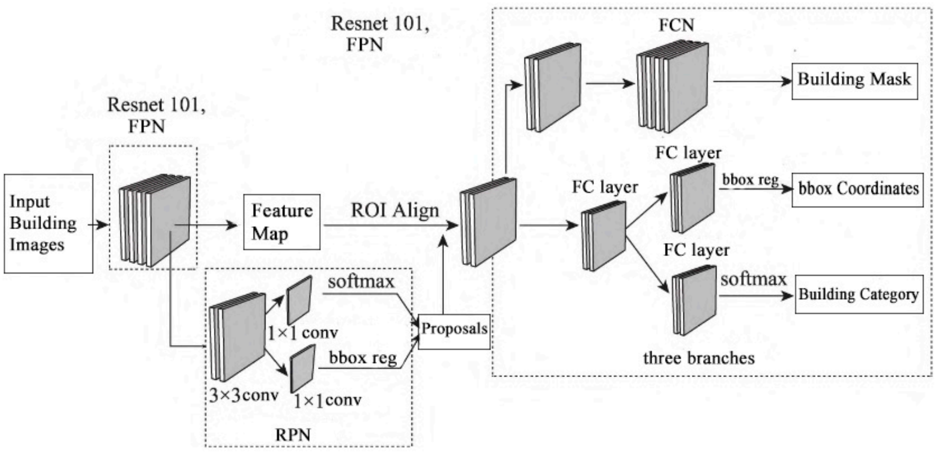

Figure 2. Mask R-CNN working principle diagram [56].

2.3.2. Model Training

Limited by the difference in image quality in different regions, the effect of the model on building detection and recognition will be different to some extent, and factors such as topography, cloud cover, and vegetation will also have a certain impact [57] on the prediction results. In addition, rural building detection is different from general building detection. The background in rural areas is complicated, such as the shadow of trees, complex terrain, distance, height, and spectral changes of buildings, all of which make it more difficult [58] to detect buildings in rural areas.

In this paper, rural housing buildings in East Asia and Southeast Asia were selected as samples for model training. The reason is that the characteristics of rural houses in Vietnam are similar to those in these areas. On the one hand, most of the countries in these regions are traditional agricultural countries like Vietnam, where agriculture has been dominant for a long time in history, and their rural buildings have the characteristics of traditional agricultural societies. On the other hand, East Asia and Southeast Asia belong to the Confucian cultural circle, and the buildings of the

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countries in these regions have highly similar cultural characteristics. To ensure the generalization ability of the model and reduce the influence of different background information on the recognition effect, 3932 images of rural settlements with different settlement forms and landforms in the model training stage were collected. The ArcGIS polygon vector editing tool was used to manually outline the outer outline of each building in the satellite image and assign the building attributes. Then, the vector files mentioned above were converted into JSON files required by the model training through Python, and the training labels were finally formed. The training index results show that the average accuracy, recall rate, and accuracy rate of the model validation set are 62%, 64%, and 72%, respectively.

In the validation stage of the recognition effect, the study adopts the method of manual calibration and quantitative validation to carry out a comprehensive test. Satellite images of representative rural areas in the six major geographical regions of Vietnam with different background factors such as topography, vegetation, and settlement patterns are manually compared with the predicted images of the model to check the recognition accuracy of the model under different background conditions. Finally, to quantitatively test the accuracy of the prediction results, the study used the Pearson correlation coefficient test on the number of identified rural buildings using the rural population data of the provinces and municipalities in Vietnam.

2.3.3. Manual verification

The latest provincial administrative division of Vietnam consists of 58 provinces and 5 central municipalities totaling 63 provincial administrative units. The study divides Vietnam into six regions according to topographic features, geographic location, and level of development: Red River Delta, Northern Midlands and Mountain areas, Northern Central area and Central coastal area, Central Highlands, South East, and Mekong. Central coastal area, Central Highlands, South East, and Mekong River Delta (Figure 3).

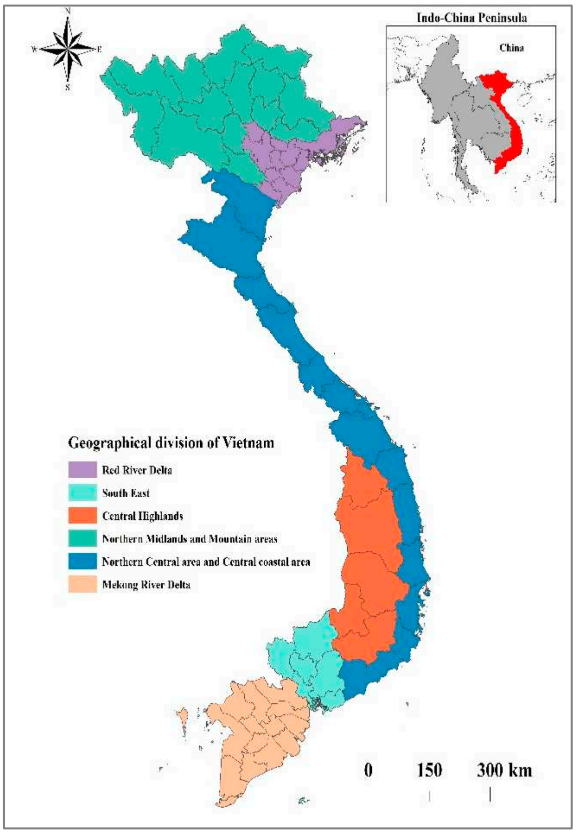

Figure 3. Geographical division of Vietnam.

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2.3.4. Quantitative testing

Given the coupling between rural buildings and population distribution in traditional agricultural countries, this study selected the rural population data of provinces and municipalities in the National Statistical Yearbook of Vietnam in 2021 and used the Pearson coefficient to test the correlation between rural buildings data and macro population survey data, to measure the accuracy of data results and the reliability of the case segmentation model.

3. Results

3.1. Results of rural buildings extraction

Through remote sensing interpretation and elimination of rural buildings within urban built-up areas, the study successfully identified about 28.6871 million rural buildings (Figure 4), and the average density of rural buildings in Vietnam is 87/km². The total area of rural buildings is about 2.492 billion m², and the per capita area of rural buildings is 40.97 m².

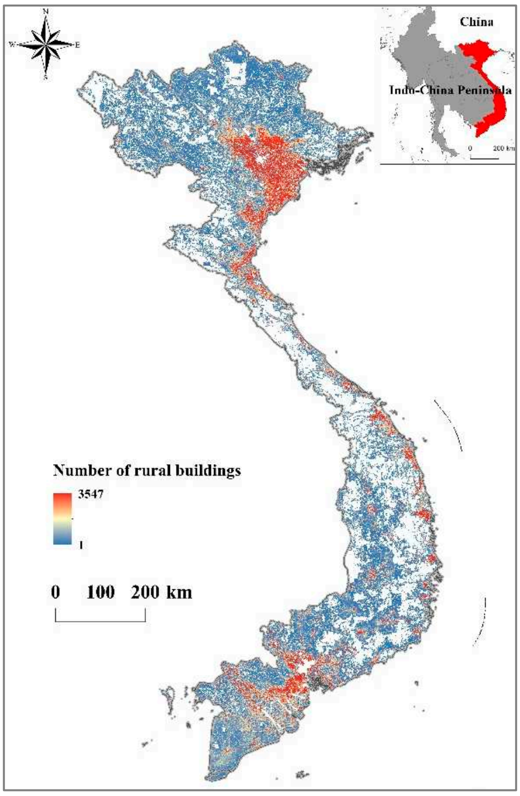

Figure 4. Patterns of rural buildings in Vietnam.

3.2. Date verification

3.2.1. Manual sampling verification

To verify the accuracy of model prediction under different background information, a total of 20 sets of satellite images with different background information such as terrain, vegetation cover, settlement form, and shooting time in six regions were selected for manual comparison and screening with the corresponding model prediction vector data, and typical regions were selected for effect display (Figure 5).

Altitude and latitude are two key geographical factors that determine settlement density. Latitude influences climate differentiation, while elevation is linked to topography and geomorphology complexity. Different combinations of these factors result in variations in housing

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layout, land cover, and land use between regions, ultimately affecting forecast outcomes. To verify the model's prediction effectiveness, this study conducted manual verification using terrain and latitude as the main variables. Thirty groups of regional satellite images were randomly selected from six regions, with a focus on plain (Figure 5a–c) and mountainous terrains (Figure 5d–f). Corresponding vector data were also compared. In total, 158 buildings were examined, with nearly zero architectural misidentification and a recognition error rate of less than 0.1%.

The manual verification results show that different background information has little influence on the prediction results of the model, and the recognition model used in the study has a high degree of generalization and accuracy (Figure 5). The identification model can not only accurately identify the grain-scale rural housing data under the influence of different terrain, dimensions, land cover, and shooting time, but also directly reflect the typical characteristics of regional settlement forms.

After a manual inspection of 20 groups of samples from 5 combinations, a total of 158 missing buildings were screened out, and almost none of them were misidentified. The manual check results show that different background information has little influence on the prediction results of the model, and the recognition model used in the study has a high degree of generalization and accuracy.

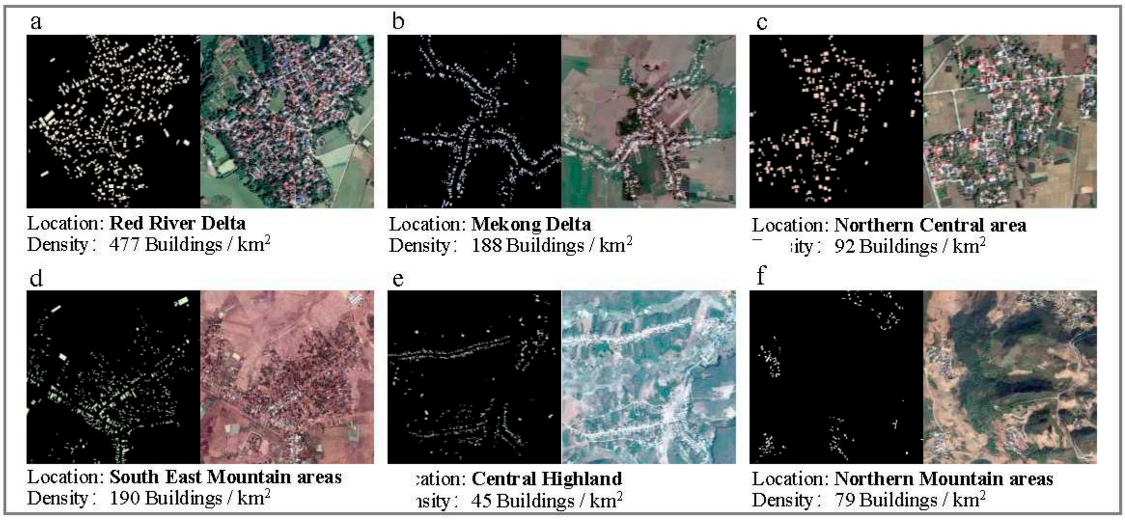

Figure 5. The effect of rural building recognition varies under different background information.

3.2.2. Correlation testing

After calculation, the Pearson correlation coefficient between the number of rural buildings in the provinces and municipalities identified in the study and the rural population in the provinces and municipalities of Vietnam in 2021 is 0.91(Figure 6).

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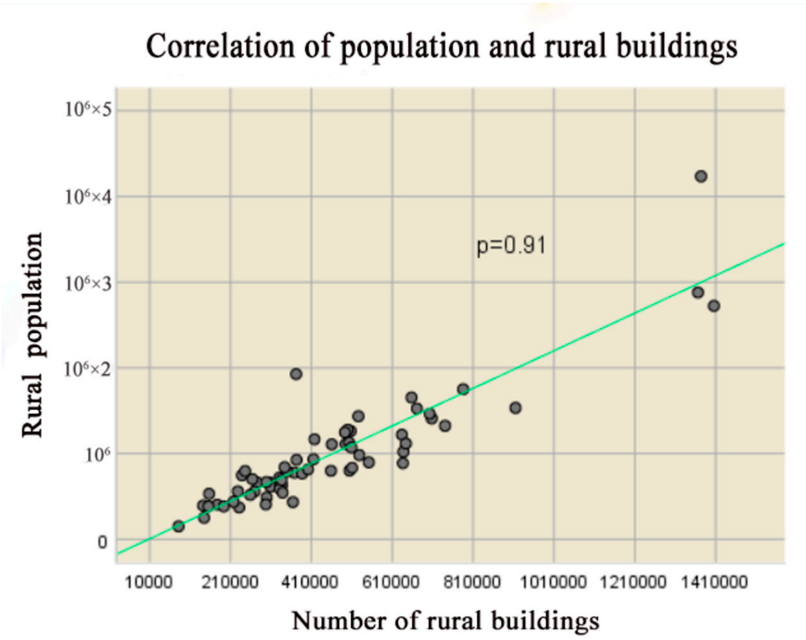

Figure 6. Comparison and analysis of recognition results and macro statistical data.

The correlation coefficients are all significant except the South East region among the six major geographical regions. The correlation coefficient between the number of agricultural population and the predicted number of rural buildings is 0.96 in the Red River Delta, 0.97 in the Northern Midlands and Mountain areas, 0.98 in the Northern Central area and Central coastal area, 0.87 in the Central Highlands, 0.93 in the Mekong Delta, and 0.40 in the South East areas. The reason for the low correlation coefficient in the South East areas is that the South East area is close to Ho Chi Minh City, the economic center of Vietnam, and a large number of people flow into Ho Chi Minh City, which makes the separation of people and households in the southeast region more obvious [59]. In addition, from the provinces and municipalities across the country, rural building and population are also highly consistent, with a correlation coefficient as high as 0.91. According to the manual sampling verification results of remote sensing satellites and prediction results under different terrain and ground objects, the phenomenon of missing and wrong identification rarely occurs and has almost no impact on the prediction results. This remote sensing interpretation work is highly scientific, and the research results are consistent with the actual situation and statistical data, and the results are highly accurate and reliable.

Table 1. Test of regional scale correlation coefficient.

Geogrephic region	correlation coefficient
Red River Delta	0.96
Northern Midlands and Mountain areas	0.97
Northern Central area and Central coastal area	0.98
Central Highlands	0.87
South East	0.40
Mekong River Delta	0.93

Note: Rural population data from the National Statistical Yearbook of Vietnam[3].

3.3. Analysis of rural buildings distribution

Based on the valid interpretation of the rural building data of 63 provinces and municipalities, the paper analyzes the distribution of rural buildings on three scales by taking the whole country, six major geographical regions, and provinces as units in turn.

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3.3.1. Analysis on national scale

On a national scale, the distribution of rural buildings is generally uneven, with more in the north more in the south, and less in the center. Generally speaking, places with flat terrain and sufficient water supply are suitable for agricultural production areas. To obtain long-term fixed land resource use rights, farmers will spontaneously build their buildings in this area, thus forming a certain density of rural settlement landscape. The terrain of Vietnam is high in the northwest and low in the southeast, with about 3/4 of its territory being mountainous and highland. The northern and northwestern parts of the country are highland and mountainous, the central part of the country has mountain ranges running north and south, and the two major deltas are the main plains in the country. Therefore, rural buildings in the northern region of Vietnam are mainly distributed in the plains with Hanoi as the core, rural buildings in the southern region are mainly distributed in the plains of the delta with Ho Chi Minh City as the core, while rural buildings in the central region are mainly distributed in the coastal plains, with a clear phenomenon of regional clustering in the distribution of rural buildings.

3.3.2. Analysis on regional scale

The Red River Delta comprises 20.5% of rural structures, occupying just 6.4% of the land. It has the highest density of rural buildings, with 477/km². Moreover, the Gini coefficient is impressively low at 0.13, suggesting a uniform and densely distributed arrangement of rural buildings in the area (Figure 7a), Meanwhile, the region is among the first echelon. The South East and the Mekong Delta areas are in the second echelon. The density of rural buildings is 190/km² and 188/km² respectively, and the Gini coefficient of rural buildings density in the areas is 0.17. The distribution of rural buildings in the South East and Mekong Delta regions showed obvious regional concentration characteristics, with the high-value area mainly appearing in the vicinity of Ho Chi Minh City (Figure 7e). The number of rural buildings in other regions was more evenly distributed, the density was small, and the Gini coefficient was small. The Mekong Delta is the main rice-growing region in Vietnam, known as the "land of fish and rice" in Vietnam, and the most of rice production in the country comes from this region [60]. Due to the developed agricultural economy, the high proportion of the rural population in the region and the developed smallholder peasant economy has led to large-scale rural building construction activities. From the satellite pictures, it can be seen that the southwestern area of Ho Chi Minh City is densely covered with farmland, with developed agriculture. A large number of rural buildings are built around the farmland, showing a grid distribution pattern of "field" font. Therefore, the segmentation effect formed also restricts the further agglomeration of rural buildings.

Northern Central area and Central coastal area, Northern Midlands, and Mountain areas are in the third echelon, with the density distribution of rural buildings being 92/km² and 79/km². Northern Midlands and Mountain areas account for 28.7% of the country's total land area. The terrain in the region is mainly mountainous and hilly, with large relief and small plain areas. The rugged mountainous terrain leads to a greater concentration of agricultural production in the gentler intermountain and river valleys and a small number of plain areas, so rural buildings are mainly distributed in the intermountain and river valleys or small basin areas. The high value of the number of rural buildings is found in the Red River Delta and the nearby plains (Figure 7b), and there are obvious regional differences in the distribution of rural buildings, with a high Gini coefficient of 0.47 for the density of rural buildings. In the Northern Central area and Central coastal area, the high value of the number of rural buildings is mainly distributed in the coastal plain in dots and patches, and the rural buildings are mainly distributed in a north-south strip, with obvious east-west differentiation (Figure 7c). The Gini coefficient of the density of rural buildings in the region is relatively high, which is 0.40.

Central Highlands are in the fourth echelon. The density of rural buildings in the region is 45/km², accounting for 16.5% of the land area, but the number of rural buildings only accounts for 6.9% of the country, the lowest density of rural buildings in the region. The rugged terrain and less agricultural production land lead to a sparse distribution of rural buildings on the whole. The terrain and landform dominated by mountains and plateaus make rural buildings present a linear cluster layout along the foot of the mountains and the main transportation lines (Figure 7d). Therefore, the Gini coefficient of the density of rural buildings in this region is not high, which is 0.3.

Table 2. Basic information and distribution of rural buildings in six regions of Vietnam.

Echelon	Area	Number of rural buildings	Density of rural buildings	Rural population (million)	Gini coefficient
一	Red River Delta	6496812	477/km²	1.47	0.13
二	South East	2687616	190/km²	7.67	0.17
	Mekong River Delta	5412507	188/km²	1.23	0.17
三	Northern Central area and Central coastal	7248274	92/km²	8.31	0.47
	Northern Midlands and Mountain areas	4860459	79/km²	7.95	0.40
四	Central Highlands	2040244	45/km²	4.29	0.30

Note: Population data from the National Statistical Yearbook of VietNam[3].

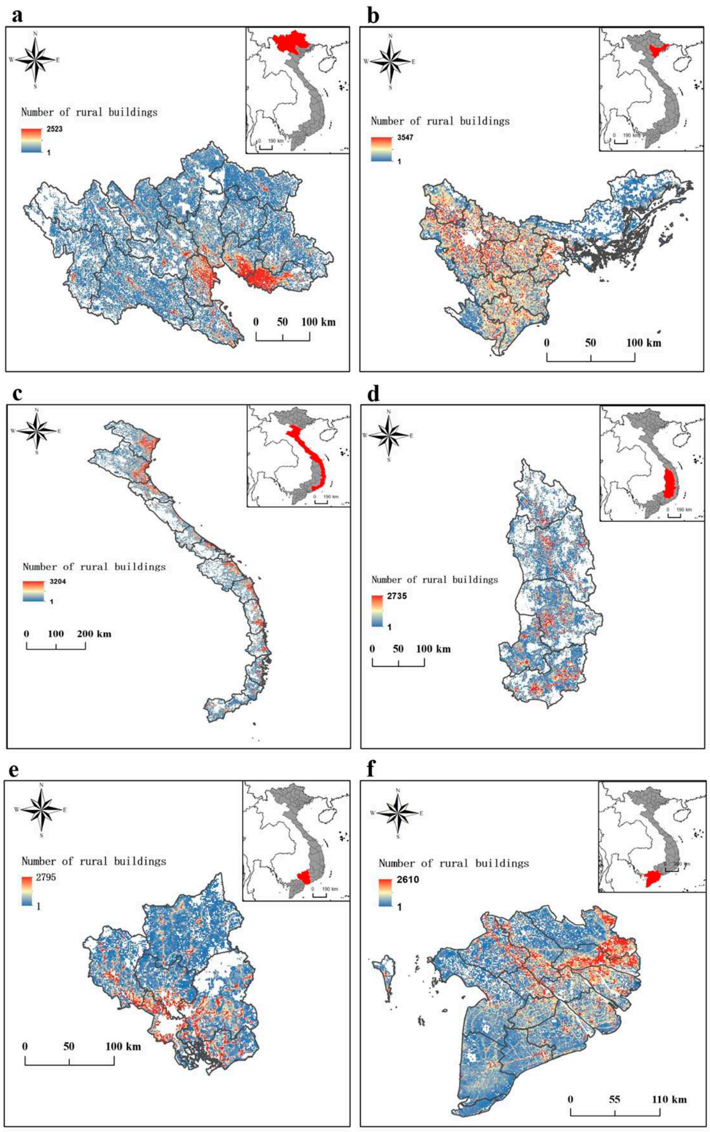

Figure 7. Map of the distribution of rural buildings in six regions.

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3.3.3. Analysis on provincial scale

Following the end of Western colonial rule and the country's reunification, Vietnam has adopted a socialist development model. Despite administrative changes, Vietnam has consistently employed the provincial and municipal system, resulting in 58 provinces and 5 municipalities. On average, rural building density in Vietnam's provincial areas is 142 buildings/km², with a Gini coefficient of roughly 0.47. Rural building footprints average 7,519m²/km², with a Gini coefficient of 0.46. Bac Ninh Province has the highest density of rural buildings at 123,363 m²/km², while Nghe An Province has the lowest at 1443 m²/km². The Gini coefficient statistics and density map of rural buildings in provincial administrative units (Figure 8) indicate significant variations in the number of rural buildings across Vietnam's provinces due to differences in natural environmental factors and regional development levels.

The average density of rural buildings in Vietnam's provinces is 142 buildings/km². In 24 provinces and municipalities, the density of rural buildings is above the average, accounting for about 38%. Among the municipalities directly under the central government, Da Nang has the lowest density at 63 buildings/km². In 2021, the rural population of Da Nang will account for about 12.6%. Due to high urbanization and a low rural population, Da Nang has the lowest density of rural buildings among provinces and municipalities. On the other hand, Hung Yen province has the highest density of rural buildings at 547 buildings/km². The province is located in the southeast of the Red River Delta and has a small area. In 2021, the population density of Hung Yen Province will be 1,381 people/km², with a relatively high population density, of which 83.4\% are rural residents. The province's flat terrain, large rural population, and developed small-scale peasant economy have led to large-scale rural building construction activities, resulting in a high density of rural buildings in the region. In contrast, Lai Chau province has the lowest density of rural buildings at 16 buildings/km² among provinces and municipalities. The province is located in the northwest of Vietnam and has mainly mountainous terrain, with a population density of only 53 people/km². The rugged mountainous terrain results in a low population density and low level of development, making rural building construction rare.

Overall, the distribution characteristics of rural buildings in the provinces of Vietnam align with the population distribution pattern, which is characterized by "more in the north and south, less in the middle, more on the east coast, less in the west" [61].

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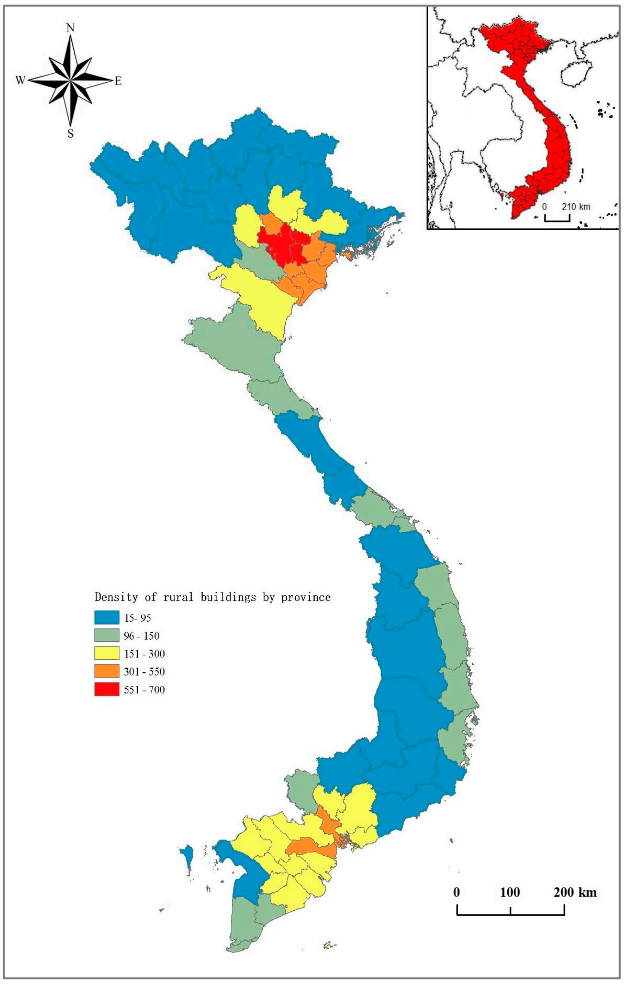

Figure 8. Distribution map of rural buildings density in Vietnam provinces.

4. Conclusions and Prospects

In this paper, Mask R-CNN deep learning technology and remote sensing images are used to realize large-scale remote sensing interpretation, extraction, and vectorization of rural buildings in Vietnam for the first time, and a nationwide multi-scale "settlement-town-county" database of rural buildings in Vietnam based on vector building monomeric buildings is constructed, and the distribution map of rural buildings in Vietnam with a precision of 500 m is drawn. After manual verification and cross-verification of the national rural demographic data, the reliability and generalization ability of the identification model as well as the scientific and accuracy of rural buildings data are ensured, indicating that the method can effectively make up for the limitations of traditional rural data acquisition methods, and lay a foundation for the rural research in Southeast Asia and the construction of basic database.

Based on the statistics of individual rural buildings, this paper calculates the density of national, regional, and provincial units, and reveals the spatial distribution characteristics of rural buildings and the characteristics of settlement patterns on three scales. First of all, the distribution of rural buildings in Vietnam as a whole presents a high-density area with Hanoi and Ho Chi Minh City as the core. Secondly, the density of rural buildings is highly correlated with regional development degree and topographic and geomorphic features, with high regional similarity and obvious inter-regional heterogeneity. Finally, the study found that the distribution of rural buildings is consistent with the distribution of population, showing the spatial characteristics of "more in the north and south, less in the middle, more in the eastern coastal area, and less in the western inland area".

Vietnam's national rural buildings database is based on individual buildings with spatial information, which can be aggregated at multiple scales to realize the measurement of the rural built environment at various spatial scales centered on rural buildings in the country, which helps to overcome the problems of the fault between special and general, overall and local, macro and micro in rural research. The rural building database has the characteristics of wide coverage, high accuracy, fine scale, correctability, and complementarity, which can effectively make up for the poor availability of rural data at present. At the same time, the national rural building database can integrate social, economic, population, and other multi-source data, increase the integrity of rural research data, and promote the transformation of rural research from case field investigation to "case field investigation + global 'computability'" [62], laying the foundation for sustainable research on urbanization development and urban-rural relationship evolution in Southeast Asia [63].

There are still many improvements that can be made to the data on rural buildings in Vietnam. Because the average floor height of local rural buildings in Vietnam has not yet been obtained, this paper only analyzes and explains the number of rural buildings and the base area, and does not make a detailed prediction of the floor area of rural buildings. The image quality varies greatly in different regions, and factors such as topography, cloud cover, vegetation, etc. all affect the prediction results to a certain extent. This paper initially realizes the closed loop of database construction and its application, proving the feasibility and significance of the construction of rural buildings' databases. In the future, we will continue to optimize the identification model, improve the database, and further characterize the distribution pattern and evolution of rural buildings in Vietnam based on spatial and temporal scales, and cover all the countries in Southeast Asia, to provide reliable and accurate data support for the study of Southeast Asian regional development.

References

1. Nguyen, T. A., Gillen, J., & Rigg, J.; Economic transition without agrarian transformation: the pivotal place of smallholder rice farming in Vietnam's modernisation. *J. Rural Stud. 2020*, 74, 86-95.
2. Qiming, Jin. The Rural Settlement Geography in China.; Jiangsu Science and Technology Press: Nanjing, China, 1989. (in Chinese)
3. Le, T.H.; Tran-Nam. Relative costs and FDI: Why did Vietnam forge so far ahead? *Econ Analysis and Policy.* 2018, 59, 1-13.
4. Vu, H.T.D.; Tran, D.D.; Schenk, A.; etc. Land use change in the Vietnamese Mekong Delta: New evidence from remote sensing. *Sci. Total Environ.* 2022, 813, 151918.
5. Tong, Sun.; Xiao Xiao. Analysis of regional differences and influencing factors of rural housing conditions in China. *China Market*. 2016, 20, 36-39. (in Chinese)
6. McKinley, T.; Wang, L.N. Housing and wealth in rural China. *China Econ. Rev.* 1992, 3, 195-211.
7. Wanlin, Z.; Zhigang W. Design of a settlement residential space based on fractal structures and isomorphism: A case study on traditional Yi settlements in Chu Xiong. *South Architecture*. 2021, 5, 130-137. (in Chinese)
8. Lichter, D.T.; Johnson, K.M. Emerging rural settlement patterns and the geographic redistribution of America's new immigrants. *Rural Social.* 2006, 71, 109-131.
9. Hosseini, S.B.; Faizi, M.; Norouzian-Maleki, S.; Karimi Azari, A.R. Impact evaluation of rural development plans for renovating and retrofitting of rural settlements: Case Study: Rural Districts of Tafresh in Iran. *Environ. Earth Sci.* 2015, 73, 3033-3042.
10. Dao, M.Q. Rural poverty in developing countries: an empirical analysis. *J. Econ. Stud.* 2004, 31(6), 500-508.
11. Saksena, S.; Fox, J.; Spencer, J.; Castrence, M., DiGregorio, M., Epprecht, M., ... & Vien, T. D. Classifying and mapping the urban transition in Vietnam. *Appl Geogr.* 2014, 50, 80-89.
12. Linard, C.; Gilbert, M.; Snow, R.W.; Noor, A.M.; Tatem, A.J. Population distribution, settlement patterns and accessibility across Africa in 2010. *PloS one.* 2012, 7, e31743.
13. Oliver.; Schulte.; Trung, Thanh, Nguyen. Agricultural commercialisation, asset growth and poverty in rural Vietnam. *Aust. J. Agric. Res. Econ,* 2023. https://doi.org/10.1111/1467-8489.12517
14. Kerkvliet, B. J. T.; & Porter, D. J. Rural Vietnam in rural Asia. *Vietnam's rural transformation*. 2018, 1-37.
15. Eva, Salve, T.; Bacud.; Ranjitha, Puskur.; Tran, Nhat, Lam, Duyen.; Bjoern, Ole, Sander.; Joyce, Luis. Rural outmigration – feminization – agricultural production nexus: Case of Vietnam. *Migration for Development.* 2021. https://doi.org/10.1080/21632324.2019.1679962
16. Yutao, G. New initiatives of agricultural reform in Vietnam in recent years and a review. *Agric Econ.* 2014, 5, 14-16. (in Chinese)
17. Chuc, N. D.; Anh, D. T. Digital Transformation in Vietnam. *J. Sou. Asi. Econ.* 2023, 40(1), 127-144.
18. Manh, Hai, Nguyen.; Duc, Anh, Dang.; Amy, Y.C.; Liu. Study of Rural–Urban Migration in Vietnam: The Survey. *Res. Pap. Econ.* 2019. https://doi.org/10.1007/978-3-319-94574-3_2

 doi:10.20944/preprints202311.0873.v1

19. Dacai, D.; Four paradigms beyond the village: A methodological perspective: A case study of Skinner, Friedman, Zongzhi Huang and Zanqi Du. *Soc. Sci. Res.* 2010, 2, 130-136. (in Chinese)
20. Cuong, Hoang, Van.; Yen, Hai, Thi, Nguyen. A quantitative analysis of housing and its correlates in rural Vietnam. *Mana. Sci. Let.* 2020. https://doi.org/10.5267/J.MSL.2020.4.009
21. Thi, Anh, Dao, Vo.; Tien-Khai, Tran. Climate change and rural vulnerability in Vietnam: An analysis of livelihood vulnerability index. *Hum. Eco. Risk. Ass.* 2022. https://doi.org/10.1080/10807039.2022.2052262
22. Nguyen, Thi, Bich, Thuan.; Curt, Löfgren.; Nguyen, Thi, Kim, Chuc.; Lars, H, Lindholm. Are the Estimates of Catastrophic Health Expenditure Among Rural Population too High? A Comparison of Studies in Vietnam. *The Open Pub. Hea. J.* 2009. https://doi.org/10.2174/1874944500801010025
23. Yifan, C.; Weipan X. Evaluation of village view AI-assisted rural construction. *World Arch.* 2022, 11, 20-21. (in Chinese)
24. Andrew, McKay.; Saurabh, Singhal.; Finn, Tarp. Welfare dynamics in rural Vietnam: Learning from regular, high-quality panel data. *Res Pap Econ.* 2018. https://doi.org/10.35188/UNU-WIDER/2018/611-1
25. Duc, Loc, Nguyen.; Ulrike, Grote.; Trung, Thanh, Nguyen. Migration, crop production and non-farm labor diversification in rural Vietnam. *Econ Anal. Policy*. 2019. https://doi.org/10.1016/J.EAP.2019.06.003
26. Ngoc-Wen-Li. North-South Differences in Vietnamese Villages and Cultural Characteristics of Water Trade in the South. *Taiw. J. Southeast Asia.* 2018, 13(2), 59-77. (in Chinese)
27. Hui, W.; Xueqiong, T. Symbolic symbolization and identity construction of rural residential landscapes along the Sino Vietnamese border - A case of border villages in Long Zhou County, Guangxi. *Sci Geo Sin.* 2017, 37(4), 595-602. (in Chinese)
28. Arouri, M.; Nguyen, C.; & Youssef, A. B. Natural disasters, household welfare, and resilience: evidence from rural Vietnam. *World dev*. 2015, 70, 59-77.
29. Yuan, Q.; Shen, H.; Li, T.; Li, Z.; Li, S.; Jiang, Y.; ... & Zhang, L. Deep learning in environmental remote sensing: Achievements and challenges. *Rem Sens. Env.* 2020, 241, 111716.
30. Hernández, J.; Garcıa, L.; & Ayuga, F. Integration methodologies for visual impact assessment of rural buildings by geographic information systems. *Bios Eng.* 2004, 88(2), 255-263.
31. Chen, S.; Ogawa, Y.; Zhao, C.; & Sekimoto, Y. Large-scale individual building extraction from open-source satellite imagery via super-resolution-based instance segmentation approach. *ISPRS J.Pho. Rem Sens.* 2023, 195, 129-152.
32. Amo-Boateng, M.; Sey, N.E.N.; Amproche, A.A.; etc. Instance segmentation scheme for roofs in rural areas based on Mask R-CNN. *The Egy. J. Rem Sens. Space Sci*. 2022, 25(2), 569-577.
33. Luo, L.; Guo, X. Recognition and Extraction of Blue-roofed Houses in Remote Sensing Images based on Improved Mask-RCNN. *Int. Core. J. Eng.* 2022, 8, 639-645.
34. Wu, W.; Liu, H.; Li, L.; Long, Y.; Wang, X.; Wang, Z.; ... & Chang, Y. Application of local fully Convolutional Neural Network combined with YOLO v5 algorithm in small target detection of remote sensing image. *PloS one.* 2021, 16(10), e0259283.
35. Conrad, C.; Rudloff, M.; Abdullaev, I.; etc. Measuring rural settlement expansion in Uzbekistan using remote sensing to support spatial planning. *Appl Geogr*. 2015, 62, 29-43.
36. Zhou, Y.; Liu, Y. Solar power brings money to rural areas. *Nature.* 2018, 560, 29-30.
37. Gassar, A.A.A.; Cha, S.H. Review of geographic information systems-based rooftop solar photovoltaic potential estimation approaches at urban scales. *Appl Ener.* 2021, 291, 116817.
38. Zou, S.; Wang, L. Individual vacant house detection in very-high-resolution remote sensing images. *Ann. Am. Assoc. Geogr.* 2020, 110(2), 449-461.
39. Schuegraf, P., Schnell, J., Henry, C., & Bittner, K. (2022). Building Section Instance Segmentation with Combined Classical and Deep Learning Methods. *ISPRS Ann. Photo, Rem Sens. Spa. Inf. Sci.* 2022, 2, 407-414.
40. Wang, W.; Shi, Y.; Zhang, J.; Hu, L.; Li, S.; etc. Traditional Village Building Extraction Based on Improved Mask R-CNN: A Case Study of Beijing, China. *Remote Sensing*. 2023, 15(10), 2616.
41. Zhang, X.; An, G.; & Liu, Y. Mask R-CNN with feature pyramid attention for instance segmentation. In 2018 14th *IEEE International Conference on Signal Processing (ICSP)* (pp. 1194-1197). 2018, IEEE.
42. Ghanea, M.; Moallem, P.; Momeni, M. Building extraction from high-resolution satellite images in urban areas: Recent methods and strategies against significant challenges. *Int. J. Rem Sens.* 2016, 37(21), 5234-5248.
43. Stiller, D.; Stark, T.; Wurm, M.; etc. Large-scale building extraction in very high-resolution aerial imagery using Mask R-CNN. *Joint Urban Remote Sensing Event (JURSE).* 2019, 1-4.
44. Tiede, D.; Schwendemann, G.; Alobaidi, A.; etc. Mask R- CNN- based building extraction from VHR satellite data in operational humanitarian action: An example related to Covid-19 response in Khartoum, Sudan. *Transactions in GIS.* 2021, 25(3), 1213-1227.
45. ISPRS 2D Semantic Labeling Contest, 2018. http://www2.isprs.org/commissions/comm3/wg4/semantic-labeling.html.
46. Mnih, V. Machine learning for aerial image labeling. University of Toronto: Toronto, Canada, 2013.
47. Maggiori, E.; Tarabalka, Y.; Charpiat, G.; etc. Can semantic labeling methods generalize to any city? The Inria aerial image labeling benchmark. *Int Geosci. Remo Sens Sym (IGARSS)*. 2017, 3226-3229.

 doi:10.20944/preprints202311.0873.v1

48. Ji, S, P.; Wei, S, Q.; Lu, M. Fully convolutional networks for multisource building extraction from an open aerial and satellite imagery data set. *IEEE Transac. Geosci. Remo Sens*. 2019, 57(1), 574-586.
49. Ghanea, M.; Moallem, P.; Momeni, M. Building extraction from high-resolution satellite images in urban areas: Recent methods and strategies against significant challenges. *Int. J. Remo Sens.* 2016, 37(21), 5234-5248.
50. Nguyen, Q.; Kim, D. C. Reconsidering rural land use and livelihood transition under the pressure of urbanization in Vietnam: A case study of Hanoi. *Land Use Policy*. 2020, 99, 104896.
51. Institute of International Trade and Economic Cooperation, Ministry of Commerce of China, Economic and Commercial Section of the Chinese Embassy in Viet Nam, Department of Foreign Investment and Economic Cooperation, Ministry of Commerce. *Country (Region) Guide for Outward Investment Cooperation–Vietnam (2020 Edition)* [DB/OL]. Beijing,2021.
52. Xuecao, Li.; Peng, Gong.; Yuyu, Zhou.; etc. Mapping global urban boundaries from the global artificial impervious area (GAIA) data. *Envi Res Letters.* 2020, 15(9), 094044.
53. He, K.; Gkioxari, G.; Dollár, P.; etc. Mask r-cnn. *Proceedings of the IEEE international conference on computer vision*. 2017, 2961-2969.
54. Xun, LI.; Weipan, XU.; Yaofu, Huang.; etc. Spatial distribution of rural building in China: Remote sensing interpretation and density analysis. *J. Geogr*. 2022, 77(04), 835-851
55. He, K.; Zhang, X.; Ren, S.; etc. Deep residual learning for image recognition. *Proceedings of the IEEE Computer Society Conference on Computer Vision and Pattern Recognition.* 2016, 770-778.
56. Huiming, Y.; Fuxin, X. A remote sensing image target recognition method based on improved Mask-RCNN model. International Conference on Big Data, *Art. Int. Int. Thi. Engin (ICBAIE)*. 2021, 436-439.
57. Zhao, K.; Kang, J.; Jung, J.; etc. Building extraction from satellite images using Mask R-CNN with building boundary regularization. *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition Workshops*. 2018, 247-251.
58. Sun, L.; Tang, Y.; Zhang, L. Rural building detection in high-resolution imagery based on a two-stage CNN model. *IEEE Geosci. Remo Sens. Letters*. 2017, 14(11), 1998-2002.
59. Shibuya, S. Urbanization, Jobs, and the Family in the Mekong Delta, Vietnam. *J. Compar. Fam. Stu*. 2018, 49, 93–108.
60. Nguyen, Hong, Nhung., Nguyen, Quang, Thai., Bui, Trinh., Nguyen, Viet, Phong. (2019). Rural and Urban in Vietnam Economic Structure. *Int. Busi. Res*. https://doi.org/10.5539/IBR.V12N3P31.
61. Yin, X.; Li, P.; Feng, Z. M.; etc. Population Dataset in Vietnam (2000–2019). *J. Glob. Cha. Data. Disc.* 2022, 1, 1-11.
62. Liu, Y.; Ke, X.; Wu, W.; etc. Geospatial characterization of rural settlements and potential targets for revitalization by geoinformation technology. *Sci. Rep*. 2022, 12, 8399.
63. Rigg, J. (2003). Evolving rural-urban relations and livelihoods. Southeast Asia transformed: A geography of change, 231-256.