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A Data Optimization and Updating Method for Single Building

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National geographic conditions refer to the sum of information on the natural and human elements related to the geography of a country, reflecting the status and development changes of the country's nature, economy, and humanity in space and time sequence. Beijing has carried out the monitoring of single buildings and established a semi-annual dynamic updating mechanism, forming full-coverage information data of single buildings. However, owing to the effect of the single building data acquisition method, there are problems such as low acquisition accuracy, the inaccuracy of the area, the imprecision of calculating the scale of special-shaped buildings, and the incompleteness of the data acquisition, which limit the promotion and application of single building data in many fields. Therefore, in view of the shortcomings in the updating of the single building data, we propose a technical method that can optimize the accuracy and quickly update the single building in the monitoring of national geographic conditions. First, we constructed a graphical correction model, which can achieve the consistency of the structural expression of two maps. Secondly, we combined the spatial similarity and attribute association to construct a spatial change detection and rapid update model, which updates single building data on the basis of multi-source heterogeneous data space and attribute information fusion. Finally, the low-code technique was designed to check and automatically correct various attributes of updated data. This method was successfully applied to the datasets of six districts of Beijing, and the result was compared with the field investigation results to validate the performance of the algorithm.

1. Introduction

National geographic conditions refer to the sum of information on the natural and human elements related to the geography of a country, reflecting the country's natural, economic, and human conditions and their development and change in space and time sequence. The monitoring data of national geographic conditions are characterized by the integration of multiple sources, which is a deepening and expansion of basic mapping work. The monitoring of national geographic conditions in Beijing is updated annually since the first survey. Because the results of single-building monitoring have been used in many areas, including the dissolution of noncapital functions, the supervision of urban planning, the management of state-owned natural

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resources, the management of illegal land use and illegal buildings, and the construction of urban subcenters, environmental protection and governance are required. Beijing has put forward higher requirements for continuous time, complete and standardized information content, and the stable and reliable quality of single building data; thus, it is necessary to carry out a continuous and rapid monitoring of single buildings to provide a steady stream of solid information support. Currently, single buildings are mainly updated passively and regularly, and each update is based on remote sensing images to collect and produce data on the entire changing area, which has problems such as large granularity, insufficient precision, long cycle, and long time consumption. Therefore, an efficient and accurate updating and optimization mechanism for single building data with a high degree of automation is an urgent need.

At present, there are two main methods for updating vector data of basic geographic information.[1,2] The first is to extract the change area through target detection and identification, and at the same time, to collect and update the data of the change area, the advantage of which is that the updating efficiency is high, but it cannot solve the problem of insufficient positional accuracy. The second method is based on the existing high-precision data fusion method to realize the update. The disadvantage lies in the low level of automation, the investment of manpower and resources is substantial, and there may also exist error information due to the inconsistency of data expression.

Aiming at the problems of large granularity, insufficient precision and low update efficiency of the single building data, combined with the production plan and stock data situation, in this paper, we propose a technical method that can optimize the accuracy and quickly update the single building. We took six administrative districts in Beijing as the research areas and updated the single building data using multi-source heterogeneous data fusion techniques. On the basis of this, we conducted the in-depth change analysis and validation of the experimental data results. The results indicated that this method can considerably enhance the accuracy of the original data and achieve single-time collection, multi-frequency and multi-level utilization, and the rapid updating of the same building.

2. Related Work

Multi-source geospatial data fusion is a means of the fusion expression of data from different sources and structures, and its prerequisite is spatial data matching. On the premise of achieving positional matching among multi-source data, establishing dependency relationships is crucial for enabling the fusion of graphical and attribute information from these various data. The research of data fusion first originated in the 1960s, and the United States Department of Defense applied the data fusion technology to the military field for carrying out data processing as well as automatic decision-making on multi-source data obtained from multiple sensors. Vector data fusion was introduced in the 1980s with the concept of map merging technology,[3] mainly to improve the data quality of the United States Geological Survey and the United States Census Bureau, to eliminate or reduce the geometric errors of map data, and to exchange attribute information. In 1986, the Joint Directors of Laboratories (JDL), a consortium of laboratory directors in the United States Department of Defense, first established a search dictionary of terminology and a basic system model for data fusion, and made further improvements in 1988. Lemarie and Raynal conducted a study on merging data from multiple sources using a common database.(4) Chen and He planned to develop an overlay combiner for overlaying and reorganizing basic data from different departments in the integrated program of Land Resources, Environment, and Regional Economic Information System, which is similar to the map merging system.(5) Walter and Fritsch studied the merging techniques of the European Geographic Data File (GDF) and the German Topographic Spatial Database (ATKIS).(6) Filin and Doytsher conducted in-depth research on the fusion technology for line elements.(7) Liu and Su proposed a multi-spatial database location matching method and its application, which illustrates the idea and method of utilizing the characteristic of spatial location to establish the database linkage by taking the highway and river elements of 1:250000 and 1:1000000 data nationwide as an example.(8) Aboulnaga *et al.* designed the μBE data fusion system, which evaluates the quality of data sources in terms of the degree of inter-matching of the data source schema, the characteristics of the data in the data source, and the characteristics of the data itself.(9) Chen *et al.* proposed a program to produce and update spatial data by using the spatial data fusion method.(10) Huang investigated the merging technique of multi-source vector polygon features and designed a DLG database updating system of polygon features for the merging and updating of multi-source vector building data on this basis.(11)

Although data fusion has identified and solved a large number of problems in the matching method,(12–20) and carried out data management, analysis, and application and quality inspection,(21,22) the technical solution in the direction of the entire process from fusion to inspection and update remains to be determined. Therefore, in response to the existing problems of single-building data, such as large data granularity and insufficient precision, through comprehensive data analysis, we leveraged the “one-status map” housing thematic data by integrating it to update the single building data. Additionally, we established an automated quality inspection platform, thereby providing a novel model and approach for monitoring single buildings.

3. Methods

In this paper, we propose a single-building monitoring data optimization and rapid updating method based on data fusion and automatic checking, and the main flow chart is shown in Fig. 1, which mainly includes the following three research contents: (1) separate accessory buildings from a single house based on the correction model to realize the consistency of the expression of a single house and single building in the current situation of a single map and to provide accurate base map data for the subsequent fusion, (2) conduct a thorough change analysis of the two datasets utilizing spatial similarity, generate the latest spatial data results based on the analytical findings, and update attribute information based on the fusion of matching change information, and (3) build an automatic checking and assignment model based on the low-code(23) technique that guarantees and checks the accuracy of the data while assigning the value to the rules efficiently.

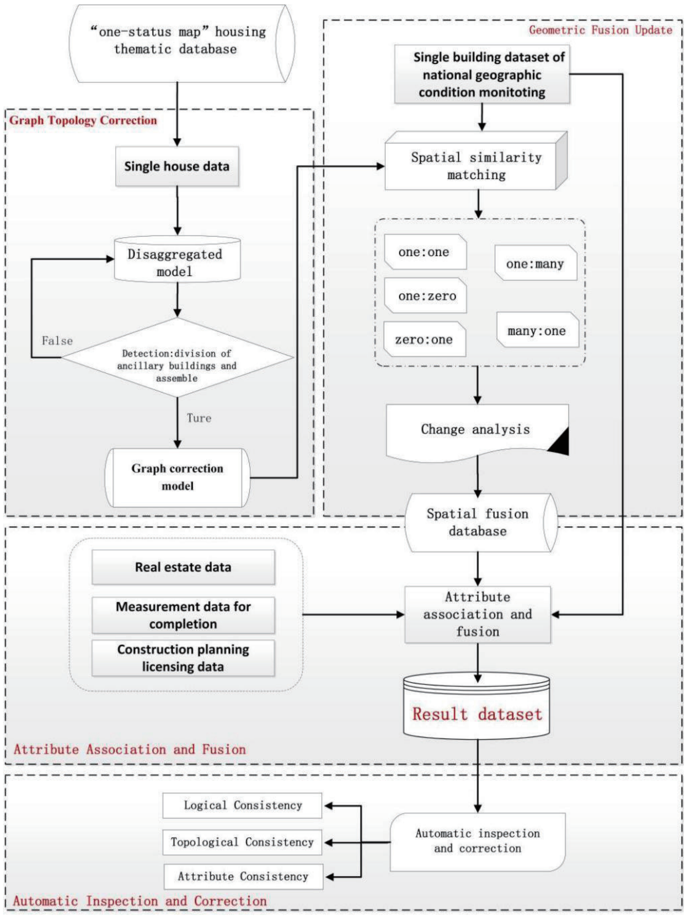

Fig. 1. (Color online) Flowchart of technical approach.

3.1 Building reconstruction based on graphical correction model

Owing to the multi-source heterogeneity of data, there are certain differences in the expression and graphics of the data accuracy and semantic information directly collected from various data sources. Therefore, heterogeneous data fusion necessitates achieving consistency in both the expression and logic of single buildings sourced from multiple origins, which requires reorganization and correction processing for the composite expression of a single house. First, a graphical correction model is established on the basis of the results of the analysis of data difference, which classifies ancillary buildings contained in the “one-status map” housing thematic data, such as outdoor stairs, underground building entrances, galleries, and other features, which separate these accessory buildings from the single house. Then, we optimize the single house, through the model combined with the mapping relationship, addressing scenarios such as a floating building, permanent structures superimposed on the house, and the consolidation of the single house. Finally, the graphical correction is completed by topological relationship processing. There are four topological relationships between the floating building, permanent structures superimposed on the house, and the single house as shown in Fig. 2.

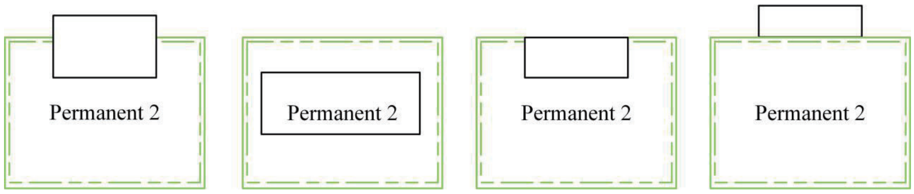

Fig. 2. (Color online) Spatial relationship between split house and outbuildings.

In this paper, on the basis of the topological adjacency and topological containment relationship between face elements, we established a graphical correction model to address the problem of correcting the topological relationship between the data. For example, the house on the house needs to be completely overlapped and the floating floor must not have a gap. The graphical correction model between different polygon features needs to determine the relationship between all line segments of the boundary of the polygon and other polygons, and when the line segments are on the outside of the other polygons, it means that there is a gap between the two polygons, and graphical correction is needed. To ensure the accuracy of the graphical correction model mainly through the calculation of the existence of intersection points between the line segments of the two polygons, the formula used is as follows. In the presence of intersection points, traverse all line segments to compute the coordinates of these intersection points. Subsequently, merge the intersecting line segments sequentially on the basis of the coordinates of their intersection points, until no intersection points exist between the line segments of the two polygons. At this point, the graphical correction process is deemed complete.

$$L_1 : ax + by + c = 0 \tag{1}$$

$$L_2 : dx + ey + f = 0 \tag{2}$$

When $ea - db = 0$, it is proved that there is no intersection of the two lines; otherwise, there exists an intersection with coordinates (X_i, Y_i):

$$X_i = \frac{(fb - ec)}{(ea - db)}, \tag{3}$$

$$Y_i = \frac{(cd - af)}{(ea - db)}. \tag{4}$$

3.2 Change analysis and rapid updates based on spatial similarity

After obtaining single house data with a consistent data expression through the graphical correction model, data with similar data structures establish a mapping relationship through spatial matching between elements, and then we use certain rules to realize the change detection analysis of architectural elements and find matching elements for rapid updating. In this study, we designed and constructed the spatial similarity matching and change analysis scheme of elements to carry out the comparative analysis between elements, and established the spatial data structure of the updating results, as well as the spatial data model that can save the information of the elements before updating.

3.2.1 Spatial similarity judgment

3.2.1.1 Position similarity

Position similarity is an important feature for the spatial comparison of buildings. Although the two types of data collection method cause different location accuracies of the same building, the closer the spatial location of the two buildings, the higher the probability that they are the same building. In this paper, the Euclidean distance of the center of gravity of spatial elements is used as the position similarity metric, and the smaller the distance, the greater the probability that the building has not changed. The calculation formula is as follows:

$$G_x = \frac{\sum_{i=1}^{n} x_i}{n}, G_y = \frac{\sum_{i=1}^{n} y_i}{n}, \tag{5}$$

$$D = \sqrt{\left(x_2 - x_1\right)^2 + \left(y_2 - y_1\right)^2}. \tag{6}$$

3.2.1.2 Planar coincidence degree

The planar coincidence degree of two buildings is an important index for calculating the geometric similarity of the polygon features. This study is based on the overlap of the polygon features as a measure of the planar coincidence degree, and the calculation formula is

$$\varepsilon_\alpha = \frac{S\left(T_1 \cap T_2\right)}{S\left(T_1 \cup T_2\right)}. \tag{7}$$

Here, T_1 is the "one-status map" housing thematic data plane element and T_2 is the national geographic conditions data plane element, as shown in Fig. 3. The closer the planar coincidence degree index is to 1, the higher the probability that both are the same building.

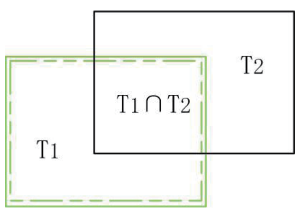

Fig. 3. (Color online) Planar coincidence degree.

3.2.1.3 Spatial similarity

Buildings with high spatial similarity should have a closer position, and the two elements have features such as closer spatial coordinates, a higher planar coincidence degree, and a higher shape similarity. On the basis of the similarity of the above single feature items, the composite similarity can be calculated using the hierarchical analysis method with the following formula:

$$S = \sum_{i=1}^{n} \left(W_i \times S_i \right), \tag{8}$$

where W_i is the weighted value and S_i represents the normalized value of single feature items.

3.2.2 Spatial change analysis and rapid updating

Through spatial similarity judgment to achieve spatial data matching between the two maps, the matching results combined with the construction of rules can be used to analyze the changes of each building, such as the new, alteration, and extinction types, and assign the resultant data with information that effectively reflects alterations in various elements. Building changes can be categorized into spatial and attribute changes, with the key to spatial change analysis being the achievement of spatial matching based on spatial similarity judgments. The results of spatial matching utilizing high-precision single house data and single building data (rapid updating process known as "base data") can be categorized into five types: one-to-one, one-to-zero, one-to-many, many-to-one, and zero-to-one.

3.2.2.1 Change analysis and rapid update for one-to-one, one-to-zero, and zero-to-one relationships

Buildings that have remained unchanged should exhibit a high degree of similarity, and their polygon features have the characteristics of relatively close spatial coordinates and higher planar coincidence degree. The one-to-one case is that the spatial similarity between the single house and base data is greater than 80% and the building is directly detected as belonging to the unchanged type. The single house data directly replace the space graph matched by the base data and the ChangeType is assigned the value of "6". The one-to-zero case for the single house and base data has a spatial similarity of less than 10%, and single house data shows the existence of a building, but no building in the base data; the detection of this building belongs to the new changes in type. Then, upon the loading of high-precision data spatial graphics into the results database, the ChangeType is assigned the value of "2". The zero-to-one case is that the spatial similarity between the single house and base data is less than 10%, and this building is directly detected as belonging to the extinction type of change, and the ChangeType is assigned the value of "3". The graphical topological relationships are shown in Fig. 4.

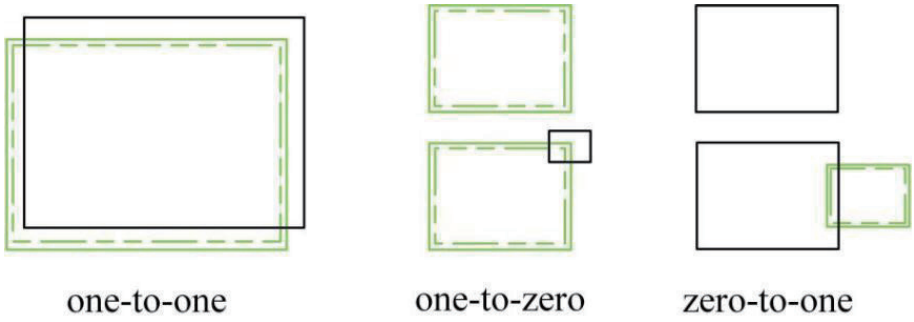

Fig. 4. (Color online) Simple topological relationships between two graph matchings.

3.2.2.2 Change analysis and rapid update for non-one-to-one relationships

The one-to-many case is unchanged in the field, a single house data graphic covers multiple base data graphics, the spatial similarity of the outer boundary with the combination of the covered base data graphics is greater than 80%, the high-precision data spatial graphic is directly loaded into the results database, and the ChangeType is assigned the value of "−2". This implies an increase in the precision or accuracy of the background data.

The many-to-one case for the field has not changed, a base data graphic matches multiple single house data graphics, the outer boundary spatial similarity with the combination of overlaying single house data graphics is greater than 80%, the single house data spatial graphic is directly loaded into the results database, and the ChangeType is assigned the value of "−1". This is equivalent to interrupting or cutting relevant base data elements according to editing needs to improve the precision of the building. The graphical topological relationships are shown in Fig. 5.

3.2.3 Attribute association and fusion

After rapid updating, the latest time-point result data are formed, which need to be associated with the previous time-point base data, as-built data, engineering certificate data, and other related thematic data. When the attribute association and fusion are based on the spatial matching results, the attribute fusion mapping rules of multi-source heterogeneous data are established according to the change information, and the field names corresponding to the target elements are traversed to find the target values and inherit or replace the current data values. The element matching and attribute fusion include the following five cases: (1) The matching results indicate the unchanged building that directly inherits GQ_H_PROPER, GQ_U_PROPER, GQ_OLDCC, USECODE, ZJW_ABOVEAREA, ZJW_UNDERAREA, ZJW_ALLAREA, SOURCEFID, ADDRESS, and PFHOUSEID field values of the base data. (2) The matching results are one-to-one precision enhancement changes for buildings, with the building scale pegged to the sum of multiple graphs. (3) The matching results are many-to-one precision-enhancing changes in the building, and the building scale does not need to be integrated. For the completion and engineering certificates, only the issuance numbers are linked, while other

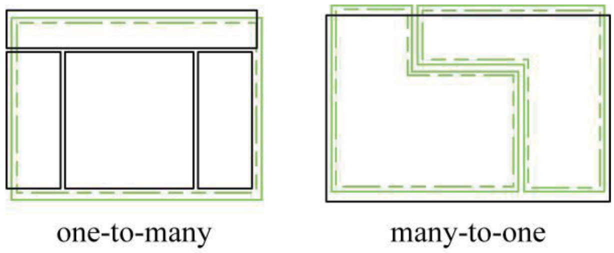

Fig. 5. (Color online) Complex topological relationships between two graph matchings.

attributes inherit the corresponding field values of the base data. (4) The building with the matching results is the new type, and its attribute values are linked to the completion and engineering certificate data field values according to the rules. (5) The building with the matching results is the extinction type, and its attribute values are inherited from the base data field values.

3.3 Automatic rule checking based on the low-code technique

After the fusion and updating of the single building results and "one-status map" housing data, the data structure has changed, and the quality check of data results is crucial for the later remittance of the results, data loading, analysis, and application. To further improve the efficiency of the quality checking of the results and ensure the topological, attribute, and logical consistencies of results, on the basis of the existing informatization platform, we realized the development of a quality checking platform based on the low-code system. Through the introduction of low-code and visualization technology, the low-code quality check module based on the editing platform is developed and realized, which can check the single building spatial data updated by multi-source heterogeneous data fusion. According to the rules and requirements of quality checking, the database is processed and checked through the platform editor. The inspection items mainly comprise null value checking, legality checking, accuracy checking, attribute consistency checking, logic checking, default value correctness checking, topology consistency checking, and so forth. The processing operation mainly focuses on the batch assignment of values to the relevant fields, as shown in Fig. 6.

4. Experiments and Analysis

4.1 Dataset

The base dataset used in the experiments of this paper is the monitoring dataset of single buildings in the six districts of Beijing, namely, Dongcheng District, Xicheng District, Chaoyang District, Haidian District, Fengtai District, and Shijingshan District. The multi-source heterogeneous dataset used in this paper to optimize the spatial location accuracy of the base data is the "one-status map" housing thematic dataset. The "one-status map" housing thematic

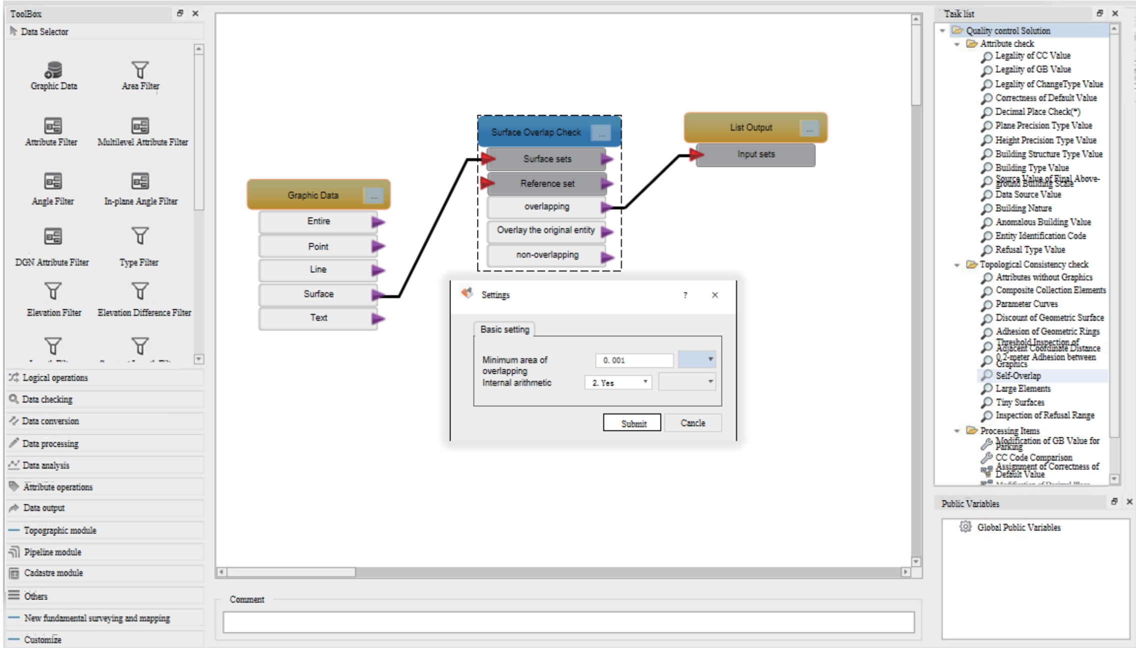

Fig. 6. (Color online) Quality check and automated processing program (part of topology consistency checking).

data are classified into two types according to the entity concept: detached house and single house. The detached house is divided into multiple parts according to the different floors, and the single house is understood as a house in the usual sense. Attribute fusion also utilizes thematic datasets such as the as-built dataset. Some of the datasets are shown in Fig. 7.

4.2 Experiments of building reconstruction based on graphical correction model

To make the "one-status map" housing thematic data and the single building data expression consistent, we conducted graphical topology correction on single house data in the six districts using the graphical correction model. The appurtenant buildings included in the single house are categorized, and features such as outdoor staircases, underground building entrances, and corridors are separated from the single house; the house-on-house and floating buildings are merged in the single house to form a new single house dataset. As shown in Figs. 8 and 9, the outdoor stairs and underground entrances in the single house are separated to form a four-part spatial pattern; the accessory rooms and floating floors connected to the single house are detected, and the merger is completed by matching them to the single house based on the graphical correction model.

4.3 Spatial-similarity-based change analysis and rapid updating experiments

On the basis of the spatial similarity model proposed in Sect. 3.2, spatial matching analysis was carried out between the "one-status map" housing thematic data completed with graphical correction and the last point in time single-building base data. Moreover, on the basis of the

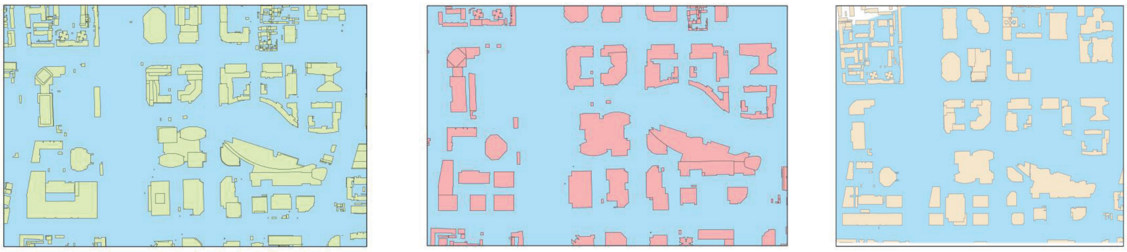

Fig. 7. (Color online) Schematic of datasets.

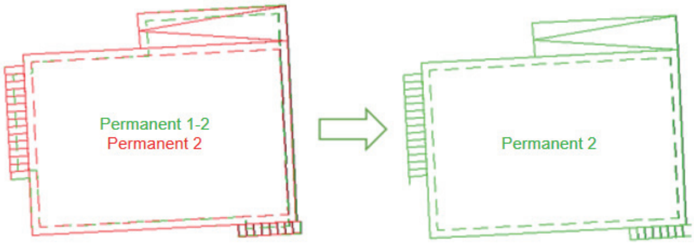

Fig. 8. (Color online) Accessory building separation results.

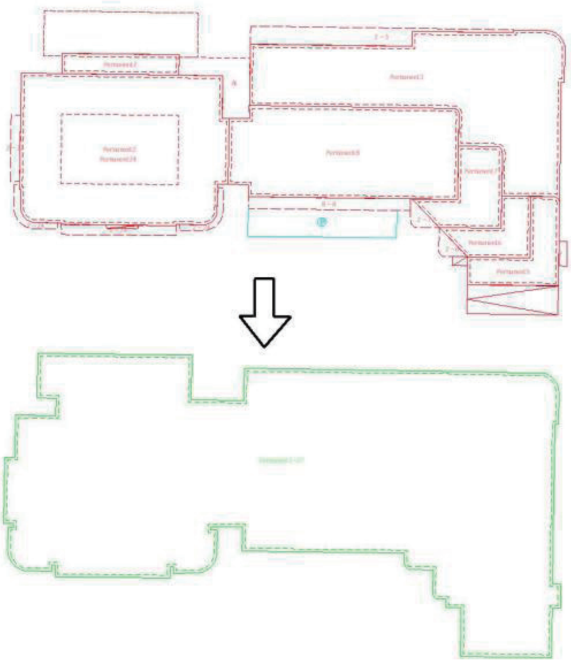

Fig. 9. (Color online) Building reconstruction results.

matching results, the latest points in time single-building result data were updated and formed, and then the data attribute correlation and fusion were completed. In the change detection method based on spatial similarity, the position similarity weight is 0.2, the distance threshold is 5 m, and the planar coincidence degree weight is 0.8.

The before-and-after comparison chart of the spatial data matching and updating experimental results is shown in Fig. 10. The gray pieces are formed by clipping the geometric shapes of the base and single house data. On the basis of these pieces, it is possible to initiate spatial matching and change analysis, determine the types of building variations, and accomplish data update. Figure 11 shows some of the results; the numbers represent the types of building changes identified by change analysis. The comparison of the precision between the updated results and the base data is presented in Fig. 12. It can be clearly observed from the figure that the results updated by the method proposed in this paper are completely superior in terms of completeness and positional accuracy to the base data. Through manual and algorithmic automatic checks, as well as statistical analyses, the accuracy rate for change detection and attribute correlation exceeds 97%, which proves the accuracy and practicability of the updating method proposed in this paper.

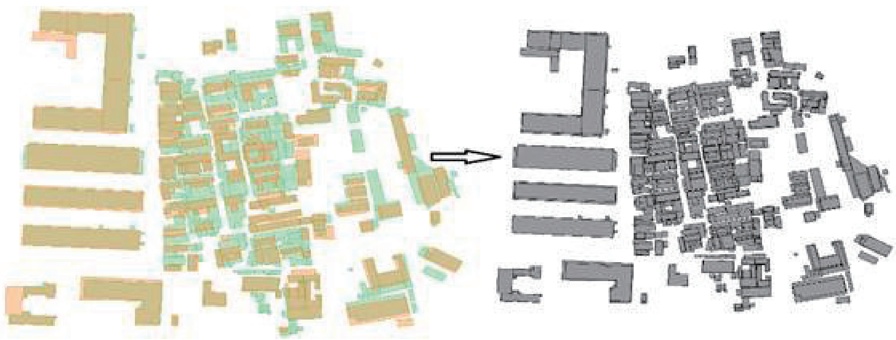

Fig. 10. (Color online) Spatial data matching (the yellow color is the base data, the green color is the single house, and the gray color represents pieces).

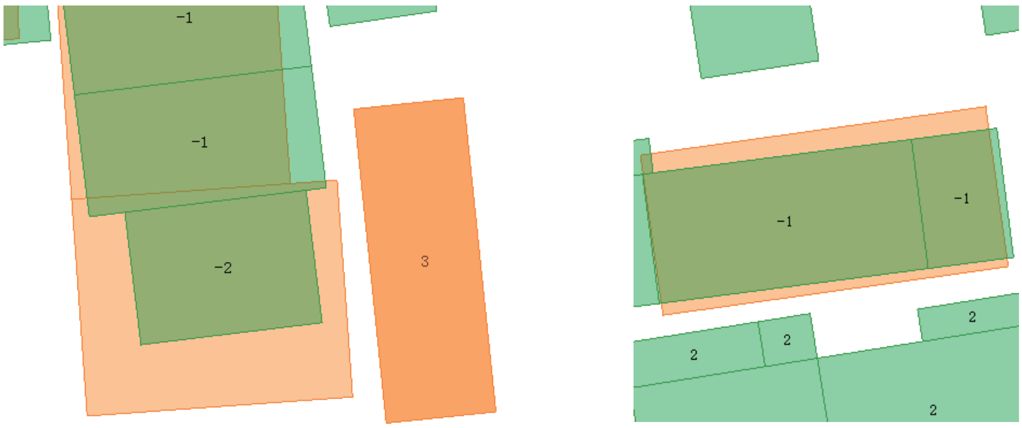

Fig. 11. (Color online) Change monitoring and rapid update results (the red color is the last point in time and the green color indicates the updated results).

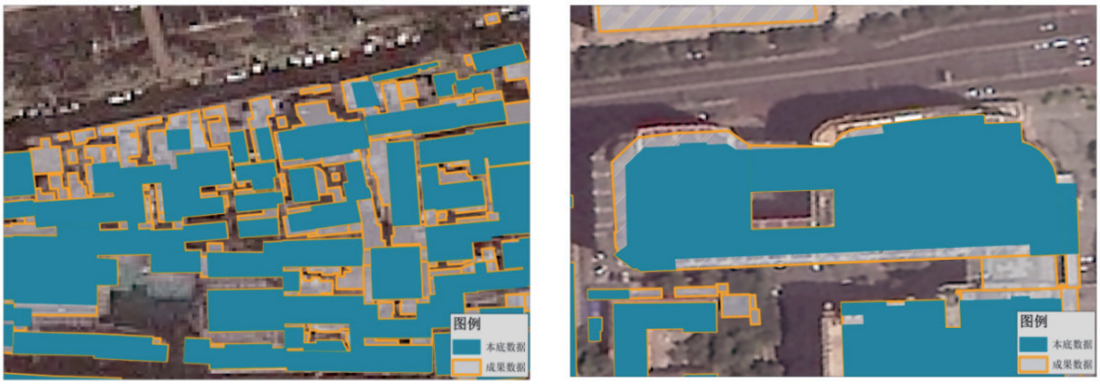

Fig. 12. (Color online) Comparison of completeness and positional accuracy improvements of results (the blue color is the single building of base data and the yellow line indicates the updated results).

5. Conclusions

This paper commenced from the aim of facilitating the production of actual data. Through the correction and integration of multi-source heterogeneous spatial data, and by undergoing processes such as spatial data matching, change analysis, and attribute relationship processing, the data were made mutually confirmatory, interrelated, and rapidly updated in terms of geometry and attributes, and enabled the fusion and update of spatial information and the examination of achievements and automatic correction, thereby realizing the optimization of the precision and rapid update of single-building data. In terms of data updating, the method proposed in this paper realized the real-time interconnection and intercommunication of information between multiple levels and departments, effectively breaking the information silo phenomenon that has existed for a long time, and considerably improved the efficiency of data updating, realizing the enhancement of the efficiency of the whole process of operation. In terms of data accuracy optimization, based on the topology correction and spatial similarity method proposed in this paper, the fusion of multi-source heterogeneous data achieved a significant increase in the spatial accuracy of the graphics, a consistent graphical expression, an accurate building scale, and a consistent statistical caliber. In terms of data quality checking, we constructed the low-code-based quality checking technology that realizes the improvement of data checking efficiency and automation and ensured the stable and reliable quality of data.

Although this paper has achieved certain results in the rapid update of the single building, several issues remain, which require optimization and resolution owing to limitations in time and conditions during the research process. On the one hand, in the implementation process, the data matching algorithm based on spatial similarity necessitates determining weights according to specific datasets, experiences, and requirements, which is a time-intensive endeavor. On the other hand, some aspects still require manual verification during the update process. In the future, we will continue to optimize the data matching and correction algorithms to improve the quality of data, reduce manual intervention, and enhance support data production.

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