Extracting invariant characteristics of sketch maps: Towards Place Query-by-Sketch

Abstract

In geography, invariant aspects of sketches are essential to study because they reflect the human perception of real-world places. A person's perception of a place can be expressed in sketches. In this paper, we quantitatively and qualitatively analysed the characteristics of single objects and characteristics among objects in sketches and the real world to find reliable invariants that can be used to establish references / correspondences between sketch and world in a matching process. These characteristics include category, shape, name, and relative size of each object. Moreover, quantity and spatial relationships, such as topological, ordering and location relationships, among all objects are also analysed to assess consistency between sketched and actual places. The approach presented in this study extracts the reliable invariants for query-by-sketch and prioritizes their relevance for a sketch-map matching process.

Keywords: Query-by-sketch, matching, platial sketches, platial representations, sketch matching, invariant characteristics, spatial cognition, topology, location, shape

1 Introduction

Platial GIS, or place-based GIS, is a trending research area. Platial GIS is different from traditional GIS in the sense that places are spaces that involve social relationships (Massey, 2001). People usually perceive spaces cognitively; that is, they do not generally model space quantitatively accurately, preferring to prioritize what is visibly, semantically or emotionally significant for them (Davies & Peebles, 2010), and people usually simplify "uninteresting" aspects of the space between key places (Meilinger, Riecke, & Bülthoff, 2014). Decades of research have shown that human spatial cognition closely links "what" and "where", it distorts distance and direction and seems to record it non-transitively (Lloyd & Heivly, 1987).

This paper approaches platial GIS with respect to human-made sketches. We are interested in studying how humans characterize places by sketching and how faithfully these places are represented compared to reality to discover invariant characteristics that could guide a computational application. These invariant objects/characteristics can help determine a suitable correspondence between sketched objects and objects in the real world.

A sketch can be made by drawing objects using paper and pen or by using drawing software on an electronic device. Annotated attributes of the sketched place can accompany the sketch. When a person draws a sketch, it usually reflects their cognitive perception of the place, because the sketch objects are often simplified, rotated and even omitted according to the person's perception. Therefore, a sketch is a visual method for communicating about "places". However, how well does a sketch represent the real world? This paper analyses the similarity between the features of a sketched place and the corresponding features in the real world to determine the characteristics that can be used to align an artificial agent's perception with reality. To accomplish this, we analysed and compared the characteristics of single objects and among objects in sketches with the real world. The result is a proposal for a set of useful and prioritized invariants for query-by-sketch.

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People usually describe places or ideas using maps, charts, and drawings. In the literature, Tolman (1984) called this behaviour "creating cognitive maps". A cognitive map is a picture or visual aid that represents the mapper's understanding of particular elements of their thoughts (Eden, 1992) to facilitate decision support, problem solving, etc. Barbara Tversky (2000) stated that graphics/drawings/sketches reflect the author's conceptions of reality rather than reality. Sketch maps are frequently combined with verbal descriptions of spatial features and vice versa (Suwa, Gero, & Purcell, 1998). Freksa et al. (2000, 2018) pointed out that people use different map types, such as aerial photographs, topographic maps, city maps, road maps, and symbolic sketch maps, to approach various types of tasks; a sketched map characterizes an abstract mental concept in which only topological arrangements are spatially represented.

Analysis is needed to align a sketched place with a real-world place to establish the correspondence between the sketch representations of objects and relationships with those of other spatial data sources (Wallgrün, Wolter, & Richter, 2010). Describing object geometry and attribute information is relatively simple. Describing spatial relationships between two objects includes spatial topological relationships, azimuth, and metric relationships (Egenhofer & Franzosa, 1991). The diverse information contained in a sketched place includes object semantics (category, name), geometric features (perimeter, area, shape, etc.), and spatial relationships between objects (topology, direction, distance, etc.). All these features establish a comprehensive multi-scene/place semantic description model (Song & Wang, 2012).

The remainder of this paper is structured as follows. Section 2 demonstrates related work. Section 3 introduces the study, including the scenario, requirements, and volunteers' data. Section 4 describes the methods used for extracting and analysing the characteristics of sketched objects, and separately, those in the real world. Section 5 investigates the invariants suitable for query-by-sketch by comparing the characteristics between the sketched place and the metric map. Section 6 presents a detailed discussion with related work and an analysis of the experimental results. Finally, Section 7 presents conclusions and discusses directions of future work.

2 Related Work

Studies of sketch-based spatial queries, scene query-by-sketch and sketch matching are popular. Some of the more relevant studies are briefly described here. Egenhofer (1997) first proposed sketch-based spatial queries and used network models to describe sketched scenarios. In his network, each object corresponds to a node, the value of which includes numerical attributes such as category, name, size, and length. The connecting line between the two objects represents their relationship. In the study by Egenhofer (1997), a nine-intersection model is used to describe object topology to group the object relationships, and the constraint relaxation mechanism is used to obtain query results that are more aligned with users' expectations. Blaser (2000a) studied the sketching habits of people, including characteristics of objects, relationships between objects, and annotations on sketches. Blaser (2000a) established a query-by-sketch that reduced the spatial relationship association graph of sketched objects by analysing only the spatial relationships between adjacent objects. Blaser's (Blaser 2000a; 2000b) work shows that (i) objects in sketches are highly abstract representations of their real-world counterparts, as a typical sketch only contains a small number of objects (typically 12–17), and the attention given to human-built objects such as roads and buildings is often higher than that given to natural objects, such as green spaces; (ii) the spatial arrangement of objects and topological relationships is most relevant, while the metric and orientation relationships are refinements; consequently, he focuses on topological relationships for scene query-by-sketch and uses the spatial relationships between objects as a second-level correction. Yuan, Wu, & Zhuang (2006) pointed out that the traditional spatial data query-and-retrieval does not use spatial topological relationships. They introduced the invariant moment method based on the 9-intersection topology model (Egenhofer, 1997) and used the invariants to describe complex spatial scenes. In a study by Yuan et al. (2006), component analysis and fuzzy support vector machine techniques reduced the redundancy of high-dimensional topological relationships in spatial scenes and established independent topological relationships. Forbus et al. (2005, 2008) proposed the CogSketch model, which considers the relative size of the glyph in the sketch and uses Region Connection Calculus (RCC-8) (Cui, Cohn, & Randell, 1993) to calculate the topological relationship between glyphs and the orientation relationship between adjacent glyphs based on that topological relationship. The shape similarity between corresponding glyphs is calculated using the SME (Structure-Mapping Engine) algorithm. Wuersch and Egenhofer (2008) proposed a perceptual sketch graphic translation algorithm, which uses the concepts of optimal scalability rules and functional morphology to distinguish and extract regions, and it also sorts the extracted regions according to the morphological values. Wallgrün et al. (2010) described a scene as a Qualitative Constraint Network (QCN) and used it for spatial information matching by considering the spatial orientation relationship and the object connection relationship. Wallgrün et al. (2010) solved the scene matching challenge by finding the largest matching subgraph. Falomir (2011) automatically obtained sketches of digital images by colour segmentation and automatically described them by their qualitative shape, colour, topology, and orientation using Qualitative Image Descriptors (QID) and then matched the QIDs by their similarity to identify indoor landmarks (corners in rooms) for robot self-location. Shen et al. (2011) combined the 9-intersection model, the depth-direction relationship matrix model, the conceptual neighbourhood graph, the difference matrix, and the primary direction relationship model to study a sketch-based spatial data retrieval method. Wang and Schwering (2015) analysed sketches to clarify the sketched qualitative spatial information without distortion and schematizations. In the study by Wang and Schwering (2015), seven sketch features that can contain invariant spatial information were proposed: topology of street segments, orientation of street segments, orientation of landmarks with respect to a street segment, cyclic order of street segments and landmarks around a junction, linear order of street segments and landmarks along a route, topological relations of landmarks and city blocks, and topology of city blocks. These seven sketch aspects of a sketch map are formalized with QCNs based on existing qualitative calculi and aligned with the Tabu search metaheuristic (R3Q5) (Schwering et al., 2014; Chipofya, Schultz, & Schwering, 2016; Jan et al., 2017).

All the studies described above provide evidence for the effectiveness of extracting invariants from sketches for query-by-sketch, but all these studies have been targeted towards qualitative characteristic analysis. The quantitative characteristics of objects in the sketched place (e.g. shape of roads) are missed or poorly studied. The work by Egenhofer et al. (1997), Blaser (2000a, 2000b), Yuan et al. (2006), Wallgrün et al. (2010) and Shen (2011) focused on spatial relationship analysis for matching, including topological, direction and ordering relationships. Wang and Schwering (2015), Chipofya et al. (2016) and Jan et al. (2017) proposed seven spatial invariants regarding relationships among sketched objects which actually are still based on qualitative spatial relationships. Here our approach presents quantitative characteristic comparisons for query-by-sketch: the shape of road, relative size of regions, frequency of object appearances, quantitative location relationships between regions, and topological closeness between regions, and topological closeness between regions and roads. Moreover, some characteristics were analyzed quantitatively and qualitatively in our paper, e.g. the location relationship between objects were described in azimuth distance (quantitative) and Location Reference System (qualitative). Wallgrün et al. (2010) and Shen et al. (2011) depicted the direction relationship only in qualitative cardinal directions (e.g. North, Northwest). Wang and Schwering (2015), Chipofya et al. (2016) and Jan et al. (2017) also only adopted the local orientation relationship for comparison, such as front, back, etc. The topological relationship comparison was also conducted quantitatively and qualitatively in our

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paper. The 9-intersection model was adopted for qualitative description while spatial closeness was used for quantitative illustration. This is different from the work by Egenhofer et al. (1997), Blaser (2000a, 2000b), Yuan et al. (2006), Wallgrün et al. (2010), Shen (2011), Chipofya et al. (2016) and Jan et al. (2017) in which the 9-intersection model was only adopted for comparison. Summarily, we analysed the characteristics of objects in a sketch map quantitatively and qualitatively.

There are many ways to sketch spatial environments; nevertheless, we can find lots of commonalities that allow us to extract useful information from sketches, even if they have not been constructed based on a fixed convention. Not all sketches employ all structural means that can be used to sketch environments; therefore, not all sketches can be compared along all dimensions. Our study explores commonalities and differences in sketching spatial environments. The objective of our contribution is not to provide representative data, as there are great interindividual differences in sketching styles, i.e. in the features employed in a given sketch. However, in our study we can identify stable characteristics for the features that are employed.

3 Sketching Place Study

A sketching experiment was carried out to study which invariants are useful for aligning sketched places with real maps. We asked volunteers to sketch the same place: the northern part of Xianlin University District of Nanjing Normal University[1], shown in Figure 1.

Place. The reasons for selecting this place as the experimental scenario are as follows:

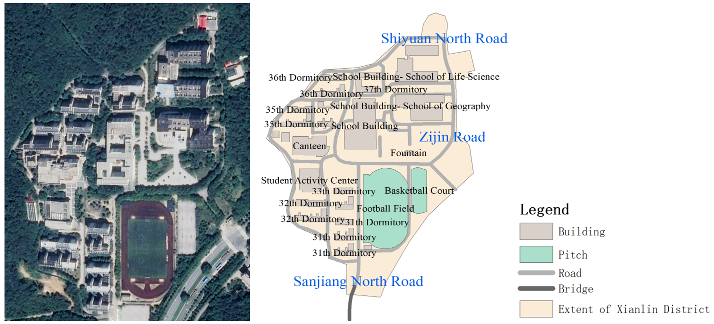
- The richness of geographic elements: the scenario includes varied objects, including teaching buildings, playgrounds, dormitories, roads, and bridges. These objects can be represented by polygons, ellipses, rectangles, polylines, etc. in the sketch.
- The complexity of spatial relationships: road intersections, the adjacency relationship between one of the roads and the school building, the disconnection between buildings, and the intersection of a road and a bridge are all reflected in this scenario.

Task. Volunteers were told to sketch the place as they like. They could draw objects in any shape. They were also free to add annotations, such as objects' names or types on their sketches. The only requirement was that all volunteers were required to sketch the place (familiar regions and roads) entirely by memory, without assistance from a mobile phone, Google Maps, OpenStreetMap (OSM[2]), or other data sources.

Results. Figure 2 shows the sketches produced by the 11 volunteers, which were numbered S1, S2, S3, S4, S5, S6, S7, S8, S9, S10, and S11. Notice that although the volunteers sketched the same place, the general similarity between the sketches is quite low, which emphasizes the need to identify invariant relationships that allow us and any artificial agent to align objects in the sketched places with the actual places.

[1] The northern part of Xianlin University District of Nanjing Normal University: http://www.njnu.edu.cn/Link/map.html

[2] OpenStreetMap: https://www.openstreetmap.org/



(a) (b)

Figure 1. The experimental area: (a) North part of Xianlin University District of Nanjing Normal University (from Google Earth) and (b) The digital map of the study area (from OpenStreetMap).

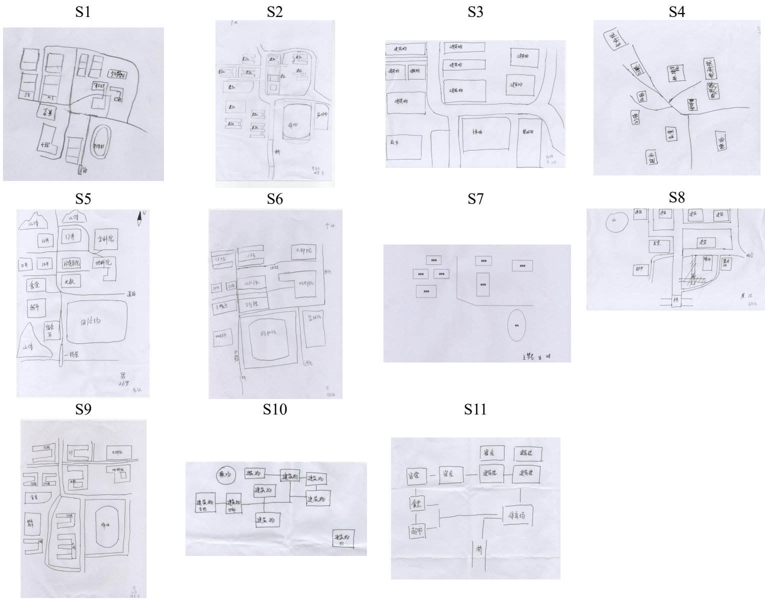


Figure 2. Sketches drawn by the 11 volunteers who took part in the experiment.

4 Extracting Invariant Characteristics from a Sketched Place

After obtaining the sketches of our use-case place, we analysed them to find invariants. To extract and compare the quantitative and qualitative characteristics of objects appearing in both the sketches and OSM, we identified object-level characteristics (described in Section 4.1) and structure-level characteristics (explained in Section 4.2). Figure 3 shows a diagram of the multi-

level characteristics analysed by our approach: (1) characteristics of a single object such as a road or building, including shape, name, category, and relative size; and (2) characteristics of the whole place, or the spatial structure of the place, such as the quantity of objects, topological relationships among objects, order of appearance of objects along a road, and location relationships of objects in the place.

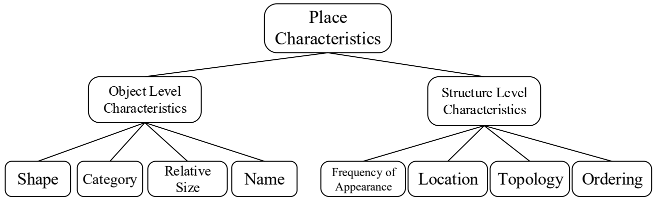


Figure 3. Multi-level characteristics of a sketched place.

Figure 4 shows the methods used in this study to represent the characteristics above and compare a sketch of a place with the actual place. Additional details are presented in the following sections.

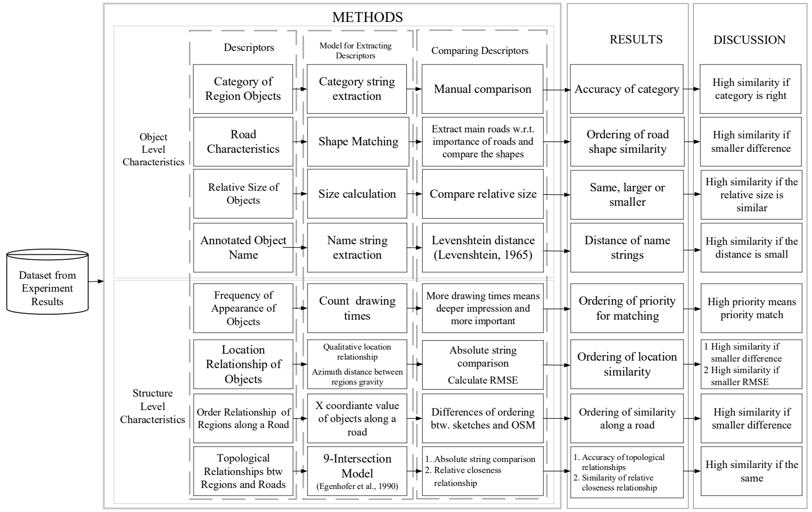


Figure 4. Methods for describing and comparing characteristics.

4.1 Analysing Object-Level Characteristics

In different types of geographical places, the objects of interest also differ. In urban scenes, people usually pay attention to objects that are dominant in the visual range, such as buildings and roads. In the countryside, people pay attention to villages, farmlands, roads, ponds, etc. In the forest, more attention is paid to trees, roads, etc. In this study, ‘objects’ refers to tangible objects, such as buildings, roads, trees, playgrounds, and ponds. Additionally, because the selected experimental place is an urban scene, buildings are the most common object type. In our approach, objects are divided into two groups: region and road. Region refers to an independent object that is not located on a road and has human relevance, such as a building, pitch, or playground. The characteristics of a sketched object (i.e., building, road, bridge, or pitch) include category (Section 4.1.1), shape (Section 4.1.2), relative size (Section 4.1.3), and name (Section 4.1.4). These characteristics are analysed as follows.

4.1.1 Analysing the Category of Region Objects in a Sketched Place

Our approach adopts the category definition from OSM[3] to determine the similarity of region category objects between a sketch and OSM. Since there is no Chinese definition of the object type in OSM, our approach manually compares the sketch's annotations (which represent the sketched region categories) with the actual region categories in OSM. Figure 5 shows the category consistency between OSM and sketch S2, which shows 2 pitches at the bottom right, and the rest of the objects are buildings. Moreover, our approach digitized the sketch annotations into region attributes (shown in Figure 6), which is consistent with the annotations in Figure 5.

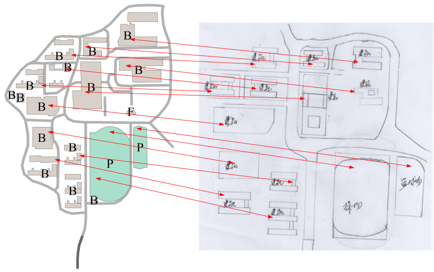


Figure 5. Arrows show the correspondence between region categories in sketch S2 (right) and those that are consistent with OSM (left). ("B" means building, "P" means pitch, "F" means fountain, "建筑" means a building, "操场" means a football field, "篮球场" means a basketball court).

In Figure 6, the field "OBJECTID" represents region ID, the field "fclass" represents OSM region category, and the field "Annotation" represents the region category annotated in a sketch. "建筑" means building, "操场" means football field, and "篮球场" means basketball court.

OBJECTID	fclass
0	pitch
1	pitch
2	building
3	building
4	building
5	building
6	building
7	building
8	building
9	building
10	building
11	building
12	building
13	building
14	building
15	building
16	fountain
17	building

OBJECTID	Annotation
0	篮球场
1	操场
2	建筑
3	建筑
4	建筑
5	建筑
6	建筑
8	建筑
9	建筑
10	建筑
11	建筑
12	建筑
14	建筑
15	建筑

Figure 6. Attribute tables from OSM (left) and sketch S2 (right) of regions in Figure 5; there are 14 objects in S2 and 18 OSM regions in this district. Note that "建筑" means building (objects 2–15), "操场" means football field (object 1), and "篮球场" means basketball court (object 0).

[3] https://download.geofabrik.de/osm-data-in-gis-formats-free.pdf

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4.1.2 Describing and Analysing the Shape of an Object in a Sketched Place

We compared the shape of roads and regions (in terms of style, slope, and integrity) appearing in the sketches and those appearing in OSM. Many drawing styles describe a road shape since, due to its improvised nature, usually people do not pay attention to drawing accuracy in sketch maps. For example, after analysing the sketches obtained in our study, we observed that roads can be drawn using a single line, or using double lines which can be parallel or not, they can have open or closed ends and their angular shapes may not correspond to those appearing in OSM. These challenges are similar to those found by Broelemann K., Jiang X. and Schwering A. (2016). Figure 7 shows examples of roads sketched with either single or double lines. Figure 8 shows the same road sketched with different angular shapes. Additionally, the integrity of a single road is different in various sketches, depending on the person sketching. Note also that in Figure 9, only a few segments of a single road are drawn.

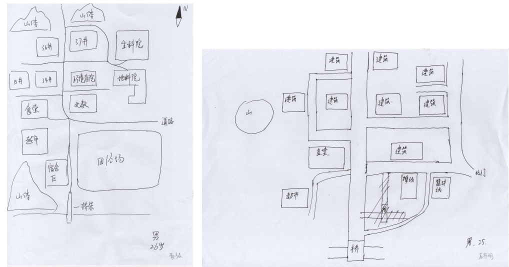

Figure 7. Sketches S5 (left) and S8 (right). Roads are drawn with single or double lines, depending on the person sketching.

Analysing region shapes, we identified the same challenge as by Broelemann K., Jiang X. and Schwering A. (2016) that is "*objects of similar appearance can have different meanings and objects of the same meaning can be drawn in different ways*". Figure 10 shows that some sketched regions can be approximated by rectangles which seem similar to the boundary boxes of the same objects in OSM. On the other hand, as Figure 11 shows, some sketched regions are partially similar to the real object; the sketched region has a similar concavity to the actual region, although the shapes are mirrored.

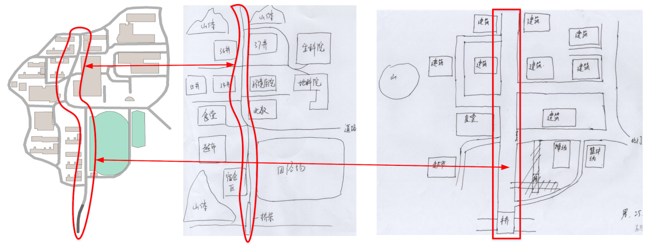

Figure 8. OSM map (left), sketches S5 (middle) and S8 (right). The different angular shapes of the same road drawn in different sketches (marked by the red line), depend on the person sketching.

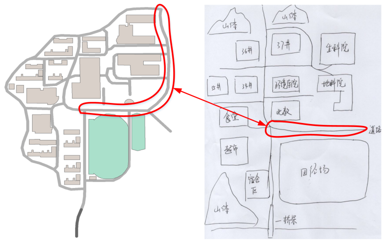

Figure 9. OSM map (left) and sketch S5 (right). Incomplete drawing of a single road (marked by the red line). Sometimes volunteers only sketch the part of the road adjacent to the relevant regions they intend to highlight.

To deal with this challenge, we adopt the approach used by Vatavu, Anthony, and Wobbrock (2012) to represent the shape of objects. This method uses unordered points to represent the shape and ignores the points' quantity and direction. When comparing two point-clouds, this method uses an approximation of the Hungarian algorithm to solve the classical assignment problem. Our approach uses this recognizer to compare the shape of each road in the sketch with the shape of the actual road, one by one. Moreover, we calculate the composite shape of roads according to the ordering of similarity of a single road's shape, as Figure 12 shows. Due to the diversity and complexity of real buildings' shapes, our approach mainly compares the shape of roads between OSM and sketches.

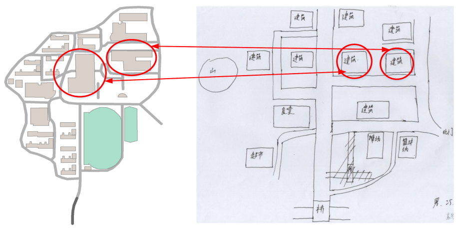

Figure 10. OSM map (left) and sketch S8 (right). Regions sketched in rectangular shapes are the bounding boxes of the regions in OSM.

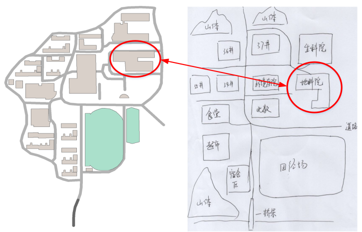

Figure 11. OSM map (left) and sketch S5 (right). A region sketched with a partially similar shape to the real region. Note that their shapes both involve concavity, but are mirror-reflected.

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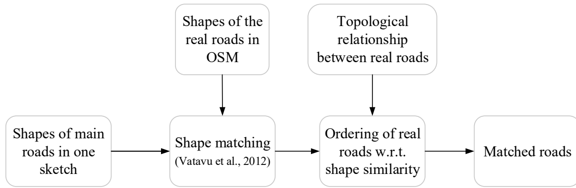

Figure 12. Flow chart for shape comparison.

4.1.3 Analysing the Relative Size of Objects in a Sketched Place

People often use area to describe the size of a region and length to specify the size of a road. Size, as a characteristic, has been extensively studied for qualitative and quantitative analysis in the area of visualization, beginning with Bertin's work (1983), and followed by the work of Card, Mackinlay, and Robertson (1990). Although size is a mathematically precise characteristic, it is not practical to compare this factor absolutely between a sketch and OSM, because the scale of the sketch is different from that of OSM. Most people without a professional background do not think of scale during drawing. Additionally, according to the above analysis of shape factor, the shape of one object differs significantly between OSM and the sketch, so the object sizes also vary. Instead of an absolute comparison, we compare the relative sizes between objects to detect similarity between the sketch and OSM. Relative size in our study mainly refers to an area comparison of regions in the same sketched place, because drawings of roads in a sketch are often incomplete (as discussed above). Note that people usually differentiate between larger and smaller regions in a place when describing it.

Our approach uses the geometric areas of regions (as Figure 13 shows) to analyse the relative area/size characteristic. The area of each region is iteratively compared with other regions in the sketch and OSM to obtain the relative size between regions. The relative area relationships between two regions (denoted by RelSize) is defined by the Relative Size Reference System or $RelSizeRS = \{SR, RelSize_{CON}, RelSize_{INT}\}$, where SR or Size Relation refers to the relationship between the areas of two regions, that is, SR = (area of 1st region) / (area of 2nd region); $RelSize_{CON}$ refers to the set of labels of relative size; and $RelSize_{INT}$ refers to the values of SR related to each label.

$$RelSize_{CON} = \{\text{smaller } (<), \text{ same } (=), \text{ bigger } (>)\}$$

$$RelSize_{INT} = \{(0, 0.9), [0.9, 1.1], (1.1, \infty)\}$$

Table 1 shows an example of the relative area comparison of sketched regions in Figure 13. Then, we analyse the similarity between corresponding regions in the sketch and OSM using string comparison.

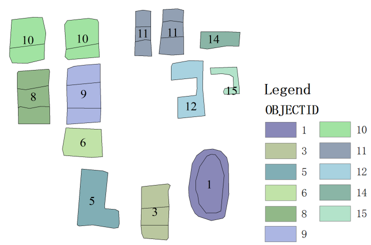

Figure 13. Regions in sketch S1 symbolized with different colours w.r.t. their IDs. (The numbers represent region

IDs.)

Table 1. Relative size comparison between regions drawn in Figure 13: each cell indicates the relative area of the region ID in the row compared to the region in the column. Region 0 and Region 2 were not drawn in this sketch.

Object ID	3	5	6	8	9	10	11	12	14	15
1	>	>	>	>	>	<	>	>	>	>
3		<	>	<	<	<	<	>	>	>
5			>	>	<	<	>	>	>	>
6				<	<	<	<	<	>	>
8					<	<	<	>	>	>
9						<	>	>	>	>
10							>	>	>	>
11								>	>	>
12									>	>
14										<

4.1.4 Analysing the Annotated Object Name in a Sketched Place

The annotations drawn on sketches (object names) were extracted and compared to the corresponding names in OSM. We found that volunteers prefer to describe objects with abbreviated names. As Figure 14 shows, the real name of one region in OSM is "地理科学学院" ('school of geography' in English), while in sketches, volunteers just marked "地", or "地科院" (the abbreviated name of school of geography in Chinese, outlined in red in Figure 14), which is an abbreviated name of that building. Figure 15 displays object names annotated in OSM, S1 and S5.

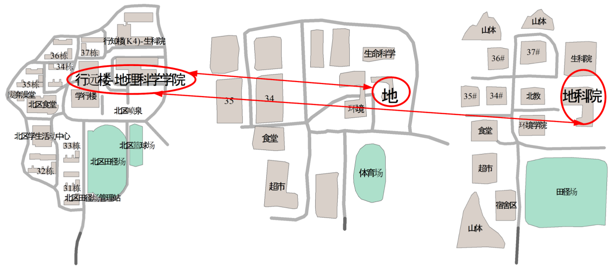

Figure 14. Place in OSM (left), sketch S1 (middle) and sketch S5 (right) showing regions annotated with names.

OBJECTID	Name	EnName
0	北区篮球场	Basketball Court
1	北区田径场	Football Field
2	33栋	33th Dormitory
3	31栋	31th Dormitory
4	32栋	32th Dormitory
5	北区学生活动中心	Student Activity Center
6	北区食堂	Canteen
7	废弃澡堂	Abandoned Bathhouse
8	35栋	35th Dormitory
9	34栋	34th Dormitory
10	36栋	36th Dormitory
11	37栋	37th Dormitory
12	学行楼	School Building
13	北区田径场管理站	Field Management Station
14	行知楼(K4)-生科院	School Building- School of Life Science
15	行远楼-地理科学学院	School Building- School of Geography
16	北区喷泉	Fountain
17	废弃锅炉房	Abandoned Boiler House

(a) Object names in OSM

OBJECTID	Name	EnName
1	体育场	Playground
3		
5	超市	Supermarket
6	食堂	Canteen
8	35	35
9	34	34
10		
11		
12	环境	Environment
14	生命科学	Life Science
15	地	Geography

(b) Object names in sketch S1

OBJECTID	Name	EnName
1	田径场	Football Field
2	宿舍区	Domitory Area
5	超市	Supermarket
6	食堂	Canteen
8	35#	35#
9	34#	34#
10	36#	36#
11	37#	37#
12	环境学院 北教	School of Environment
14	生科院	School of Life Science
15	地科院	School of Geography
19	山体	Hill

(c) Object names in sketch S5

Figure 15. Object names in OSM (left), sketch S1 (middle), and sketch S5 (right). (Field "OBJECTID" represents the object ID, field "Name" represents the object name, and "EnName" represents the English object name.)

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Our approach compares the object annotations in sketches with their names in OSM using the Levenshtein distance (Levenshtein, 1966), which obtains the similarity of two strings by taking into account how many characters are different, and their position in the string, as Table 2 shows.

Table 2. Levenshtein distances between names in OSM and sketch S1 (column 5) and between names in OSM and sketch S5 (column 6) w.r.t. Figure 15. ('-' indicates that this object was not drawn in this sketch, and a blank cell indicates that the volunteer did not annotate this object.)

Object ID	Name in OSM	Name in Sketch S1	Name in Sketch S5	Levenshtein Distance btw. OSM and sketch S1	Levenshtein Distance btw. OSM and sketch S5
1	北区田径场	体育场	田径场	4	2
2	33 栋	-	宿舍区	-	3
3	31 栋		-	3	-
5	北区学生活动中心	超市	超市	8	8
6	北区食堂	食堂	食堂	2	2
8	35 栋	35	35#	1	1
9	34 栋	34	34#	1	1
10	36 栋		36#	3	1
11	37 栋		37#	3	1
12	学行楼	环境	环境学院 北教	3	6
14	行知楼(K4)-生科院	生命科学	生科院	10	8
15	行远楼-地理科学学院	地	地科院	9	7

4.2 Analysing Structure-Level Characteristics

Regarding the spatial structure of the sketched places, the following features can be extracted: (i) quantitative characteristics, such as the frequency of appearance of objects in sketched places (Section 4.2.1), and (ii) qualitative characteristics, such as the location relationship (Section 4.2.2), the order relationship (Section 4.2.3), and the topological relationship (Section 4.2.4) among objects in the sketched place and OSM.

4.2.1 Calculating the Frequency of Appearance of Objects in a Sketched Place

The frequency of appearance of objects in a place can help us determine the common objects that are repeated in several sketches, which indicates that the objects are considered relevant for more people. To accomplish this, we numbered all the regions from right to left and from bottom to top.

One example of counting the drawing frequency of regions is shown in Figure 16 and Table 3. The numbering for the corresponding regions in OSM and the two sketches are shown in Figure 16. Table 3 counts whether each region is drawn to the corresponding region in OSM and the frequency of appearance of these different regions in two sketches (S1, S8).

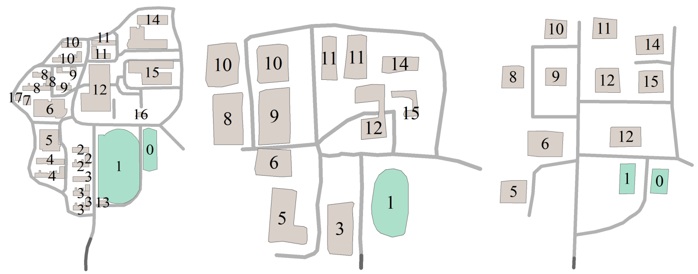


Figure 16. Numbering of regions of a place in OSM (left), sketch S1 (middle) and sketch S8 (right). (The numbers

represent region IDs.)

Table 3. Frequency of regions drawn in sketches according to Figure 16. ('×' means drawn and blank cell means not drawn.)

Sketch ID \ Region ID	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
S1		×		×		×	×		×	×	×	×	×		×	×		
S8		×				×	×		×	×	×	×	×		×	×		
Drawing Frequencies	0	2	0	1	0	2	2	0	2	2	2	2	2	0	2	2	0	0

We also compared the drawing frequency of each road in a sketch. One example of counting the frequency of drawn roads in sketches is shown in Figure 17 and Table 4. Figure 17 shows the numbering of roads from one place in OSM and two sketches (S1, S8). The statistics of whether each road is drawn in the place from Figure 17 and the frequency of drawn roads in these two sketches are shown in Table 4.

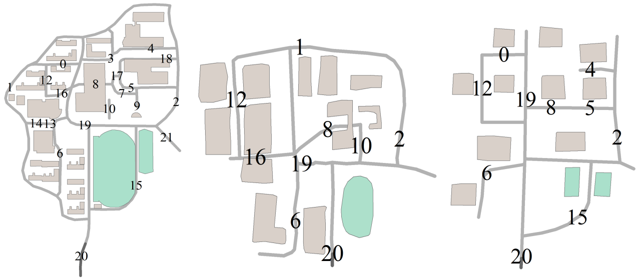


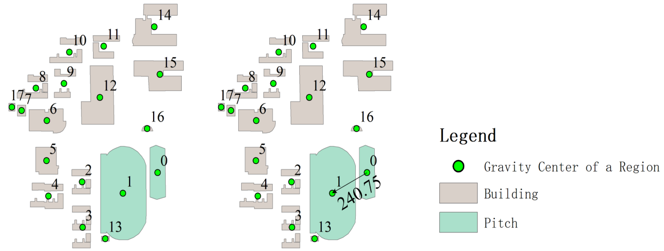
Figure 17. Numbering of all roads of a place in OSM (left), sketch S1 (middle) and sketch S8 (right). (The numbers represent road IDs.)

Table 4. Frequency for roads drawn in the sketched place according to Figure 17. (Note that × means drawn and blank means not drawn.)

Sketch ID \ Road ID	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
S1		×	×				×		×		×		×				×			×	×	×
S8	×		×		×		×		×				×			×				×	×	×
Drawing Frequencies	1	1	2	0	1	0	2	0	2	0	1	0	2	0	0	1	1	0	0	2	2	2

4.2.2 Location Relationship of Object in the Sketched Place

As described in Section 4.1.2, sketched road drawings can be incomplete, so the location relationships of sketched objects in our approach are focused on location relationships between regions. The location relationships are described qualitatively and quantitatively. The qualitative location refers to the relationship between two objects, for example, object A is located south of object B. The quantitative location involves the azimuth distance between two objects. To locate objects with respect to each other, we calculated the azimuth distance between their centres of gravity, as shown in Figure 18.



(a) Calculating the OSM region centres of gravity (b) The OSM azimuth distance from Region 0 to Region 1 is 240.75

Figure 18. Quantitative location relationship. (The numbers represent region IDs.)

Table 5 shows the azimuth distances between Region 0 and other regions in OSM and sketch S2.

Our approach also obtains the qualitative location relationship between two objects (denoted by L), which is defined by the Location Reference System or LRS = {UL, L_{CON}, L_{INT}}, where UL or Unit of Location is the azimuth distance (in degrees over an interval of [0°, 360°]); L_{CON} refers to the set of qualitative location relationship labels; and L_{INT} refers to the internal values of UL related to each label, as Figure 19 shows.

L_{CON} = {North(N), NorthEast(NE), East(E), SouthEast(SE), South(S), SouthWest(SW), West(W), NorthWest(NW)}

L_{INT} = {[0°, 10°] or (350°, 360°), (10°, 80°], (80°, 100°], (100°, 170°], (170°, 190°], (190°, 260°], (260°, 280°], (280°, 350°]}

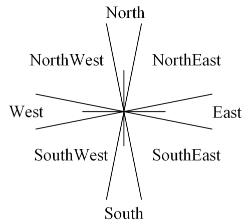


Figure 19. Judgement model of qualitative location relationship between regions.

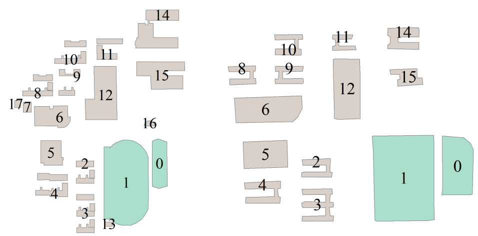


Figure 20. Object numbering in OSM (left) and sketch S2 (right) for the following location analysis. (The numbers represent region IDs)

Table 6 shows the results of the qualitative location relationships of objects shown in Figure 20. We used a string comparison to compare the similarity of the qualitative location between the corresponding objects in sketch S2 and OSM.

Table 5. Azimuth distance between Region 0 and other regions in OSM and sketch S2.

	Region ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
OSM	0	240.75	263.42	235.67	258.59	354.29	336.28	336.89	327.03	318.36	308.06	294.53	309.43	220.22	272.42	1.41	284.35	337.20
S2	0	258.09	269.31	254.56	262.46	356.38	343.19	–	336.98	331.66	324.08	312.93	325.44	–	292.60	299.01	–	–

Table 6. Qualitative location relationship between Region 0 and other regions in OSM and sketch S2.

	Region ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
OSM	0	SW	W	SW	SW	N	NW	NW	NW	NW	NW	NW	NW	SW	W	N	NW	NW
S2	0	SW	W	SW	W	N	NW	-	NW	NW	NW	NW	NW	-	NW	NW	-	-
Consistent w.r.t. OSM?		√	√	√	×	√	√	–	√	√	√	√	√	–	×	×	–	–

4.2.3 Analysing the Order Relationship of Regions along a Road

The spatial order relationship refers to the arrangement of geographical features in geographical space. In this paper, the order relationship refers to the order of regions along roads. Our approach computes the shortest distance between the centre of gravity for each region and roads to obtain the intersection between a region and a road.

Figure 21 shows an example of region order along Road 19, as presented in Table 7. Note that if the nearest point on a road to the centre of gravity of a region is at one of the road's endpoints, that region is not considered in computing its order of appearance along that road. For example, as shown in Figure 21 and Table 7, Region 14 is not included in the order of appearance calculation along Road 19 in OSM.

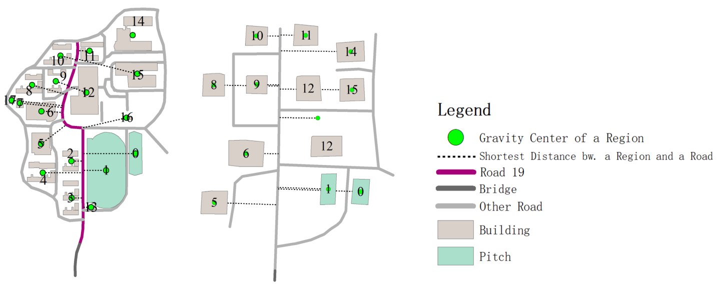


Figure 21. Regions' ordered relationship along one road from OSM (left) and sketch S8 (right). Road 19 is shown in dark purple.

Table 7. Region order along Road 19 in OSM and sketch S8.

	Region Order along Road 19
OSM	11, 15, 10, 9, 12, 8, 17, 7, 6, 5, 16, 0, 2, 1, 4, 3, 13
S8	11, 10, ~~14~~, 9, 8, **15**, **12**, 6, **1**, 0, **5**

In Table 7, numbers with a strikethrough indicate the corresponding object does not appear in the OSM order, and numbers in bold indicate that their order is inconsistent with OSM.

The total number of regions in S8 is 10, and the order relationship of 6 regions in S8 are consistent with the corresponding region order relationships in OSM. Thus, the accuracy of regions along Road 19 in S8 compared to OSM is 6/10.

4.2.4 Topological Relationships between Regions and Roads

For each sketched place, our approach describes the topological relationships between regions, between roads, and between regions and roads, as shown in Figure 22.

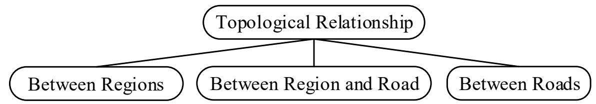


Figure 22. Different topological relationships.

The 9-intersection model is used to represent the topological relationship between objects, which include *equal*, *disjoint*, *touch*, *contains*, and others. While most of the real buildings are separated, our approach also uses relative closeness to refine topological relationships between disjoint regions and between disjoint regions and roads. Figure 23 shows the flow chart of computing topological relationships between regions in our approach.

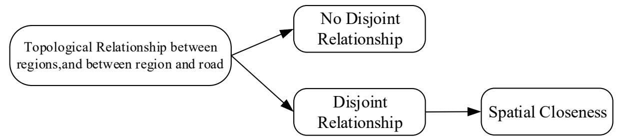


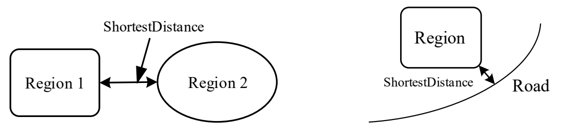
Figure 23. Flow chart of computing topological relationship between regions.

The relative closeness between two disjoint objects (denoted by RelCloseness) is defined by the Relative Closeness Reference System or RelClosenessRS = {CR, $\text{RelCloseness}_{\text{CON}}$, $\text{RelCloseness}_{\text{INT}}$}, where CR or Closeness Relation refers to the relative closeness between two objects; $\text{RelCloseness}_{\text{CON}}$ refers to the set of relative closeness labels; and $\text{RelCloseness}_{\text{INT}}$ refers to the values of CR related to each label.

$\text{RelCloseness}_{\text{CON}}$ = {Short Distance (SD), Middle Distance (MD), Long Distance (LD)}

$\text{RelCloseness}_{\text{INT}}$ = {(0, 0.3], (0.3, 0.7], (0.7, 1]}

Our approach uses the shortest distance between objects to represent the closeness relationship (shown in Figure 24). The distances between all points on the two regions/roads are compared in turn, and the shortest distance between the points is considered to be the shortest distance between the two regions/roads. Due to the inconsistent scale between OSM and the sketch, the shortest distance is normalized. The normalization here is the shortest distance divided by the largest distance in OSM and sketches, respectively. Table 8 shows the normalized closeness values between Region 1 and other regions in sketch S1 and OSM. The relative closeness according to Table 8 is shown in Table 9.



(a) Closeness between regions (b) Closeness between region and road

Figure 24. Calculation of closeness or the shortest distance between two regions or a region and a road.

Table 8. Normalized spatial closeness values between Region 1 and other regions in OSM and sketch S1. ('–' represents an object not drawn in the sketch.)

	Region ID	0	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
OSM	1	0.021	0.054	0.052	0.207	0.232	0.241	0.460	0.413	0.337	0.482	0.461	0.120	0.004	0.526	0.312	0.103	0.525
S1	1	-	-	0.115	-	0.448	0.558	-	0.922	0.633	0.878	0.629	0.218	-	0.644	0.359	-	-

Table 9. Relative Closeness relationship between Region 1 and other regions in OSM and sketch S1 according to RelClosenessRS. ('–' represents an object not drawn in the sketch.)

	Region ID	0	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
OSM	1	SD	SD	SD	SD	SD	SD	MD	MD	MD	MD	MD	SD	SD	MD	MD	SD	MD
S1	1	-	-	SD	-	MD	MD	-	LD	MD	LD	MD	SD	-	MD	MD	-	-

The qualitative topological relationships between roads are also analysed with the 9-intersection model. Figure 25 shows roads in OSM and sketch S1; the topological relationship between Road 19 and other roads from OSM and sketch S1 are shown in Table 10. It can be found that the topological relationships are consistent between OSM and sketch S1. But there are also inconsistencies of topological relationships between roads from the sketches and the metric map. The inconsistencies stem from two reasons: (i) incorrectly drawn roads. For example, Figure 26 (a) shows the topological relationship between two roads (displayed in red and green) was *disjoint* in the metric map, while that of the corresponding two roads in sketch S1 was *touching* (see Figure 26 (b)); and (ii) partially drawn roads. In Figure 26 (c), the topological relationship is *touching* between two roads (displayed in red and green) in the metric map, while the corresponding two roads (displayed in red and green) in sketch S6 is *disjoint* (see Figure 26 (d)).

Table 10. Topological Relationship between Roads in OSM. ("D" represents *disjoint*, "T" represents *touching*, "C" represents *contains* and "–" represents an object not drawn in this sketch.)

	Road ID / Road ID	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	20	21
OSM	19	T	T	T	T	D	D	T	D	T	D	D	D	D	D	D	T	T	D	D	T	D
S1	19	-	T	T	-	-	-	T	-	T	-	D	-	D	-	-	-	T	-	-	T	D

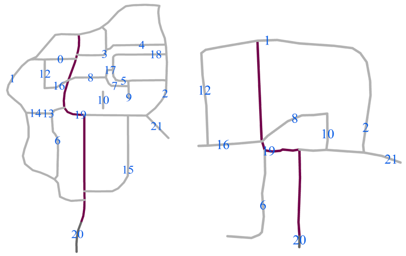
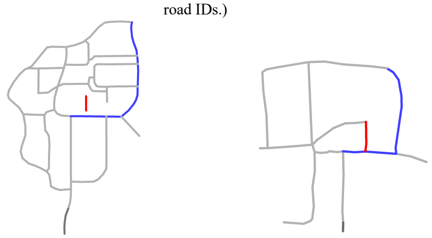


Figure 25. Roads in OSM (left) and sketch S1 (right). (Road 19 is shown in dark purple, and numbers represent road IDs.)



(a) Two roads (red and green lines) in OSM. (b) Two roads in sketch S1(red and green lines). One road was incorrectly drawn (red line) w.r.t.(a).

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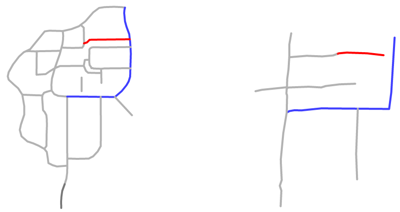


(c) Two roads (red and green lines) in OSM. (d) Two roads in sketch S1 (red and green lines). One road was partially drawn (red line) w.r.t.(c).

Figure 26. Inconsistently drawn roads in OSM and two sketches.

Our approach also uses relative closeness to describe the spatial proximity between a region and a road. Figure 27 shows regions in OSM and sketch S1. Table 11 shows the normalized closeness between Road 19 and all regions in OSM and sketch S1, and Table 12 shows the relative closeness according to Table 11.

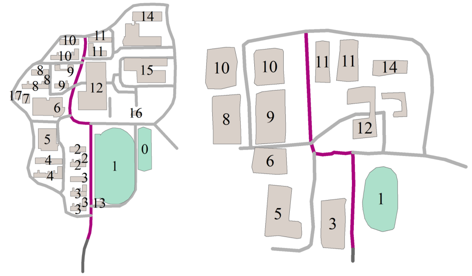


Figure 27. Roads and regions in OSM (left) and sketch S1 (right). (The numbers represent region IDs; Road 19 is shown in dark purple.)

Table 11. The normalized closeness between Road 19 and all regions in OSM and sketch S1. ('–' represents an object not drawn in this sketch.)

	Region ID / Road ID	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
OSM	19	0.23	0.02	0.02	0.02	0.14	0.09	0.02	0.20	0.12	0.02	0.01	0.01	0.01	0.02	0.18	0.20	0.20	0.25
S1	19	-	0.05	-	0.03	-	0.22	0.14	-	0.36	0.12	0.12	0.03	0.07	-	0.35	0.29	-	-

Table 12. The relative closeness between Road 19 and all regions in OSM and sketch S1 according to RelClosenessRS. ('–' represents an object not drawn in this sketch.)

	Region ID / Road ID	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
OSM	19	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD
S1	19	-	SD	-	SD	-	SD	SD	-	MD	SD	SD	SD	SD	-	MD	SD	-	-

5 Analysis of Invariant Characteristics as Matching Factors

We compared all sketches with OSM using the characteristics mentioned above to find suitable invariants between them. Comparisons of object-level characteristics include region categories and relative sizes (Section 5.1 and Section 5.2), region names (Section 5.3), relevance of regions and roads (Section 5.4 and Section 5.5), and object shape (Section 5.6). Moreover, we also analysed structure-level characteristics, including location relationship (Section 5.7) and topological relationship (Section 5.8). To find the invariants between a sketched place and OSM, we divided all characteristics into either matching characteristics or non-matching characteristics.

5.1 Comparing Region Categories

Due to the lack of object category definition in Chinese, our approach uses visual comparison to obtain the similarity between the categories annotated in sketches with the corresponding actual categories in OSM. According to our comparison, as Table 13 shows, the selected categories for the sketched objects are entirely correct in this sketched place. It means that in people's spatial cognition, the judgement of the categories of sketched objects is accurate. Note that some volunteers preferred to annotate objects with names, so only sketches with category annotations were compared here.

Table 13. Categories correctly defined in sketches.

Sketch ID	S2	S3	S7	S8	S10	S11
Quantity of Objects Drawn	14	12	8	12	10	10
Quantity of Category Correctly Defined	14	12	8	12	10	10

5.2 Comparing the Relative Sizes of Regions

As described in Section 4.1.3, the size of each region is calculated separately, and then our approach compares the areas of two regions to find the relative size. Table 14 shows the consistent rate of relative size between regions in each sketch to those in OSM.

Table 14. The consistent rate of relative size in each sketch w.r.t. OSM.

Sketch ID	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
Quantity of Region Pairs	55	91	66	36	55	55	28	55	78	45	36
Consistent Quantity w.r.t. OSM	26	75	51	12	35	46	10	38	40	13	12
Consistent Rate w.r.t. OSM	0.47	0.82	0.77	0.33	0.63	0.84	0.36	0.69	0.51	0.29	0.33

In Table 14, the row labelled "Quantity of Region Pairs" gives the number of region pairs included in each sketch, the row "Consistent Quantity w.r.t. OSM" means the number of object pairs that have the same relative size as the corresponding objects in OSM, and the row "Consistent Rate w.r.t. OSM" means the consistent rate of relative size in each sketch to those in OSM through comparing the numbers from the "Consistent Quantity w.r.t. OSM" row and the "Quantity of Objects Pairs" row.

A ranking of sketch similarity with OSM based on the relative size consistency between regions gives the following order: S6>S2>S3>S8>S5>S9>S1>S7>S4=S11>S10, where the sketch with the worst relative size consistency is S10, and S6 has the best relative size consistency.

5.3 Comparing Region Names

Our approach uses the Levenshtein distance (1966) to compare the annotations of objects in the sketched place with the names of the corresponding objects in OSM, as described in Section 4.1.4. Figure 28 shows the names defined in OSM, and Table 15 shows the Levenshtein distances between names defined in each sketch and OSM, from which we can find that bigger distances occur in objects with longer names, because volunteers preferred to use abbreviated names. Some volunteers used different names to annotate one region, which resulted in a distance larger than 1. For example, in S4, the name Region 12 that volunteer annotated was "环境学院", which is different and longer than the corresponding object name annotated in OSM. With regard to name similarity, the worst sketch is S1, and the best are S4 and S9.

OBJECTID	Name	EnName
0	北区篮球场	Basketball Court
1	北区田径场	Football Field
2	33栋	33th Dormitory
3	31栋	31th Dormitory
4	32栋	32th Dormitory
5	北区学生活动中心	Student Activity Center
6	北区食堂	Canteen
7	废弃澡堂	Abandoned Bathhouse
8	35栋	35th Dormitory
9	34栋	34th Dormitory
10	36栋	36th Dormitory
11	37栋	37th Dormitory
12	学行楼	School Building
13	北区田径场管理站	Field Management Station
14	行知楼(K4)-生科院	School Building- School of Life Science
15	行远楼-地理科学学院	School Building- School of Geography
16	北区喷泉	Fountain
17	废弃锅炉房	Abandoned Boiler House

Figure 28. Regions names defined in OSM.

Table 15. Levenshtein distances between names defined in each sketch and OSM. (Note that - represents annotation of an object not drawn in the sketch; only sketches with name annotations are compared.)

Object ID / Sketch ID	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
S1	-	0.80	-	1.00	-	1.00	0.50	-	0.33	0.33	1.00	1.00	1.00	-	0.91	0.90	-	-
S4	-	0.80	-	-	-	1.00	0.50	-	0.00	0.00	0.00	-	1.33	-	0.73	0.70	-	-
S5	-	0.40	1.00	-	-	1.00	0.50	-	0.33	0.33	0.33	0.33	2.00	-	0.73	0.70	-	-
S6	0.40	0.80	-	-	-	1.00	0.50	-	0.33	0.33	0.00	0.00	1.67	-	0.73	0.70	-	-
S9	-	0.80	0.00	0.00	0.00	1.00	0.50	-	0.00	0.00	0.00	0.33	1.00	-	0.73	0.70	-	-

5.4 Obtaining Region Relevancy

We counted the frequencies of all regions drawn in each sketch to detect the importance of various regions in volunteers' perceptions. Table 16 shows the statistics of different regions drawn in all sketches according to their categories.

We draw the following conclusions through an analysis of Table 16:

- Regions closely related to everyday needs, such as supermarkets, restaurants, dormitory buildings and teaching buildings are most often drawn, indicating that these region categories are most profound in the human perception and these object categories can be used as the primary matching factors in place query-by-sketch.
- The drawing frequencies of the abandoned bathhouse and boiler house are relatively small.

Additionally, because the basketball court and football field are adjacent to each other, some volunteers combined these two into one. This is why the basketball court was drawn less frequently. This is also called semantic neighbourhood (Rodríguez & Egenhofer, 2003), which means semantically similar entity classes (i.e., sport fields and courts, and bars and restaurants) can have quite different names but are likely to share some common features, and their spatial relationship is often "next-to" each other in a specific area (Schwering 2004).

Table 16. Drawing frequencies of regions in all sketches.

Place ID	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Name Code	B	F	33rd	31st	32nd	SA	C	AB	35th	34th	36th	37th	SB	FMS	SLS	SG	FT	ABH
Drawing Frequencies	4	11	3	6	2	10	11	0	10	10	9	10	11	0	11	10	0	0

In Table 16, B represents a basketball court, F represents a football field, 33rd represents the 33rd dormitory, 31st represents the 31st Dormitory, 32nd represents the 32nd Dormitory, SA represents the student activity centre, C represents a restaurant, AB represents an abandoned bathhouse, 35th

represents the 35th dormitory, 36th represents the 36th dormitory, SB represents a school building, FMS represents a field management station, SLS represents a School of Life Science building, SG represents a School of Geography building, FT represents a fountain, and ABH represents an abandoned boiler house.

5.5 Obtaining Roads Relevance

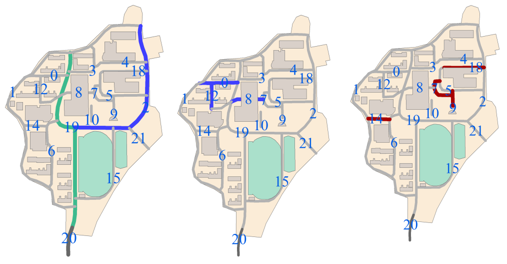
We also counted the frequencies of all roads in each sketch to obtain the importance of roads in volunteers´ perceptions. Table 17 shows the drawing frequencies of different roads drawn in all sketches according to their categories.

- Roads 2 and 9 with the highest drawing frequencies are the central roads in the experimental scenario, as Figure 29(a) shows.
- Roads 0, 8, and 16 are those leading to the dormitory and the teaching building, as Figure 29(b) shows.
- Roads 7, 9, 11, 13, 14, 17, and 18 with the lowest drawing frequencies are auxiliary roads leading to the restaurant and the teaching building, as Figure 29(c) shows.

As a result, the roads at the centre position can be given a higher matching priority. It is essential to point out that road 20 is a bridge, so although it is drawn less frequently in all sketches, due to its uniqueness, it still can be given a higher matching priority.

Table 17. Frequency of roads in all sketches.

Road ID	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Drawing Frequencies	6	4	9	4	3	1	4	0	5	0	1	0	2	0	0	3	6	0	0	9	3	4



(a) (b) (c)

Figure 29. (a)The most frequently drawn central roads in all sketches (displayed in green)
(b)The roads that were less frequently drawn in all sketches (displayed in blue)
(c)The roads that were never drawn in the sketches (displayed in red)

We also found that some roads were schematically sketched, and the drawings did not reflect their actual shapes, as Figure 30 shows; these schematics only represent the accessibility between two regions. The volunteers who drew these sketches lack a geoscience background. Consequently, the sketched roads were not considered in our subsequent road-related calculations.

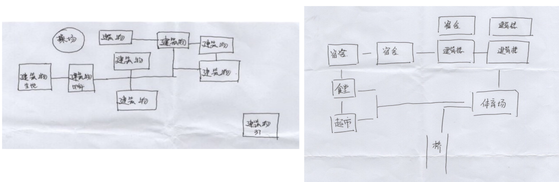


Figure 30. Accessibility of roads with schematic significance in some sketches.

5.6 Comparing the Shapes of Sketched Roads with those in OSM

As described in Section 4.1.2, some roads are sketched completely, while others are sketched partially. Additionally, the angular shapes of sketched roads in different sketches vary. Our approach compares all roads in OSM (shown in Figure 31) with the roads drawn in all sketches (shown in Figure 32) and finds that it is difficult to find any similarities.

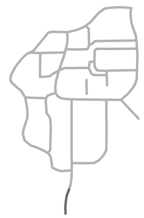


Figure 31. Roads in OSM.

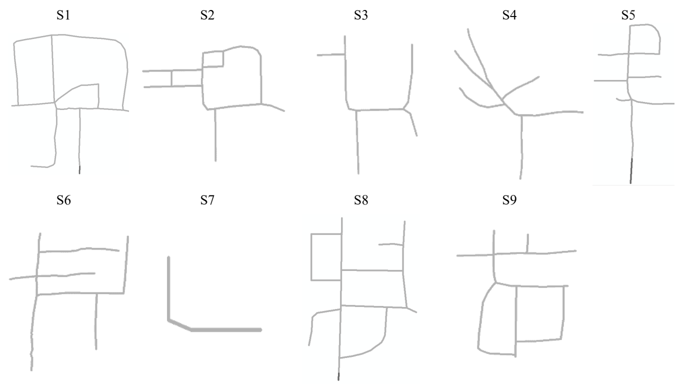


Figure 32. Roads extracted from the volunteers' sketches.

To further clarify the similarity in road shapes between sketches and OSM, Road 19 and 2 with the highest drawing frequencies were analysed for specific shape analysis, as Figure 33 shows. Table 18 shows that Roads 19 and 2 are present in all sketches. The shapes of these two roads in all the sketches have a higher similarity to the shapes of the corresponding two roads in OSM.

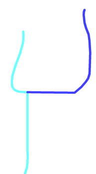


Figure 33. Road 19 (cyan line) and Road 2 (blue line) in OSM have the highest sketched frequencies in all sketches.

We adopt a shape matching approach to sort the roads from OSM by similarity. The approach includes comparison of shape distance (Vatavu et al., 2012), topological relationship between roads, and others. The results from searching all roads in Nanjing (data from OSM, including a total of 15,242 records) are shown in Table 19 and Table 20.

Table 18. Road 19 and Road 2, most frequently sketched by volunteers.

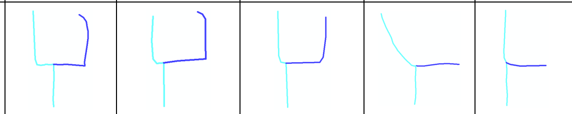
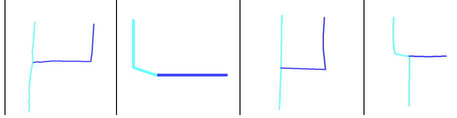
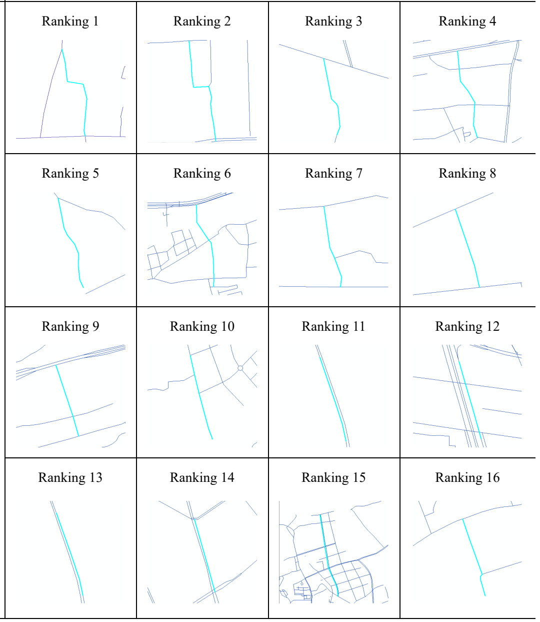
Sketch ID	S1	S2	S3	S4	S5
Most Frequently Drawn Road 19 and 2					
Sketch ID	**S6**	**S7**	**S8**	**S9**	
Most Frequently Drawn Road 19 and 2					

Table 19. Some matching results with Road 19 from OSM.

Road 19 in Sketch S1	Matched Roads in OSM Ranked according to Similarity.
	

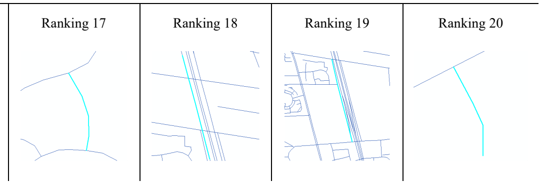
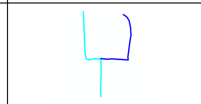
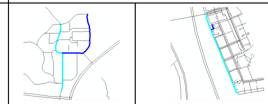
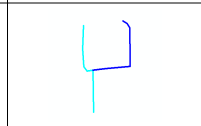
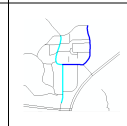
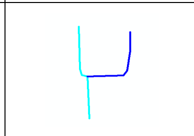
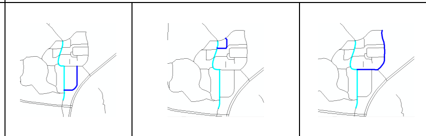
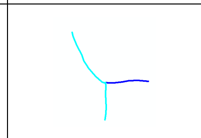
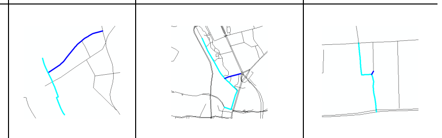
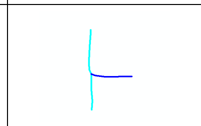
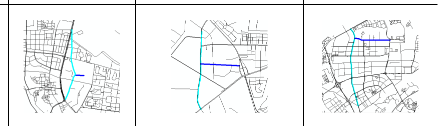
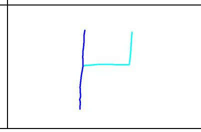
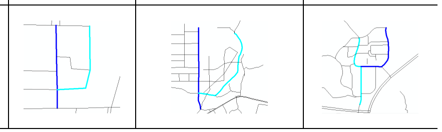
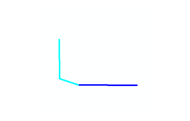
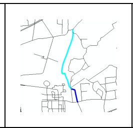
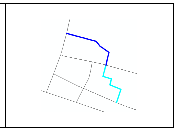
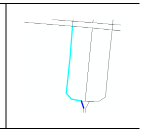
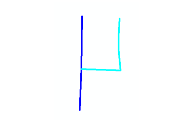
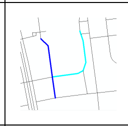
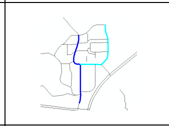
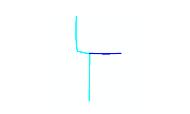
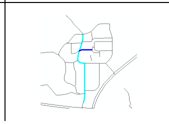
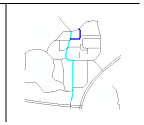


Table 20 shows the results of matching the two composite main road shapes (Road 19 is shown in green and Road 2 is shown in blue). If the road is completely drawn, we can obtain the correct result through shape retrieval, but if the road is only partially drawn, the search results differ from the actual road. If there were more than three matching results, Table 20 displays only the top three results for each match.

Table 20. Results of matching the composite shape of two main roads -Road 19 (cyan line) and Road 2 (blue line)- in sketch S1 with OSM.

Sketch ID	Two Main Roads: Road 19 and 2 from Sketches	Matched Roads in OSM Ranked According to Similarity
S1		
S2		
S3		
S4		
S5		
S6		

S7				
S8				
S9				

Due to the differences in building shapes between sketches and OSM described in Section 4.1.2, and because sketched buildings are typically drawn as rectangles, our approach does not consider shape matching for buildings.

5.7 Analysis of the Relative Location Relationship

In our approach, qualitative location relationship between regions (Section 5.7.1), quantitative location relationship between regions (Section 5.7.2), and order relationships of regions along roads (Section 5.7.3) are used to compare the similarity between sketched places and OSM to represent the overall location relationship.

5.7.1 Analysis of the Qualitative Location Relationship between Regions

The qualitative location relationship between regions includes east, west, south, north, northeast, southeast, northwest, and southwest, as described in Section 4.2.2. We used the absolute string comparison method to obtain the correct rate of qualitative location relationship between regions from all sketches, as Table 21 shows.

Table 21. The correct rate of qualitative location relationship between sketched regions.

Sketch ID	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
Correct Number/Total Number	36/45	60/78	39/55	13/36	40/55	36/45	22/28	35/45	59/78	23/45	27/36
Correct Rate	0.80	0.76	0.70	0.36	0.72	0.80	0.79	0.78	0.76	0.52	0.75

The similarity of all sketches to OSM based on the accuracy of the qualitative location relationship has the following order: S1=S6>S7>S8>S2>S9>S11>S5>S3>S10>S4. The worst sketched place in terms of qualitative location relationship is S4, and the best are S1 and S6.

5.7.2 Analysis of Quantitative Location Relationship between Regions

Our approach uses the azimuth distance to represent the quantitative location relationship, as described in Section 4.2.2. To compare the quantitative location relationships between the corresponding regions in a sketch and OSM, the RMSE (Root Mean Square Error) is calculated to get the difference between them. RMSE is defined as:

$$\mathrm{RMSE}_{(i,j)} = \sqrt{\frac{\sum_{j=1}^{n}\sum_{i=1}^{n}(A_{sketch(i,j)} - A_{OSM(i,j)})^2}{n}}$$

where $A_{sketch(i,j)}$ refers to azimuth distance, which represents the quantitative location relationship (described in Section 4.2.2) between the i^{th} region and the j^{th} region in one sketch. $A_{OSM(i,j)}$ refers to azimuth distance, which represents the quantitative location relationship between the i^{th} region and the j^{th} region in OSM. The RMSE statistics are calculated between each sketch and OSM, as Table 22 shows.

Table 22. RMSE of the azimuth distances between sketches and OSM.

Sketch ID	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
RMSE	0.64	0.24	1.41	9.53	1.05	2.48	0.64	0.70	0.45	27.66	0.95

An analysis of Table 22 yields the following results:

- A complete sketch with a small RMSE value has a high region location similarity to OSM. According to the RMSE numerical analysis of all sketches and OSM, sketches with higher similarity to OSM, such as S2 and S9, have smaller RMSE values.
- Some sketches with small RMSE values have high similarity to OSM. Sketch S7, which contains few regions, still has a high similarity to OSM regions, and its RMSE value is small.
- Sketches with large RMSE values have low OSM region location similarity. Sketches S4 and S10 are less similar to OSM, which is consistent with their larger RMSE values.
- The volunteers have varying geographical backgrounds. Sketches S10 and S11 were drawn by volunteers whose only geographical experience was using Google Maps. The RMSE value obtained for S11 indicates little similarity to OSM, so the geographical background of the volunteer is not a decisive factor affecting sketching.

The order of similarity of all sketches based on the quantitative location relationship RMSE value is: S2>S9>S1>S7>S8>S11>S5>S3>S6>S4>S10. The sketched place with the worst quantitative location relationship is S10, and the best is S2.

5.7.3 Analysis of the Order Relationship of Regions along Roads

To compare the order relationship of sketched regions with OSM, the order correctness rate of each sketch is calculated using the method described in Section 4.2.3. Considering Road 2 and Road 19, which had the highest drawing frequencies, we analysed the correct rate of the order relationship of regions along these two roads, and the results are shown in Table 23. The sketches are presented in each column. In rows, we analyse (i) the quantity of order accuracy along Road 2 (in Row 1) and Road 19 (in Row 3) with respect to the corresponding order in OSM; (ii) the accuracy rate of ordering along Road 2 (in Row 2) and Road 19 (in Row 4), which refers to the proportion of the correct order of regions along one road with respect to the corresponding order in OSM.

Table 23. The order relationship for Road 2 and Road 19 in all sketches.

Sketch ID	S1	S2	S3	S4	S5	S6	S7	S8	S9
Order Accuracy along Road 2	3/3	5/5	5/5	2/2	3/3	5/6	3/4	5/6	2/3
Accuracy Rate along Road 2	1	1	1	1	1	0.83	0.75	0.83	0.67
Order Accuracy along Road 19	8/10	10/12	7/11	6/8	7/10	7/10	4/5	6/10	8/12
Accuracy Rate along Road 19	0.80	0.83	0.63	0.75	0.70	0.70	0.80	0.60	0.67

From Table 23, the order accuracy along Road 2 is higher than the order accuracy along Road 19. By sorting the sketches according to order accuracy along Road 2 and Road 19, we obtain the following:

- Along Road 2: S1=S2=S3=S4=S5>S8=S6>S7>S9. The worst sketched place regarding region order relationship along Road 2 is S9, and the best is S1.
- Along Road 19: S2>S1=S7>S4>S5=S6>S9>S3>S8. The worst sketched place regarding region order relationship along Road 19 is S8, and the best is S2.

Regions 0, 1, 5, 8, 12 and 15 have the highest frequency of arrangement differences in all sketches based on Roads 2 and 19. Figure 34 shows the reason: these objects are in a nearly parallel position in OSM. As a result, volunteers can decide to alternate their relative positions in sketches.

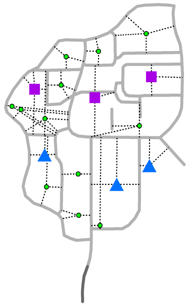


Figure 34. Regions with the highest frequency of order errors based on Roads 2 and 19 in sketches (displayed with blue triangles and purple squares).

5.8 Topological Relationship between Regions and Roads

The 9-intersection model is used to calculate the topological relationships between objects, as described in Section 4.2.4. Due to the differences of scale between the sketch and OSM, our approach uses spatial closeness to analyse the topological relationships between regions (Section 5.8.1), topological relationships between roads (Section 5.8.2) and topological relationships between a region and a road (Section 5.8.3).

5.8.1 Analysis of Topological Relationship between Regions

Figure 1 shows that the topological relationship between all pairs of regions in this place is *disjoint*. Our approach uses the method described in Section 4.2.4 to obtain the relative closeness relationship between regions in all sketches and OSM. The absolute string comparison method is adopted to analyse the similarity between sketches and OSM.

Table 24 shows the consistent rate of closeness between sketched regions to OSM. By arranging the sketches in terms of the consistent rate of closeness between regions to those in OSM, we obtain: S2>S3=S6>S9>S8>S5>S10>S1>S4>S11>S7; the most consistent is S2 and the least consistent is S7.

Table 24. Consistent Rate of Closeness between Regions in Sketches w.r.t. OSM.

Sketch ID	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
Pairs of Objects	55	91	66	36	55	55	28	55	78	45	36
Quantity of Closeness Consistent with OSM	16	70	44	10	30	37	2	32	51	19	5
Consistent Rate	0.29	0.77	0.67	0.28	0.54	0.67	0.07	0.58	0.65	0.42	0.14

5.8.2 Analysis of Topological Relationship between Roads

Our approach adopts the 9-intersection model to analyse the qualitative topological relationship

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between roads, as described in Section 4.2.4. Table 25 presents the rate of correct identification of the topological relationships between roads and two main roads (Road 2 and Road 19) in our experimental area for all sketches. Inconsistencies appear in Table 25. For example, the ratio of correct / total quantity of topological relationships between roads in sketch S1 w.r.t OSM is 8/9. This means one of the topological relationships in sketch S1 is inconsistent with the corresponding relationship in OSM. The inconsistency is caused by: incorrectly drawn roads and partially drawn roads in sketches, as described in Section 4.2.4. According to our statistics, the quantity of inconsistent topological relationships due to incorrect drawing is 2, and that due to partial drawing is 3.

Table 25. The rate of correct identification of the topological relationships between roads and two main roads (Road 2 and Road 19) in all sketches.

Sketch ID	S1	S2	S3	S4	S5	S6	S7	S8	S9
Correct Quantity/Total Quantity and Road 2	8/9	6/6	3/3	4/4	6/7	6/7	2/2	10/10	5/6
Correct Quantity/Total Quantity and Road 19	8/8	6/6	2/2	4/4	7/7	6/7	2/2	8/8	7/7

Based on Table 25, by sorting by rate of correct topological relationships between roads and two main roads (Road 2 and Road 19), we obtain the following results:

Topological relationship w.r.t Road 2: S2=S3=S4=S7=S8>S1=S5=S6=S9;

Topological relationship w.r.t Road 9: S1=S2=S3=S4=S5=S7=S8=S9>S6;

Sketches S10 and S11 were not analyzed because the roads in these two sketches are not geospatial.

5.8.3 Analysis of Topological Relationship between Regions and Roads

Our approach uses relative spatial closeness to obtain the spatial topological relationships between roads and regions, as described in Section 4.2.4. Table 26 shows the spatial closeness between roads and regions in all sketches compared to OSM.

Table 26. Rate of Consistent Closeness between Region and Road in Sketches w.r.t. OSM.

Sketch ID	S1	S2	S3	S4	S5	S6	S7	S8	S9
Pairs of Objects	108	111	47	44	98	77	16	109	104
Quantity of Closeness Consistent with OSM	48	73	25	31	74	36	5	88	69
Consistency Rate	0.44	0.66	0.53	0.70	0.76	0.47	0.31	0.81	0.66

The order of spatial closeness similarity between roads and regions in the sketches and OSM is S8 > S5 > S4 > S2 = S9 > S3 > S6 > S1 > S7; the best is S8 and the worst is S7.

6 Discussion

Let us sum up our findings. Table 27 summarizes the comparisons between the sketches and OSM for each characteristic (in bold) with a similarity greater than a given threshold. We chose a threshold of 0.75 as a baseline for this study, which has been found by experimentation and can be turned for more precise similarity. The average value (represented as $\bar{X}$), standard deviation (represented as S) and reliability are calculated to determine which characteristics can be used as reliable invariants for aligning sketch maps and metric maps.

According to the values presented in Table 27, only three characteristics have higher similarities between the sketch maps and the metric map: *category of regions, shape of main roads, and topological relationship between roads and main roads.* As Table 27 shows, the averages in *category of regions* are all 1, and the S value is all 0. Comparing the shapes of main roads and topological relationship between main roads, our approach can obtain reasonable matching results from OSM, as Table 20 shows. In this table, five of the nine sketches had the correctly matched results in the top 3, including sketches S1, S2, S3, S6, and S8. The other four sketches (S4, S5, S7, and S9) did not get correctly matched results, because the sketched roads in these sketches were partially drawn. This means more accurate matching results can be obtained by using a completely drawn road rather than a partially drawn road. And, the accurate matching rates based on completely drawn roads are all 1. Characteristic *topological relationship between roads and main roads* also has large $\bar{X}$ values (0.94 w.r.t Road 2 and 0.98 w.r.t Road 19), and small S values (0.03 w.r.t Road 2 and 0.01 w.r.t Road 19).

For object level characteristics, similarities in *relative size of objects* and *annotated object name* are low between the sketch maps and the metric map. As illustrated in Table 27, the $\bar{X}$ value in *relative size of objects* is low (0.55<0.75), because only three sketches (S2, S3, and S6) have high similarities (>0.75) to OSM. Furthermore, the S value of this characteristic (0.20) is large. The reason is volunteers tend to use rectangles, which are similar to bounding boxes of regions that do not accurately represent a region's shape, as explained in Section 4.1.3. For characteristic *annotated object name*, although the S value (0.06) is relatively small, the $\bar{X}$ value is low (0.50) and similarities in this characteristic are wholly lower (<0.75), see Table 27. This is because volunteers all preferred to use abbreviated names to describe regions (Section 4.1.4). For example, volunteers annotated "地" or "地科院" (the abbreviated name of the School of Geography in Chinese), which is an abbreviated form of the full name "行远楼-地理科学学院" (School of Geography in Chinese).

The structure level characteristics also have low similarities, including *qualitative and quantitative location relationship between regions, order of appearance of regions along Road 19, topological closeness between regions and between regions and roads*. The S value of characteristic *qualitative location relationship between regions* is large (0.13), due to the low similarities in sketches S3, S4, S5 and S10 (0.70, 0.36, 0.72 and 0.52). The average and standard deviation of RMSE values in *quantitative location relationship* are large (4.16 and 8.23, calculated based on Table 22), because of the big RMSE values in sketches S4 and S10 (9.53 and 27.66, respectively—see Table 22). The S value of characteristic *order of appearance of regions along Road 19* is small (0.07), while that for Road 2 is large (0.12). This instability is due to the erroneous location of some regions drawn in one sketch. Volunteers alternated objects locations that are almost parallel, as analysed in Section 5.7.3. The *topological closeness between regions and between regions and roads* are two characteristics with low $\bar{X}$ values (0.46<0.75, 0.59<0.75) and large S values (0.22, 0.14). The can be attributed to the inconsistent distance scale between the sketched map and OSM, as explained in Section 4.2.4.

Table 27. Summary of all characteristics in all sketches: similarity values (> 0.75) are highlighted in bold. QCH represents the quantity of qualitative characteristics with higher similarities (>0.75) in one sketch. ACH represents the quantity of all characteristics with higher similarities (>0.75) in one sketch. $\bar{X}$ shows the average precision of each characteristic, and S shows its standard deviation. The best invariant characteristics are highlighted in italic.

Characteristic	Section	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	$\bar{X}$	S
Category of Regions	5.1	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	1	0
Relative Size of Objects	5.2	0.47	**0.82**	**0.77**	0.33	0.63	**0.84**	0.36	0.69	0.51	0.29	0.33	0.55	0.20
Annotated Object Name	5.3	0.38	-	-	0.57	0.48	0.51	-	-	0.57	-	-	0.50	0.06
Qualitative Location btw Regions	5.7.1	**0.80**	**0.76**	0.70	0.36	0.72	**0.81**	**0.79**	**0.78**	**0.76**	0.52	**0.75**	0.70	0.13
Order of Regions along Road 2	5.7.3	**1**	**1**	**1**	**1**	**1**	**0.83**	**0.75**	**0.83**	0.67	-	-	0.90	0.12
Order of Regions along Road 19	5.7.3	**0.80**	**0.83**	0.63	**0.75**	0.70	0.70	**0.80**	0.60	0.67	-	-	0.72	0.07
Topological Closeness btw Regions w.r.t. OSM	5.8.1	0.29	**0.77**	0.67	0.28	0.54	0.67	0.07	0.58	0.65	0.42	0.14	0.46	0.22
Topological Relationship btw Roads and Road 2	5.8.2	**0.89**	**1**	**1**	**1**	**0.86**	**0.86**	**1**	**1**	**0.83**	-	-	0.94	0.03
Topological Relationship btw Roads and Road 19	5.8.2	**1**	**1**	**1**	**1**	**1**	**0.86**	**1**	**1**	**1**	-	-	0.98	0.01
Topological Closeness btw Region and Road w.r.t. OSM	5.8.3	0.44	0.66	0.53	0.70	**0.76**	0.47	0.31	**0.81**	0.66	0.44	0.66	0.59	0.14
Quantity of Higher Consistence w.r.t. OSM	-	6	8	5	5	5	6	6	6	4	1	2	-	-
QCH/ACH	-	6/6	6/8	4/5	5/5	4/5	5/6	6/6	5/6	4/4	1/1	2/2	-	-

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According to our analysis, the qualitative characteristics have higher similarities than the quantitative characteristics between the sketched map and the OSM map in this paper, as shown in Table 27 (row QCH/ACH).

The shapes of roads drawn by study volunteers with low geography knowledge differed profoundly from the real roads in the OSM, as discussed in Section 4.1.2. We found no difference with respect to other characteristics. For example, S11 has a high similarity value in "Qualitative Location btw Regions" to the OSM, as Table 27 shows.

Reliability was used to measure the extent to which an accurate sketch aspect yielded the same result in repeated conditions of same participants and homogeneous study areas (Wang & Schwering, 2015). If the similarity of one characteristic differs significantly among each sketch, we consider that characteristic a significant one and vice versa. The Shapiro-Wilk test (W test) (Shapiro et al., 1965; Ghasemi & Zahediasl, 2012) was adopted in our approach to compute accuracy distributions, because of its robustness when being applied to small data sets. The Null-Hypothesis that distributions are the same is retained on a 95% confidence level. We identify those insignificant variations with having a p-value higher than 0.05.

We set the null and the alternative hypothesis as:

H_0: The accuracy of each sketch aspect is normally distributed.

H_A: The accuracy of each sketch aspect is not normally distributed.

Table 28 shows the obtained results. As an example, note that the similarity in the characteristic *relative size of objects* has a 95% probability of falling within the interval [0.4, 0.69]. The rest is read similarly. Note that characteristic *category of regions* is not involved in this statistical computation, because the similarities in this characteristic between each sketch and OSM are all 1 which means there is no difference.

Table 28. W test of sketch aspect accuracy including degree of freedom (Df) and significance (Sig.).

Characteristic	Df	Sig.	95% Confidence Interval for Mean	
			Lower Bound	Upper Bound
Relative Size of Objects	11	0.17	0.40	0.69
Annotated Object Name	5	0.35	0.40	0.59
Qualitative Location btw Regions	11	**0.01**	0.61	0.79
Order of Regions along Road 2	9	**0.01**	0.79	0.99
Order of Regions along Road 19	9	0.66	0.65	0.78
Topological Closeness btw Regions w.r.t. OSM	11	0.36	0.30	0.62
Topological Relationship btw Roads and Road 2	9	**0.01**	0.88	0.99
Topological Relationship btw Roads and Road 19	9	**0.00**	0.94	1.02
Topological Closeness btw Region and Road w.r.t. OSM	11	0.57	0.48	0.69

Table 28 shows that four characteristics have significances lower than 0.05 (in bold). The similarities in these four characteristics do not have 95% probability of falling within the corresponding confidence intervals, including *qualitative location between regions*, *order of* *regions along Road 2*, *topological relationship btw roads and Road 2, and topological relationship btw roads and Road 19*. While combining with the similarities in Table 27, characteristics *topological relationship btw roads and main roads* (Road 2 and Road 19) both have large $\bar{X}$ values (0.94 and 0.98) and low S values (0.03 and 0.01). Therefore, these two characteristics still can be taken as reliable invariants for alignment. The other five characteristics in this table have higher significances (>0.05). Thus, the differences of similarities in these characteristics among each sketch are not significant. Furthermore, it can be found that the upper bounds of the confidence intervals in four of these characteristics (*relative size of objects, annotated object name, topological closeness btw regions and road w.r.t. OSM and topological closeness btw regions w.r.t. OSM*) are all lower than 0.75 (0.69, 0.59, 0.69 and 0.62, respectively). As a result, these four characteristics are not reliable invariants for alignment. Characteristic *order of regions along Road 19* (main road in the experimental area) has a high upper bound of the confidence interval (0.78>0.75), but characteristic *order of regions along Road 2* (the other main rod in the experimental area) has low significance (0.01<0.05). So characteristic *order of regions along main roads* is not a reliable invariant for query-by-sketch.

Since RMSE values were calculated for analysing the differences in the characteristic *quantitative location btw regions*—azimuth distance—between each sketch and OSM (see Table 22), Cronbach's Alpha (Cronbach, 1951) is adopted for computing the coefficient of consistency in this characteristic. Table 29 shows the results. According to DeVillis's (1991) study, it is acceptable if the Cronbach's Alpha is higher than 0.70. Based on this, only one sketch (S2) has higher Cronbach's alpha than 0.70 (0.78 in bold) in Table 29. So, the characteristic *quantitative location btw regions* has no consistency among each sketch. It is not a reliable invariant for alignment.

Table 29. Cronbach's Alpha coefficient of azimuth distances between each sketch and OSM.

Sketch ID	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
Cronbach's Alpha	0.48	**0.78**	0.63	0.23	0.50	0.38	0.32	0.56	0.30	0.55	0.66

Finally, Table 30 summarizes the invariant characteristics based on our above analysis. The *shapes of main roads*, *categories of objects*, and *qualitative topological relationship between main roads* can be taken as reliable invariants for aligning the sketched map with the metric map.

Table 30. Invariant characteristics/factors that can be used as a reference for comparing/matching sketched and actual places.

	Object Level Matching Factors			
Can it be used as an invariant factor?	Shapes of Main Roads	Categories of Objects	Relative Size of Objects	Annotated Object Name
	Yes	Yes	No	No

	Structure Level Matching Factors				
Can it be used as an invariant factor?	Order of Regions along Main Roads	Quantitative Location between Regions	Qualitative Location between Regions	Topological Relationship between Roads and Main Roads	Topological Closeness between Regions and between Region and Road if Disjoint
	No	No	No	Yes	No

7 Conclusion and Future Work

This paper described a sketching study in which 11 volunteers drew the "place" where they study, that is, the North part of Xianlin University District of Nanjing Normal University. We proposed eight types of characteristics to represent and analyze objects in the sketch map from the object level and scene level. Among these characteristics, location relationship and topological relationship were further compared quantitatively (azimuth distance and spatial closeness) and qualitatively (Location Reference System and 9-intersection model). Moreover, the similarity and

reliability were evaluated for each characteristic statistically. The experimental results demonstrated that three characteristics can be chosen as reliable invariants for alignment: *categories of regions*, *topological relationship between roads and main roads* and *shape of main roads.* The similarities of characteristic *categories of objects* are all 1. The similarities of characteristic *topological relationship between roads and main roads (Road 2 and Road 19)* are both large (0.94 and 0.98). Sketches with complete drawn roads can be used to query out the corresponding place from OSM in top 3 based on matching the shapes of main roads. The evaluation also shows that the characteristics *qualitative location btw regions* and *ordering of regions along Road 2* cannot be chosen as reliable invariants, as the differences in these two characteristics are significant (<0.05, 95% confidence interval). Furthermore, characteristics *relative size of objects*, *annotated object name*, *ordering of regions along Road 19*, *topological closeness btw regions* and *topological closeness btw region and road* are also not selected as reliable invariants, even though they have higher significance (>0.05, 95% confidence interval), because their average accuracy precisions are all smaller than 0.75. The characteristic *quantitative location btw regions* is also not chosen as a reliable invariant for alignment due to the low Cronbach's Alpha coefficients (<0.7 in ten of eleven sketches).

Moreover, we also observed that volunteers' level of geographical knowledge is not correlated with their production of sketches more or less similar to OSM. We had two cases: the volunteers who produced sketches S10 and S11 did not have a GIS studies background, and one obtained a sketch quite close to OSM (sketch S11), while the other (sketch S10), was not as spatially precise. Although the sample size of our study was small, the dataset collected had enough potential to allow us (i) to find out diverse examples of different human spatial perceptions of a place (i.e. roads drawn using one or two lines, same regions drawn with different shapes even approximated to bounding boxes, etc.) and (ii) to identify useful invariants for finding a match between a sketched place and a place in OSM (i.e. using a road network).

As future work, we intend to explore this cognitive aspect further by performing another empirical study to assess volunteers' level of spatial reasoning skills (i.e., using psychological tests). Moreover, we also intend to use the same methods adopted in the approach presented in this paper (summarized in Figure 4) to analyse the sketches of other places (i.e., other university campuses) drawn by different volunteers, to validate whether these additional sketches have the same invariant characteristics as those obtained in the current study, and to analyse the cause of any differences found.

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