Shared Mental Models as a Psychological Explanation for Converging Mental Representations of Place – the Example of OpenStreetMap

Maren Mayer[1], Daniel W Heck[1], and Franz-Benjamin Mocnik[2,3]

[1]*School of Social Sciences, University of Mannheim, Germany*
[2]*Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, the Netherlands*
[3]*Institute of Geography, Heidelberg University, Germany*

People perceive the environment in various idiosyncratic ways, letting them conceptualize places differently. Representation in a data set and communication about places, however, create the need to reach agreement in the place a symbol or word represents. People have thus to integrate their views about a place. In this paper, we discuss how idiosyncratic views about places and their integration can be traced in OpenStreetMap. Then, we explore novel ways of how to model the integration processes of such idiosyncratic views by the means of psychological models. In particular, we explore the concept of Shared Mental Models. Such formal modelling and the corresponding better understanding of how people integrate their views about places improves the way we can make sense of collaborative shared data sets.

Keywords: concepts of place; shared mental models; collaborative behaviour; knowledge integration; ontology merging; OpenStreetMap (OSM)

History: received on 16 July 2019; accepted on 16 August 2019; published on 27 January 2020

1 Introduction

Where in Coventry does the International Symposium on Platial Information Science take place? This question will most likely be answered differently by the various participants and conveners ahead of the symposium because they have different ways to get to the symposium and because they have different experiences about Great Britain. If this question is asked at the end of the symposium, however, the participants would provide more similar answers. Many of them possibly would, e.g., include the Zeeman Building in their answer, i.e., the building in which the symposium takes place. This expected difference in how participants describe the place where the symposium takes place can be explained in terms of the mental model that each of the participants has. These mental models differ because the participants have different backgrounds and experiences. They conceptualize differently. During the symposium, the participants stay in the same room, they interact, and they have possibly similar ideas about why they participate. By this shared experience their mental models can become entangled and thus closer aligned, which is why they describe the place in a potentially more similar way than before.

Social interaction can reveal how individuals align their mental models about places. Places are at least in parts socially constructed (e.g., Kyle and Chick, 2007; Low and Altman, 1992), as is also the case in the introductory example. When contributing to OpenStreetMap (OSM), a major example of Volunteered Geographic Information (VGI; Goodchild, 2007) and of Geographical Shared Data

M Mayer, DW Heck, FB Mocnik (2020): *Shared Mental Models as a Psychological Explanation for Converging Mental Representations of Place – the Example of OpenStreetMap*. In: FB Mocnik and R Westerholt (eds.), Proceedings of the 2nd International Symposium on Platial Information Science (PLATIAL'19), pp. 43–50

https://doi.org/10.5281/zenodo.3628871

PLATIAL'19 Second International Symposium on Platial Information Science (PLATIAL'19)
Coventry, UK; 5–6 September 2019

Sources (Mocnik et al., 2019), individuals compare their own mental model of a place to the representation they find in the data or on the map, potentially leading to an adaption of the representation. Thereby, it needs to be kept in mind that the way individuals read the map is strongly affected by the way information is visually represented (Keil et al., 2018). Also, the information conveyed by a map is strongly limited with respect to places (Mocnik and Fairbairn, 2018), which is a particular reason for why map reading is strongly influenced by our mental models. The folksonomy of OSM is a result of a shared representation. Individuals semantically annotate elements in a certain way, which is then adopted by others in a social process. This way of how the elements are annotated is documented in the OSM Wiki, but this documentation is merely a representation of the social process and its results (Mocnik et al., 2017). The differences in the way individuals cognitively experience and conceptualize places and the geographical environment can be traced in the data, as has been done in the case of social fragmentation and corresponding cartographic epistemologies in Jerusalem (Bittner, 2014, 2017; Bittner and Glasze, 2018).

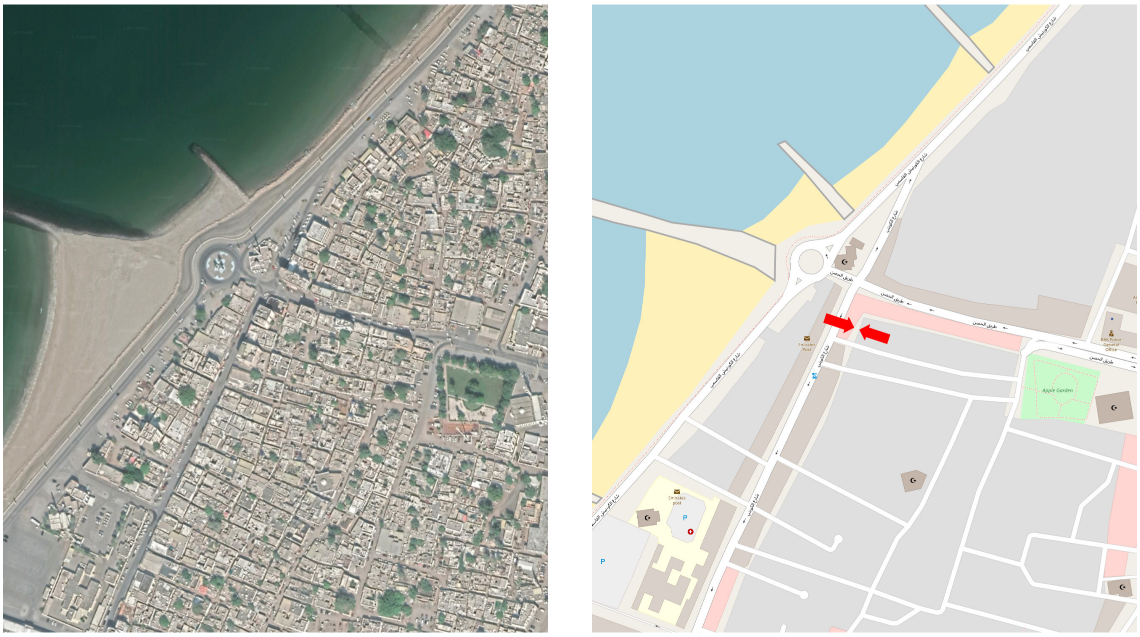
The paper is structured as follows. First, we discuss examples of how individuals represent places in idiosyncratic ways in OSM data (Section 2). Tracing these conceptualizations in the data is not straightforward – places are represented differently because they are different. Such differences in how we conceptualize can, however, be revealed when several representations of the same place at different points in time are compared (Section 3). As these differences do not coexist in the current version of the data (but only in their history), they need to be integrated. Such integration can be conceptualized by referring to the mental model that the contributors have (Section 4). Shared mental models, an approach from psychological research, can be used to understand and model how contributors decide for or against adapting the representation of places in OSM data (Section 5). Future research may use the proposed theoretical and methodological advances for explaining and predicting future inconsistencies in how we represent places in socially created data sets.

2 Examples of Idiosyncratic Representations of Places

Places are cognitively constructed by perceiving and making sense of what exists in space (Malpas, 1999; Tuan, 1977). The way we perceive and cognitively process our environment is subject to systematic distortion (Tversky et al., 1999). We thus conceptualize the same environment in different ways (Freundschuh and Kitchin, 1999; Tversky et al., 1999), leading to different ideas of the places we are in. For instance, we tend to align compass directions with the axes of the maps we use (Tversky, 1981). Sketch maps provide means to examine in detail the various ways in which individuals conceptualize places (Boschmann and Cubbon, 2014). Classical maps are, unlike sketch maps, different in the sense of that they usually adhere to space and geometries rather than to our perception. These maps provide the illusion of objectivity, which is despite the fact that the use of different map projections leads to very different geometrical representations. Further, maps offer the advantage that they can be created largely independently of the viewer and according to intersubjective scales, at least when compared to sketch maps.

Data sets and projects that form part of VGI are the result of a social creation process, in which usually a large number of individuals are involved. Many OSM elements have, e.g., been edited by several contributors, who potentially conceptualize places differently. These various conceptualizations lead to potentially differing representations. Some of the differences might no longer be visible in the data or the map representation because the folksonomy used is not fine-grained enough. Differences in water temperature, e.g., are so far not represented – there exists no corresponding OSM key. Other differences are, however, visible in the data. As an example, single trees are represented as such in the OSM data set while forests are often represented as 'tree-covered areas'. Contributors might judge in different ways whether a group of trees shall be mapped as single trees or as a tree-covered area. Accordingly, cognition and the way we conceptualize places has an impact on mapping behaviour.

Individuals experience a separation between public and private space, in particular in Arabic cultures (Costa and Noble, 1986). This difference, often referred to as public/private space dichotomy, can be traced in OSM. In Figure 1, a part of the city Ras Al Khaimah in the United Arab Emirates is depicted. The blocks of houses are interrupted by streets. Within a block of houses, no systematic gaps are visible on the satellite imagery (Figure 1a). The corresponding part of OSM, however, shows an elongated gap. The contributors have added a retail area that is received as public space and another



(a) Satellite imagery **(b)** OpenStreetMap

Figure 1: Representation of public and private space in Ras Al Khaimah, United Arab Emirates. In the centre part of (b), the map shows a gap between public retail space and private space (indicated by red arrows). This gap is most likely the result of the experienced separation between public and private space, because the satellite imagery (a) does not reveal any spatial structure alike. Copyright of map data: (a) Google Earth, DigitalGlobe, (b) OpenStreetMap contributors (cf. www.openstreetmap.org/copyright)

area that is received as private space (Figure 1b). The public/private space dichotomy is a seemingly plausible explanation for the gap between these two areas, but the validity of this explanation cannot be proven in retrospect.

3 Tracing Conceptualizations in the OpenStreetMap History

The various conceptualizations of place coexist in the OSM data set. A geographical feature can, e.g., be represented in one way while another feature is represented in a different way. Also, the representation of a geographical feature can change over time. That is, a contributor can change the geometric or thematic representation of a geographical feature in order to adapt it to his or her own conceptualization. As an entity can, however, only be represented in one way at a time, the contributors have to finally agree on a representation. That is, they have to find a coherent conceptualization of a place in the context of the used folksonomy, and they have to align their implicit assumptions about space. This situation is different to conventional data sources in the context of Geographic Information Systems (GIS), the latter of which are not able to capture places (Couclelis, 2005; Freundschuh and Egenhofer, 1997; Goodchild and Li, 2011). It seems, however, to be important to understand the ways individuals conceptualize places and negotiate these, because the conceptualization of a place underlying a map has an influence on the cartographic representation.

The history of a data set is the key to tracing conceptualizations. When examining the representation of a geographical feature, the conceptualization by the contributor who added the feature can at least to some degree be traced. Such knowledge would, however, not reveal how the conceptualization relates to the geographical feature, i.e., how the contributor distorts certain geometric and thematic features, unless ground truth is known. In order to minimize the effort and ensure that the results are of high quality, an intrinsic assessment would be favourable.[1] The different ways contributors conceptualize a feature can be traced intrinsically by comparing how one contributor created a representation of a geographical feature and how another one changed this representation. The history of the data, which is available in case of OSM,[2] is needed to examine such changes and accordingly the various representations of the feature.

4 Conceptualizing the Integration of Idiosyncratic Representations

Every person holds an idiosyncratic mental representation of their surrounding environment including geographical and geometrical features as well as information about properties, affordances, and functions (Freundschuh and Kitchin, 1999; Tversky et al., 1999). Nevertheless, the OSM community integrates these individual mental representations into a single shared conceptualization represented in the data. Many different processes such as the motivation to contribute, decision making on what to add or to change, and the emergence of shared editing rules among contributors can affect the development of the data. The resulting OSM data contain a shared representation formed among the contributors. Thus, each entry, either as history or currently used information, can be considered as a behavioural outcome of the processes that formed this shared representation.

In a first step, methods adapted from multiattribute decision making (Heck et al., 2017) could be applied to OSM data in order to understand in which situations users tend to adapt existing representations. Research on multiattribute decision making examines how individuals consider the attributes of available options, e.g., technical properties of different smart phones, and how these attributes contribute to the decision made. This notion could be adapted to contributions to the OSM data set by examining which attributes or settings are relevant for the decision whether to adapt the currently used representation (e.g., in case of non-rectangular corners, coarse mapping of buildings and streets, and missing tags). The obtained findings about this decision process can later be verified through a laboratory experiment. In such a setting, OSM data with different levels of mapping and tagging accuracy can be presented to participants who then decide whether they want to adapt the fictitious representation or not. This experiment can help to gain deeper insights into the preconditions of changes within OSM data.

Even though multiattribute decision making theories focus on individuals, analysing the OSM data with these methods offer the opportunity to apply these individual centred theories to a collaboration setting. This may extend theories on multiattribute decision making, may help to further understand decision making in social contexts as well as convergence among contributors in a decision context.

5 Shared Mental Models – a Potential Explanation for Converging Data

An understanding of how individuals make sense of the environment by forming a mental representation of entities and their relationships has been approached in the past (Johnson-Laird, 1980). The concept of mental models formalizes this idea by defining mental models as cognitive structures that resemble the structure of what is represented and allow logical connections between entities within the mental models (Johnson-Laird, 1980, 2005). When information changes or new information is available, mental models are adjusted accordingly (Johnson-Laird, 2005).

Research about mental models mostly concentrated on individual processes, in particular reasoning, by examining the logical inferences participants draw from given statements (Johnson-Laird, 2005). However, work and organizational psychology adapted this idea to group processes of team members working together in organisations, called shared mental models (Converse et al., 1991; Klimoski and Mohammed, 1994). Among several theories on how shared representations among team members foster team performance (Akkerman et al., 2007; Klimoski and Mohammed, 1994; Turner et al., 2014), the idea of shared mental models (Converse et al., 1991), sometimes also referred to as team mental models (Klimoski and Mohammed, 1994; Mohammed et al., 2010), could serve as a theoretical basis for research on OSM data as well. Shared mental models are mental models that overlap to a certain degree between team members (Converse et al., 1991). This overlap is conceptualized by the *degree of detail* and *accuracy*, the latter of which describes the extent to which the shared mental model captures the real-world environment. Other authors only differentiate between similarity as the degree of the sharedness of the model among team members and accuracy (Mohammed et al., 2010). In the context of organizations, shared mental models cover all facets of task completion, such as which tasks are performed, how these are performed and by whom, and which resources are available for completing a task.

To examine whether shared mental models are applicable, it needs to be tested whether contributors actually hold shared mental models. These models are expected to comprise contribution rules about mapping and tagging. They can be measured in surveys by asking contributors to describe how they would add or change certain objects to the data set. Since shared mental models are not only characterized by their content but also by the structure of their content, specific methods can be applied to measure these structural components along with the content (DeChurch and Mesmer-Magnus, 2010). To measure the accuracy of the measured shared mental models, the OSM Wiki can help to create a baseline model as a standard for comparison.

After exploring to what extent mental models are shared by the contributors, further research could examine the integration process of individual mental models leading to the development of shared mental models in more detail. While research on shared mental models often addresses the consequences of shared mental models on the performance of a team inside an organization (Mohammed et al., 2010; Turner et al., 2014), OSM data offer the opportunity to examine how shared mental models emerge – every element can be traced back to its creation in the data set. Research already demonstrated that shared mental models are the result of an extensive communication process (Van den Bossche et al., 2011). Especially, constructive conflicts, i.e., the discussion of differences in understanding between team members, is positively associated with the extent of similarity of mental models in teams. This communication process seems to be facilitated through the possibility to use visualization during the communication (Bittner and Leimeister, 2014). Unfortunately, however, OSM contributors mostly communicate only indirectly, which limits the examination of shared mental models. Nevertheless, hypotheses derived from the concept of shared mental models about how the contributed information is adapted over time, how contribution behaviour changes, and which contributors remain active within the community can still be tested. Constructive conflict, although not verbally, can emerge when contributors correct one another. As this correction is less interactive and less comprehensive as verbal communication and as it lacks any direct visualization, it might not suffice to change the mental models of other contributors. While some contributors may change their contributing behaviour and thus further participate in the development of a shared mental model, others may refrain from contributing when being corrected frequently.

6 Conclusions

Combining Geographical Information Science and Psychology to explore contribution behaviour to the OSM data set can lead to a deeper understanding of the relationship between idiosyncratic mental representations and shared representations of places in the data. Analysing the relative importance of feature properties for the decision whether and how to change the feature in question can lead to further insights on how geographical features are represented by contributors. Furthermore, it could be expected that, due to continuous changes of the representation, the contribution behaviour of all contributors converges over time. The OSM data include the representation of geographical features and their history, thereby potentially reflecting the assumed mental models. Extracting the mental model from the data seems, however, to be challenging because one cannot properly distinguish between the mental model, conventions of how to represent, and properties of the represented feature. The analysis of the data should therefore be complemented by experiments under controlled conditions and in a laboratory setting. These experiments would, e.g., examine whether the mental models of the contributors shift over time, or whether only the contribution behaviour and thus the representation within the OSM data changes. Findings obtained from the theoretical and methodological advances proposed in the present paper may help to explain current and predict future inconsistencies in representing places in the long run.

Notes

1. For a discussion of the ways to intrinsically assess the data, see the corresponding publication by Mocnik et al. (2018a).

2. For a computational examination of the history of OSM data, the framework *OSHDB* (Raifer et al., 2019) can be used. Further OSM-related data sources can provide additional context (Mocnik et al., 2018b).

Author Contributions

M Mayer, DW Heck, and FB Mocnik contributed the main idea jointly. M Mayer wrote Sections 4–6, while FB Mocnik wrote Sections 1–3. The writing and conceptualization of the paper was coordinated and supervised by FB Mocnik.

Funding

M Mayer has been supported by the Heidelberg Academy of Sciences and Humanities, and by the DFG graduate school *Statistical Modeling in Psychology* (GRK 2277). DW Heck has been supported by the DFG graduate school *Statistical Modeling in Psychology* (GRK 2277). FB Mocnik has been supported by the DFG project *A framework for measuring the fitness for purpose of OpenStreetMap data based on intrinsic quality indicators* (FA 1189/3-1).

ORCID

Maren Mayer https://orcid.org/0000-0002-6830-7768
Daniel W Heck https://orcid.org/0000-0002-6302-9252
Franz-Benjamin Mocnik https://orcid.org/0000-0002-1759-6336

References

Akkerman, Sanne; Van den Bossche, Piet; Admiraal, Wilfried; et al.: *Reconsidering group cognition: from conceptual confusion to a boundary area between cognitive and socio-cultural perspectives?* Educational Research Review, 2(1), 2007, 39–63. doi: 10.1016/j.edurev.2007.02.001

Bittner, Christian: *Reproduction of social fragmentations in OpenStreetMap: the example of Jerusalem*. Kartographische Nachrichten, 64(3), 2014, 136–144

—— *Diversity in volunteered geographic information: comparing OpenStreetMap and Wikimapia in Jerusalem*. GeoJournal, 82(5), 2017, 887–906. doi: 10.1007/s10708-016-9721-3

Bittner, Christian and Glasze, Georg: *Excluding effects of cartographic epistemologies – thinking about mapping paradigms in OpenStreetMap and Wikimapia*. Kartographische Nachrichten, 3, 2018, 120–125

Bittner, Eva Alice Christiane and Leimeister, Jan Marco: *Creating shared understanding in heterogeneous work groups: why it matters and how to achieve it*. Journal of Management Information Systems, 31(1), 2014, 111–144. doi: 10.2753/MIS0742-1222310106

Boschmann, E Eric and Cubbon, Emily: *Sketch maps and qualitative GIS: using cartographies of individual spatial narratives in geographic research*. The Professional Geographer, 66(2), 2014, 236–248. doi: 10.1080/00330124.2013.781490

Van den Bossche, Piet; Gijselaers, Wim; Segers, Mien; Woltjer, Geert; and Kirschner, Paul: *Team learning: building shared mental models*. Instructional Science, 39(3), 2011, 283–301. doi: 10.1007/s11251-010-9128-3

Converse, Sharolyn A; Cannon-Bowers, Janis A; and Salas, Eduardo: *Team member shared mental models: a theory and some methodological issues*. Proceedings of the Human Factors Society Annual Meeting, 35(19), 1991, 1417–1421. doi: 10.1177/154193129103501917

Costa, Frank J and Noble, Allen G: *Planning Arabic towns*. Geographical Review, 76(2), 1986, 160–172. doi: 10.2307/214622

Couclelis, Helen: *Space, time, geography*. In: Longley, Paul A; Goodchild, Michael F; Maguire, David J; and Rhind, David W (eds.), *Geographical information systems: principles, techniques, management and applications*, New York: Wiley, 2005. 2nd edn., 29–38

DeChurch, Leslie A and Mesmer-Magnus, Jessica R: *Measuring shared team mental models: a meta-analysis.* Group Dynamics: Theory, Research, and Practice, 14(1), 2010, 1–14. doi: 10.1037/a0017455

Freundschuh, Scott M and Egenhofer, Max J: *Human conceptions of spaces: implications for GIS*. Transactions in GIS, 2(4), 1997, 361–375. doi: 10.1111/j.1467-9671.1997.tb00063.x

Freundschuh, Scott M and Kitchin, Rob: *Contemporary thought and practice in cognitive mapping research: an introduction*. The Professional Geographer, 51(4), 1999, 507–510. doi: 10.1111/0033-0124.00187

Goodchild, Michael F: *Citizens as sensors: the world of volunteered geography*. GeoJournal, 69(4), 2007, 211–221. doi: 10.1007/s10708-007-9111-y

Goodchild, Michael F and Li, Linna: *Formalizing space and place*. Proceedings of the International Colloquium on Founding Territorial Sciences (CIST), 2011, 177–183

Heck, Daniel W; Hilbig, Benjamin E; and Moshagen, Morten: *From information processing to decisions: formalizing and comparing psychologically plausible choice models*. Cognitive Psychology, 96(1), 2017, 26–40. doi: 10.1016/j.cogpsych.2017.05.003

Johnson-Laird, Philip N: *Mental models in cognitive science*. Cognitive Science, 4(1), 1980, 71–115. doi: 10.1207/s15516709cog0401_4

—— *Mental models and thought*. In: Holyoak, Keith J and Morrison, Robert G (eds.), *The Cambridge handbook of thinking and reasoning. Thinking and reasoning: a reader's guide*, Cambridge, UK: Wiley, 2005. 185–208

Keil, Julian; Mocnik, Franz-Benjamin; Edler, Dennis; Dickmann, Frank; and Kuchinke, Lars: *Reduction of map information regulates visual attention without affecting route recognition performance*. ISPRS International Journal of Geo-Information, 7(12), 2018, 469. doi: 10.3390/ijgi7120469

Klimoski, Richard and Mohammed, Susan: *Team mental model: construct or metaphor?* Journal of Management, 20(2), 1994, 403–437. doi: 10.1016/0149-2063(94)90021-3

Kyle, Gerard and Chick, Garry: *The social construction of a sense of place*. Leisure Sciences, 29(3), 2007, 209–225. doi: 10.1080/01490400701257922

Low, Setha M and Altman, Irwin: *Place attachment. A conceptual inquiry*. In: Altman, Irwin and Low, Setha M (eds.), *Place attachment*, New York, NY: Plenum, 1992. 1–12. doi: 10.1007/978-1-4684-8753-4_1

Malpas, Jeff E: *Place and experience. A philosophical topography*. Cambridge, UK: Cambridge University Press, 1999

Mocnik, Franz-Benjamin and Fairbairn, David: *Maps telling stories?* The Cartographic Journal, 55(1), 2018, 36–57. doi: 10.1080/00087041.2017.1304498

Mocnik, Franz-Benjamin; Ludwig, Christina; Grinberger, A Yair; et al.: *Shared data sources in the geographical domain—a classification schema and corresponding visualization techniques*. ISPRS International Journal of Geo-Information, 8(5), 2019, 242. doi: 10.3390/ijgi8050242

Mocnik, Franz-Benjamin; Mobasheri, Amin; Griesbaum, Luisa; et al.: *A grounding-based ontology of data quality measures*. Journal of Spatial Information Science, 16, 2018a, 1–25. doi: 10.5311/JOSIS.2018.16.360

Mocnik, Franz-Benjamin; Mobasheri, Amin; and Zipf, Alexander: *Open source data mining infrastructure for exploring and analysing OpenStreetMap*. Open Geospatial Data, Software and Standards, 3(7), 2018b. doi: 10.1186/s40965-018-0047-6

Mocnik, Franz-Benjamin; Zipf, Alexander; and Raifer, Martin: *The OpenStreetMap folksonomy and its evolution*. Geo-spatial Information Science, 20(3), 2017, 219–230. doi: 10.1080/10095020.2017.1368193

Mohammed, Susan; Ferzandi, Lori; and Hamilton, Katherine: *Metaphor no more: a 15-year review of the team mental model construct*. Journal of Management, 36(4), 2010, 876–910. doi: 10.1177/0149206309356804

Raifer, Martin; Troilo, Rafael; Kowatsch, Fabian; et al.: *OSHDB: a framework for spatio-temporal analysis of OpenStreetMap history data*. Open Geospatial Data, Software and Standards, 4(3), 2019. doi: 10.1186/s40965-019-0061-3

Tuan, Yi-Fu: *Space and place. The perspective of experience*. Minneapolis, MN: University of Minnesota Press, 1977

Turner, John R; Chen, Qi; and Danks, Shelby: *Team shared cognitive constructs: a meta-analysis exploring the effects of shared cognitive constructs on team performance*. Performance Improvement Quarterly, 27(1), 2014, 83–117. doi: 10.1002/piq.21163

Tversky, Barbara: *Distortions in memory for maps*. Cognitive Psychology, 13(3), 1981, 407–433. doi: 10.1016/0010-0285(81)90016-5

Tversky, Barbara; Morrison, Julie Bauer; Franklin, Nancy; and Bryant, David J: *Three spaces of spatial cognition*. The Professional Geographer, 51(4), 1999, 516–524. doi: 10.1111/0033-0124.00189