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Executive Summary

This document reports the outcomes of work leading to deliverable D3.3 which is the third deliverable for work package WP3, Draw and Make. D3.3 reports on the implementation of spatial relations for the qualitative representations of input maps.

Qualitative representation of spatial information involves representing only the relevant distinctions in a spatial configuration. For example, spatial objects being on the *left_side*, or *right_side* with respect to reference objects in the given scene. In the area of Qualitative Spatial Reasoning (QSR) dozens of qualitative representations (known as spatial calculi) have been proposed focusing on different aspects of space and time such as topology, orientation, relative distances, and linear ordering etc. These calculi formalize the semantics of the qualitative distinctions by considering them as relations over the set of spatial entities in the scene.

We have developed a qualifier, a software tool that takes vector representation of input sketch and geo-referenced map and generates Qualitative Constraint Networks (QCNs). QCNs are graphs where the nodes represent geometric features and the edges represent spatial relations between them. These extracted QCNs provide the basis for the alignment of spatial objects in the input maps.

The qualifier consists of a set of python modules. Each module represents different spatial aspects. For the considered spatial aspect, the qualifier takes geometries from the input maps and formalizes the spatial configures qualitatively. As a result, the tool generates *.json files that contain QCNs along with other attributes of the input features. In the alignment process, we use these files for the alignment of spatial features from a sketch map with corresponding features in the geo-referenced map.

Contents

Abbreviations

QSR	Qualitative Spatial Reasoning
QCNs	Qualitative Constraints Networks
RCC	Region Connection Calculus
OPRAm	Oriented Point Relation Algebra
IA	Allen's Interval Algebra
DE9IM	Dimensionally Extended 9-Intersection Model
9IM	9-Intersection Model
CMB	Calculus Based Method

1. Introduction

Its4land is a European Commission Horizon 2020 project funded under its Industrial Leadership program, specifically the 'Leadership in enabling and industrial technologies – Information and Communication Technologies ICT (H2020-EU.2.1.1.)', under the call H2020-ICT-2015 – and the specific topic – 'International partnership building in low and middle-income countries' ICT-39-2015.

Its4land aims to deliver an innovative suite of land tenure recording tools that respond to sub Saharan Africa's immense challenge to rapidly and cheaply map millions of unrecognized land rights in the region. ICT innovation is intended to play a key role. Many existing ICT-based approaches to land tenure recording in the region have failed: disputes abound, investment is impeded, and the community's poorest lose out. its4land seeks to reinforce strategic collaboration between the EU and East Africa via a scalable and transferrable ICT solution. Established local, national, and international partnerships seek to drive the project results beyond R&D into the commercial realm. its4land combines an innovation process with emerging geospatial technologies, including smart sketch maps, UAVs, automated feature extraction, and geocloud services, to deliver land recording services that are end-user responsive, market driven, and fit-for-purpose. The transdisciplinary work also develops supportive models for governance, capacity development, and business capitalization. Gender sensitive analysis and design is also incorporated. Set in the East African development hotbeds of Rwanda, Kenya, and Ethiopia, its4land falls within TRL 5-7: 3 major phases host 8 work packages that enable contextualization, design, and eventual land sector transformation. In line with Living Labs thinking, localized pilots and demonstrations are embedded in the design process. The experienced consortium is multi-sectorial, multi-national, and multidisciplinary. It includes SMEs and researchers from 3 EU countries and 3 East African countries: the necessary complementary skills and expertise is delivered. Responses to the range of barriers are prepared: strong networks across East Africa are key in mitigation. The tailored project management plan ensures clear milestones and deliverables, and supports result dissemination and exploitation: specific work packages and roles focus on the latter.

This document is directly linked to work package (WP3)- "Draw and Make" of the its4land project. WP3 aims at developing a software tool, SmartSkeMa (pronounced smärt skē-mə) in short for recording land tenure information within the context of rural and peri-urban communities based on hand-drawn sketch maps. The tool is composed of several components including a specialized domain model and a visual language for sketching, a system for automated recognition and extraction of objects in sketch maps, qualitative representation, and qualitative alignment of sketched information with underlying geo-referenced datasets. All these components come together to provide a single function: integrating the user's sketch into a base topographic dataset. The system is being designed to support a bottom-up approach for land tenure recording. In particular, the system is evolving to target local authorities and non-governmental organizations in the use of sketching as a method for creating land tenure, land use and land resource maps.

The deliverable D3.3 reports on the qualitative representation part of the task T3.3 "*Implementation of qualitative representation of sketch map*". The qualitative representation of maps is part of the SmartSkeMa system, directly linked with other components of the system such as semantic recognition of sketch objects (D3.2) and qualitative alignment component (D3.5). Figure 1 illustrates the workflow across three major components of the system.

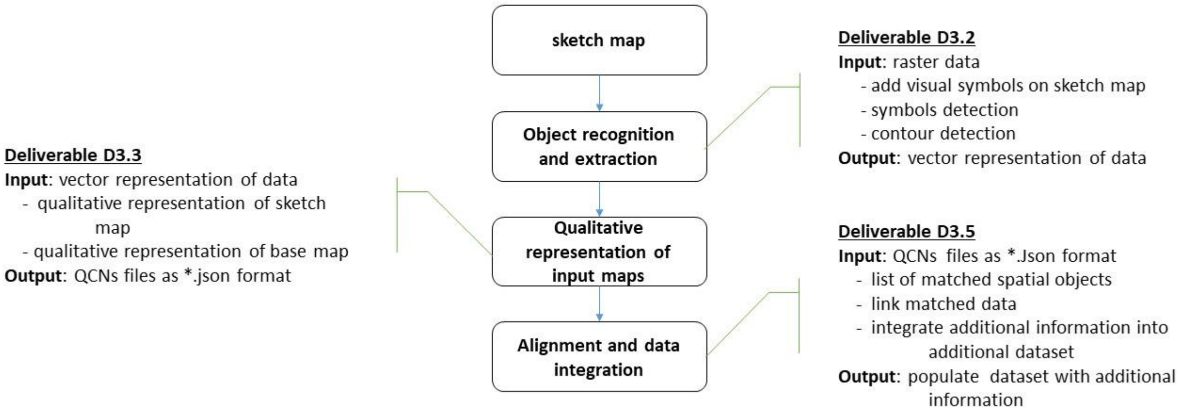

Figure 1: Workflow across three major components of the SmartSkeMa system.

Qualitative representation of sketch maps involves representing only the relevant distinctions in a spatial configuration using some form of qualitative relations such as *left_of, right_of, near*, and *far*. Qualitative representations together with logical and algebraic mechanisms, for performing some useful computations on them form what are known as qualitative spatial calculi and their study as Qualitative Spatial Reasoning (QSR) [1]. During the last two decades, a series of spatial calculi have been proposed, focusing on different aspects of space and time such as representations for the topological relations [2], [3], orderings [4], [5], directions [6], [7], and others. The set of base relations in these calculi enable users to formalize spatial configurations in some form of qualitative distinctions.

For the qualitative representation of input maps, we have implemented a *qualifier* that calculates qualitative spatial relations among features in the sketch map based on various formal calculi. The qualifier consists of a set of python modules. Each module formalizes different spatial aspects such as topology (connected, overlays, etc.), orientation (left_of, right_of, etc.), relative distances (near, far, etc.), and linear ordering (before, after, etc.). We have also implemented additional relations, depending on the required qualitative distinctions for the alignment of sketched objects. The qualifier takes vector representations of maps (map objects) as input and generates Qualitative Constraint Networks (QCNs) of the spatial configurations in a standard *.json file format. Later these *.json files are used as an input for the alignment of spatial objects from sketch maps with underlying based geo-referenced map. For the demonstration purpose, we have integrated the implemented qualifier in a web-based user interface (see Appendix 1).

This report is structured as follows. Section 2 gives overview on how spatial scenes can be represented qualitatively, Section 3 demonstrates the qualitative representation of sketch and geo-referenced maps using spatial relations from the LeftRight calculus. The main outcomes of our research in task T3.3 are discussed in Section 4 and Section 5 concludes the report on deliverable D3.3.

2. Qualitative Representation of Spatial Scenes

The qualitative spatial representations/calculi in the area of QSR enable users to formalize these spatial configurations in the scene [8]. A qualitative calculus formalizes the semantics of the distinctions by considering them as relations over the set of spatial entities. The spatial entities from the domain of the calculus and are usually of the same primitive type (i.e. points, line segments, lines, regions, etc.).

To describe a spatial scene using a qualitative calculus, one associates with each pair of entities, a relation from the calculus. The resulting structure is what is called a Qualitative Constraint Network (QCN). The QCN is a complete graph where the nodes are variables (represent spatial entities) and the edges are labelled by general relations from the calculus. For a qualitative calculus R with base relation set B, a QCN over R is a graph (N, R) where N is a set of variables, $R: \in B$ for every pair $(u, v) \in N \times N$.

3. Qualitative Representation of Input Maps

The spatial information in a sketch map is often, if not always, schematized, distorted, and generalized [9], [10]. In contrast, cartographic maps contain geometric representations that specify the exact location of an object within a fixed frame of reference. The main motivation for considering qualitative approaches to represent the input maps is that using qualitative representation maps can be represented at a certain level of generality or abstraction at which the deviation of spatial information content of a sketch map from that of a corresponding cartographic map almost disappears. This allows correct mapping of spatial objects from sketch map with corresponding objects in the cartographic map automatically [11].

The qualitative representation requires geometric representation of input maps. In our previous deliverable D3.2 under the “draw and make” work package, we have demonstrated how our sketch recognition component extracts and interprets the drawn objects into some meaningful geometric primitives such as points, lines, and polygons. Figure 2 shows a real sketch map example, drawn by a member of the Maasai community during our field visit in Kenya (early, 2017). The spatial objects in the drawn map are automatically extracted using the advance recognition methods proposed in [12].

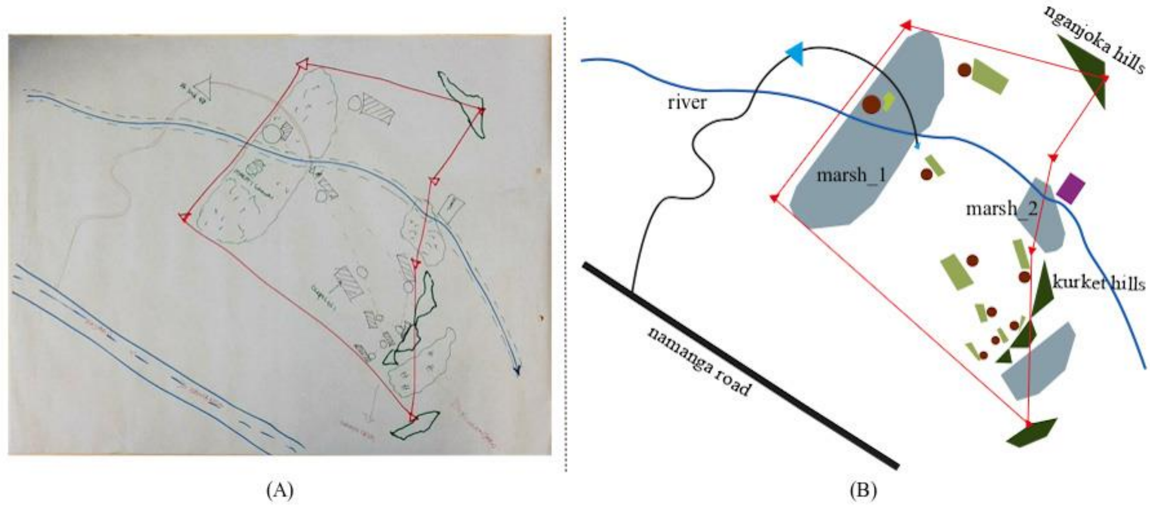

Figure 2. (A) sketch map drawn by community members, (B) Vector representation of sketch map using implemented recognition methods in the deliverable D3.2.

For the qualitative representation of input maps, we have implemented a qualifier. The qualifier contains a set of modules representing spatial relations in the qualitative calculi. Each module represents spatial aspects. For each spatial aspect, the implemented qualifier formalizes the spatial configurations between objects in the input maps as QCNs. Figure 3 shows the QCNs representing the LeftRight relations between spatial objects with respect to rivers in the input maps. For example, the river crosses marsh grass (marsh_1 and marsh_2) in both maps, while the Naganjoka hills and Kurket hills are on the left and right side of the river.

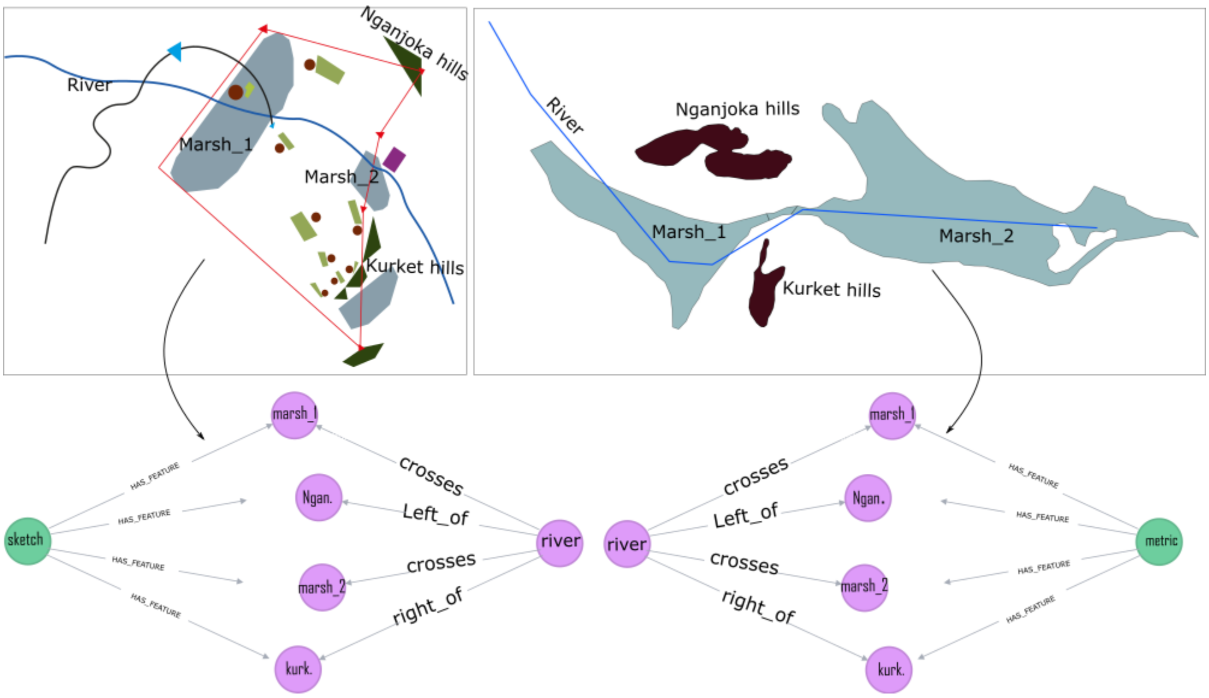

Figure 3. Vectorized sketch map, corresponding geo-referenced map and qualitative representation of input maps as QCNs using the LeftRight relations (left_of, right_of, and crosses).

4. Implemented Qualitative Spatial Relations

For the qualitative representation of input maps, we have implemented spatial relations of the calculi as modules. We also implemented other computational methods such as computing adjacency, relative distances, linear projections, and method for filtering spatial features based on their feature types such as mountains, rivers, roads, etc. The adjacency and relative distances are used to compute spatial relations between near-by objects only. For example, the LeftRight relations of near-by objects along rivers (see figure 3). The filtering method is used to compute spatial relations between predefined spatial objects. For example, relative orientation of other spatial objects with respect to predefined objects of a type “mountain”. This enable user to capture the relative position of spatial objects with respect to mountains in the map. The modules and computational methods in the qualifier are implemented using python 3.6.4**.** The spatial aspects we considered are as follows:

4.1. Topological Relations

For modelling topological relations the three models: the 9-Intersection Model (9IM) [13], RCC-family [2], and Calculus Based Method (CMB) [14] play an important role both in terms of theoretical developments and practical applications.

4.1.1. Topological Relations between Polygonal Features

To formalize the topological relations between polygonal features, we have implemented spatial relations from RCC8 [3] and RCC11 [15] algebras of the RCC family. The RCC8 distinguish eight different topological relations such as DC (disconnect), P (part of), PP (proper part), PO (partially overlap), EC (externally connected), TPP (tangential proper part), NTPP (non-tangential proper part), EQ (equal), O (overlay), DR (discrete) and the inverse relations of the TPP, and NTPP, while the RCC11 is finer version of RCC8 with 11 base relations. Figure 4 illustrates the RCC8 topological relations between region A and B.

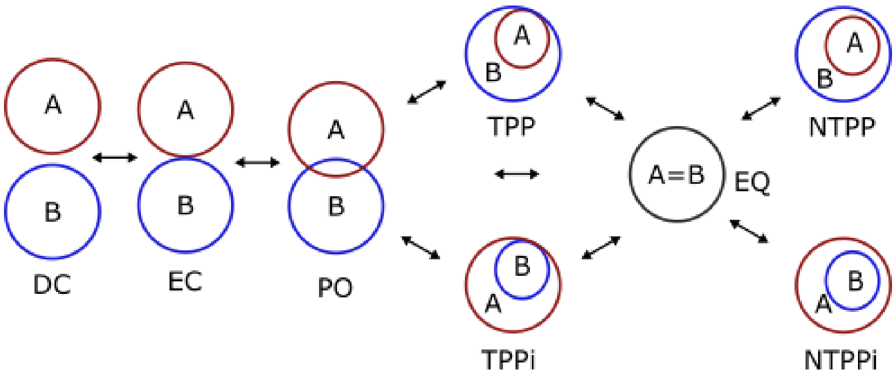

Figure 4. RCC8 relations between region A and B

4.1.2. Topological Relation between Spatial Features of Different Dimensions

In order to formalize the topological relations between spatial objects of different dimensions (different geometric types) such as between lines-polygons and lines-points, we have implemented relations from the Dimensionally Extended 9-Intersection Model (DE9IM) [16]. The implemented relations extract the spatial configurations in term of qualitative distinctions such as *equal*, *disjoint*, *intersections*, *touches*, *crosses*, *overlaps*, *within*, *contains*, etc. For example, using DE9IM relations; the river *crosses* marsh grass (marsh_1 and marsh_2) in both maps, while mountains (Naganjoka and Kurket hills) have *disjoint* relation with respect to river (see Figure 3).

4.1.3. Topological Relation between Linear Features

For the topological relations between linear features (i.e. streets, paths, etc.), we used a subset of DE9IM relations. These relations are captures connectivity of streets or paths such as a street being connected and/or disconnected with other streets at junctions.

4.2. Relative Orientation Relations

4.2.1. Relative Orientation of Polygonal Features

It is common to use points as basic entities in positional reasoning [17], [18]. However, in sketch and cartographic maps landmarks (i.e. buildings, houses, mountains, etc.) are extended objects approximated by polygons. In order to formalize the relative orientation between these polygonal features, we proposed a new spatial calculus named “regionStarVars”. The calculus contains a set of orientation relations at conceptual level by dividing the plane in the cone based regions/sectors. Given the granularity factor m, the calculus divide plane into 2m sectors, with (360/m)-degree angle between any consecutive pair of lines. This leads to a set of (2*m+1) basic relations such as {EQ, 0, 1, 2, …, 2*m-1}, where EQ is the identity relation with respect to the reference point. Every even-numbered relation corresponds to a semi-infinite line fanning away from the origin, and the odd-numbered relations cone-based regions between lines. These sectors help to formalize the relative orientation of polygonal features with respect to each other.

4.2.2. Relative Orientation of Spatial Features of Different Dimensions

In maps, streets are linear features represented as lines and landmarks are approximated by polygons. To formalize relative orientation of landmarks with respect to adjacent linear features (i.e. rivers, streets, paths, etc.), we defined LeftRight relations such as *left_of*, *right_of*, *front*, *back* and *crosses* etc. We defined a method to compute adjacency of landmarks with respect to linear features [19]. Figure 3 illustrates the possible LeftRight relations of mountains and marsh grass with respect to river in both maps.

4.2.3. Relative Orientation of Linear Features

For relative orientation of linear features, we defined a set of cone-based relations derived from the existing eight orientation sectors in [20] together with Oriented Point Relation Algebra (OPRAm) [21]. The granularity factor in OPRAm offers the flexibility to define orientation sectors. The eight orientation sectors together with OPRA8 define the *front (f),* *half-left (hl), left (l), back (b), right (r),* and *half-right (hr)* orientation relations. These relations define the orientation of two connected streets at junctions.

4.3. Linear Ordering of Polygonal Features

Linear ordering defines the positional information of spatial objects along given linear features. In order to formalize the linear ordering of adjacent landmarks along any given route, we have implemented relations from the well-known Allen´s Interval Algebra (IA) [22]. The algebra considers intervals of spatial objects as representational primitives and computes linear ordering of adjacent landmarks on a defined route. The implemented relations are: *before(<), after(>), meets(m), met_by(mi), overlaps(o), overlapped_by(oi), during(d), during_inv(di), start(s), start_by (si), finishes (f), finished_by(fi),* and *equal(eq).*

4.4. Relative Distances between Polygonal Features

In order to capture the relative distances between polygonal features, we have implemented method to compute qualitative distances (i.e. *near*, *far*, and *vary far*) based on relative metric distance between spatial objects. The method computes minimum distances and clusters into three groups. These groups represent the *near*, *far*, and *vfar* relation between polygonal features in the sense.

5. Conclusion

The spatial information presented in sketch maps is always schematized, distorted, and generalized, while the corresponding cartographic map contains precise geometric information of an environment. As a part of task T3.3[1], we have implemented a qualifier for qualitative representation of input maps. The qualifier brings both, the sketched and corresponding cartographic information from a land administration system on the same qualitative level on which it can be compared. It represents the input maps at certain level of abstraction at which the deviation of sketched information from that of a corresponding cartographic map almost disappears. This allows users to align spatial information from sketch maps with the information in the corresponding cartographic maps [11].

The qualitative alignment involves finding correspondences between spatial objects in the input maps. The alignment of certain spatial objects (i.e. mountains, rivers, roads, etc.) are used as anchoring positions to relate other sketched objects and to integrate additionally sketched information into cartographic maps. Additionally, sketched information particularly refers to information that has not been surveyed yet or other ambiguous non-spatial information carried by the sketch maps. For example, when people are communicating an object or land use boundary in the form of a sketch, they may represent (“draw”) the object as a point, line, or contour. However, the object being communicated is not a geometric object; it is a much richer concept that has complex relationships with other meaningful concepts. By

[1] T3.3: Sketch-to-Geo (ref: its4land proposal)

aligning these spatial objects, we can integrate their relationship (i.e., legal rights) into the geometric data captured by land administration information systems.

The reported qualifier consists a set of python modules. The implemented spatial relations in each module formalizes the spatial configurations in the input maps as QCNs. It generates QCNs in standard *.json format along with other important information such as feature attributes. The QCNs and other information provides the basis for the alignment of drawn objects with corresponding objects in the base/cartographic maps. The implemented spatial aspects are as follows.

- Topology
    - topological relations between polygonal features
    - topological relation between spatial features of different dimensions
    - topological relation between linear features
- Relative Orientation
    - relative orientation of polygonal features
    - relative orientation of spatial features of different dimensions
    - relative orientation of linear features
- Linear Ordering
    - linear ordering of polygonal features
- Relative Distances
    - relative distances between polygonal features

Bibliography

[1] A. G. Cohn and J. Renz, "Qualitative spatial representation and reasoning," *F. van Hermelen, V. Lifschitz, B. Porter, eds., Handb. Knowl. Represent.*, vol. 3, pp. 551–596, 2008.

[2] D. A. Randell, Z. Cui, and A. G. Cohn, "A Spatial Logic based on Regions and Connection," in *Proceedings of the 3rd National Conference on Principles of Knowledge Representation and Reasoning*, 1992.

[3] A. G. Cohn, "Qualitative Spatial Representation and Reasoning Techniques," in *Advances in Artificial Intelligence 1997. LNAI, Vol. 1303*, 1997, pp. 1–30.

[4] H. W. Guesgen, "Spatil reasoning based on Allen´s Temporal Logic," 1989.

[5] A. Osmani, "Introduction to Reasoning about Cyclic Intervals," *Imam, I. , Kodratoff, Y., El-Dessouki, A. Ali, M. Mult. Approaches to Intell. Syst. LNCS, Vol. 1611*, vol. 1611, pp. 698–706, 1999.

[6] A. U. Frank, "Qualitative spatial reasoning: cardinal directions as an example," *Int. J. Geogr. Inf. Syst.*, vol. 10, no. 3, pp. 269–290, Apr. 1996.

[7] J. Renz and D. Mitra, "Qualitative Direction Calculi with Arbitrary Granularity," in *C. Zhang, H. Guesgen,W.Yeap (eds.), PRICAI-04: Trends in Artificial Intelligence, LNCS, Vol. 3157*, Auckland, New Zealand: Springer, Berlin Heidelberg, 2004, pp. 65–74.

[8] G. Ligozat and J. Renz, "What is a qualitative calculus? A general framework," in *In Chengqi Zhang, Hans W. Guesgen, and Wai-Kiang Yeap, editors, PRICAI: Trends in Artificial Intelligence ,vol. 3157 of LNCS*, 2004, pp. 53–64.

[9] B. Tversky, "Distortions in Memory for Maps," *Cogn. Psychol.*, vol. 13, pp. 407–433, 1981.

[10] B. Tversky, "Cognitive Maps, Cognitive Collages, and Spatial Mental Models," in *In Frank, A.U. and Campari, I. (Eds.), Spatial Information Theory: A Theoretical Basis for GIS, Proceedings COSIT '93. Lecture Notes in Computer Science, Vol .716, Springer, Berlin Heidelberg*, vol. 716, 1993, pp. 14–24.

[11] M. Chipofya, C. Schultz, and A. Schwering, "A metaheuristic approach for efficient and effective sketch-to-metric map alignment," *Int. J. Geogr. Inf. Sci.*, vol. 30, no. 2, pp. 1–26, 2016.

[12] C. S. M. Chipofya, C. Murcia Galeano, S. Jan, A. Schwering , M. Karamesouti, "Smart Sketch Maps : A Tool for Community-driven Land Documentation using Hand Drawn Maps," in *Land and Poverty Conference 2018: Land Governance in an Interconnected World , March 19-23*, 2018.

[13] M. J. Egenhofer, R. D. Franzosa, and F. Ranzosas, "Point-set topological spatial relations," *Int. J. Geogr. Inf. Syst.*, vol. 5, no. 2, pp. 161–174, Jan. 1991.

[14] E. Clementini, P. Di Felice, and P. Van Oosterom, "A small set of formal topological relationships suitable for end-user interaction," in *Advances in Spatial Databases*, Singapore: Springer Berlin Heidelberg, 1993, pp. 277–295.

[15] S. Jan, A. Schwering, C. Schultz, and M. Chipofya, "RCC11: A Finer Topological Representation for the Alignment of Regions in Sketch Maps," in *28th International Workshop on Qualitative Reasoning (QR-2015)*, 2015.

[16] S. Christian, "Dimensionally Extended Nine-Intersection Model (DE-9IM)," in *Encyclopedia of GISPublisher*, H. X. Shashi Shekhar, Ed. Springer, 2008.

[17] C. Freksa, "Using orientation information for qualitative spatial reasoning," *Lncs*, vol. 639, no. 1, pp. 1–17, 1992.

[18] R. Moratz, J. Renz, and D. Wolter, "Qualitative spatial reasoning about line segments," in *Proceedings of the 14th European Conference on Artificial Intelligence (ECAI 2000)*, 2000, pp. 234–238.

[19] S. Jan, C. Schultz, A. Schwering, and M. Chipofya, "Spatial Rules for Capturing Qualitatively Equivalent Configurations in Sketch maps," in *1st Workshop on Logics for Qualitative Modelling and Reasoning, 13-16 Sep, 2015, Lodz, Poland*, 2015.

[20] S. Jan, A. Schwering, M. Chipofya, and J. Wang, "Qualitative Representations of Schematized and Distorted Street Segments in Sketch Maps," in *Spatial Cognition IX , LNCS, Vol. 8684,* 2014, pp. 253–267.

[21] R. Moratz, F. Dylla, and L. Frommberger, "A Relative Orientation Algebra with Adjustable Granularity," in *proceedings of the Workshop on Agents in Real-time and Dynamic Environments (IJCAI05)*, 2005.

[22] J. F. Allen, "Maintaining Knowledge about Temporal Intervals," *Commun. ACM*, vol. 26, no. 11, pp. 832–843, 1983.

Appendix 1: Web-based User Interface

The SmartSkeMa system is composed of several components including a system for automated recognition and extraction of sketched objects, qualitative representation, and qualitative alignment of sketched information. All these components come together to provide a single function: integrating the user's sketch into a base topographic dataset.

In order to demonstrate the functionality of three components (sketch recognition, qualitative representation, and alignment), we have implemented a prototype, a web-based user interface[2]. The interface takes sketch and geo-referenced maps as an input, processes sketch map (D3.2), qualifies input maps (D3.3) and aligns the sketch information (D3.5). The object recognition component D3.2 is not fulling integrated in the web-interface. However, we used its output in the web-interface to demonstrate the workflow.

Step 1: Load maps

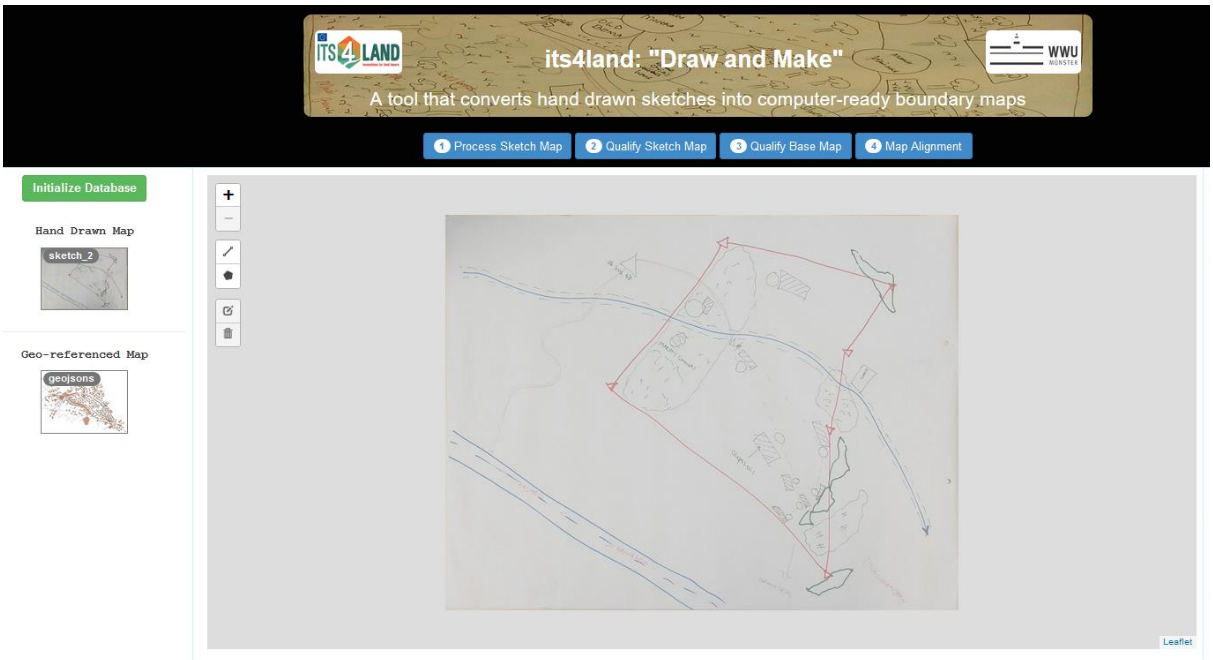

Figure 5. Web-interface for loading sketch and corresponding geo-referenced maps.

[2] https://share4land.itc.utwente.nl:5566/sharing/eoaWuDHjv

Step 2: Process sketch map

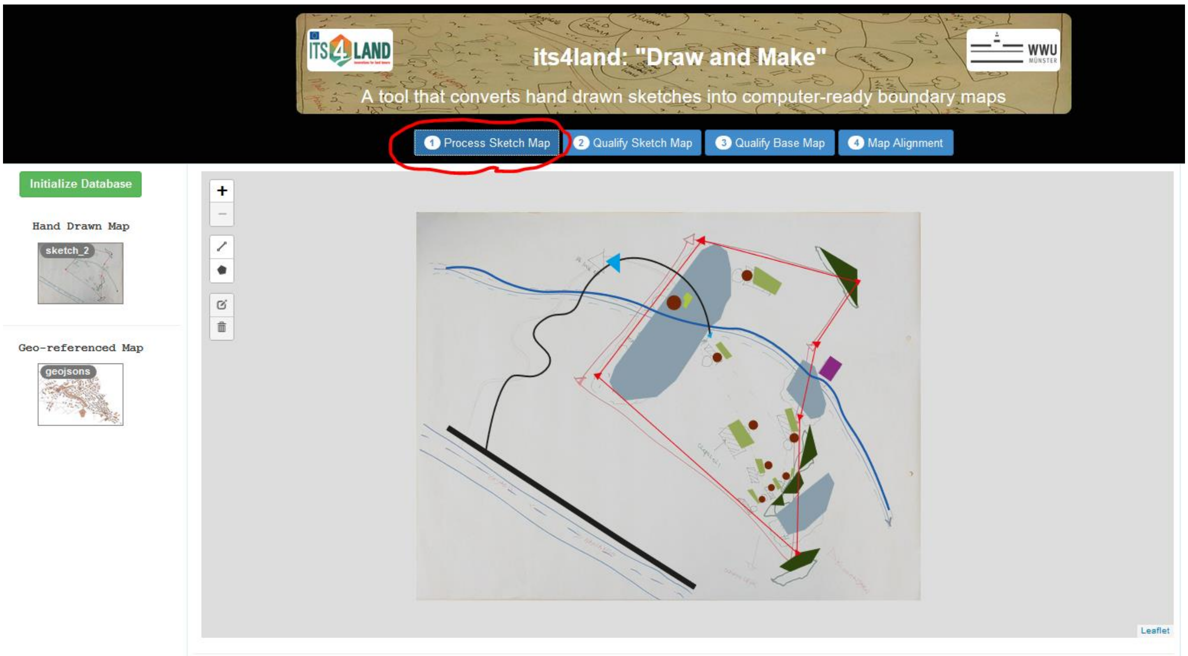

Figure 6. The process recognizes and extracts drawn objects in sketch map and represent them as a vector data.

Step 3: Qualify sketch map

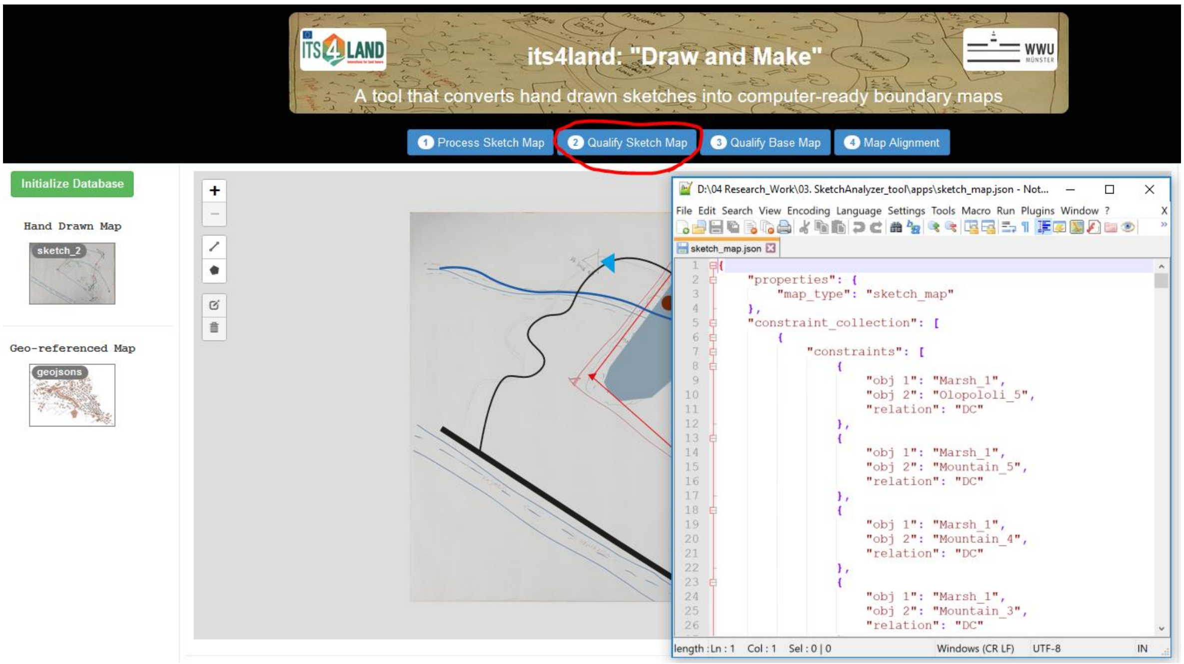

Figure 7. The process takes extracted objects in sketch map and generates QCNs along with other attributes of the geometries in a standard (*.json) format.

Step 4: Qualify metric map

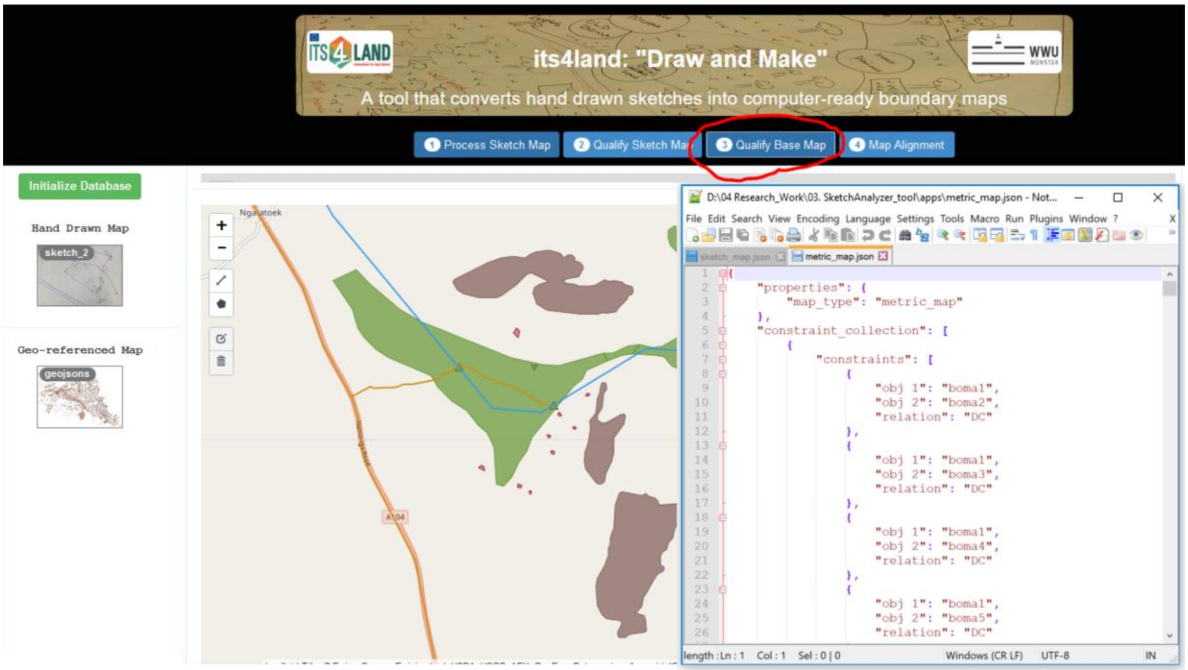

Figure 8. The process takes geo-reference map as an input and generates QCNs along with other attributes of the geometries in a *.json) format.

Step 5: Qualitative alignment of drawn features

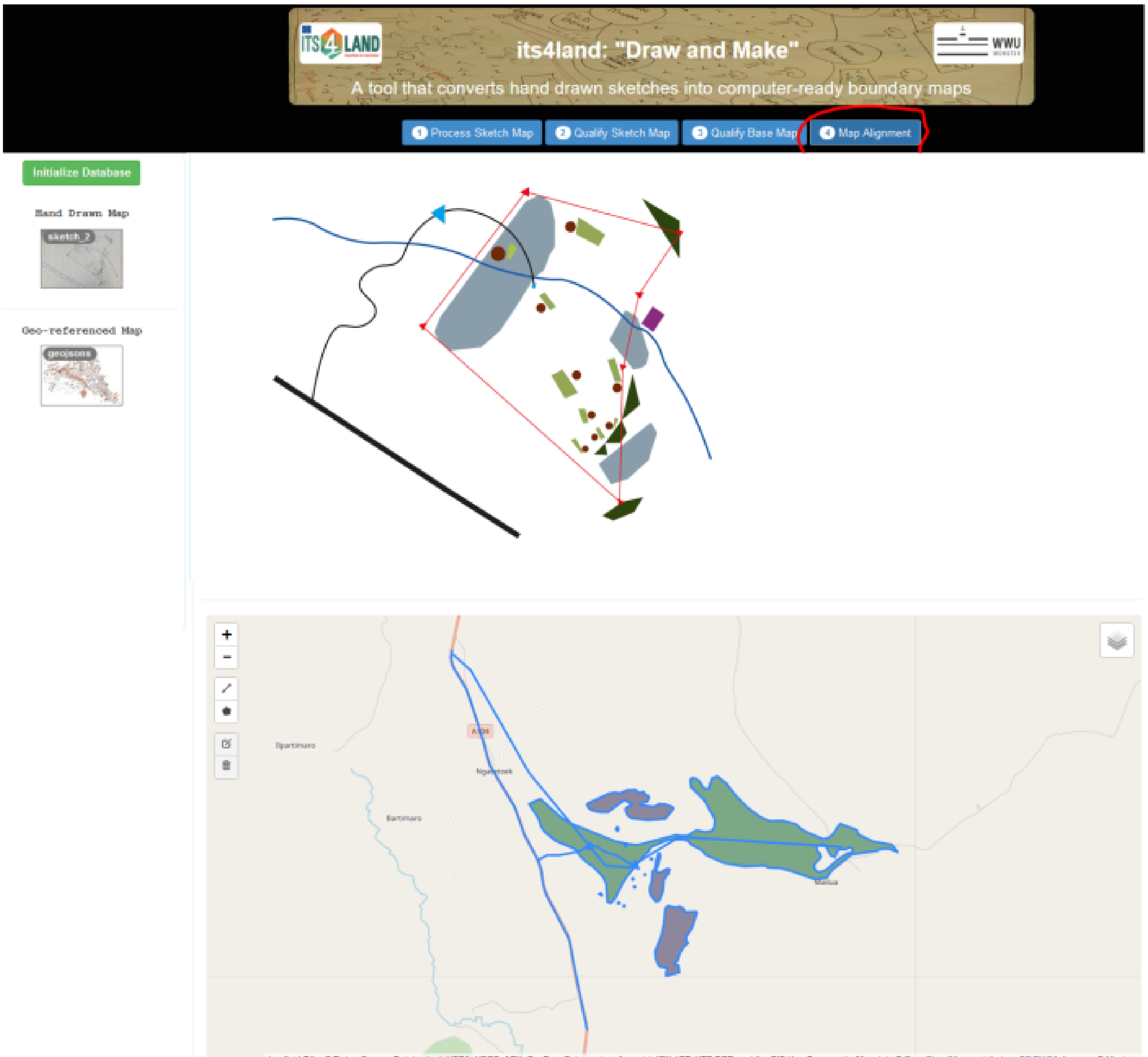

Figure 9. The process aligns spatial objects from sketch map with corresponding object in the geo-referenced map. The interface allow user to interact with aligned objects by mouse click events. When the user clicked on object in sketch map, the corresponding object in the geo-referenced map will highlight.