USING OSM, GEO-TAGGED FLICKR PHOTOS AND AUTHORITATIVE DATA: A QUALITY PERSPECTIVE

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Abstract
The appearance of OpenStreetMap (OSM) in 2004 sparked a phenomenon known as Volunteered Geographic Information (VGI). Today, VGI comes in many flavours (e.g. toponyms, GPS tracks, geo-tagged photos, micro-blogging or complete topographic maps) and from various sources. One subject that has attracted research interest from the early days of VGI is how good such datasets are and how to combine them with authoritative datasets. To this end, the paper explores three intertwined subjects from a quality point of view First, we examine the topo-semantic consistency of OSM data by evaluating a number of rules between polygonal and linear features and then paying special attention to quality of Points of Interest (POIs). A number of topo-semantic rules will be used to evaluate the valididy of features' location. The focus then turns to the use of geo-tagged photos to evaluate the location and type of OSM data and to disambiguate topological issues that arise when different OSM layers overlap.

Keywords: *VGI, OpenStreetMap, geo-tagged photos, authoritative data, quality*

1. INTRODUCTION

While the crowdsourced and collaborative creation of spatial content is not something new in the Geomatics domain, the appearance of OpenStreetMap (OSM) in 2004 sparked a phenomenon known as Volunteered Geographic Information (VGI). The term was introduced by Goodchild (2007) in an effort to describe "*the widespread engagement of large numbers of private citizens, often with little in the way of formal qualifications, in the creation of geographic information*" (Goodchild, 2007: p.217). A set of enabling factors helped the early forms of collaboration in Geomatics to move to a different level. This collaboration was usually in the form of Public Participation Geographic Information Systems (PPGIS), which were used by researchers and institutions to work with active citizens and local communities on controversial issues leveraging both scientific and local knowledge. This form of collaboration generally took place over a backdrop maps where stakeholders or community members could provide their inputs including data, requirements and analysis in order to better understand a particular issue and then find the best solution for all parties involved. Since then, the amount of VGI has increased rapidly, fueled by factors such as the removal of the selective availability of the Global Positioning System (GPS) in 2000 (Clinton, 2000); the proliferation of accurate and low cost GPS-enabled devices and the turn towards a bi-directional Web, where the lines between content users and content producers has increasingly blurred, leading to what is known as "produsers" (Bruns, 2006:2; Coleman et al., 2009).

This study focuses on two seemingly independent sources of VGI and how they can be used together in quality assessments. First, we examine the topo-semantic consistency of OSM data by first evaluating a number of rules between polygonal and linear features and then paying special attention to quality of Points of Interest (POIs). Then, we turn our focus to the availability and usability of geo-tagged photos for verifying OSM entities. Quality evaluation of VGI datasets is anything but a straightforward process and there are many measures and indicators that could potentially be useful in determining quality (Antoniou and Skopeliti, 2015). The most rigorous evalution efforts involve the use of authoritative data as reference datasets. Instead, here we use another VGI source (i.e geo-tagged photographs) as the validation mechanism of OSM entities. We demonstrate this approach through two selected case studies. In the first, geo-tagged photographs are used to evaluate POIs that are difficult to interpret via satellite imagery. In the second, geo-tagged photos are used to disambiguate inconsistencies between different OSM thematic layers (for more on this see Fonte et al., 2016).

The remainder of the paper is structured as follows: Section 2 describes the study area and the datasets used for the study; Section 3 includes the topo-semantic checks of the OSM POIs; Section 4 describes the use of geo-tagged photos in the evaluation of OSM features. The paper closes with a discussion and conclusion in Section 5.

2. STUDY AREA AND DATASETS USED

The study area is the broader area of Paris (Ile de France), France. The datasets used for this study include (as of November 2015) the following layers: i) OSM Roads, Railways, Waterways, Natural, Landuse and Points of Interest (POIs), extracted from Geofabirk; ii) OSM Buildings extracted using OSMOSIS. Additionally, the following layers were used for the city of Paris: iii) Landuse, Points of Interest (POIs) and Road layers from the Institut Geographique National (IGN, France); iv) Geo-tagged images uploaded to Flickr between April and November 2015, which were retrieved using the public API (in total 129,222).

3. QUALITY ISSUES OF OSM POIs

Topo-semantic consistency (Servigne et al., 2000) is a subset of logical consistency as defined by Kainz (1990). Topo-semantic consistency concerns the correctness of the topological relationship between two objects according to their semantics. It can be divided into the consistency of geographic objects with other geographic objects of the same theme (intra-theme consistency) or geographic objects of other themes (inter-theme consistency). Some typical examples of topo-semantic constraints are: two parcels must not overlap, a house must be inside a parcel, two roads must not be equal, a river and a road cannot cross except in the geographic object bridge, land-parcels must not overlap etc. In order to check the validity of data, constraints can be formulated based on these topo-semantic relations and errors can be spotted when these constraints are violated. Both the geometry and the semantics of objects are required to check such constraints. Checking processes meet two difficulties: the problem of exhaustiveness of all kinds of errors likely to be met, and the problem of proving the completeness of each checking process (Servigne et al., 2000).

A number of measures to evaluate the degree of violation of topo-semantic constraints are proposed in the literature such as the number of objects in the dataset that exhibit at least one violation of a topological constraint (Martínez et al., 2006) and Semantic Distance (SD) (Papadias et al., 1998), which quantifies inconsistencies as the normalized semantic distance in the conceptual graph of topological relations. Rodríguez et *al.* (2010) have presented a number of measures that compare topological relations between geometries stored in a database instance with respect to expected topological relations; from these measures, after cognitive validation (Brisaboa et al., 2011), the overlapping area and the external distance are considered as the main measures. These measures can be aggregated to globally describe the data quality of a database instance, to determine if constraints are satisfied and whether conflicting representations are present (Brisaboa et al., 2014).

VGI quality assessment includes the consistency issue as well. Inconsistency exists in VGI due to the absence of integrity constraints, and therefore, it depends on the expertise of the data contributor. In addition, the data capturing process can take place at different levels of detail (i.e. zoom level) resulting in more than one geometric representation of the same object, which leads to additional potential inconsistency problems. The existence of consistency problems in OSM data has been verified in a number of studies (e.g. see Girres and Touya, 2010; Jokar Arsanjani et al., 2013; Ali and Schmid, 2014; Sehra et al., 2014).

In this study, a number of tests are applied in order to find inter-layer and intra-layer inconsistencies in the OSM data. The tests are based on evaluation of consistency utilizing topological relations that should be satisfied taking also into account data semantics as described by their attributes. Apart from the geometry capture, the existence of a plethora of tags provides a semantic rich dataset and thus sophisticated topo-semantic relations can be explored. A case study is performed with OSM data that covers the broader Paris area, transformed to the spatial reference system used by IGN France. The OSM data used cover the following thematic layers: buildings, POI, Roads, Railways, Waterways, Natural and Landuse. While this is not an exclusive list, a number of topo-semantics constraints are proposed in Table 1 for each type of geometry. Data processing is performed with ArcGIS 10.3.

Table 1. A list of topo-semantic constraints.

Polygons	Lines	Points

Buildings must not overlap	*Roads* must not overlap	Specific *POIs* are situated inside *buildings*
Landuse polygons must not overlap	*Roads* must not self-intersect	Specific *POIs* are situated outside *Buildings*
Buildings should not cover roads	*Roads* must not self-overlap	Specific *POIs* are situated on *Roads* intersections
Buildings should not cover rails	*Rails* must not overlap	Specific *POIs* are situated on *Rail* intersections
Buildings should not cover *Waterways*	*Rails* must not self-intersect	Specific *POIs* are situated on roads and *Rail* intersections
	Rails must not self-overlap	Specific *POIs* are situated inside *Landuse* polygons
	Waterways must not-overlap	Specific POI are situated outside natural polygons
	Waterways must not self-intersect	
	Waterways must not self-overlap	

Evaluation of the above constraints on the dataset described in section 2 produced the following results described below.

3.1 Polygonal and Linear Features

According to the OSM wiki, some of the building polygons may overlap and in this case the "*layer*" tag is used to express the overlay sequence. Based on "*the polygons must not overlap*" test, the majority of the polygons (101,852 – 99.6%) do not overlap while only very few do (433 – 0.4%). Of this small number, some of them (85 – 19%) can be considered as silver polygons based on a thinness indicator. From the remaining polygons, 252 (58%) have different layer values and thus can be overlaid but 97 (22%) need additional investigation as they are erroneously overlapping. As 98% of all the buildings are characterized as "building = yes", which according to OSM wiki is used when "*it is not possible to determine a more specific value*", it is not possible to extract any additional conclusions about the nature of the buildings and their topo-semantic relations.

The majority of roads do not overlap, i.e. only 0.21 % of the total length of the roads violates this rule. When examining the topological relation of the road network in relation to other thematic layers, problems are found only in relation to buildings. A small percentage of roads overlap with buildings (0.82 % of the total length of the roads), which are mostly tagged as "*pedestrian streets*".

Based on the "polygons must not overlap" test, only 1% of the total area of the land use OSM layer exhibits this problem. Of this 1%, the majority (40%) is tagged as "*pitch*" in combination with military, grass, residential, construction, school and "*recreation ground*".

Based on the "polygons must not overlap" test, 21% of the total area of the natural OSM layer exhibits this problem. Overlaps mostly appear between the "*forest*" and "*park*" natural areas (86%), which are quite difficult to distinguish in imagery or even by in-situ contributors.

3.2 Points of Interest (POIs)

The OSM POIs thematic layer has 222,527 points in the entire area of interest (60,136 are inside the buildings' convex hull which were used for the test below). Each POI has two main tags (i.e. "Name" and "Type"); the "Type" tag has 764 unique values. The topo-semantic relations of POIs against other thematic layers were examined as described below.

3.2.1 Points vs. Buildings

A topology check was performed to check the POI position in relation to the building footprints. A number of points (21,872 – 36%) are situated inside the building polygons, 2,338 (4%) are situated on the building borders and 35,926 (60%) are situated outside. First, we examine whether the POI position outside the buildings is valid based on their semantics captured with the "Type" attribute (for example, examine if a POI with type "Bank" is outside of a building). Based on this test, and judging by their type, 30,497 (85% of the subclass) can reside outside of a building but 5,429 (15% of the subclass) should be inside a building polygon.

Then, we examined the reverse rule: for the points (24,210) located inside or on the border of a building, we examined whether their position was valid. Based on this test, 22,047 (91%) can possibly be situated inside but 2,163 (9%) should be situated outside the building polygons. In this study, the "correct position" of the points in relation to the buildings was decided based on common sense.

3.2.2 POIs vs. Roads

From the POI thematic layers, points that are semantically related to roads such as *bus_station, bus_stop, crossing, mini_roundabout, motorway_juction, parking, parking_entrance, parking_exit, parking_space, traffic_calming, traffic_signals, tram_stop, wayside_cross* and *wayside_shrine* were selected. Regarding the POIs that are tagged as crossings (12,612 in total), the majority (12552 – 99.5%) is located on road intersections and only 60 of them (0.5%) have a different position. From the POIs that are tagged as traffic lights (2310 in total), again the majority (2292 - 99.2%) is located on road intersections and only 18 of them (0.8%) have a different position.

3.2.3 POIS vs. Railways

From the POI thematic layers, points that are semantically related to rails such as *railway_crossing, station, station_disued, subway_entrance, subway_exit, train_station_en, tram_stop* and *level_crossing* are selected. All the POIs tagged as level crossings (209) and railway_crossing (1) are situated on the rail network intersections. This is also the case for POIs characterized as "*tram_stop*" exhibiting a maximum distance of two meters.

3.2.4 POIS vs Crossings (Railway and Roads)

Points semantically related to the intersections of the rail and road network, such as level crossings, were checked based on their geometry. From the 1,101 points in total, 949 (86%) are located on the intersections while 152 (14%) have a different position.

3.2.5 POIS vs. Landuse and Natural

A number of points (2,498 - 4%) is located inside the Landuse polygons whereas 1,774 (3%) are located in the Natural polygons. Although it is possible to examine the topo-semantic validity of these intersections based on the POIs and polygon types, in reality there are hundreds of possible combinations for each type of polygons. Thus, a more systematic recording of the constraints and an automated evaluation process would be needed.

3.3 OSM POI distribution

This section focuses on OSM and IGN POI comparisons specific to the study area in Paris. There are 61,220 OSM point features in the study area, roughly 10 times more than the 6,202 POIs in the IGN dataset for the same area. A preliminary analysis on the spatial distribution shows that there is a bias, resulting in over-representation of points related to certain categories of potential interest to the public (e.g. parking spaces). Despite the much richer OSM dataset, there are issues of consistent recording and description of POIs. A striking example of such an inconsistency is the recording of 304 POIs described as "*parking*" in addition to the 2,017 POIs recorded as "*parking_space*". This discrepancy would not present a serious a problem, but there is a spatial bias, as shown in the Figure 1. Given the spread of "*parking*" coded POIs throughout Paris (left). it is very unlikely that parking spaces exist exclusively in the western parts of Paris. Instead we can conclude that it is a matter of interpretation and recording bias.

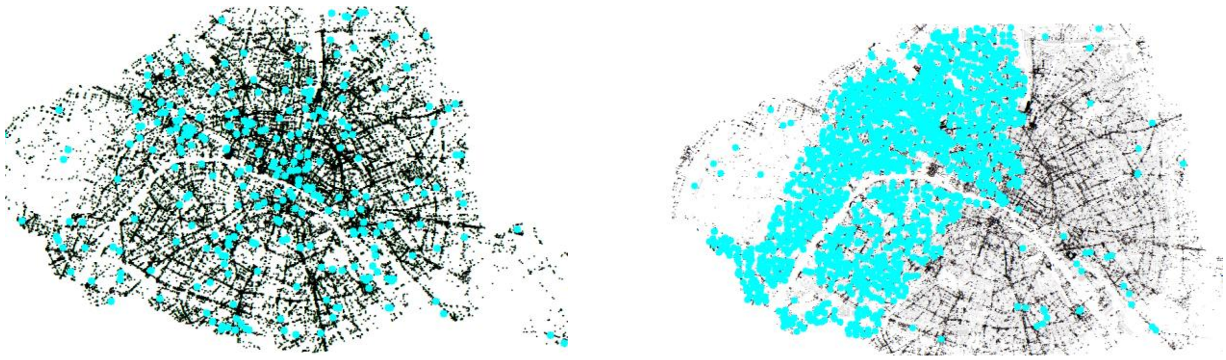


Figure 1. OSM 304 "Parking" (left) and 2,017 "Parking_spaces" (right)

4. QUALITY EVALUATION WITH THE USE OF GEO-TAGGED PHOTOGRAPHS

Section 3 provided examples of possible inconsistencies that a VGI dataset can have. Semantic mis-matches, topological and positional errors and vague and ambiguous cases of overlaps and intersections should be expected when handling such GI. This set of quality caveats can be added to other disadvantages of VGI such as heterogeneity, lack of metadata, patchwork, social and participation biases etc.

The disambiguation of all these cases is a challenging task. In most cases, in academic research, such efforts use authoritative data. The VGI datasets are compared against reference datasets of known quality. Alternatively, such cases should first be recognized, located, and then corrected or verified by the contributors. Indeed, it has been documented that the positional quality of features improves as more contributors add data or modify a feature (Haklay et al., 2010). However, participation biases (Antoniou and Schlieder, 2014) and the digital divide (Graham et al., 2013) can negatively affect a widespread effort of quality improvement.

Hence, either because of lack of authoritative data or because it is difficult for contributors to locate such inconsistencies, we need to devise methods that can more easily identify such potential sources of error. Another obstacle could be that, in many cases, VGI datasets have surpassed the equivalent authoritative data in detail and field of scope (Vandecasteele and Devillers, 2015). We suggest that the solution to this problem can come from the VGI world itself. A line of research in this direction uses the intrinsic VGI characteristics as indicators of the overall quality (see for example Antoniou and Skopeliti (2015) for an overview). Here, we focus on the use of other VGI sources (i.e. Flickr geo-tagged photographs) to evaluate the validity of OSM POIs. We use two case studies: i) we try to verify the OSM points that could not have been created through image interpretation as there are objects that obscure the view (i.e. trees and wooded areas); and ii) we try to disambiguate areas of overlapping OSM land use/land cover types

However, it is first necessary to examine the quality of the geo-tagged photos in the study areas to understand the uncertainties that can be introduced by their use. While the quality of geo-tagged photographs is a very broad subject that is closely related to the needs of each application, here we look into one of the most basic, yet highly important factors: whether the photographs are located inside or outside built up areas. The first step is to separate those photographs taken outside, and thus can show the existence of a feature, from those taken inside buildings. Table 1 shows the total number of photographs that fall inside a buffer of 20m around buildings as well as the number of those inside and outside of the OSM building footprints

Table 2. Number of photographs inside and outside of building footprints

Photographs in scope	Photographs inside building footprints	Photographs outside building footprints (<20m)
79,722	38,106	41,616
	48%	52%

Table 2 shows that for the urban area of Paris, the number of photographs is almost split between those taken outside and those taken inside a building. This is important as it can quickly orient researchers regarding the number of possible useful photographs. However, as the results of Table 2 have been computed automatically, we then manually examined the photographs to determine how many are actually inside or outside buildings. Table 3 shows the confusion matrix for 1,000 randomly selected photographs. The “Inconlusive” category means that we could not verify from where the photograph was taken (i.e. a close-up of a face or an object).

Table 3. Confusion matrix comparing photographs inside and outside buildings comparing an automated and manual approach

		Topology Checks			
		Inside Buildings		**Outside Buildings**	
Visual Checks	**Inside Buildings**	613	61%	347	35%
	Outside Buildings	308	31%	557	56%
	Inconclusive	79	8%	96	10%

Note that these inconsistencies are in addition to the positional error that the geo-tagging process introduces (either via GPS or by locating the image on a map by hand). In the next section we use the Flickr geo-tagged photos to evaluate OSM.

4.1 Evaluation of OSM point features

As a case study for this kind of evaluation, the OSM POIs that were located in, what IGN categorizes as, wooded areas (i.e. under trees) were used. The existence of POIs under trees limits the pool of contributors that can offer their services in data capturing or data updating as an individual cannot digitize the entity by using satellite imagery but needs to actually visit the POI and offer local knowledge. Figure 2 shows (left) a satellite image of a selected area and (right) the polygons of wooded areas provided by IGN for the same area.

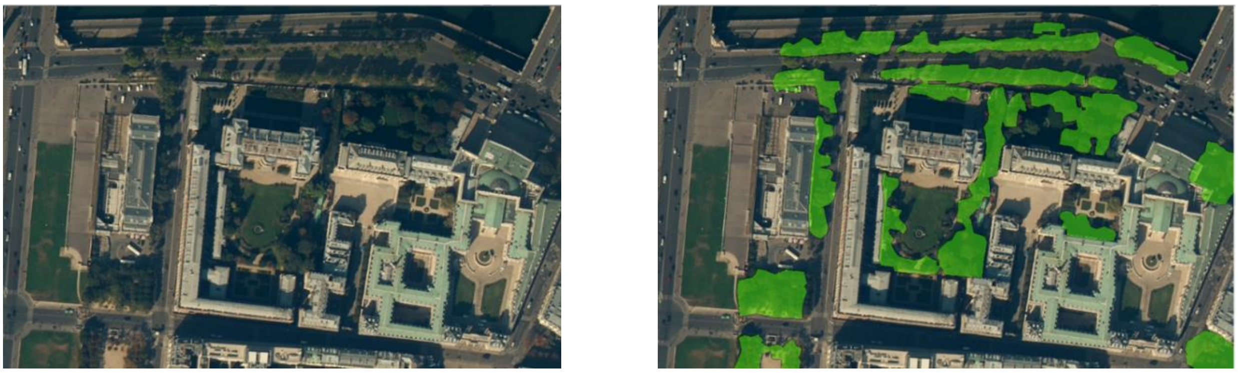


Figure 2. Snapshot of Parisian Wooded Areas (source: IGN)

The polygons of Wooded Areas were used to clip the OSM POIs (2,448 in total) and the geo-tagged photographs (10,333) that were inside a 20m buffer zone from those POIs located outside of buildings. These two datasets resulted in 16,351 possible combinations as a photograph could be in the vicinity of more than one POI. A Postgresql (with Postgis) database was used to store the location of the geo-tagged photographs, the Wooded Areas layer from IGN and the POI and Building layers from OSM. An online application was then developed which displayed a geo-tagged photograph, retrieved using the Flickr API, and asked a user whether a specific POI could be recognized in approximately ‘*X meters*’. Thus, for example, the questions had the form “*Do you see a(n)* ***monument*** *about* ***2m*** *away, in the photo below?”*. Figure 3 shows a number of illustrative examples generated by the application. We proceeded with the visual evaluation of 1,000 pairs (i.e. POI – geo-tagged photograph) and it was possible to positively evaluate the POI in 78 cases. In these cases, the POIs could be positively identified and thus evaluated for their existence and validity (e.g. the POI had not changed).

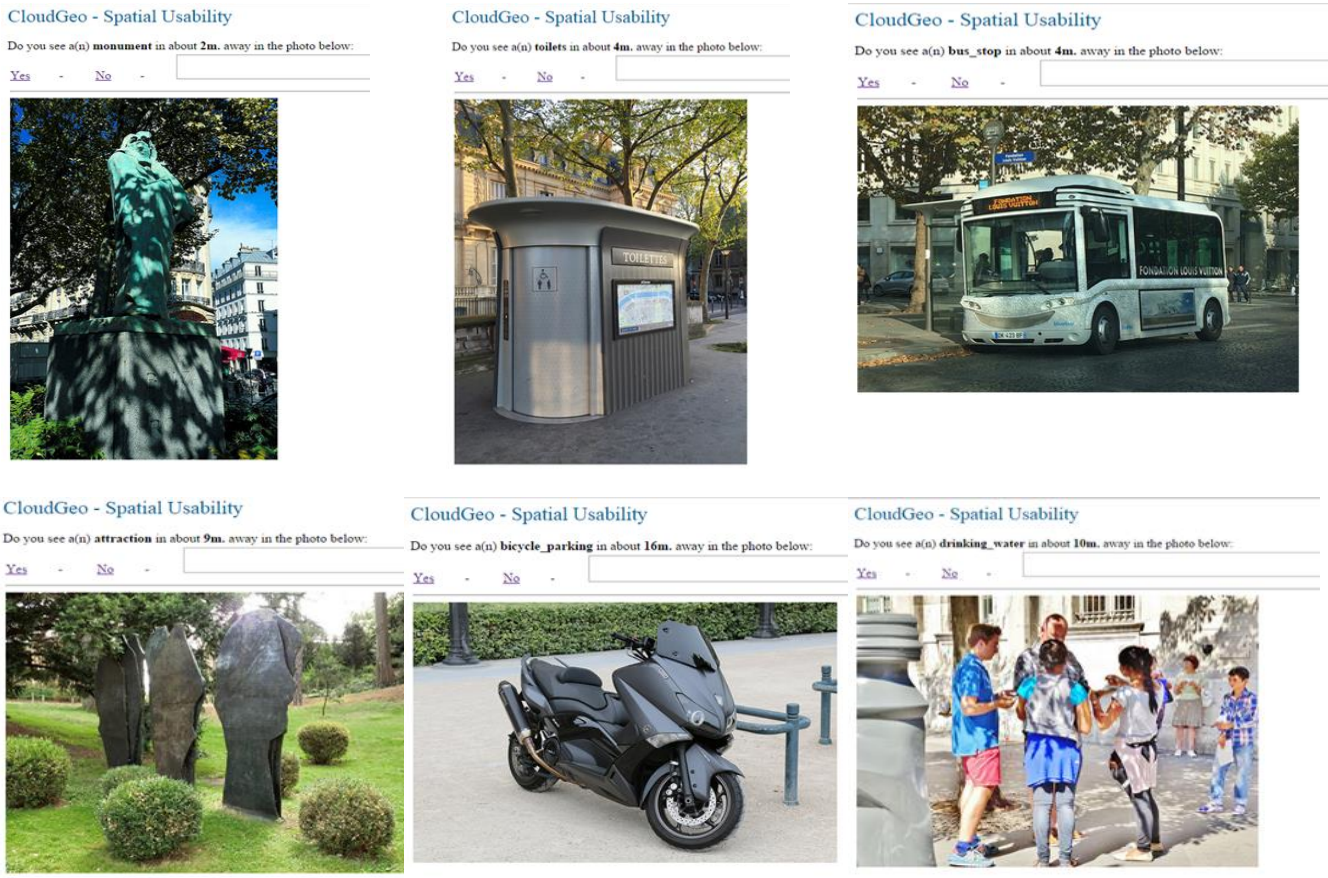
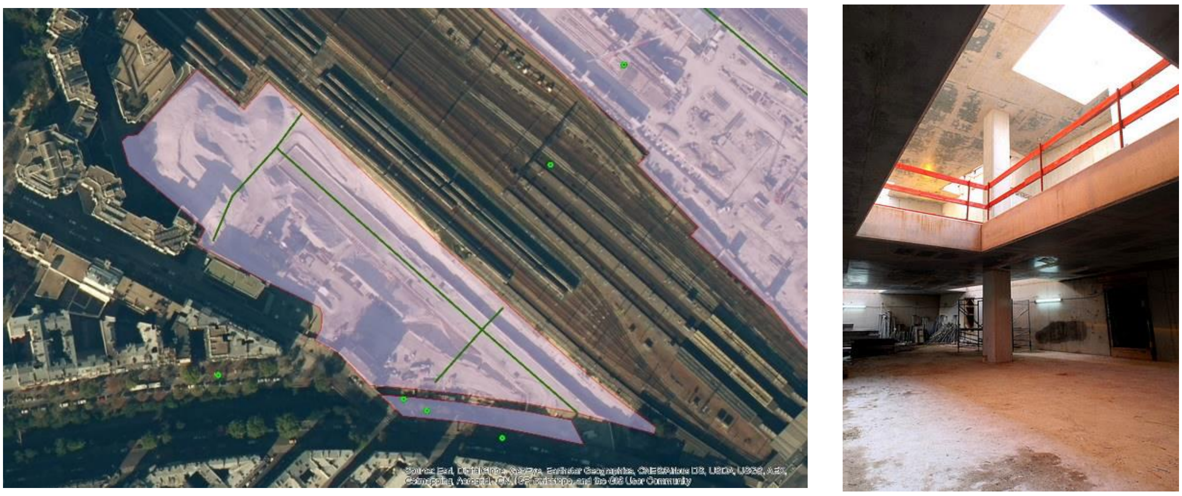


Figure 3. Illustrative screen-shots of an ad-hoc application that retrievess geo-taggged photos for POI evaluation.

4.2 Evaluation of LULC overlaps

The second case study for using geo-tagged photographs to evaluate a VGI dataset was selected from the Land Use/Land Cover (LU/LC) domain. In this case, inconsistencies regarding the actual LU/LC resulting from contradictory feature types that come from different OSM layers (e.g. between the Landuse and Natural OSM layers) were recognized (for more on this see Fonte et al. 2016). The LU/LC at each given point should be unambiguously retrieved. This requirement not only contributes to the overall quality of OSM and the correct cartographic output but also enables the use of OSM data for the creation of LU/LC products. Thus, overlaps between different and contradictory LU/LC feature types create inconsistencies that could possibly be disambiguated with the use of geo-tagged photographs. For, example Figure 4a shows the overlap of a closed construction site (purple polygon) and a residential road (green line) (green dots are the locations of Flickr photos). It is obvious that it is not possible for both layers to correctly denote the actual use of the area. The use of geo-tagged images could provide the necessary information to clarify the mismatch. In Figure 4b, a Flickr photo clearly shows that the area has been turned into a construction site. A valuable characteristic of the VGI datasets used is the time information they bear. Using the individual timestamps of features, it is possible to analyse and understand the currency of each feature, which could be valuable in updating the overlapping features with outdated information.



(a) *(b)*

Figure 4. Mismatches between the OSM Roads and Landuse layers (a). A Flickr photograph of the area.

Although no systematic approach has yet been followed for this line of research, manual examination of similar cases allows us to suggest that geo-tagged photographs can be used as an external validation mechanism of other VGI sources.

5. DISCUSSION AND CONCLUSIONS

In this study we have explored selected quality aspects using topo-semantic rules. At the beginning the focus was on the inter- and intra-theme validity of the rules using polygonal, linear and point encoded features. We examined selected rules and the findings show that OSM data, for the study area, adhere to the rules set by the OSM wiki. For example, a mere 0.18% of the total buildings might be erroneous cases (either sliver polygons or unjustified overlaps). A similar picture can be seen for the *Roads* layer itself or when compared with other OSM layers. This process gave us a better understanding of the quality of the inter- and intra-theme quality of OSM layers and how topo-semantic rules could be applied.

Then the focus turned specifically to POIs. Until recently, topographic maps provided very few details about important features of everyday life. Local-level mapping was out of the scope of National Mapping Agencies or private corporations. Exceptions could be found in products like touristic maps and guides that included touristic attractions or POIs. Still, even these products did not provide a detailed description of the urban fabric. Today, thanks to VGI sources, a vast amount of local-level data in form of POIs is available and, in a sense, drive online maps and applications towards a totally different level. In this context, and recognizing the importance of POIs, we turned our focus to the examination of inter-theme topo-semantic rules for POIs or intra-theme with layers like *Buildings* and *Roads*. The analysis of the Parisian POIs showed that, in general, POIs adhere to the topo-semantic rules with very few exceptions (e.g. crossings) or distribution biases (e.g. parking spaces).

However, notwithstanding their merits, POIs have a challenging intrinsic characteristic: volatility. It is obvious that a local POI can change its name, use or stop existing as a POI far more easily than a road segment or a park. Thus it is imperative for POIs to be verified regularly by local contributors. Alternatively, a solution might come about through combining information from various VGI sources. For example, geo-tagged photographs can prove a trustworthy alternative, in particular for POIs that cannot be verified through interpretation of satellite imagery,. To this end, an ad-hoc application was developed to prove the validity of the concept. Indeed, it was possible to positively verify POIs that were under trees. Thus, the study makes a step towards the use of geo-tagged images in quality evaluation and improvement of OSM.

We recognize that this is a first and admittedly rudimentary approach for using geo-tagged photographs as a reference dataset for evaluating OSM features. There are many issues that need to be considered and various ways in which this process could be further improved. For example, each photograph faces a certain direction and there is no information if another, more relative, POI is missed by the photograph. Digital compasses, added to modern cameras or smartphones, might provide information about the viewshed of each photograph. Furthermore, here we used only Flickr geo-tagged photographs. The combination of photographs from all major photo-sharing social applications (e.g. Twitter, Instagram, Facebook, Google Picasa etc.), which provide global coverage, can give more options in observing and validating OSM features. Another issue is the need to reduce the noise introduced in the automated process. In our example, we evaluated 1000 POI-photo combinations to end up with 78 positive matches. By automatically eliminating all geo-tagged photographs that are adding noise to the process (such as close-ups, photos with no natural light etc.), we can make the whole process more efficient.

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