Measuring urban vitality in Trento through geospatial analysis

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Abstract

The goal of the current project is to measure the levels of urban vitaly inside a given city through the analysis of georeferenced data. According to literature research urban vitality is an essential aspect of urban development since it reflects the liveability of cities (Zhang *et al.*, 2024). Consistent with recent studies, the current project aims to investigate this aspect through the geospatial analysis of the city itself, considering therefore physical elements, such as buildings and surface areas, and their georeferenced coordinates.
The city of Trento was chosen as a study case for the current analysis.

Introduction

In urban development studies the urban vitality is usually used to define the level of activity of a specific unit of analysis, which can be the blocks, districts or neighborhoods of a city.
The definition of activity itself can vary depending on the dimensions one wants to consider, therefore it is often a good practice to construct an index comprehensive of multiple dimensions to avoid the bias caused by relying on a single indicator (Zhang *et al.*, 2024).
In the current project the definition of urban vitality relies on six different indicators, summarized into four dimensions:

A. **Commercial vitality**: refers to the level of presence of commercial activities inside the unit (indicator 1).
B. **Transportation convenience**: refers to the level of presence of means of transportation. It considers:
   a. the number of sustainable transportation means' stops in the unit (indicator 2).
   b. the level of street density (indicator 3).
C. **Development intensity**: refers to the level of presence of green areas in the unit (indicator 4).
D. **Function diversity**: refers to the level of mixture of different elements in the same unit. It considers:
   a. the diversification of land use (indicator 5).
   b. the diversification of points of interest related to the main urban functions (indicator 6).

These indicators were chosen considering both the city's structure and the results obtained by the most recent studies on urban vitality. Each of the indicators is computed differently considering the nature of the data retrieved to measure the indicator itself.
The final urban vitality index is then constructed using spatial analysis methods that will be explained in the next sections.

Considering the city's structure, the units of the current analysis are the so-called *poli sociali*, which can be compared to the concept of neighborhood of a city. These units are not homogeneous in the area and correspond to territorial organizational units constructed using a social perspective. Currently, these borders have no meaning at the administrative level, since this function is solved by the so-called *circoscrizioni*. Each *circoscrizione* can contain one or more *poli sociali*.
From the official page of the Trento Open Data[1] 48 *poli sociali* were retrieved, which will become the units of the following analysis. The geographic distribution of these units is shown in Figure 1.

Figure 1: plot of the poli sociali of Trento

All the data were analyzed using the CRS:25832 reference system, which is suitable for the European area and therefore also for the city of Trento. This choice was also considered for two additional reasons:

- computational cost: the data obtained from the municipality of Trento were already encoded in this reference system, thus it was not necessary to convert them.
- geometric computations: the current system uses meters as unit measure, allowing to compute calculations such as the area of polygons and the length of street without additional computations.

Data preparation

Data were collected through two main sources, the OpenStreetMap application and the Trento Open Data site of the city. Data from OpenStreetMap were retrieved using Overpass API.
Table 1 shows the main information regarding the indicators used in the current project: one can see the description of each indicator, the source of the data and the size, and the mathematical formula used to compute the indicator itself.

[1] source file at the page: (https://www.comune.trento.it/Aree-tematiche/Politiche-sociali-e-abitative/Quartieri/Localizzazione-dei-quartieri-e-dei-poli-sociali).

Considering the heterogeneity of the units of the analysis (the *poli sociali*), it was decided to normalize the indicators dividing the result by the area of the unit to provide more accurate results.

Table 1: general description of the indicators.

Dimension	Indicator	Source	N	Mathematical formulation
Commercial density	presence of commercial activities (1)	OpenStreetMap	1226	$\frac{n\ commercial\ POIs}{n\ total\ POIs} \cdot \frac{1}{unit\ area}$
Transportation convenience	number of sustainable transportation means (2)	OpenStreetMap	705	$\frac{n\ stops}{unit\ area}$
	level of street density (3)	OpenData Trentino[2]	5610	$\frac{street\ surface}{unit\ area}$
Development intensity	level of presence of green areas (4)	OpenData Trentino[3]	6343	$\frac{green\ surface}{unit\ area}$
Function diversity	diversification of land use (5)	OpenData Trentino	12155	$entropy\ =\ -\Sigma_{j=1}^{n} p_j ln(p_j) \cdot \frac{1}{unit\ area}$
	diversification of urban function (6)	OpenStreetMap	2401	$entropy\ =\ -\Sigma_{j=1}^{n} p_j ln(p_j) \cdot \frac{1}{unit\ area}$

Data analysis

The steps implemented to obtain the urban vitality index were the following:

1. **Indicators computation**: each indicator is calculated through its specific mathematical formulation, as reported in Table 1. After obtaining the indicators' values for all the units, all the indicators were normalized through the z-score standardization, computed through the formula:

$$z\ =\ \frac{x - mean}{std}.$$

   By doing so it was possible to compare the results and to have a better understanding of the results themselves.
2. **Spatial matrix construction**: The spatial distance matrix is constructed considering the Queen contiguity calculation. This method defines as neighbors two polygons sharing a common edge or a common vertex (PySAL documentation).
3. **Global Moran index computation**: for each indicator the global Moran index was computed to observe directly the spatial autocorrelation. In cases where this index was close to zero (thus indicating the absence of spatial autocorrelation), the indicator was then removed from the set. The closer the index is to -1 or 1, the stronger is the spatial autocorrelation, with a negative or positive effect respectively (PySAL documentation).
   The global Moran index is computed as follows:

[2] source file at the page: (https://www.comune.trento.it/Aree-tematiche/Cartografia/Download/Stradario).
[3] source file at the page:(https://www.comune.trento.it/Aree-tematiche/Cartografia/Download/Carta-uso-del-suolo).

$$I = \frac{n}{\Sigma_{i=1}^{n}\Sigma_{j=1}^{n}w_{ij}} \cdot \frac{\Sigma_{i=1}^{n}\Sigma_{j=1}^{n}w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\Sigma_{i=1}^{n}(x_i - \bar{x})^2}.$$

This index was used to consider the global spatial spillover effect that similar studies have underlined: adjacent neighborhoods continuously interact with each other (Chen Y. *et al.*, 2023)

4. **Spatial empirical Bayes smoothing**: it provides an estimate considering the combination of local and global spatial information. It is computed through the formula:

$$\hat{y}_n^{SEB} = w_n \cdot spatial\ lag + (1 - w_n)i_n,$$

for n parameters and with $spatial\ lag = \Sigma_{j=1}w_{ij} \cdot y_j$.

5. **Urban vitality index construction**: the urban vitality index was in the end assessed through the formula:

$$urban\ vitality\ index = \Sigma_1^n w_n i_n,$$

where w is the weight assign to the corresponding indicator i.

In the current project the weights assigned to the indicators are all the same and obtained through the computation: $\frac{1}{n\ indicators}$.

In the end, the obtained index was first normalized through z-score standardization and then its values divided in quintiles to construct a five categories index.

Therefore each units was defined as:

- very high level of urban vitality,
- high level of urban vitality,
- medium level of urban vitality,
- low level of urban vitality,
- very low level of urban vitality.

Results

By applying the previously explained model to the dataset we were able to construct the urban vitality index for Trento's neighborhoods. Table 2 shows the Moran index values and the respective p-values for each indicator. Through the analysis of the results derived from this computation the following indicators were considered useful to the analysis and therefore used to construct the index:

- presence of commercial activities (1),
- sustainable transportation level (2)
- level of street density (3),
- presence of green areas (4),
- diversification of urban function (6).

Further analysis shall be implemented to obtain accurate results also for the remaining indicators.

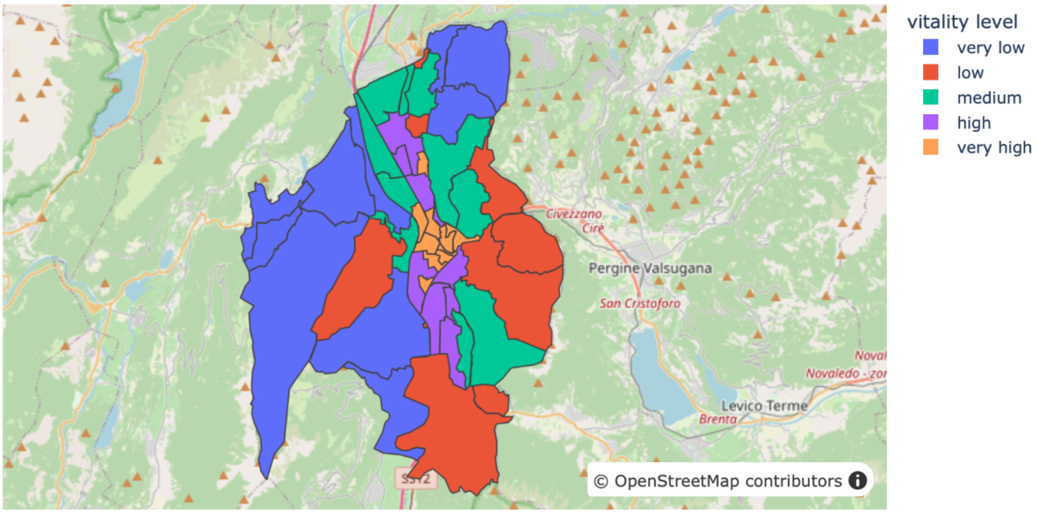
Table 2: results for the Moran index computation on the indicators.

indicator	Moran index	p-value
presence of commercial activities (1)	0.226893	5.399591e-03
number of sustainable transportation means (2)	0.528571	7.083012e-10
level of street density (3)	0.561721	6.324363e-11
level of presence of green areas (4)	0.638343	1.416645e-13
diversification of land use (5)	0.006096	7.589437e-01
diversification of urban function (6)	0.407633	1.521320e-06

Figure 2 shows the neighborhoods of Trento, i.e., the 48 units of the analysis, coloured by the level of the urban vitality index. One can immediately see that the districts belonging to the city center have very high levels of urban vitality, while the ones along the administrative borders of the city tend to have low levels of vitality. Moreover, the neighborhoods adjacent to the ones with very high levels of urban vitality also tend to have high and medium levels of vitality, proving the theory of global spillover effect.

It's also important to notice how the neighborhoods with the lower levels of urban vitality tend to concentrate on the left side of the city, while on the right side medium levels categories are more present. This distribution could be derived from the geographical structure of the city itself: neighborhoods on the left side are characterized by a more natural environment due to the presence of the Monte Bondone, small and compact living areas and a low presence of any type of activities.

Figure 2: distribution of Trento's 'poli sociali' by level of urban vitality



Conclusion

The current project aimed to construct an urban vitality index considering multiple dimensions together. The goodness of the indicators relies on the source data and on the methods used to model the data themselves: it is therefore necessary to have a complete knowledge of the area of study.
In the current analysis the units used, the so-called '*poli sociali*' present very heterogeneous features, among these the area of each unit stands out. A better approach, though complex and time-consuming, would have been to divide the city in blocks using the street network and the natural elements (as rivers) to construct adjacent polygons.
In this case the same analysis could provide interesting results for some areas of the city.
Secondly, the current project assigns the same weights to all the indicators such that they all have the same impact on the urban vitality. It is not excluded that adjusting the weights to the indicators considering different impacts could provide different results.
Nonetheless the current urban vitality index is able to provide an insight into the urban development of the city of Trento, which could be useful to policy makers, urbanists and citizens in the future developments of the city itself.

References

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PySAL's official documentation (https://pysal.org/packages/)

Musse, M. A., Barona, D. A., & Santana Rodriguez, L. M. (2018). Urban environmental quality assessment using remote sensing and census data. *International Journal of Applied Earth Observation and Geoinformation,* Vol. 71, 95–108. DOI: https://doi.org/10.1016/j.jag.2018.05.010.

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Python Libraries

geopandas==0.14.3
geoplot==0.5.1
geopy==2.3.0
libpysal==4.7.0
matplot==0.1.9
numpy==1.23.5
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