Article

Urban Ecosystem Services (UES) Assessment within a 3d-Virtual Environment: A Methodological Approach for the Larger Urban Zones (LUZ) of Naples (Italy)

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Abstract: The complexity of urban spatial configuration, which affects human-well being and landscape functioning, needs acquisition and 3d visualisation data to inform decision-making process better. One of the main challenges in sustainability research is to conceive spatial models which are capable of adapting to changes in scale and recalibrating the related indicators depending on the degree of detail and data availability. In this perspective, the inclusion of the third dimension into Urban Ecosystem Services (UES) assessment studies highlights the details of urban structure-function relationships, improves modelling and visualisation of data and impacts, aiding decision-makers to localise, assess and manage urban development strategies. The main goal of the proposed framework concerns mapping, evaluating and planning of the UES within a 3d-virtual environment to improve the visualisation of the spatial relationships among the services allocation and the urban fabric density.

Keywords: Sustainability, Urban Ecosystem Services (UES), Landscape Services (LS), Larger Urban Zones (LUZ), LIght Detection And Ranging (LIDAR), Multi-Criteria Analytical Scoring Tool (MASCOT)

1. Introduction

Cities, as complex socio-ecological systems, need transdisciplinary approaches through which the definitions of sustainability and resilience involve not only the urban structure but also the assessment of available resources in terms of services, and the continuous cooperation among specialists, decision-makers and stakeholders to reach common goals, supported by the co-production of knowledge through Information Technology and 3d-modeling (Ahern 2014; Ostrom 2009). Within a cross-scale approach, both the concepts of Landscape Services (LS) and Urban Ecosystem Services (UES) are useful depending on: investigation field, data quality/quantity, specific objectives of the assessment and geographical scale of analysis (Tress et al., 2009).

In this paper, it has been adopted a definition of LS including the spatial pattern and social dimension as a result of human and natural processes interaction in the provision of services and benefits for citizen. Nevertheless, when dealing with urban dimension, as the place in which built environment prevails over natural features and population density is high, the specification of UES has to be introduced to understand the actual demand for ecosystem services (Costanza et al, 2017; Haase et al., 2014; Valles-Planells 2014; Termorshuizen and Opdam 2009).

According to Potschin & Haines-Young (2016), LS and UES must be understood, definitively, as a *boundary object* for sustainability, namely an idea embedding different opinions which preserve a sense of continuity. In this framework, one of the main challenges in sustainability research is to

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conceive models which are capable of adapting to changes in scale and recalibrating the selected indicators depending on the degree of detail and data availability.

Furthermore, cross-scale analysis aid understanding the regional planning outcomes on local-scale processes, considering that the overall choices could negatively affect urban and neighbourhood scales (Barreto et al., 2010). Moreover, mapping UES mostly improves data communication and interactions with stakeholders and local communities, which become aware of the most valued and used locations in terms of service/resource provisioning (Balzan et al., 2018; European Commission, 2013; Klein et al., 2015; Gomez-Baggethun and Barton, 2013; Scorza et al., 2020; Zoppi, 2020).

The complexity of urban spatial configuration, which affects human-well being and landscape functioning, needs acquisition and 3d visualisation data to inform decision-making process better and communicate the system complexity. In this perspective, LIDAR (LIght Detection And Ranging) technology improves knowledge of urban context, providing precise elevation-based information about buildings, vegetation and other surfaces. Definitively, the inclusion of the third dimension into UES assessment studies highlights the details of urban structure-function relationships (De Groot et al., 2010; Geneletti, 2011; Pickett et al., 2001; Sadroddin and Panah, 2019).

The available data relating to three-dimensional features of the urban system can be collected not only from the official database but also from open source and Volunteered Geographic Information (VGI) platforms, such as OpenStreetMap (OSM), Flickr, Wikiloc, etc. Indeed, VGIs enrich the knowledge at a more in-depth scale with user-generated contents which are related to buildings, infrastructures, facilities, and points of interest. Indeed, planning and managing interventions within urban decision-making environment and about complex urban landscapes need suitable methods and tools to support the identification of potential and critical cities' features, to establish priorities, and to geo-locate optimal solutions rapidly and effectively.

On the one hand, the Geographic Information System (GIS) capabilities refer to spatial data modelling and visualisation through the elaboration of composite maps, tables and diagrams, on the other hand, the Multi-Criteria Decision Aiding (MCDA), in its more general meaning, allows explaining the complexity of phenomena and detecting trade-off among feasible scenarios by considering multiple attributes and trade-offs (Attardi et al., 2018; Balena et al. 2014; Cerreta and Panaro, 2017; Cerreta and Poli, 2017).

According to the survey of Alavipanah et al. (2017), the gap of knowledge within the ES literature about the third dimension for an understanding of the ecological functions in urban systems is significant. In particular, studies which take into account the volume of the urban services and height of buildings are few or completely lacking.

From these foundations, two main questions that motivate the paper to arise:

- How could 3d modelling with GIS-based procedures better transfer relevant information to decision-makers about the localisation, assessment and management of UES?
- Which is the role of 3d modelling and virtual decisional environment concerning the communication, democratisation and negotiation of the UES?

The paper aims at experimenting of a methodological approach which relates 3d urban modelling and visualisation to the UES assessment, testing it on a case study related to the Larger Urban Zones (LUZ) of Naples, in the South of Italy. Moreover, the further purpose of UES mapping may aid decision-makers to localise strategies for landscape development in terms of multi-functionality enhancement and/or supply, whenever those services are scarce.

The articulation of paper proceeds as follows: the first part (Section 2) shows materials and methods, describing the different phases of the proposed methodological approach; the second one (Section 3) introduces the case study through data, indicators and multi-criteria procedures to be implemented within the approach; the third (Section 4) analyses the results; while the fourth (Section 5) explains the discussion and conclusions about the opportunities of 3d methodology in city policy and planning.

2. Materials and Methods

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The methodological framework for 3d-modelling of UES has been conceived according to four interrelated phases: knowledge (K), methods (M), tools (T) and outcome (O) (Figure 1).

The main goal of the proposed approach concerns mapping, evaluating and planning of the UES within a 3d-virtual environment in order to improve the visualisation of the spatial relationships among the services allocation and the urban fabric density.

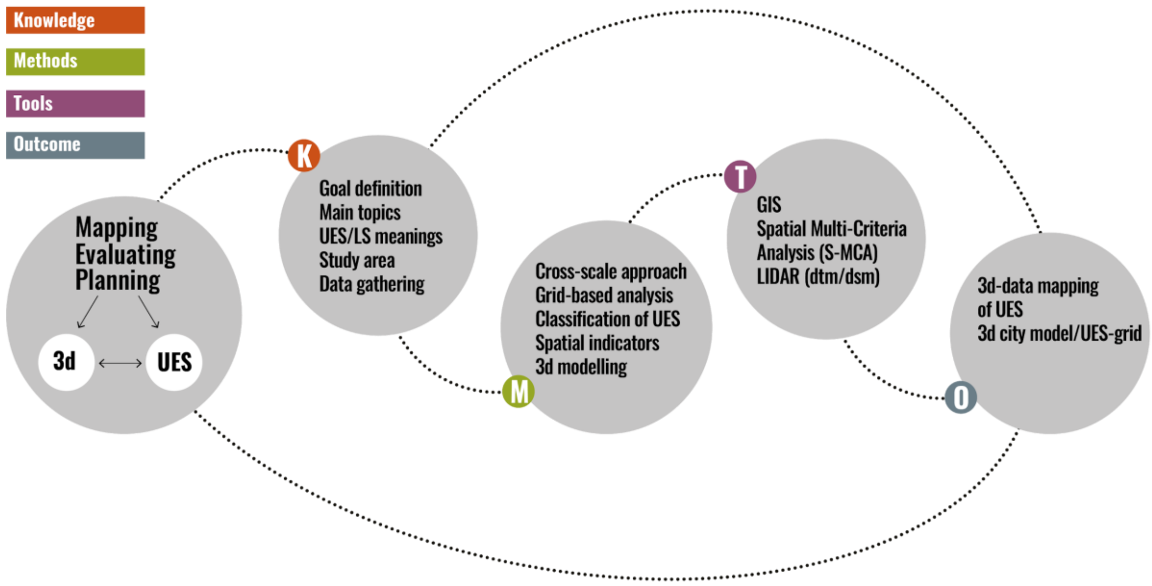

Figure 1. The workflow of the methodological approach: phases and interactions

The first phase seeks to identify main topics and goals concerning the recognition of the UES and their spatial benefits in the selected focus area within the GIS environment. Since the preparatory step of the proposed approach involves data gathering and processing, both authoritative sources and Volunteered Geographic Information (VGI) were a useful starting point to enhance knowledge flows related to the urban context (Goodchild & Li, 2012).

The second phase concerns the application of a cross-scale approach and a grid-based analysis to normalise data on a common surface. A grid of 500 X 500 meters, which extends over the boundaries of the selected focus area, has been assumed as Minimum Mapping Unit" (MMU), cause it better includes natural and built features for the examined environment.

The third phase aims at choosing the suitable tools to reach the goal. The Spatial Multi-Criteria Analysis (S-MCA) allows us to compute the value of the normalised indicators representing the performance of each cell in terms of UES supply. To combine UES values with three-dimensional city visualisation, it has been adopted LiDAR technology, which is broadly applied in 3D urban modelling (Zhou et al., 2004; Popovic et al., 2017).

The fourth phase allows for producing a twofold outcome. On the one hand, it has been shown 3d data mapping of three macro-categories of UES, on the other hand, 3d city model has been overlaid to the reference grid of UES to enhance the spatial results.

In particular, the expected results are focused on the application of the methodology within different research fields (i.e. urban planning, forestry, agriculture, landscape, etc.) for different typologies of issues, i.e.: the resolution of spatial problems which involve the allocation of resources/services in the urban context; the 3d-visualisation of the UES indicators' values at the regional scale; the spatial assessment of multiple scenarios related to stakeholders preferences; the development of a common platform by which specific planning demands can be answered by evaluations skills.

2.1. Data sources for 3d modelling

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Advancement of 3D modelling needs input data which can be traced in the authoritative and unofficial spatial datasets, and through Remote Sensing (RS) technology (Hecht, 2015). Notwithstanding some limitations, dealing with incompleteness for wide zones and geometrical heterogeneity, sometimes VGI system data are as accurate as authoritative sources or even preferable (Arsanjani 2015). Indeed, several authors, through comparisons among official and unofficial data, have proved the completeness and semantic accuracy of OSM dataset (Campagna 2016; Goodchild & Li 2012; Fan et al., 2014). One of the main advantages in using these type of data, in particular, those derived from Flickr, Panoramio, Instagram, etc., may concern the coverage of zones with scarce or limited availability of official information, due to financial and governmental restrictions (Cerreta, Panaro, Poli 2016; Hecht 2013). About the control of users' contribution, indeed, the statistical sampling methods, which allocate points in a grid system, have been using for limiting uncertainty, understanding where data needs, and what type of information is request (Fonte et al. 2017).

The preliminary data for 3d modelling also involve the RS technology since it provides a high level of detail about the elevation information.

According to Schiode (2001), indeed, the LIDAR technique is one of the data-acquiring methods used for 3D urban modelling setting in geospatial technology. The process is based on a system which employs laser rays that measure the position of a point by calculating the time that passes between the ray emission, the impact on the object to be detected and the return, after reflection, to the starting point. LIDAR system records first-pulse and last-pulse return rays depending on the different properties of absorption and reflection of laser beams of the objects (Schiode, 2001). The system produces two types of information about the objects height respect to the ground, which is collected into two products: Digital Terrain Model (DTM) and Digital Surface Model (DSM). DTM is a mathematical grid model of the earth surface, in which each pixel has a unique elevation value. In contrast, DSM is a mathematical grid model which includes the elevation values of the off-ground objects such as buildings and vegetation (Mallet, 2016). Finally, height objects information can be excerpted subtracting DSM from DTM.

2.2. Cross-scale approach and grid-based analysis for UES detection

The cross-scale approach can be adopted for identification and evaluation of services, mainly if spatial indicators are used as proxies to identify features and dynamics of UES, through mapping of geographical entities which produce benefits (Englund, 2017). This approach requires choosing a homogeneous statistical surface on which data and indicators with different sources, formats, attributes and spatial resolutions can be processed (Li et al. 2013).

According to this issue, the European Union, through the Directive 2007/2/EC (European Parliament and Council 2007), has been starting data interoperability process which has been aiming at the construction of Infrastructure for Spatial Information in Europe (INSPIRE). It could be useful to improve the availability, quality, accessibility and sharing of data, to endorse the dissemination of spatial information. Indeed, one of the specific tasks of the Directive refers to the definition of the geographical grid as a common reference system for the European Countries, intending to facilitate data communication and evaluate the spatial heterogeneity of cities' features.

Within RS techniques and theories, the MMU has been defined by Knight & Lunetta (2003) as "the smallest areal entity to be mapped as a discrete entity", and it has been preparatory for processing of spatial indicators of UES. The use of regular shape, i.e. rectangular or square grid, is generally preferred in environmental studies since the orthogonal coordinate system and raster format is the most common parameters in the release of spatial data (Birch et al. 2007).

3. Quantifying, assessing and 3d-visualizing of UES: a case study

The selected case study aims at testing the methodology of 3d-UES modelling. The purpose is mapping and evaluating the status of services within the administrative boundaries of Naples city (Italy) and its surroundings, through a Spatial Decision-Making Support System (SDSS) combining

Geographic Information System (GIS) and spatial multi-criteria extension of the Analytic Hierarchy Process (AHP) method (Saaty & Vargas 2001).

In this study, the results of the Spatial Multi-Criteria Analysis presented in Mele & Poli (2015) have been adopted. In a nutshell, the aggregation rule of the spatial AHP method, which has been implemented into the Multi-Criteria Analytical Scoring Tool (MASCOT) software, allowed us to produce a normalised index of UES per cell through the pairwise comparison of indicators and distance decay method. The enhancement offered by the tool, indeed, consists of the twofold processing of the cell-by-cell weighted sum and Euclidean distance among the spatial elements. Finally, the amount of the objects within the distance decay and their weighted sum provide the weight per each category per cell. The UES values have been processed on the reference grid through the Multi-Criteria Spatial Analysis and have been standardised in range 0 - 1.

3.1. The focus area

The focus area extends over the Larger Urban Zones (LUZ) of Naples (Italy) as conceived and mapped by the European Environment Agency (EEA) through the project "Urban Atlas". It offers highly detailed land use/land cover maps, at scale 1:10,000, for the highest density cities and their surroundings with more than 100,000 inhabitants, as stated by Eurostat (European Commission 2012). The focus area is approximately 560 sq km and includes Naples city with its 960,000 inhabitants, 14 satellite-municipalities directly connected to the urban centre, and 21 municipalities affecting the city in terms of economic, social, and environmental pressures (Figure 2).

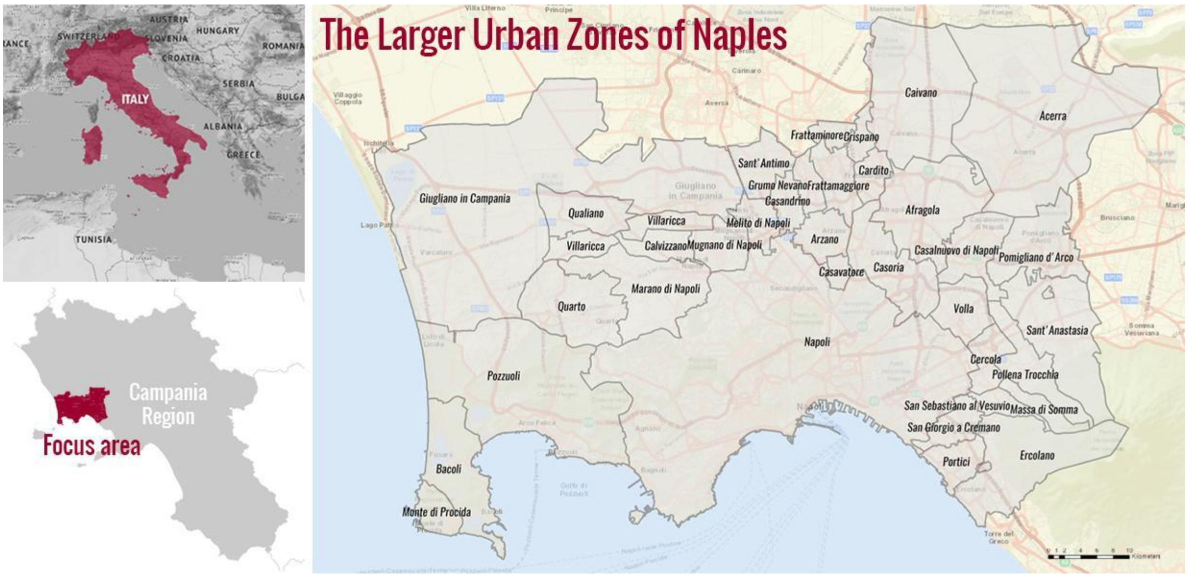

Figure 2. The focus area

3.2 The classification of UES

The classification of UES for the study area has been derived from the LS categorisation proposed by Valles-Planells (2014), since it provides more flexibility about the consideration of a broader range of functions, i.e. the *carrier* functions referred to as the daily routine activities (Valles-Planell 2014; De Groot 2006). The selection of indicators has been structured in six levels identifying: the three macro-functions of the landscape, the spatial data as the specification of the function, the different units of measure (U.M.), the type of geometric entity, the distance decay in metres (D.D.), and the data source (Table 1).

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Table 1. Table of indicators of UES

Landscape Function	Spatial data/tier	U.M.	Entity	D.D. (m)	Source
Regulation	Environmental protection area	sq km	polygon	2500	Natura 2000 - EC
	Waterbody	sq km	polygon	300	Urban Atlas - EEA
	Forest	sq km	polygon	2500	Urban Atlas - EEA
	Land without current use	sq km	polygon	100	Urban Atlas - EEA
	Waterway	km	line	300	OpenStreetMap
Carrier	Railway	km	line	100	OpenStreetMap
	Road	km	line	100	OpenStreetMap
	Airport	sq km	polygon	1000	Urban Atlas - EEA
	Port	sq km	polygon	1000	Urban Atlas - EEA
	Bus/underground stop	number	point	500	OpenStreetMap
	Mineral extraction site	sq km	polygon	100	OpenStreetMap
	Habitation density	sq km	polygon	100	Urban Atlas - EEA
	Waste disposal	sq km	polygon	100	OpenStreetMap
	Tourism facility	number	point	500	OpenStreetMap
Information	Cultural site	number	point	2000	OpenStreetMap
	Place of worship	number	point	500	OpenStreetMap
	Sport and leisure	sq km	polygon	500	Urban Atlas - EEA
	Green urban area	sq km	polygon	1000	Urban Atlas - EEA
	Attraction place	number	point	500	OpenStreetMap
	Attractive landscape feature	number	point	1000	Panoramio/Flickr

The geographical data have been processed through multi-criteria procedures to provide indicators as proxies for UES status detection. The following list explains specifically each tier of the database which has been gathered for the focus area. Three categories of functions, from De Groot (2006) and Valles-Planells (2014), has been selected referring to regulation, carrier and information services and amounting to 21 tiers of geographical data with physical information.

Within the category of regulation functions, the followings six tiers have been processed:

1. "Environmental protection area" tier includes the surface per cell of the communitarian interest sites (SIC) and special protection zones (ZPS) of Italy. These areas provide a relevant contribution to maintenance/conservation of the regulation services.
2. "Waterbody" tier shows the surface per cell of the sea, lakes, fish ponds (natural or artificial), rivers and canals. For specific locations, the indicator has to be considered a dis-service since the quality of water in the proximity of the urban centre is compromised by pollution. More detailed data needs in these cases.
3. "Forest" tier includes both protected and non-protected areas which provide a positive contribution to urban ecosystems in terms of biological exchanges, air quality, raw materials and green footprint.
4. "Land without current use" tier refers to the abandoned areas which, if correctly managed, improve the regulation services maintenance/conservation.
5. "Waterway" tier includes the pipeline, streams, ponds etc. and it has been obtained by computing the values through the distance between the cell and the nearest waterway.

The following nine tiers belong to the carrier functions category:

1. "Railway" tier shows the network of transportation by computing the values through the distance between the cell and railways' track.
2. "Roads" tier shows the network of roads by computing the values through the distance between the cell and the road's track.
3. "Airport" tier shows the surfaces on which airport are allocated and the buffer of influence for the surroundings. Although the airports are crucial for long-distance connections, they have a negative impact in terms of noise and environmental disturbance on ecosystems.
4. "Port" tier shows the surface of coast addressed to port-functions and the buffer of influence for the surroundings in terms of noise, pollution, transportation of people and wares, and proximity to boarding points.
5. "Bus/underground stop" tier identifies the location of bus-metro stops visualising the most accessible zones of the focus area.
6. "Mineral extraction site" tier shows the caves by which extract raw materials for the construction sector.
7. "Habitation density" tier shows institutional dataset provided by EEA with information about housing density.
8. "Waste disposal" tier localises the waste disposals which gather the waste from the study area.
9. "Tourism facility" tier identifies the highest concentration of the touristic facilities points (e.g. hotel, B&B, guesthouse).

Finally, the last six tiers belong to information functions category:

1. "Cultural site" tier highlights the cultural heritage by identifying the number of cultural sites.
2. "Place of worship" tier shows the location of worship which are related to landscape spiritual values.

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3. “Sport and leisure” tier shows the sport and leisure surface, which are very important since they contribute to regulation and cultural functions of the landscape.
4. “Green urban area” tier shows the green urban areas, which are very important in contributing to regulation and cultural functions.
5. “Attraction place” tier represents the places of attraction which polarise the flows of tourists and citizens (i.e. theatres, cinema, and observatories).
6. “Attractive landscape feature” tier represents an excerpt of point pattern, based on a code which keeps most photographed places by citizens and tourists in the focus area. It simulates landscape attractiveness, as citizens or tourists perceive it. A perceptual investigation about the relationship between aesthetic value and landscape features would require surveys, which are not faced in this paper.

In the same way as data resolution and MMU, the choice of distance decay influences the final results of the spatial evaluation. It, therefore, must be made following criteria that are congruent with the initial objectives of the decisional processes. Indeed, the environmental studies are affected by the landscape configuration, which includes the distance and the interaction among elements in terms of effect decay, mostly when dealing with ES approach (Verhagen et al 2018).

3.3. Operative steps for 3d modelling

Three main steps have been carried out to visualise the 3d-data mapping of UES. Firstly, the geographic entities - which represent the urban services - have been selected and georeferenced (A), then the standardised indicators’ values have been obtained per cell on the reference grid through the spatial AHP multi-criteria method (B). Finally, the overall services have been shown as three-dimensional histograms associating the normalised value of the indicator to the z-value of the cell with the software Arc Globe within ArcGIS 10.3 platform (C) (Figure 3).

Afterwards, the three-dimensional model of the urban environment has been achieved to understand better the existing relationships between the urban districts and the status of UES.

In this paper, elevation data processed for this phase have been derived from DSM and DTM models, while, the building footprints have been gained from the ancillary dataset of Geofabrik service provider, distributed by OSM.

Specifically, the process undertaken to develop 3d modelling is shown in the following four steps:

1. It has been necessary to create a random point pattern within the polygonal footprints which represent buildings. The maximum number of points per polygon within the random process has been set as 50, depending on shapes’ features and computational power. The points lying inside the boundaries of a building polygon have the same object identifier.
2. Surface information derived by DSM elevation data has been assigned to each point pattern inside the polygons with an average statistical interpolation.
3. A table join operation has been performed to arrange point surface information to building polygons.
4. Buildings z-value has been used as extrusion value in ArcGlobe 10.3, and it showed the elevation information in metres above sea level.

The figures 4 and 5 highlight an excerpt of the 3d modelling for the focus area zooming on Naples city and overlapping the grid of information function (Figures 4 and 5).

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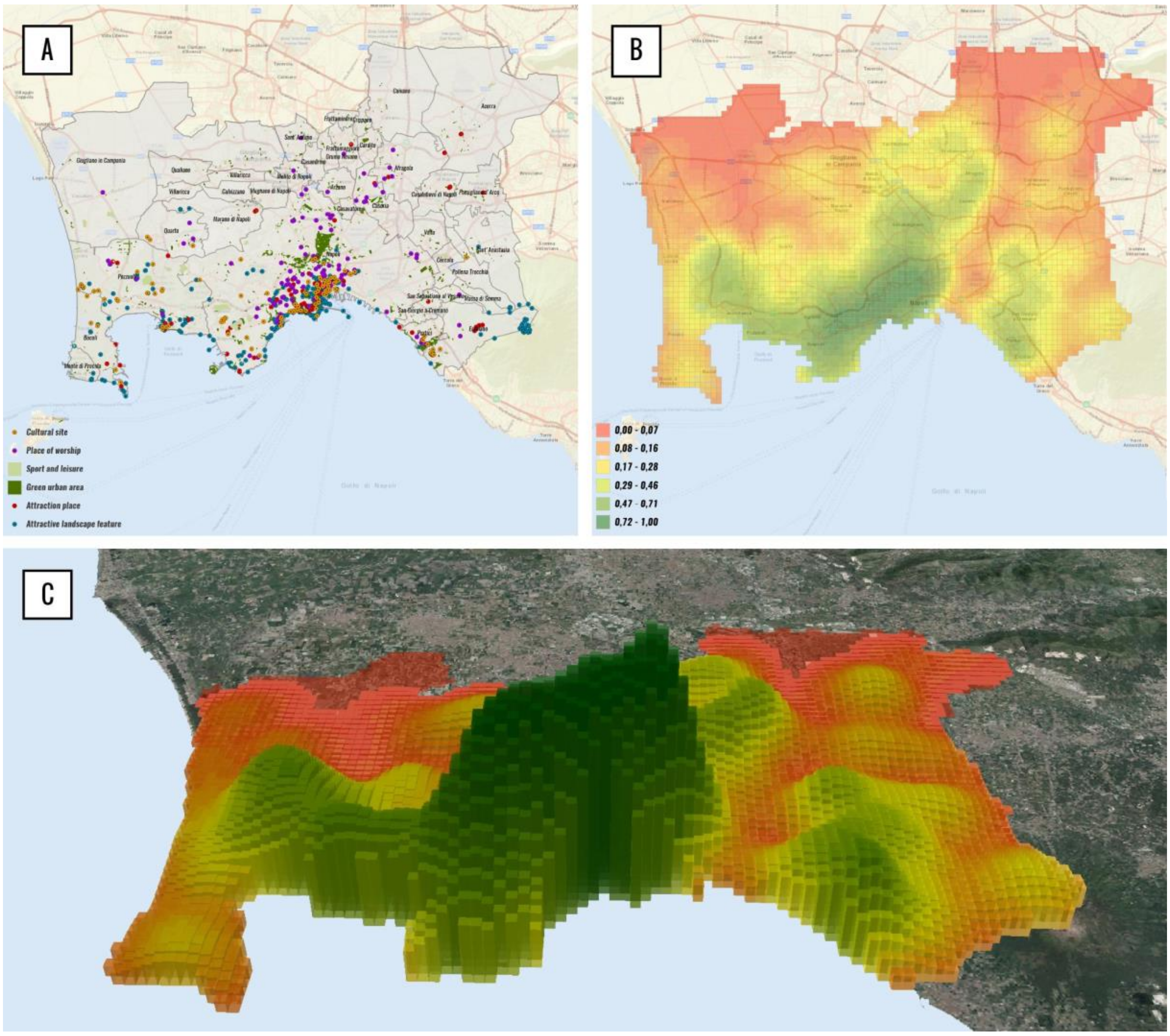

Figure 3. (A) Spatial indicators map for information functions of UES; (B) The reference grid (500m x 500m) with standardised values of indicators in range 0 - 1; (C) 3d-data visualisation of information functions values

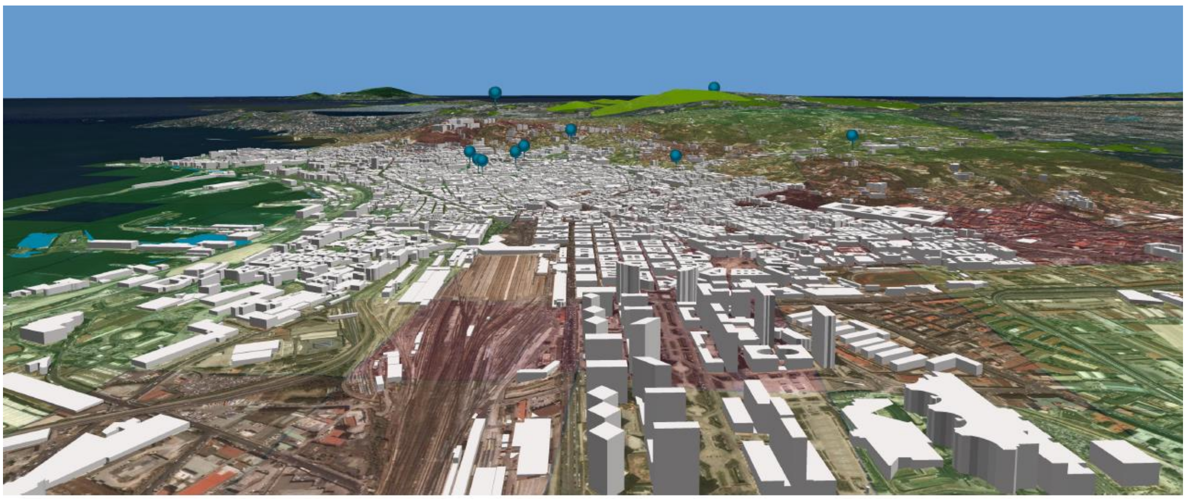

Figure 4. An excerpt of the 3d modelling for the focus area (view n.1)

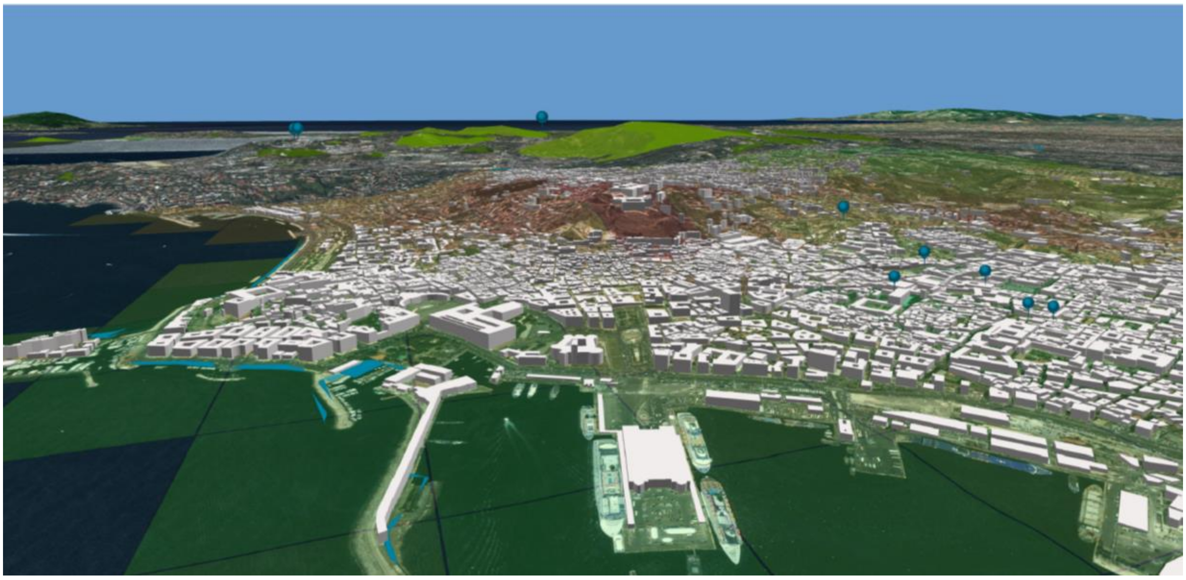

Figure 5. An excerpt of the 3d modelling for the focus area (view n.2)

The operative steps allow enhancing spatial visualisation of urban morphology and, simultaneously, overlaying the UES indicators grid to overlap the UES values per each category with the building density of the neighbourhoods.

4. Outcome

The AHP multi-criteria aggregation rules, implemented by MASCOT software, allowed us to map the distribution of the UES per each macro-function. The results of the applied approach have been focused on three primary outcomes: the assessing of the multi-functionality levels per MMU of 25 hectares (with a cell size of 500 X 500 metres); the visualisation of the spatial distribution of services and its surrounding benefits by applying a distance-based method; and lastly the scenario planning for the spatial implementation of UES by considering the degree of suitability per MMU. Table 2 shows the minimum, maximum and standard deviation values of the UES per each municipality within the focus area concerning the three categories of landscape functions (Table 2) for each municipality of Naples UES.

Table 2. Urban Ecosystem Services values standardised per municipality

	Regulation function			Carrier function			Information function		
Name	Min	Max	St. Dev.	Min	Max	St. Dev.	Min	Max	St. Dev.
Acerra	0,000	0,460	0,104	0,000	0,298	0,051	0,000	0,142	0,036
Afragola	0,000	0,372	0,105	0,000	0,271	0,078	0,015	0,298	0,084
Arzano	0,008	0,259	0,057	0,004	0,214	0,062	0,120	0,343	0,064
Bacoli	0,127	0,987	0,184	0,003	0,178	0,044	0,042	0,202	0,034
Caivano	0,000	0,255	0,061	0,000	0,272	0,063	0,000	0,188	0,044
Calvizzano	0,000	0,476	0,130	0,042	0,206	0,053	0,044	0,133	0,022
Cardito	0,064	0,361	0,084	0,080	0,232	0,037	0,152	0,213	0,017

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Casalnuovo di Napoli	0,000	0,372	0,095	0,005	0,115	0,028	0,025	0,116	0,022
Casandrino	0,012	0,296	0,084	0,004	0,252	0,076	0,121	0,250	0,030
Casavatore	0,017	0,268	0,074	0,119	0,259	0,040	0,253	0,387	0,037
Casoria	0,000	0,462	0,108	0,007	0,260	0,075	0,025	0,315	0,091
Cercola	0,004	0,324	0,092	0,050	0,164	0,029	0,135	0,253	0,032
Crispano	0,000	0,221	0,066	0,001	0,261	0,083	0,055	0,212	0,049
Ercolano	0,000	0,648	0,178	0,000	0,218	0,055	0,051	0,351	0,061
Frattamaggiore	0,000	0,298	0,081	0,011	0,262	0,071	0,105	0,213	0,027
Frattaminore	0,000	0,221	0,073	0,009	0,234	0,072	0,049	0,191	0,040
Giugliano in Campania	0,000	0,672	0,116	0,000	0,211	0,043	0,000	0,248	0,042
Grumo Nevano	0,000	0,105	0,036	0,018	0,200	0,058	0,121	0,197	0,023
Marano di Napoli	0,000	0,608	0,191	0,021	0,204	0,037	0,010	0,143	0,037
Massa di Somma	0,040	0,633	0,189	0,000	0,231	0,072	0,068	0,208	0,036
Melito di Napoli	0,021	0,306	0,081	0,019	0,205	0,044	0,111	0,282	0,040
Monte di Procida	0,127	0,473	0,110	0,003	0,154	0,041	0,047	0,130	0,025
Mugnano di Napoli	0,014	0,497	0,120	0,060	0,264	0,049	0,087	0,251	0,038
Napoli (Naples)	0,000	1,000	0,216	0,002	1,000	0,143	0,031	1,000	0,245
Pollena Trocchia	0,000	0,540	0,127	0,000	0,184	0,049	0,061	0,197	0,035
Pomigliano d'Arco	0,000	0,330	0,082	0,000	0,261	0,058	0,002	0,116	0,027
Portici	0,018	0,355	0,115	0,021	0,192	0,044	0,189	0,393	0,060
Pozzuoli	0,093	0,693	0,113	0,001	0,206	0,035	0,067	0,423	0,094
Qualiano	0,000	0,171	0,039	0,005	0,260	0,069	0,004	0,129	0,039
Quarto	0,000	0,464	0,155	0,038	0,150	0,025	0,008	0,203	0,054
San Giorgio a Cremano	0,000	0,329	0,093	0,048	0,183	0,032	0,195	0,357	0,036
San Sebastiano al Vesuvio	0,000	0,603	0,170	0,023	0,247	0,061	0,089	0,254	0,057
Sant'Anastasia	0,000	0,372	0,082	0,000	0,208	0,043	0,020	0,161	0,036
Sant'Antimo	0,002	0,321	0,099	0,016	0,252	0,070	0,026	0,207	0,051
Villaricca	0,000	0,167	0,052	0,016	0,206	0,053	0,004	0,135	0,041
Volla	0,000	0,374	0,092	0,005	0,152	0,041	0,027	0,257	0,063

It can be observed from data comparison that the municipality of Naples reaches the value of services for all three categories. In case of regulation services, while having the highest

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value, the standard deviation is high, which implies a deviation from the very significant average value, i.e. the areas with high regulative ecosystem values are interspersed with more urbanised areas with a low level of green features. Moreover, it is interesting to observe that the Municipality of Bacoli, which borders with Naples city, reaches a very high value of the regulation function and has a slightly lower standard deviation in comparison with Naples. This implies an even of this type of services within its boundaries. All other municipalities reach much lower values. The following figures show 3d-data mapping results. Figure 6 highlights high peaks of carrier functions in Naples' downtown. In these zones, transportation and tourism facilities are most thick, while the suburban area is lacking in these type of facilities (Figure 6). The regulation functions are evenly spatially distributed on the overall investigation area, but high values can be detected in the southwestern zones (Figure 7).

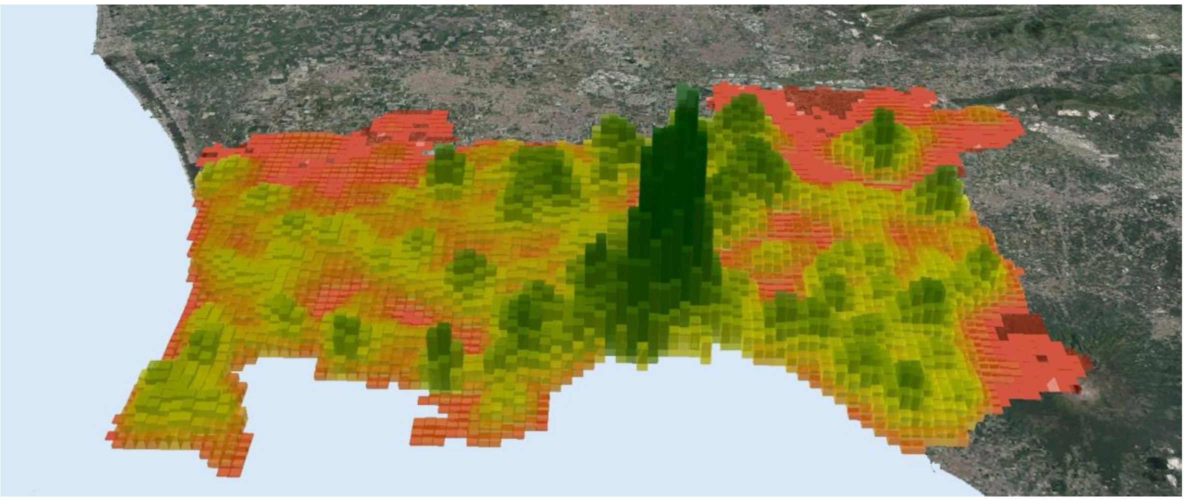

Figure 6. 3d-visualization of the carrier function values

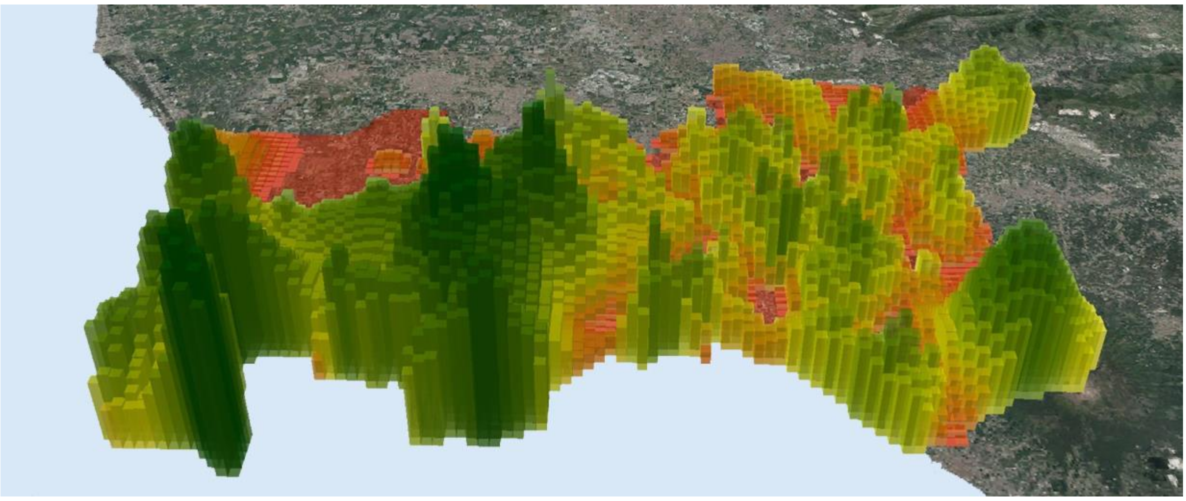

Figure 7. 3d-visualization of the regulation function values

The map shown in figure 8 highlights the comparison among the UES values per each macro-function by overlapping the z-values of the grid. The three colour gradients represent the regulation function (green), the information function (red) and the carrier function (dark green) (Figure 8) respectively.

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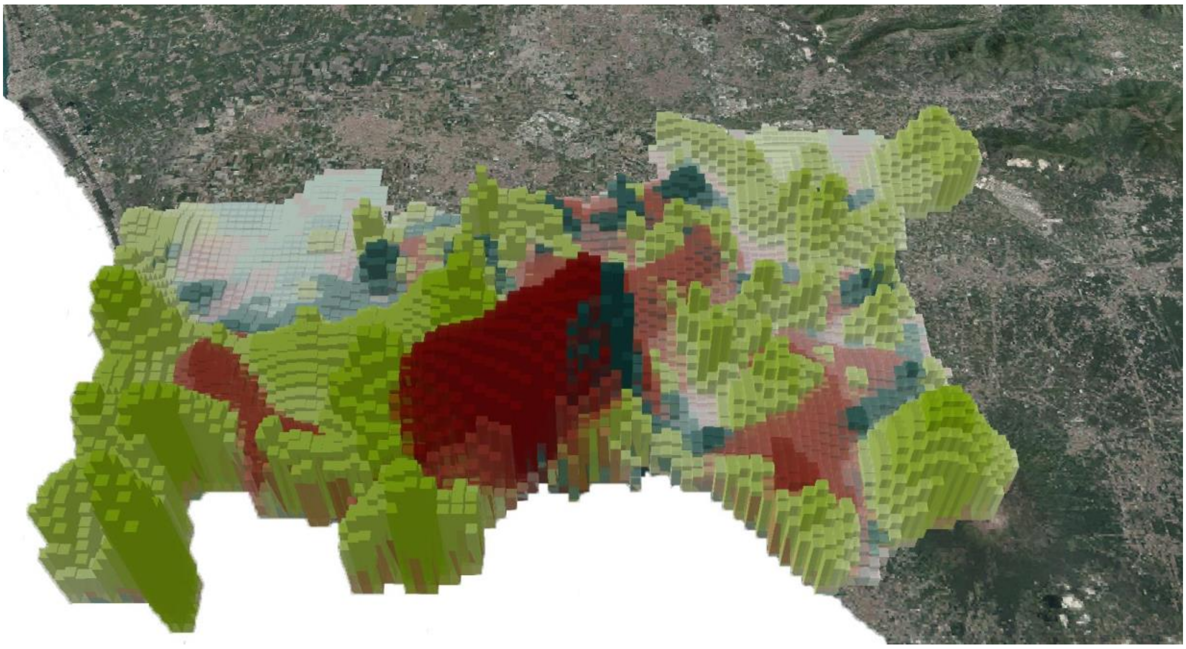

Figure 8. The overlay of values for the three functions categories

The northern-east areas score low values or lack of carrier and information functions, while moderate values of regulation functions balance this gap. Null values in the northern-west regions of the focus area can be attributed both to the absence of services and/or information gap.

5. Discussion and conclusions

The proposed methodological approach allows identifying a particularly useful process that helps to combine and integrate the potentials of different techniques, highlighting the specificity of each and the synergistic contribution that everyone can provide to the other. The interaction between the different methods allows you to structure an articulated analysis of the UES, highlighting the opportunities to map and evaluate the status of services within the administrative boundaries of Naples city and its surroundings.

The elaboration of a Spatial Decision-Making Support System (SDSS), able to combine Geographic Information System (GIS) and spatial multi-criteria method, supported by the Multi-Criteria Analytical Scoring Tool (MASCOT) software, have produced a normalised index of UES per cell through the pairwise comparison of indicators and distance decay method. According to the proposed SDSS, processing of the cell-by-cell weighted sum and Euclidean distance among the spatial elements was a relevant result, able to describe the specificity of the characteristics of the entire urban landscape. At the same time, the amount of the objects within the distance decay and their weighted sum provide the weight per each category per cell.

The identification of the cell and the choice of a suitable MMU is particularly relevant, especially when some types of spatial data affected by statistical problems have been manipulated. In particular, a regular unit could partially resolve the Modifiable Areal Unit Problem (MAUP), which substantially compromise the final results of GIS analyses (Openshaw 1983).

An example can be represented by the use of census data, where the choice of a correct unit of aggregation should be assessed from the outset of the analysis. According to O'Sullivan and Unwin (2014), indeed, the selection of different statistical units can lead to totally different results, since it generates new patterns and spatial relations between the features that shape the investigation area.

Another advantage of using regular grids is also combining the original mapping units with more accurate cells to investigate the effects of urban changes at different scales. According to EEA

(2006), the regular grids have proved to be effective for the understanding of the spatial variability phenomena, and evaluation, mapping and data generalisation.

Another relevant potential is related to the implementation of the MASCOT software, based on the AHP multi-criteria aggregation rules, that allowed to map the distribution of the UES per each macro-function and to assess the multi-functionality levels of UES.

At the same time, the 3d-visualisation of the spatial distribution of services represents an innovative component of the methodological process that allows making the values of the three selected landscape functions categories (the regulation function, the information function and the carrier function) more easily understandable and communicable. The 3d-visualisation can be considered a suitable way to analyse and describe the UES and support the elaboration of planning and design alternatives taking into account the identification of the enabling conditions.

Some limitations of this approach can be detected in: a static visualisation of the maps; a lack of different scenarios to be compared, since it is not feasible when equal weights have been assigned to spatial criteria (tiers); time-consuming processes related to Stakeholders' preferences manipulation and sensitivity analysis, introducing or removing tiers; loss of relevant information, data noise and likely overfitting whether the criteria/tiers are multiple and dispersed on several geographical entities.

Indeed, this study has been conceived as the first step toward further implementation of the 3d-modelling approach through which a better correlation among urban services and z-value could have experimented, to explore the complexity of urban spatial configuration better and to improve the results of a decision-making process.

The third dimension included in the UES assessment identifies a relevant opportunity to understand the details of urban structure-function relationships, improving modelling and visualisation of data and impacts. The proposed methodological framework supports mapping, evaluating and planning of the UES within a 3d-virtual environment aiding decision-makers to localise, assess and manage urban development strategies, and faces one of the main challenges in sustainability research related to the elaboration of spatial models, capable of adapting to changes and managing sustainable transformations.

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