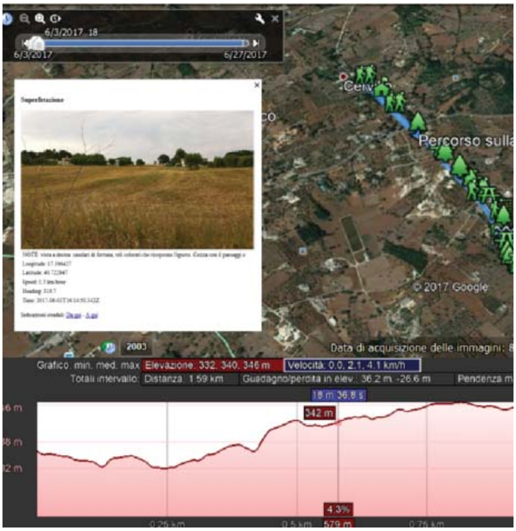

FEATURES OF AGENTS' SPATIAL KNOWLEDGE IN PLANNING OPEN SPACES

A PILOT STUDY

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ABSTRACT

Spatial environments have been largely studied over time, under different perspectives. Under a cognitivist perspective, they represent knowledge-intensive, meaningful spaces and entities that human agents relate to and adapt during their existence.
The comprehension/identification of space fundamentals by human agents can be of great interest in strategic planning, in that they may represent structures, pillars, invariant, resilient characters of the environment, on which to build/plan the layout and development of regions and towns.
The role of spatial cognition is often expressed through tacit or implicit aspects, made of perceptions, emotions, sensations relating to space, difficult to identify but characterizing the environment explored in a fundamental way. As a matter of facts, these are fundamental elements towards effective planning strategies and environmental decisions.
In particular, this work investigates these aspects of spatial knowledge in agents moving in spaces with reduced - in particular extremely reduced – population. In fact, these are apparently unstructured contexts with respect to settlement areas, where aspects concerning sensations can represent essential spatial variables in terms of structuring and interpreting spaces.

KEYWORDS
Spatial Cognition; Open Space; Spatial Variables; Environmental Planning

1 INTRODUCTION[1]

Spatial environments have been largely studied over time, under different perspectives. Under a cognitivist perspective, they represent knowledge-intensive, meaningful spaces and entities that human agents relate to and adapt during their existence (Proulx et al., 2016). They are intrinsically based on dynamic complexity, therefore trying to understand the typical spatial behaviours of a human agent is often hard task, inducing planning as well as managing problems in many domains (Denis & Loomis, 2007). For example, they are typically intricate tasks when trying to simulate spatial behaviours within AI or robotic building layouts. Therefore, in the quest for understanding the complexity of space environments, it is important to search for the possible 'fundamental' features of such spatial complexity from the standpoint of agents who have act and relate to the space.

The effort of searching for fundamental spatial features is not an easy task, though. In fact, there is a potential naivety in speaking about space 'fundamentals' as opposed to space ancillary, ornamental qualities (Goodman, 1951). Particularly experimental literature often shows that not always there is clear distinction between substance and ornament, content and form in spatial analysis (Borri & Camarda, 2013).

Understanding the way in which human agents think and operate in given spaces – i.e., space ontology, from a perceptual point of view – is commonly essential for AI robotics. In turn, because of the well known circularity between AI and cognitive science, the development of AI robotics devices help in understanding spatial human behaviours for decisionmaking. Therefore, the comprehension/identification of space fundamentals by human agents can be of great interest in strategic planning, in that they may represent structures, pillars, invariant, resilient characters of the environment, on which to build/plan the layout and development of regions and towns.

The research on the spatial knowledge forms of living agents in both micro-scale (buildings or their aggregates) and meso-scale spaces (cities as sets of built spaces and open spaces) is today in progressive development, in environments of automatic computation of psychology or engineering (Borri & Camarda, 2010, 2013). It offers ideas to engage with, for example in problems of orientation and navigation, as well as ontological intelligence.

In particular, the macro-scale concerns spaces that are still predominantly configured in a pre-anthropic way as are deserts, mountains, forests, oceans, and in perspective also spaces outside the planet. Research on forms of spatial knowledge at the macro-scale is still limited (Dolins & Mitchell, 2010; Proulx et al., 2016).

The present work investigates on such aspects of spatial knowledge in agents moving in spaces with reduced - in particular extremely reduced – population. In fact, they are spaces that are apparently unstructured, as compared to community settlements, where aspects of sensations can constitute spatial variables that are essential in terms of structuring and interpretation of spaces.

The way in which we find the progressive identification and enrichment of information during navigation in this type of space is analyzed here. In particular, we are interested in the essential information for orientation in navigation and for the identification of the resources necessary to guarantee operative systems of relationship between agents and between agents and spaces.

[1] Authors developed the present study together, as a common research work. In this framework, G. Mastrodonato wrote chapter 2, D. Camarda wrote the remaining chapters.

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Within the above research framework, the paper is then organized as follows. After the present introduction, a digression on the research background on spatial cognition issues is carried out in chapter two. The third chapter briefly deals with the main characters of the research project where the present study is structured. Chapter four shows the experimental case study carried out here, with essential, describing methodology and discussing the results of the developed analysis. Brief concluding remarks are reported in the end, dealing with achievements, suggestions and possible follow-ups.

2 SPATIAL COGNITION RESEARCH BACKGROUND

When dealing with cybernetic and artificial intelligence studies, we find large reasoning about spatial cognition features, as they are important for operational planning. Rather interestingly, they put town a basic distinction between structured and unstructured spaces. Fundamentally, it parallels a similar distinction between spaces geometrically simple (elementary profiles, few unexpected events, few secondary items, few decisions required) and spaces geometrically complex (composite profiles, recurrent unexpected events, many secondary items and many decisions required) (Danziger & Rafal, 2009; Georgiev & Allen, 2004; Kelly & Bischof, 2008). It is easy to understand that a robot develops movements and learns surrounding spaces more straightforwardly in simple geometries, so determining more identifiable cognitive situations. This seems rather clear, although robot agents can typify great part of reality and are able to move also in unstructured world - like human agents.

A different situation occurs in human agents. A reasonably recognizable space is for us geometrically simple, empty, maybe unidirectional space. This is represented, for example, by an interior corridor, long and empty, with a series of doors, windows, skylights. It consists of a point of origin and an end point, with no lateral intersections. This space could be assimilated to the arc of a graph, it is certainly simple and can be walked by the human agent with little attention. On the other hand, the human agent considers complex a very crowded space, with a multi-dimensional geometry that is difficult to recognize. This is, for example, an open space, like a rural area or a city fair, with an unclear form, origin, endpoint, thus demanding specific attention. A human walks casually through it, with the frequent risk of colliding with the imprecise trajectories of people, or getting lost, or losing her / his friend or child who still does not know how to move in a complex space. Such complex spaces may suggest human agents a preliminary action of memorization of characteristic landmarks with the aim of replace an incomprehensible "structure" or "geometry" (de Hevia & Spelke, 2009; Gero & Tversky, 1999; Hirtle, 2003). Philosopher John Goodman (Goodman, 1951) argued on a distinction between 'structure' and 'ornament', in human perceptions of complex spaces. The representation space is increasingly considered as a multiform issue, complex and intrinsically non-reducible. It also changes with time, but with features that are not always so obvious as traditionally expected (Day & Bartels, 2008; Pouget et al., 2002). Such situation is even more complex, if possible, when dealing with the potentials and problems of orientation and spatial knowledge in endogenous and exogenous agents in spaces with reduced - in particular extremely reduced - population. It is a matter of identifying and experimentally analyzing variables and systems of latent variables in spaces with reduced (or non-existent) information content on the anthropic levels of spatial structuring. It is a question of laying the foundations - also through experimentation on human agents - of the modelling of functional (operational) cognitive systems that are suitable for these spaces. In general, these are cognitively poorly structured spaces. However, we assume the research hypothesis that a good cognitive structuring of such large spaces of nature, hostile to itself to the intensive population, is possible when the essential (ontological) latent variables are identified. These variables are therefore investigated,

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which are considered quite similar to those of high-population spaces with a high degree of randomness of interactions and transformations.

Starting from the available literature, the work aims to analyze some experiential narratives focusing on the themes of the cognitive characterization of rural paths. In particular, the results of experiments conducted with students of the engineering school of the Polytechnic of Bari are analyzed in a modelling perspective.

The general research objective of the experimentation is to investigate the fundamental characteristics of the open space through spatial cognition by agents who navigate within open spaces themselves. Relevant data are analyzed in order to draw correlations between elements present in protocols collected by ad-hoc experimentation. The specific objective of the present paper is to analyze the possible dependence of spatial sensations and perceptions from the other physical and relational elements that characterize the rural open space.

3 THE CASE STUDY

During the past months, an experimentation campaign was carried out with 180 students of the 2nd year of the master's degree in Building Systems, Urban Planning course. In this experimentation, each agent had to choose and travel a route in an open rural space, photographing elements that he considered to be of interest and recording sensations, perceptions and / or emotions along the way. The track, the places of interest and the notes were recorded in a geo-referenced way through smartphones, with appropriate software app. Subsequently, the agent reported her/his personal and residential details on the online portal related to the experimentation. The present analysis was carried out on a reduced sample of 16 observations out of 180 protocols. This is a small part of the entire population involved, since the work of control, formatting and normalization of the great amount of data is only at the beginning. Apart from personal details, data are mostly stored on kml/kmz (Google Earth) files, from which numerical elements are then drawn out in the form of string, text and graph (Fig. 1 and 2). In particular, textual notes taken by each agent along the route have been analysed by using simple data mining software Concordance, to draw out word and concept frequencies. The aggregation of textual concepts into categories has then been developed by manual ex-post analysis (Le Yaouanc et al., 2010). In the end, the complete database is reported in Fig. 3, whereas specifications of acronyms, including the clusters of concepts grouped by synthetic categories, are reported in Fig. 4.

Fig. 1 Example of track with the location of photo takings

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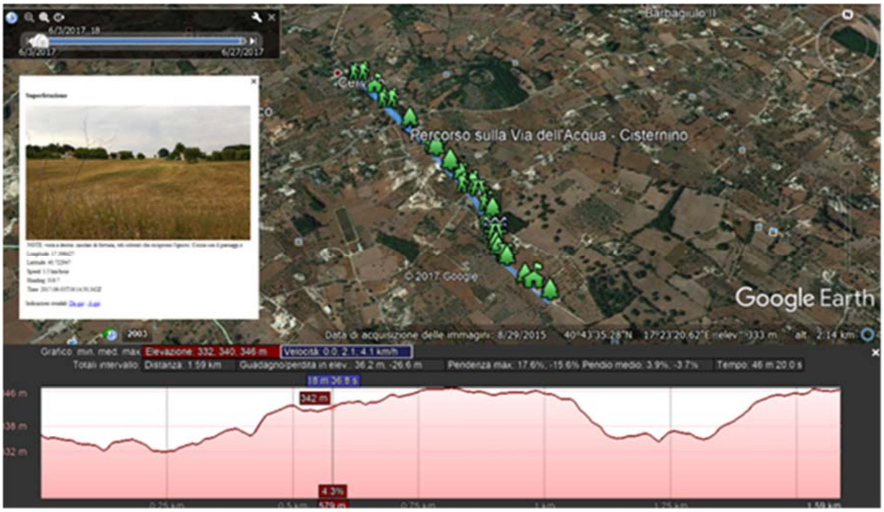

Fig. 2 Example of track with photo and note taking locations

#	ID	Town of residence	Explored location	Residence-location distance (km) LUO	Min altitude (m) ALT	Level difference (m) DIS	Length (km) LUN	Duration TEM	Buildings COS	Fauna FAU	Flora FLO	Natural landscape PAE	Dissipation and pollution INQ	Sensations SEN	Plants and installations TRA	Streets VIE	Abstract features ABS	topology TOP
1	552201	Fasano	Cisternino	12	368,2	44,9	1,6	00:46:20	11	3	11	9	4	8	5	5	14	8
2	553745	Bitritto Puglia	Bitonto	15	81	26,7	2	00:42:00	14	1	1	3	4	3	3	5	5	6
3	555252	TRIGGIANO	Carbonara	3,3	41	15,4	0,835	00:41:00	8	1	2	13	14	10	1	3	10	11
4	555512	Laterza	Laterza	6,6	350	48,4	4,3	00:40:00	7	1	1	11	8	3	1	10	7	1
5	566879	Lucera	Lucera	5	192	19,8	2,82	00:26:00	1	1	4	2	1	1	4	4	3	2
6	566927	Rocchetta S.A. (FG)	Rocchetta	1,6	596	76	1,02	00:12:04	12	1	6	6	3	7	2	4	9	4
7	567428	Altamura	Altamura	6	388	23,4	0,8	00:29:00	1	2	2	5	1	4	1	14	1	2
8	567559	Foggia	Siponto	32	1	3	2,31	00:37:00	7	1	3	2	7	13	5	8	4	10
9	567604	Foggia	Segezia	14	134	208	2	00:45:12	3	1	3	5	6	4	9	11	1	7
10	567637	Martina Franca	Chiancaro	1,5	397	423	2,9	00:51:39	14	2	1	10	3	13	1	3	1	9
11	567658	Manfredonia	Amendola	18	34	39	0,617	00:41:00	1	2	14	9	1	11	2	13	11	5
12	567719	Troia	Troia	0,6	1	1	2,29	00:30:00	1	1	1	5	1	1	2	12	1	5
13	567876	Lucera(FG)	Lucera	5	126	30,4	3,42	00:20:33	11	1	5	11	1	1	8	14	2	6
14	570501	Bari	Torre a mare	12	1	4	1,06	00:13:21	4	1	3	3	1	30	3	11	6	7
15	570643	Foggia	Ordona	17	91	9	1,73	00:36:00	1	1	1	1	1	1	1	4	4	3
16	580072	Colletorto (CB)	Colletorto	0,8	571	775	7,9	01:28:49	8	1	5	1	8	12	8	5	8	6

Fig. 3 The collected database (features are described through the citation frequencies of relevant words in the notes)

The internet portal of the experimental session, with personal details as well as relevant directions and information for respondents, is reported in Fig. 5. As said above, the specific objective of this work is to analyze the possible dependence of spatial sensations and perceptions from other physical and relational elements characterizing an open space. In this framework the statistical analysis method of multiple regression analysis was used as a pilot methodological experiment.

That method was not selected just to formally single out an algorithmic law of dependence of sensations on the various characters emerging along an open-space route. Rather, multiple regression allows to investigate on the possible correlations, relations of mutual dependence among variables, focusing on multiple independent variables at the same time. By using this approach, it is possible to aim at making a thorough and mutually comparative evaluation and discussion, which is necessary because of the small sample analyzed

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(Cohen et al., 2014, p.84). The multiple regression was carried out using the data analysis plug-in of Microsoft Excel, and statistical results are summarized in Fig. 6.

Buildings	COS	EDILIZIA, BORGO, MASSERIA, CASALE, COSTRUZIONE, URBANI, CONVENTO, FONTANA, PIETRA, PONTE, CHIESA, EDIFICIO, MURETTI, SILOS, TORRE, VILLA, ABBEVERATOIO, ABITATO, CASA, DEPOSITO, FRANTOIO, PAESE, PORTA, POZZO, TORRI, TRULLO, ARCO, ARCO, CAPANNI, CASTELLO, FINESTRE, MANUFATTO, MARMOREE, MONASTERO, SCALA
Fauna	FAU	CAVALLI, INSETTI, ANIMALI, CANI, COLEOTTERO, DOG, FAUNA, VIPERA
Flora	FLO	VEGETAZIONE, ALBERI, PIANTA, FLORA, CIPOLLE, ERBA, FICO, FIORE, FRONDE, MORE, POMODORI, VERDURE
Natural landscape	PAE	CAMPO, GRANO, RURALE, COLTIVAZIONI, TERRA, ULIVI, VIGNA, CAMPAGNA, TORRENTE, VALLE, AMBIENTALE, AMBIENTE, FLUVIALE, INCOLTO, NATURA, PAESAGGIO, AGRICOLO, AGRUMETO, BUCOLICO, FIUMETTO, PARCO, RACCOLTO, ACQUA, AMBIENTE, ARATURA, CANNETO, FILARI, MONTI, PARK, STEPPA, STERPAGLIA
Dissipation and pollution	INQ	RIFIUTI, DEGRADO, ABUSIVISMO, AMIANTO, ECOMOSTRO
Sensations	SEN	ABBAIARE, ABBANDONO, ACCIDENTATO, ACRE, AGEVOLE, APPARIVA, ARIA, ARSO, BELLO, BENESSERE, BREVE, BRUCIATA, CALDO, CALMA, COGNITIVA, COLORI, COMODO, CONFONDE, CONTRASTO, DETURPA, DISMISURA, DISSESTATO, DISTESA, EFFETTO, ESALAZIONI, ESPLORARE, FATICA, GRADEVOLE, IMMAGINE, LIBERTÀ, LUCE, ODORE, ORIENTARMI, PACE, PANORAMA, PERICOLANTE, PERICOLO, PIACEVOLE, RISTORO, RUMORE, SCORCIO, SCORGERE, SECCO, SENSAZIONE, SENSO, SGRADEVOLE, SICUREZZA, SPENSIERATEZZA, SPERANZA, STANCHEZZA, SUGGESTIVO, TORRIDO, TRANQUILLITÀ, VENTICELLO
Plants and installations	TRA	INDUSTRIALE, PALE, EOLICO, ARTIGIANALE, RECINTO, CANCELLO, ACQUEDOTTO, AZIENDA, DIGA, TRATTORE, ANTENNA, PALI, PANNELLI, PISCINA, TRALICCI
Streets	VIE	STRADA, PERCORSO, SENTIERO, ATTRAVERSARE, TRAGITTO, ASFALTO, CAMMINO, STERRATO, RAGGIUNGERE, SEGUIRE, PASSEGGIATA, SALITA, BIVIO, FERROVIA, INCROCIO, SVOLTA, CURVA, RETTILINEO, TRACCIATO, TRAFFICATA, VIAGGIO
Abstract features	ABS	VISTA, FORTUNA, INCOMPIUTI, PRESENZA, TRADIZIONI, IGNOTO, NATURA, QUALITÀ, VISTE, ASSENZA, ANTICO, PROSPETTIVA, OBIETTIVO, ILLUMINAZIONE, INTERNO, PARTI, STATO, TEMPO, APERTO, LONTANANZA,
topology	TOP	CONFINI, LUOGO, POSTO, RECINTO, TERRITORIO, SPAZIO, INGRESSO, INTORNO, LATO, AREA, ORIZZONTE, PUGLIESE, CIGLIO, LUOGHI, PUNTO, QUI, PARTE, TERRENI

Fig. 4 Legend of the aggregated variables (*Italian excerpt*)

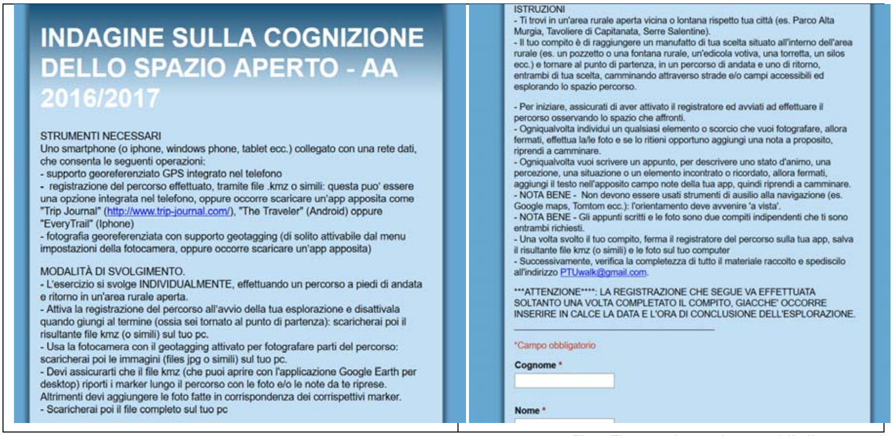

Fig. 5 The experimentation portal (*Italian excerpt*)

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Regression Statistics	
Multiple R	0,999991784
R Square	0,999983569
Adjusted R Square	0,999753529
Standard Error	0,117466051
Observations	16

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	14	839,7362017	59,98115727	4347,00461	0,01188717
Residual	1	0,013798273	0,013798273		
Total	15	839,75			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	25,02714273	0,333871773	74,9603434	0,00849225
LUO	0,269964976	0,006949165	38,8485468	0,0163836
ALT	-0,06864833	0,000777872	-88,2514665	0,00721339
DIS	0,126104067	0,000905269	139,3000343	0,00457006
LUN	1,17971297	0,043601742	27,0565561	0,02351852
TEM	-1,32767152	0,01004726	-132,142648	0,00481758
COS	0,522506398	0,017177803	30,41753346	0,02092183
FAU	19,31984334	0,209791355	92,09075045	0,00691269
FLO	-0,71345684	0,029718375	-24,0072629	0,02650248
PAE	-1,32845931	0,023628667	-56,2223559	0,01132206
INQ	2,703984806	0,043864162	61,64451045	0,01032637
TRA	-0,87958957	0,022028729	-39,9292017	0,01594038
VIE	0,556696904	0,011979752	46,46981903	0,01369753
ABS	1,412044889	0,024395856	57,88052263	0,01099777
TOP	-1,73927257	0,04533949	-38,3610974	0,01659169

Fig. 6 The multiple regression analysis output

$$Y_{SEN} = 25{,}02 + 0.27X_{LUO} - 0.06X_{ALT} + 0.126X_{DIS} + 1.179X_{LUN} - 1.32X_{TEM} + 0.52X_{COS} + 19.31X_{FAU} - 0.71X_{FLO} - 1.33X_{PAE} + 2.70X_{INQ} - 0.88X_{TRA} + 0.56X_{VIE} + 1.41X_{ABS} - 1.73X_{TOP}$$

From the statistical analysis of the database, which resulted in the above regression equation, some considerations of a certain interest emerge. Obviously, the small sample implies that just large trends and suggestions can be drawn out, not robust interpretations. Furthermore, notwithstanding the general significance acquired (R2> 0.99), many regression coefficients are rather low and show little actual correlation in absolute terms. First, it is noted that the expression of sensations and perceptions during navigation increases in relation to the quantitative variation of some features. In particular, the expression of sensations increases with pollution and dissipation of resources appearing in the route (INQ: coeff.= +2.70; p= 0.01). It also strongly increases in relation to the presence of animals (FAU: coeff.= +19.31; p= 0.007), probably due to their emerging as unexpected singularities along the route. Sensations show mixed correlations with built and artificial features, made possible by the above mentioned fluctuation of coefficients around zero value.

For example, agents' sensations increase with the perception of buildings (c= 0.52, p= 0.02) and streets (c=0.55; p=0.01), while decreasing with plants and installations (c= -0.88; p= 0.01). This may look somehow curious and substantially inconsistent. Yet perhaps the nature of the sample should be considered here, being made up entirely of engineering students of a planning course, who learn to evaluate buildings and roads as contextual parts of a larger ecological environment. They may tend to overestimate their perceptions of transformations in which they have a design responsibility (e.g., houses, farms, streets) while underestimating

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the perception of elements out of their direct design interest (plants, installations etc.) (Borri & Camarda, 2006; Selicato et al., 2012). As a matter of facts, such underestimation does not seem to affect contextual value judgements, such as the dissipation or pollution involved with physical transformations, since sensations are positively correlated with dissipating or polluting elements, as shown above. Another curious result is the significantly negative correlation with the perception of natural landscape (c= -1.33, p= 0.01). This may look somehow counterintuitive and difficult to interpret. However, some literature suggests that the perception of usual environments may not be very relevant by agents whose life, activity, dynamics continuatively occur in that environment (Kelly & McNamara, 2010; Lipinski et al., 2010). Natural landscapes are common environments for agents (students with their families) living in regions and lands still largely, traditionally characterized by agriculture and rural features. Therefore, they may be able and willing to depict landscapes even deeply, as they know them rather well, without being impressed in terms of sensations. The contrary may hold too, as agents may be stimulated to express sensations, emotions without describing their perceptions about a landscape inherently known (Campos et al., 2012; Gantar & Golobič, 2015). As a matter of facts, the flora component (c= -0.71, p= 0.03) seem to broadly confirm such interpretation.

Then there are elements that define the exercise from a spatial-temporal, geographic and topographical point of view. For example, when the distance from the agent's place of residence (c= 0.26, p= 0.02) and particularly route length (c= 1.18, p= 0.02) increase, then sensation increase -being probably due (respectively) to curiosity about a new environment and to a more changing environment. Yet, a negative correlation with the time required to cover the route (c= -1.33, p= 0,005) seems to be inconsistent with that, unless one considers that a longer time can induce a sort of addiction to perceptions, particularly if the route is short and not very varied (Kelly & McNamara, 2010; Weinreb & Rofè, 2013). However, the sensations seem to be in general barely correlated to the perception of dimensional and topographical aspects, while appearing more correlated to contextual and qualifying elements.

4 CONCLUSIONS

The analysis carried out above shows outcomes of a certain suggestion, formally significant in statistical terms, less significant in substantial terms at least in some cases. This is mainly due to the limited number of observations, which determines an overall status of a pilot study, not a proper research. From this point of view, in fact, there are many coefficients with low numerical value, so that the investigated variables have little influence on the dependent variable - i.e., the agent's spatial sensations and perceptions along the route (SEN). Furthermore, concerning the aggregation of textual concepts by categories, it has been developed with a raw and hybrid approach that has possibly determined errors. In fact, while the word frequency has been collected through data-mining tools, it has been subsequently contextualized and categorized manually by the analyst through ex post analysis. However, after carrying out the whole analysis, it was still possible to derive interesting qualitative considerations. In fact, they seem to suggest that the perception of an open space, largely devoid of the strongly structuring elements present in confined urban spaces, still depends on some recurrent physical and landscape elements that end up giving it a cognition based latent structure. The use of these suggestions can be particularly interesting to support decisions regarding the management of open spaces, their valorisation during the identification processes of physical and/or identity resources for hypothesis of environmentally sustainable development of settlements, as well as for land use planning purposes.

At the present stage, some follow-up activities seem to be important to be carried out in the next future. They will particularly aim at giving greater robustness and reliability to the analysis and develop more aware and useful considerations. First, an enlargement of the analysis to the entire sample of 180 observations will be

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an indispensable and significant step. Secondly, attempts will be made to integrate the statistical analysis with probabilistic inference techniques, in order to compensate statistical errors induced by the multiple regression tool.

As a perspective follow up, the survey carried out here will be subsequently complemented by ontological aggregative approaches, as increasing emerging in spatial cognition literature (Barkowsky et al., 2007). This effort is oriented to investigate the possible realization of formal models more suitable to replicate and/or to interpret the complexity of the relevant environmental system.

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