Urban complexity and space cognition: Modelling ontologies from spatial design tasks

Dino Borri[*], Domenico Camarda[*†], Maria Rosaria Stufano Melone[†]

Abstract

In order to face the challenges of a tumultuous social, economic, environmental complexity, urban systems have undertaken new forms of readjustments and transformations able to shock consolidated planning and design approaches. The role of agents' spatial cognition (perception, representation) has proved to be critical toward effective decision-making support in a complex environment (Chen and Lee 2003; Freksa et al. 2005).
In particular, looking at the design of urban spaces, a greater comprehension of spatial primitive elements (spatial forms, relations, memories...) becomes essential to allow effective spatial aggregations. Additionally, it is important to understand the role played by agents' association ability and creativity in those cognitive processes. In fact, there is increasing interest in the conceptualization of primitives, dynamics, mutual relations and associations in the processes embedded in urban transformations (Amedeo et al. 2008).
Hence, an essential importance is assumed by ontologies and ontological organizations of data. In fact, they represent complex relational/conceptual articulations and may help keeping the sense of space in complex and non-reductive

[*] Polytechnic University of Bari, Italy
[†] LOA CNR-ISTC, Trento, Italy

way. Also, that spatial sense can be preserved through IT based platforms, able to manage manifold computational implications of such useful complexity (Bhatt et al. 2011; Falquet et al. 2011).
In order to investigate on such issues, some experimental sessions have been set up with some planning students and planners. The paper carries out an analysis of spatial primitives of the urban contexts emerging from their design tasks. The outcomes are then formalized in spatial ontologies and discussed, toward drawing out possible urban decision-support models.

Keywords

Artificial intelligence, Planning, Scenarios, Decisionmaking

Introduction

Oftentimes, the inclusive conceptualization of space representation and management represents a critical step toward the building up of intelligent machines based of ontological space description. Also, space organization is an essential share of the spatial abilities of human agents, made up of intriguing sensorial and cognitive interplays. A deeper functional analysis of the intelligent abilities of human agents is worthwhile doing, so as to shed light on spatial features, and avoid accepting superficial explanations. As a matter of fact, human agents are able to first conceptualize spaces, then design and organize them for human organizations. For example, they can apply such features in architectural design, by making use of intriguing cognitive processes based on routinary as well as non-routinary approaches that need to be investigated (Schön, 1983). Basically, this is another case

in which the evolution of techniques and technology on automated reasoning and automated design agents, from origins to current high-level status, could not provide but flawed duplicates of human abilities (Hofstadter, 1995).
If we consider the concept of creativity, we find it is assumed as a complex non-routinary cognitive feature of human agents, that is, an intentional and intrinsically aware process used by agents' cognition to redefine in new ways her/his situations within the world. Although creativity does remain debated concept, some literature increasingly tends not to consider it as a prerogative of few special human agents. Rather, creativity is more and more seen as a particular portion of the normal cognitive patrimony of the human agent, apt to be used in specific circumstances (Bink and Marsh, 2000; Weisberg, 1993).
This research tries to add space domain to other typical creativity domains examined in cognitive science. In particular, the concepts of space understanding and space organizing are scanned by making reference to creative (non-routinary) cognitive functions, beyond the routinary ones, in a modelling perspective. In this context, we have explored suggesting case-studies of interactive creative actions among civil architects, within a game-theory framing situation (space organization) (McCain, 2010).
The knowledge about space, spatial action and organization of space contribute significantly to build the domain of civil architecture. Within such concurring participation, a critical role is played by disciplines as aesthetics and art, that are intertwined with the mechanisms of creativity. In particular, some studies deal with architectural creativity, as investigated through self-biographies by master architects. Basically they represent the architects' memories of designs, spaces, architectures, experienced along their life and reported as commented memos for new design activities. Such literature is able to suggest that space memory strongly and primarily

affects work approaches and creativity (Zumthor, 1998). Also, because architecture is made up of technology, too, then spatial memories are suitable to be scanned through the concept of technological memory.

In order to face the challenges of a tumultuous social, economic, environmental complexity, urban systems have undertaken new forms of readjustments and transformations able to shock consolidated planning and design approaches. The role of agents' spatial cognition (perception, representation) has proved to be critical toward effective decision-making support in a complex environment (Chen and Lee, 2003; Freksa et al., 2005).

In particular, looking at the design of urban spaces, a greater comprehension of spatial primitive elements (spatial forms, relations, memories...) becomes essential to allow effective spatial aggregations. Additionally, it is important to understand the role played by agents' association ability and creativity in those cognitive processes. In fact, there is increasing interest in the conceptualization of primitives, dynamics, mutual relations and associations in the processes embedded in urban transformations (Amedeo et al., 2008).

Hence, an essential importance is assumed by ontologies and ontological organizations of data. In fact, they represent complex relational/conceptual articulations and may help keeping the sense of space in complex and non-reductive way. Also, that spatial sense can be preserved through IT based platforms, able to manage manifold computational implications of such useful complexity (Bhatt et al., 2011; Falquet et al., 2011).

In this concern, a study on the way how primitives are originated and shaped in designing agents may be of basic importance. In fact, a growing literature is interested to the associative fundamentals of creativity, as well as to understand if significant connections exist among knowledge, behaviours and abilities in spatial cognition. The

urban planner/designer often carries out tasks linked to such features during her ordinary design activities. While developing her drafts, she seems to carry out spatial decisions during every step of her task, relying on the partial outcomes of her path, like a schonian reflection in action (Schön, 1983). The extent to which the creativity of decisions depends on her ongoing associative ability is a topic that is worth exploring at various stages and scales.
Starting from this background, the present paperi is organized as follows. After this introductory note, a second chapter will deal with the connections between creativity in spatial domains and the role of design decision. Subsequently, chapter 3 will introduce the research activity carried out by our group in order to investigate on the cognition features of spatial tasks, particularly stressing the role of spatial primitives to boost creative decisions in urban design tasks. In this context, chapter 4 will describe and discuss the first outcomes of an experimentation protocol started in a university planning course. Brief notes will conclude our paper, by summarizing the frame of results achieved and envisioning the subsequent research perspective of the program.

Spatial creativity and design decision

According to cognitive psychology, creative thinking (or productive thinking) is connected to a genetic consideration: it is the evolutionary side of intellectual abilities and correlated structures (Garroni, 2010, p.45). Creativity acts in favor of effectiveness and continue knowledge construction. Creativity acts according to metaoperational intention, that plans activities to reach the wanted results, a chain of operations not conceived before. So we can see that in human behavior the problem about producing something

new, i.e., the problem of the creativity, is irreducible. Only in this way it is not incorrect to distinguish culture and nature, instinct and intelligence, creativity and repetition (Garroni, 2010, p.67).
The great difficulty in the analysis of creative processes is that they are not transparent, we are not able to read inside ourselves when our mind works. When a process is observed, it changes, because it reflects on itself and the analysis study is transformed into an even greater challenge (Legrenzi, 2005).
A closer look at creativity as search activity shows a view of creative concept generation as a very general search process, but such formalisation has not been developed much in the past few years. Researchers established that it is methodologically beneficial to have fully precise, detailed and formal accounts of any mechanisms being considered as 'creative'. For example, Creative Systems Framework (CSF) (Colton and Wiggins, 2012; Wiggins, 2012) emphasises the notion of search as the central mechanism for simulating creativity, and outlines how a metalevel search could represent some phenomena sometimes discussed as 'transformational' creativity. It is important to realise the underlying intuitive ideas: creation as the exploration of a 'conceptual space', and possible 'transformation' of that space (Ritchie, 2012).
We ask ourselves about creativity in architecture and urban design. We are looking for the quid that highlights a design quality as new, original, unexpected, that is first 'impossible' and then 'a reference', once it is produced and realized. In order to develop and describe any model of creativity in urban design we need to have an acceptable conception of design. Design, in one sense, can be conceived as a purposeful, constrained, decision-making, exploration and learning activity. Decision making implies a set of variables,

the values of which have to be decided, and search is the common process used in decision making (Gero, 1996).

Spatial creativity is a place on which it is more difficult to establish an objective. It is an ambit of reference for reading artistic creation or architecture creation sending back to a game of own resemblances and reminiscences and sending back to draw memories from other artists and architects. Creative designing, which is part of non-routine designing, can be described as perturbing a spatial cognition scheme to produce unexpected and incongruous results. These new results are still understandable either in a current or shifted context. Although the boundary between routine and creative designs is difficult to be defined, there is less difficulty in articulating differences between processes used in the production of routine and creative designs (Gero, 1996; Gero and Tversky, 1999).

A model for creative design can be found by analogy to models of humour. suggests that there is a continuity of creative insights in humour with those in science and poetry. "The logical pattern of the creative process is the same in all three cases: it consists of discovery of hidden similarities" (Koestler, 1964). Creative design can be represented in such a state space by a change in the state space. Any of the subspaces for function, behaviour or structure could be changed although, in general, in design it is the structure space that is changed. There are two classes of change possible: addition and substitution (Gero, 1996).

Design has been traditionally defined as a methodology for 'harnessing' inventiveness. It aims at the control and optimization of a design process. Design is also often described as a goal-seeking process, going from broad specifications to the generation of some artifact which meets at least some of the initial requirements. The same tradition acknowledges the role of creativity techniques, but only at special steps of the process like early conceptual phases (Hactuel and Weil, 2002).

Talking about design, about projectual efforts we can have a link with the study of phenomenon of prospective memory (PM). Starting from the point of view of Haken's theory of synergetics we can see the projectual activity as a complex, self-organizing systems, in general, and to brain functioning and cognition, in particular (Haken and Portugali, 2005).

Transformational creativity (and innovative design): the necessary revision of some object's identity and definition during the process. The basic generative rules of any language or knowledge base are those which are used to stabilise the definition and semantic properties of 'objects' i.e. 'names' (Hactuel and Weil, 2002).

Analyzing a creative design action we generally recognize three different parallel processes, i.e., combination, analogy and mutation. Combination involves the addition of part or all of one design prototype called the combining design prototype to an existing design prototype called the focus design prototype. Creative design is not only the production of "novel and valuable ideas", but also using odd ideas for the generation of valuable new knowledge: the operations of creative design can be captured with a high level of generality (Gero, 1996).

So what is it in the externally represented face of a place, or of a city the city, that makes it recognizable and imaginable? What makes some urban elements and artifacts more legible and better remembered than others? Some elements, including those that compose the face of the city, are quantitatively and qualitatively more informative than others and are therefore more legible and better perceived and remembered, quantitatively, in terms of theory of information (Shannon, 1949), and qualitatively in terms of notion of semantic information (Haken and Portugali, 2005).

If the city is intended as architecture, then architecture is built up in the sense of a construction over time. It is an architecture as a community life place, which in turn creates the environment where she lives. It is an artificial climate, built up according to an aesthetic intentionality.
According to Aldo Rossi the city, which is architecture and fixed scene of the human event, grows on itself and gains self-memory and self-consciousness over time. Principles and changes of the real represent the structure of human creation (Rossi, 1966).
In architecture as well as in urban science there are some ultimate, permanent elements showing the analogy between the study of the city and the study of linguistics. In both cases we face the complexity of processes and the modification of permanencies. They are events that occur and modify time and space dimensions together (Rossi, 1966).
Therefore, we have added a fourth dimension to the qualitative dimension and to the notion of semantic information that a place, a city, a design effort are made of beyond the physical place itself. It is the time in which the existence, the story of people and objects develops. Initially time exists as embedded in own memories, then it is shaped in the design phase and ultimately it lives its 'physical' life in the designed object. Memories embedded in the creative project come from far away and are never the same. They are elaboration of reminiscences, themes, studied objects having gone through the phases of cognitive elaboration according to analogy, rearrangement, mutation, sense translation.
But the complexity of the design activity does not end up to this level, since it involves different knowledge domains and existing dimensions. It acts in the domain of intentionality, of research and production, in the domain of functionality. It aims at addressing effectively its design demand and goes through the different existence dimensions. It ranges from

the early conception before the virtual model, to designed (two-dimensional) one, to the virtual (three-dimensional) model, to the actual building up as 'stone being' (four-dimensional, in that it crosses times). Hence, the knottiness of this subject and of the attempt to read processes and mechanics leading step by step to its solution.
Hence, the need of a further structured investigation.

Spatial primitives in urban design tasks: a research program

During last years, our group has carried out a research project on the role of association ability to boost creativity by managing spatial primitive features. In in this sense, experimentations have been started up in order to investigate on the aforesaid connections at different contextual and expertize levels. Some of these researches are dealt with in recent published material (Borri and Camarda, 2013; Borri et al., 2010).
A first part of researches has dealt with the work of urban expert experts, observed in the definition of a number of projects (Borri and Camarda, 2010). A sharing-observation approach was used, complemented with interviews (Buchanan, 1993; Schön, 1983). The main objective of such experimentations was to define an ontological articulation of the design task, including conceptual elements and various types of mutual relations. Such ontology, conveniently formalized through ad-hoc systems of data management, could be basis for the elaboration of models to support decision (and creativity) in urban design. Particularly, a rather complex experimentation has dealt with a multi-session design of an urban door, carried out by a professional architect (Borri and Camarda, 2013). An excerpt of the design stages is reported in the figure below, with an

interpreting ontological research and a part of the formalized ontology (Figure 1).

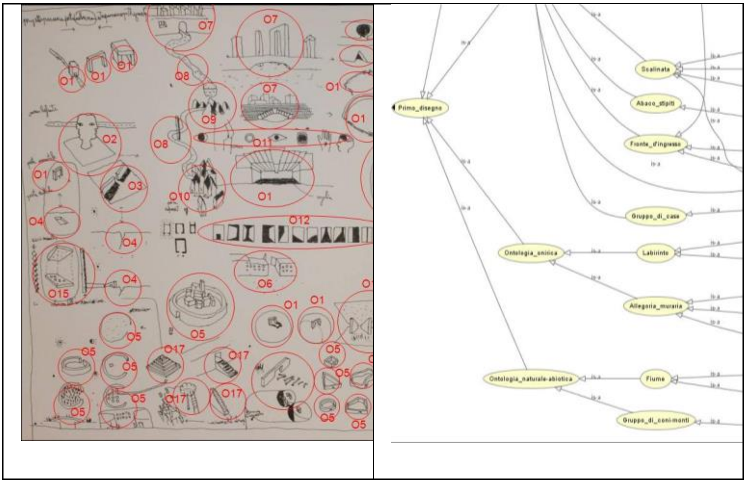

Figure 1 - Results of previous experimentation sessions (excerpts)

The result of this first pilot study was rather encouraging, particularly allowing some specific reflections (Table 1).
However, the starting conditions of this investigation were far from being general. In fact, the agent who carries out the design activity has an advanced contextual knowledge, as well as professional expertise. If the processes of creative association and design decisions involve primitive forms, then it makes sense to investigate if such basic features can be found out with different skill levels. For example, spatial abilities and knowledge might show up relevantly in the formative levels of school or university, or even earlier.
In this sense, recent research challenges the Piagetian vision according to which spatial knowledge is acquired by experience (Piaget, 1950). In fact, such research shows some important spatial-cognition innatisms in children and infants

(Lee and Spelke, 2011; Lee et al., 2012; Winkler-Rhoades et al., 2013). In our case, such apparently innate knowledge could reveal primitive cognitions as basis for associative abilities supporting creative spatial decisions.

- Signs become larger
- Signs become more defined
- Groups are less scattered
- Groups are more aligned on regular grids
- Signs and drawings are more thematically coherent to one another
- The evolution of signs is far less fragmented and more continuously put down
- The last session shows possible follow-ups beyond the mere door theme.
- Logical groups are drawn out in less time.
- There is a more intentional approach in the last drawing as compared to the first drawing: the first drawing is more explorative.

Table 1 - Qualitative results from the urban-door experimentation, along six subsequent sessions (Borri and Camarda, 2013).

Therefore, a new experimental protocol has been started off within our research activity. It is based on a plan of experimentations addressed at cognitive agents with diverse levels of skill and knowledge (Table 2).

	Undergraduate students	**Master students**	**Professional planners**
Single urban lot	completed	*forthcoming*	under way
Urban district	*forthcoming*	under way	*forthcoming*

Table 2 - Experimentation schedule.

The first experimentation of this plan, described and discussed in the present paper, deals with the design process of a simple single urban lot. It has been addressed to a numerous group of undergraduate students of the course of Planning of the Polytechnic University of Bari, Italy.

Creativity through association of spatial features: an experimental session

Layout description

In our research program, we consider the urban design action as a decision path in the spatial-cognition domain. Basically, it is an organized activity that allows the raising out of memories from knowledge databases toward the working out of new connections, concordances, correlations and associations of concepts. This is basis for a new original initiative or artwork.
Following such preliminary consideration, we our experimentation program aims at verifying if there is an underlying structure of the given problem before and during its evolution, and what is its shape. The initial aim was to collect a clear material from which to extract some recurrences, recursions, underlying orders that are implemented during a design process, based on geometric shapes (as circle, square, rectangle, etc.), as well as on the behaviours and attitudes of designing agents. We needed an elementary task, something that could let us observe, analyze planning students actions and their products. Therefore, undergraduate students were asked to perform the following tasks:

1) drawing up an urban lot with a house and annexed road, spending about 15 minutes;

2) filling up a questionnaire that basically described their personalities and abilities as young designers, by a 1-5 self-evaluation Likert scale;
3) making a video clip during the execution of their task with a zenithal shot respect to the sheet.

The task was supposed to be developed far from a class influence, preferably at home, and the video clip was primarily aimed at facilitating the ex-post research analysis of performances. Additionally, the clip was also aimed at providing a raster basis to feed a drawing analysis software for subsequent building up of system architectures. However, this step has not been developed yet, and therefore it is not dealt with in this paper.

The experimentation involved about 150 students in a spring class semester, but only 80 drawings and filled questionnaires are available to date. After the entire experimentation session, a video clip, a design draft and a filled questionnaire were available to analyzers for each respondent. An excerpt of drawings is shown in figure 2.

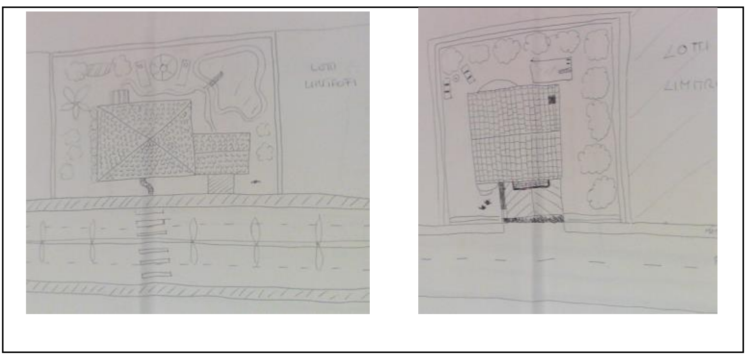

Figure 2. An excerpt of drawings from the urban-lot experimentation database.

A preliminary look at the complex and multiform database suggested to limit the analysis to some major features, in order to avoid combinatorial explosions.
The analysis was then carried out in three different stages, i.e. (i) observing videos so as to elicit some data according to major feature categories; (ii) measuring drawing shapes and organization, according to lengths, areas and Euclidean indicators; (iii) collecting responses from questionnaires. The quality of drawings was not per se an absolute discriminator of the acceptability of the drawing itself. Even if a drawing appeared unacceptable under an aesthetical and/or technical viewpoint, yet it could be considered in the analysis, provided that the features considered as criteria were readable enough to allow its actual analysis.
A large amount of data was obtained, so inducing the need of finding out computational methods that could help synthetic interpretations while preserving the richness of inherent knowledge and information.

Discussion of outcomes

The singling out of the most important features of the spatial design path has been carried out here with low-theory methods. Such decision stems from the still explorative essence of the study, oriented not to the making up of a proper model, but rather to the definition of one or more basic formal ontologies for subsequent modelling. A later phase of modellization, oriented to the actual building up of a design support system, will be possibly based on high-theory methods, such as algorithms or structural equations. This will be made up in order to enhance the functioning of the model as a proper system architecture.
Therefore, the evaluation of experimental sessions has been carried out with statistical analysis. At the beginning a

factorial-analysis approach has been carried out, using principal component (PCA) methods.

VARIABLE NAME	SCALE
1. Distance of the shape from the street edge	cm
2. Distance of the shape from the lower sheet edge	cm
3. Distance of the shape from the left sheet edge	cm
4. Inverse aspect ratio (H/A) (*)	%
5. Waviness (Pe/P) (*)	%
6. Isoperimetric quotient ($4A\pi/P^2$) (*)	%
7. Sheet coverage	%
8. Shape area / sheet area	%
9. Presence of complementary drawing details	Dummy
10. Anxiousness	Likert 1-5
11. Reflexivity	Likert 1-5
12. Extroversion	Likert 1-5
13. Artistic ability	Likert 1-5
14. Technical design ability	Likert 1-5
15. Ornate drawing ability	Likert 1-5
16. Mnemonic ability	Likert 1-5
17. Musical ability	Likert 1-5
18. Math ability	Likert 1-5
19. Orientation ability	Likert 1-5

Table 3. Variables, Scales, Measures. (*) Inverse Aspect Ratio, Measured by min to max shape dimensions ; Waviness, measured by the convex portion Pe of the perimeter to the total perimeter; Isoperimetric quotient, measured by the ratio of the area of the shape to the area of a circle (the most compact shape) having the same perimeter (Exner and Hougardy, 1988; Osserman, 1978).

Since the possible correlation among variables was neither known or easily determinable, a series of consecutive pilot calculations was made, changing the occurrence and the number of considered variables. The attempt was to avoid that variable redundancies or correlations could hamper the significance of the dimensional reduction when singling out possible clusters of agglomeration of available data. The analysis was then developed on a set of variables selected to minimize collinearity problems as much as possible (Table 3). Subsequent PCA calculations have determined a number of initial components ranging from 19 (all variables included) to 8 (only cardinal numerical variable included).

Total explained variance

Comp.	Initial eigenvalues Total	% of variance	cumulative %
1	2,061	12,126	12,126
2	1,848	10,869	22,995
3	1,532	9,012	32,007
4	1,464	8,609	40,616
5	1,305	7,674	48,290
6	1,177	6,923	55,213
7	1,082	6,366	61,579
8	1,032	6,071	67,650
9	,929	5,462	73,112
10	,851	5,006	78,118
11	,840	4,944	83,062
12	,671	3,944	87,006
13	,548	3,223	90,230
14	,508	2,986	93,216
15	,468	2,750	95,966
16	,364	2,143	98,109
17	,321	1,891	100,000

Total explained variance

Comp.	Initial eigenvalues Total	% of variance	cumulative %
1	1,746	24,941	24,941
2	1,281	18,293	43,235
3	1,128	16,112	59,346
4	,938	13,394	72,740
5	,703	10,038	82,779
6	,623	8,903	91,682
7	,582	8,318	100,000

Table 4. Explained variance in principal component analysis developed for 19 (left) and 8 (right) variables.

Yet, in order to achieve an acceptable level of explained variance, in all cases there was the need to consider a number of principal components well beyond the classic desirable minimum of 3 components. In fact, the alternative application of the three reduction rules (i.e., Keiser, knee graph, infra-unitary eigenvalues) shrunk the components to no less than 12 (in the case of 19 initial components) or 5 (in the case of 9 initial components) principal components. Rather, it is worth noting that in the cases of fewer principal components the cumulative percentage of explained variance is as low as about 50% (Table 4).

In sum, PCA has led to dimensional reductions to the relevant detriment of either reduction effectiveness or representation significance. In both cases there was an evident difficulty in mirroring the graphic-conceptual complexity of the representative intention of designers. This caused us to reflect on the opportunity of declining PCA results, because the reduction of representation complexity does not allow maintaining the ontological patrimony that instead we want to foster and manage. Therefore, that statistical work stopped at the preliminary phase of PCA, and the realization of its limitations was essential to decide to look for alternative ones, which proved to be more effective. As a matter of facts, we decided to apply a cluster-analysis (CA) method, with the objective of identifying possible agglomeration clusters of available data.

CA itself was carried out on a set of variables selected with the aim of minimizing collinearity. Meanwhile, the number of observations was maximized, through ad-hoc procedures of integration of missing data, in order to optimize the explaining effectiveness guaranteed by a larger sample of data. Moreover, the selected clustering method has aimed at keeping mutually exclusive cluster as much as possible, coherently with the objectives of ontological structuration of the spatial features of a design decision process (Bhatt et al., 2011). Therefore, we decided to carry out a hierarchical cluster analysis, which in fact allows the making up of sets of variables with null intersection.

Agglomeration schedule

stage	Cluster combined		Coefficients	Stage cluster first appears		Next stage
	Cluster 1	Cluster 2		Cluster 1	Cluster 2	
1	16	51	,023	0	0	6
2	1	36	,080	0	0	3
3	1	65	,190	2	0	13
4	47	77	,352	0	0	19
5	29	63	,551	0	0	30
73	30	41	57,236	69	65	75
74	6	7	60,268	72	67	79
75	30	54	63,470	73	70	78
76	1	10	66,696	62	71	78
77	2	4	71,130	68	46	80
78	1	30	76,456	76	75	79
79	1	6	82,539	78	74	80
80	1	2	97,284	79	77	0

Table 5. Output of the cluster analysis (top-bottom excerpt)

The analysis has been carried out using the Ward algorithm, also because it was considered more suitable for a hybrid sample of mixed numerical, cardinal and ordinal, variables. The 19 variables that were taken into consideration are listed in previous table 1, whereas the final agglomeration schedule is shown in table 5. After the analysis, the resulting layout has shown 4 mutually exclusive clusters, characterized by four different agent profiles. The variables are present in all groups but with different values (mean values of variables), so that the blend in a group contains all of the variables, whose higher-value ones characterize the profile more than the other ones. Such articulation is described in table 6, which for ease of reading shows for each group only maximum-mean variables, as well as variables and with an immediately lower mean (clusters are listed according to increasing standard deviation).

cluster #	cluster agents	variable in cluster	
1	34	reflexivity	presence of details
		sheet area	mnemonic ability
		distance of shape from lower sheet edge	ornate drawing ability
		distance of shape from left sheet edge	orientation ability
		isoperimetric quotient ($4A\pi/P^2$)	inverse aspect ratio
2	18	artistic ability	distance of shape from left sheet edge
		ornate drawing ability	distance of shape from street edge
		extroversion	shape area
		musical ability	isoperimetric quotient
		technical design ability	waviness
		sheet area	total perimeter
		distance of shape from lower sheet edge	shape area / sheet area
3	15	anxiousness	shape area / sheet area
		extroversion	math ability
		abilità disegno tecnico	sheet coverage
		max shape dimension	min shape dimension
		shape area	presence of details
		total perimeter	
4	14	math ability	min dimensione forma
		mnemonic ability	waviness
		musical ability	anxiousness
		orientation ability	artistic ability
		sheet coverage	reflexivity
		inverse aspect ratio	max shape dimension
		distance of shape from street edge	

Table 6. Clusters and variables (for each cluster, features are listed by increasing standard deviation)

The observation of groups suggests that profiles are not completely, clearly and simply synthesizable in this case. This circumstance significantly conflicts with the objective of synthesizing that is usual priority in CA, yet it was not unexpected in our case, given the high variance emerged. Instead, this circumstance allows the making up of some interesting considerations, similarly to previous PCA. In fact, the evident complexity of tasks developed by design agents proves to be preserved just because of this synthesizing difficulty, so revealing some interpretative scenarios and useful reading clues. First of all, we must say that the two types of variables (i.e., the one concerning Euclidean features and the other specific personal features) define autonomous ways by which different aspects contribute to the decisional process. This circumstance seems to show an intrinsic difficulty in terms of ontological conceptualization –which represents a primary objective of the present study, for what has been said. Indeed, the presence of two concomitant classes does not necessarily hamper their ontological formalization, since for each classifications concepts are quite well delineable.

For the 34 elements of group 1, for example, some Euclidean variables with maximum (distances from sheet edge, isoperimetric quotient) and sub-maximum (aspect ratio) value are visible, and the same occurs with personal abilities. This suggests the possibility to keep conceptual interpretations that are intrinsically coherent for the two classifications. In the example of the first cluster, a high dimensional width is associated to remarkable reflexive and good mnemonic abilities, whereas in cluster 2 (18 elements) there are high artistic abilities and good extroversion, but also sub-maximum values of Euclidean variables. In particular, the first profile, which contains a larger number of agents, seems to associate a mainly reflexive ability to large design dimensions (but not shapes), that nonetheless are told not roughly but with richness of details, due to a good mnemonic ability. The second profile resembles the classical stereotype of the artist, i.e. being extrovert, with design (and not only) abilities, interested in large dimensions and shapes but apparently without interest in detailing. A third profile is similar to the previous one, but extroversion mixed with anxiousness end up evoking a possible, more emotional and instrumental relation with the design task, perhaps only controlled by technical abilities (design, mathematics). The last, less numerous profile suggests the presence of more brainy and rational agents, having perhaps more abstracting abilities, significantly oriented to large dimensions particularly in relation to the design sheet. It is evident that they are rather forced speculations, which can hardly represent complete outcomes of a scientific research stage.

Yet, they are considerations emerging from quantitative analysis, which are able to show some interesting suggestions, which can be subsequently corroborated by the multi-context and multi-scale research program in next stages.
Moreover, when making a comparison with the qualitative results emerging from the previous experimentation, they seem to associate some profiles of unskilled agents 8students) to some stages of the evolution of the designing task of an expert planner. For example, in the last stages of the urban-door project (Borri and Camarda, 2013), the planner fills up the sheet with large and well defined shapes, so suggesting a proximity with the 'artistic' profile in the last stages. Also in these suggesting cases, however, a proper clarification is needed, concerning the different context of the two situations. In fact, in the urban-door project, the most project-oriented task carried out by the planner involved a final design definition inherently necessary.
Going back to the general articulation, although the matching of the two types of variables in the different synthesis profiles if difficult, an autonomous conceptual articulation of each class seems to be feasible. Finally, it seems possible to structure two different ontologies which coexist and contribute to the definition of the synthetic profile. It is almost an intertwined connection between a physical world and a platonic world of ideas supporting the clarification and signification of reality in the complex occurrences of a spatial-cognition process (Findlay, 2011).
This circumstance is rather important for our work. The use of ontologies notoriously allows the building up of knowledge models structured in domains with high complexity such as the spatial-environmental one. If it is true that inter-domain interactions remain a complex process per se, it is also true that they add to the ones that already link classes, subclasses and instances of a same scientific domain.

In our case, the definition of a unique ontology defining the profile of each cluster is actually the composition of two ontologies relevant to different domains. Certainly, the modalities of composing these two ontologies envisage complex relations, which need to be adequately investigated. Yet, the presence of sub-ontologic domain modularities guarantees lower-order complexities which enhance the readability and the manageability of the entire modelling effort.
By re-elaborating the results of statistical analysis, an ontological formalization can be obtaines, like the one in figure (Figure 3).

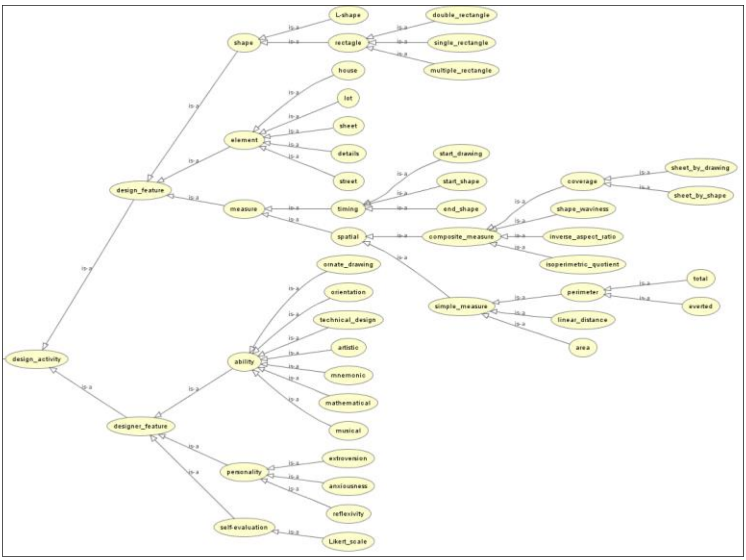

Figure 3. Ontology of the urban design activity (output of Protégé software)

The ontology represented by Protégé software defines classes, sub-classes and instances of the urban design activity that was subject of the urban lot experimentation. They are a formalization of the results obtained from statistical analyses. It is possible to note that the articulation follows the suggestion coming ouy from analyses, concerning the substantial coexistence of two sub-ontologies: design and designer's features. Such apparent juxtaposition is obviously just a formal artifice, since behavioural and design aspects are mutually related, as said before. Inside these two ontologies there are classes of elements, primitives, indicators and measures, which are all interacting and mutually connected by diverse logical relations. Such relations are only partially visible in figure 3 (is-a relation), whereas other types of linkages are included in Protégé property database. In this context, the main reference used to fill up the ontology is the DOLCE project, especially in the articulation of the frame of relations rules (Figure 4) (Masolo et al., 2002, p.14).

Parthood: "*x is part of y*" $\mathsf{P}(x, y) \rightarrow (AB(x) \vee PD(x)) \wedge (AB(y) \vee PD(y))$
Temporary Parthood: "*x is part of y during t*" $\mathsf{P}(x, y, t) \rightarrow (ED(x) \wedge ED(y) \wedge T(t))$
Constitution: "*x constitutes y during t*" $\mathsf{K}(x, y, t) \rightarrow ((ED(x) \vee PD(x)) \wedge (ED(y) \vee PD(y)) \wedge T(t))$
Participation: "*x participates in y during t*" $\mathsf{PC}(x, y, t) \rightarrow (ED(x) \wedge PD(y) \wedge T(t))$
Quality: "*x is a quality of y*" $\mathsf{qt}(x, y) \rightarrow (Q(x) \wedge (Q(y) \vee ED(y) \vee PD(y)))$
Quale: "*x is the quale of y (during t)*" $\mathsf{ql}(x, y) \rightarrow (TR(x) \wedge TQ(y))$ $\mathsf{ql}(x, y, t) \rightarrow ((PR(x) \vee AR(x)) \wedge (PQ(y) \vee AQ(y)) \wedge T(t))$

Figure 4. Basic functions and relations in DOLCE (Masolo et al., 2002, p.14)

Such articulation has been considered suitable to our context, because of its relevant cognitive and engineering components, i.e., significantly design-decision oriented. Moreover, there were many uses of DOLCE scheme in spatial-cognition domains, some of which produced through laboratories developed just around those experimentation domains (Bhatt et al., 2011; Freksa et al., 2005; Freksa et al., 2008).

Also in this case we could compare the earlier experimentation with the present one. Yet a thorough comparison would be inevitably biased, because of the too big complexity of the urban-door experimentation. In fact that would be so intrinsically rich of issues, details, intentions, memories, skill and experience that it could not be comparable to a simple ontology of a simple student's lot. Yet we can minimally compare the effects of the different experimental approach. In fact, in the urban-lot case, the resulting ontology is well structured, because classes derive from a synthesis of primitive elements, whereas the urban-door ontology derives from a strongly inclusive and qualitative analysis, so resulting highly unstructured. Such circumstance is not necessarily an absolute negative element, because the urban door reflects more accurately the inherent complexity of the cognitive space representing it. Conversely, that complexity is riverberated on the limited potentials of managing its ontology toward the building up of models oriented to actual decisions and creativity support systems. As a matter of facts, the urban door process is carried out as an ontological exploration, and the resulting ontology is nothing but a meticulous classification, particularly useful to stimulate further synthesis stages - which indeed occurred with the subsequent experimental protocol dealt with in this paper.

Brief conclusions

The present paper has tried to investigate on the linkages between spatial decision and creativity and the ability of associating spatial primitives by agents in urban design tasks. The general purpose of the study has been the building up of models and systems to support creativity in urban design and architecture. It is a preliminary work, part of a larger experimental research program on design creativity in spatial cognition. The experimental is particularly interested to understand the impact of diverse initial conditions on the different performance of behaviours and abilities of agents. An earlier study, involving high technical-professional expertises, suggested to investigate on the weight of knowledge and technical skill of design agents. In this sense we have therefore involved university students of various levels and on urban design context at diverse scales.
The first experimentations have been carried out at the urban-lot scale, and an agent-based database has been collected and then processed through statistical analysis. However, outcomes have shown a general difficulty to make a readable and manageable synthesis in a model-building process. This is certainly largely due to the intrinsic complexity of the context investigated, at the crossroads of environment and cognition –i.e., two major complex contexts. Therefore, we have tried to keep a set of mixed quali-quantitative information, rather than to force a more manageable synthesis, just to preserve the precious complexity of the task characters. However, such decision has allowed significant comparison with a previous experimental study, mostly described by qualitative results. Some considerations have been drawn out, even summary but interesting, especially in the contextual research program.

In general, an associative ability seems to emerge at various levels, linked to different behaviours, cognitions and sensibilities. Such behavioural features seem to be bound to spatial functions and primitives on the basis of some indicators such as the size of shapes and of dimensions as well as the presence of details. In particular, some profiles of more reflexive, extrovert and artistically skilled design agents seem to draw larger and more detailed shapes, whereas more technical and rational agents are less interested in details, and dimensional size seems more abstract and oriented to fill up the design area. In the previous experimentation, the architect agent had put down larger and more detailed shapes at the final stage of the designing path, so evoking a proximity with the 'artistic' profile of the skilled stages of student agents.

The results of the statistical analysis allow also the development of an ontological organization of emerged conceptualizations and relations. Also in this case it is a mixed quali-quantitative formalization, but the synthesis achieved is much more pronounced than a similar effort developed in the earlier experimentation. Rather interestingly, the ontology comes out as the matching of two sub-ontologies, spatial and behavioural, as if it were the complex interchange between two Platonic ideal and physical worlds. This is interesting also toward the building up of operational support systems.

In fact, starting from such ontology, usefully hybrid, synthetic and compendious, integrating intrinsically coherent, yet externally mutually related databases, it is possible to define models that mirror the complexity of the context. Different behaviours, skills and abilities can represent access filters by agents toward spatially relational databases through such cognitive-based ontologies. Different associating abilities of shapes and concepts can keep diverse aspects and shades, toward a useful creative

support. Such modalities are indeed not very dissimilar from what observed in the studies of ontological formalization in the domains of spatial cognition and engineering through ad-hoc systems such as DOLCE (Bhatt et al., 2011).
In this context, a partnership and cooperation initiative is being set up with the Cognitive Systems Lab in the department of informatics of the university of Bremen, aiming at organizing a common research program toward the actual building up of design creativity support systems.
The development af this experimental path is expected to contribute significantly in this context. As far as the urban lot experimentation is concerned, new sessions have been planned to be developed involving differently skilled knowledge agents beyond undergraduate students. Also, different scales of design tasks will be used, with reference to the urban neighbourhood scale and possibly beyond. While le formalization of results is expected to be similarly (or more) hard and complex, the building up of models will surely benefit from them.

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