Modelling the knowledge of urban complexity: The role of ontologies in spatial design tasks

Dino Borri, Domenico Camarda and Maria Rosaria Stufano Melone

Abstract

The interest of the present research is focused on knowledge mechanisms in the spatial domain. Given a space and a set of entities the goal is understanding the structure of intelligent analysis and classification of architectural design outcomes in terms of complexity: see an architect-agent's ability of detecting continuous/non-continuous design items within a spatial set contingent on the needs of the agent.

Adopting a cognitive approach, we analyse the design process in architecture and ponder about cognitive processes applied to the space-and-project nexus, in order to understand the role that creativity plays in the design process and the way in which variations and constraints in it shape creativity during the development of any architectural project.

The design process in architecture can resort to 'typology' and 'types' of artificially built spatial entities which conform themselves to complex functional historical social determinants in a non-deterministic process (change, creativity, convenience, etc.): typology and types are abstractions built on systems of mutual relationships among context components, the use of which as supports in computer-based ontological analysis and classification calls for specific sets of axioms (Bhatt et al., 2009; Guarino et al., 2002).

D. Borri, D. Camarda (Corresponding author), M.R. Stufano Melone
Dept of Civil, Environmental, Territorial, and Building Engineering, and of Chemistry, Technical University of Bari, Italy

Email: {d.borri,d.camarda,mariarosaria.stufano}@poliba.it

1. Introduction

Studies on creativity in design processes are still in their infancy. Knowledge-based theoretical and experimental methods for analyzing and designing design processes in real contexts of production still look at procedural routines, lacking of attention for non-routine, creative behaviors. Architectural design processes (ADPs) are good candidate for research in the field, as they are typically based on a routine-and-creation approach for the accomplishment of ordinary goals in satisfaction of basic social needs, keeping a certain distance from the complexity of the other ‘arts’. Seminal cognitive studies on reflexive professionals – architects among them – paved the way in the 1980s for theories and experiments addressing the problem of the making of the urban environment (Schön, 1983). Studies on reflexive architects in the Schonian vein, regarding theory, privileged the self-reflexive top level agent of production (Taylor, 1911) and, regarding experiments, the sharing observation potentials for knowledge elicitation postulated by AI scholars (Buchanan, 1993). These studies, regarding theory, did not fully address the entire system of cognitive mental production (for instance the area of memory) and, regarding experiments, lacked attention for some apparently crucial aspects of experiments (for instance the nexus observation-interpretation of outcomes, that is the nexus between form and semantics). The spread of spatial cognition studies in the last two decades has brought strong contribution to the research in the field, drawing to a multiplicity of disciplines (computer science, neuro-physiology, psychology, and engineering, for example) and addressing the complexity of spatial modeling when this is driven by living beings’ behaviors (Bhatt, 2012; Freksa, 2000; Tversky, 2005). Analytical studies for logical modeling of reality (see ontology-based models), in recent years, have focused on the management of semantic complexity in production environment, in a way which seems highly promising for complexity pruning and interpretation in design creativity studies (Borgo, 2005).

Our studies on creativity in architectural design processes as normal, memory-based function in partially structured production environments (Borri et al., 2010, 2014; Stufano Melone, 2011; Stufano et al., 2012) have a twofold approach: (i) regarding theory, they look at the role of memory in providing cognitive materials to the architectural design process, the operational dualism between virtuality and reality in the development of the design process, and the hybridization potentials between ‘universals’ and ‘locals’ in ontological classification; (ii) regarding practice, they look at building systematic experiments for observing these complex mind-and-hand-based design processes in mono- and multi-agent plans and for different kind of plans (reactive or intentional, with or without goals) (Simon, 1969) made by differently skilled agents (leading architects, professionals, and students), and classifying and interpreting parts and partial plans from process development via ‘augmented’ virtual-real ontologies (Borgo, 2005; Borri et al., 2012).

Architectural design processes and their outcomes in terms of drawings and architec-tural objects are structures that cannot be easily analyzed outside of specific logical frames: from this, the need of specific axiomatization, oriented to a spatial domain characterized by objects that are both material and virtual.

A general axiomatization built on extensional relationships (among axioms, systems of axioms, and primitives) is needed, in order to have ontological analyzers-classifiers that can satisfactorily support human agents working for architectural design.

The use of typology and the concept of architectural type, as an abstraction device for analyzing spatial aspects of design processes and outcomes, is a way for coping with problems of complexity in understanding spatial entities in the course of their appearance in architectural processes, at the level of both design and construction (Petruccioli, 2007).

The concept of architectural type is not manipulation of morphology or trivial func-tional classification: it is a universal concept manifested in built forms, rooted in his-torical processes and social behaviors (Petruccioli, 2008).

The Type is something permanent and complex, the Type is a logical statement that exists before of the form and constitutes it, the Type is the idea of something that as to be useful to be rule to the model (Rossi, 1966). The Type is the rule, the constitutive world of the architecture, in logical terms we can say that is an ideal constant 'ontòs'. But when we think to the Architectonic Type we know we have three contemporaneous categories that are in the ontòs of the architectural building: the form, the function, the distribution of the parts of the building (Rossi, 1966).

Following this viewpoint, the path from primitive to complex spatial shapes in the architectural design process may significantly draw upon creativity, i.e., upon the cognitive ability of associating 'architectural memories' (Stufano Melone, 2011). The design process is defined even as a co-evolution of C and K through a logic of processes of expansion of the two spaces (Hatchuel and Weil, 2002). C-K-E theory gives the possibility of a theoretical and personal background, as a creative and adaptable design tool that uses constitutive memories and foundation references (Kazakci and Tsoukias, 2005).

Creative aspects of architectural design are based on complex expert and experiential knowledge, the analysis of which is possible through ontological devices. In particu-lar, ontological analysis and classification of complex spatial forms and relations in architecture evokes the set of logical axioms usually used in standard ontological devices (Bhatt et al., 2009; Guarino et al., 2002).

Knowledge about space, spatial action and organization of space contribute signifi-cantly to build the domain of architecture. Through self-biographies by master archi-tects we read the architects' memories of designs, spaces, architectures, 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 (Borri et al., 2011).

The present paper particularly focuses on some problems of ontological classification of architectural drawings when using mainstream general purpose ontological classifiers. We propose the use of a routine, type-based design reasoning coupled with variation agents, framed into a hybrid real vs virtual model of the design process and assisted by augmented axiomatic ontology for dealing with routine 'universals' (types) and for challenging some limitations which affect axioms of parthood, constitution, quality, and abstraction in some current mainstream general purpose ontological classifiers. The present paper is organized in the following way: apart from introduction and conclusion, section 2 deals with architectural design modeling in general; section 3 deals with routine (typological) and non routine (constraints, variation, memory and metamorphosis) agents of the design process; section 4 deals with conclusions and new potentials of theory and experimentation in the field which come from hybrid virtual-real frames and augmented axiomatic ontology.

2. Architectural design modeling

The process of architectural design is quite well known, also because architecture – whose affinity and closeness with other arts is evident also from the prefix of its name – is basically an artistic profession whose origins go back to the early stage of human and urban civilization, sharing this primacy only with law and medicine (Glazer, 1974; Rodwin, 1981). Architects are trained for years in more or less formal environments (artisanal laboratories, families-fraternities of workers, more in the beginnings, academies and professional firms more recently), in a merge of theory and practice, and in general produce designs for a well definite client who gives them goals and spatial and financial constraints.

Architects are both artists and technicians and use skills that can come from tradition (history based as well as place-based) and innovation (art, scientific methods for computation, etc.). The same than what happened for other professions, architecture went along time across a robust and intense process of formation and specialization. The Accademia di San Luca (St. Luke Academy), the oldest in Europe, founded at the end of the XVI century in Rome by Raffaello's followers, still gather all the major arts – architecture included – into a unitary organization.

Time devoted to practicing and to observing architecture is source of cumulative memories that during the design process go through an intense operation of retrieval, adaptation, and use in the new circumstance, if we trust in the numerous available books in which architects tell themselves and their professional life: this routine operation, which includes resorting to 'types', is framed by architects into a system of variations which depend on contingent constraints and 'artistic' intentions (new , non routine combination of memories) (Borri, 2002). This typical blend of routine and non routine, of well structured and ill structured reasoning, of attention or lack of attention to utility functions, gives special complexity to architectural design processes, when compared with other design processes for production of applied ideas and goods.

Of course there are numerous models of production processes by single- and multi-agents. Still scarcely explored are, instead, models of design processes. Indeed, architectural design processes can be thought as mostly pertaining to single-agents but this is not a fully correct hypothesis, because of the interaction which regularly happens in designing an artifact between the architect and her/his client, or teacher or companion in a training or firm context: further complexity which will be only slightly reported in this paper in reference to some interesting features emerging from our small multi-agent design experiments.

A design process can be thought as an intentional plan, in which knowledge-in-action develops towards a goal, with specificities (for example progressive refinement of the scheme of action) deriving with the design domain.

In the design process, the accomplishment of the getting-a-goal task means investigating resources (constrained potentials) , both internal and external to the agent, in the light of the goal, making an appropriate contingent selection of these resources for building a preliminary scheme of action, progressive refinement of this scheme by design simulation of adequacy of the scheme to the goal and its world of constrained resources potentials and facts, in order to get a definitive scheme of action (implementation will need a further and well detailed scheme of action but this is nothing but an organizational operation characterized by minor theoretical cognitive challenge). In the architectural design process, depending on the availability of resources (knowledge, time, budget assigned to trials, etc.), agents go through a series of steps (insights and reflections, simulated or real examination of reality in relation to the goal, scheme refinement, etc., whose structure presumably depends also by random subjective factors. The operational presence of latent factors and structures (in form of series of steps not dissimilar from those of mathematics or music) have been postulated by literature and is under consideration in our research. Different from other plans, the influence of the artistic creative stance (intention to create new worlds through unique knowledge in-action performance) on the architectural design process makes that especially the start of the plan is conditioned by the search for a new creative combination of solving pieces within the available 'professional' memories and abilities (see figure 1, adapted from (Le Masson, 2014)).

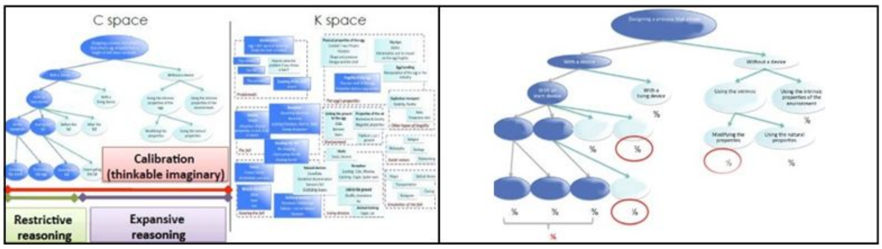

Fig. 1. Steps in decisional design process, according to C-K theory (Le Masson, 2014)

The design process can be seen as a collection of partial plans coordinated within the total plan. Plans at any level of hierarchy can be indefinitely split into hypo-ordered micro-plans (or assembled in hyper-ordered macro-plans), by using what appears as a knowledge-in-action primitive procedure: in the architectural design process this dialectic operation of analysis-and-synthesis is probably constrained by limitations which come from the virtual (non 'mechanical') nature of the involved mental objects (Barbanente et al., 1993)(see figure 2).

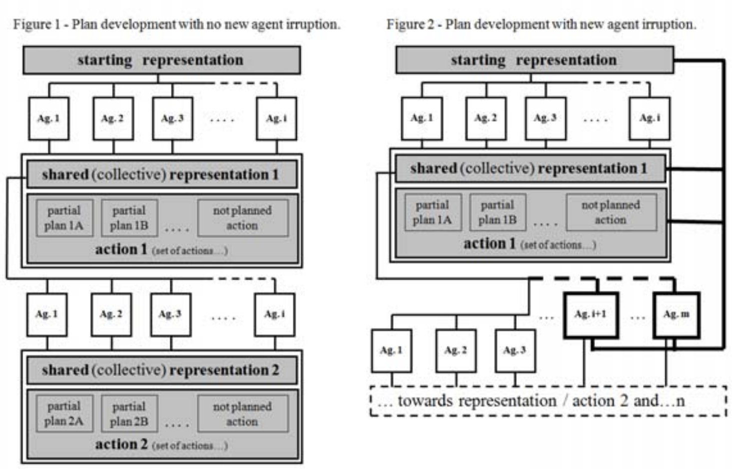

Fig. 2. Two schematizations of a partial multiagent plan(Borri et al., 2006)

3. Routine and non routine agents

Agent-based approaches to the modeling of action and knowledge-in-action processes, in a variety of operational organizations have good tradition. In automation and robotics (Minsky, 1987, 2006; Veloso, 1994; Walker et al., 2014), the same that in organizational development (Levin, 1947; Nonaka and Takeuchi, 1995; Schön, 1983), resorting to agents (and to multi-agents: see (Ferber, 1999)) in modeling virtual (cognitive) and real (action-based) processes have proved to be highly useful for both understanding, simulating, and optimizing the processes at hand. Also design – and in particular architectural design – processes can be modeled in terms of the system of agents which operate for them. Agents can be represented as having attributes and roles, modifying their own cognitive repository (memory, for instance), performing plans, and interacting with other agents. Agents can be both living (biotic, intentional) and non living (non-biotic, unintentional), real and virtual, in this way easily constituting hybrid and complex worlds particularly apt to quail-quantitative modeling and simulation of complexity. Thinking to the aims and contents of this paper, agents can perform plans and be part of organizations which can be optimized by maximizing traditional random utility functions based on individual rewards or innovative utility functions based on social vs individual rewards or also on mere disinterested behaviors and computable by fitting random utility functions to group behaviors as these are observable and statistically computable (Ben-Akiva, 2002; Lovreglio, 2014; Lovreglio et al., 2014; Tversky, 1979; Walker and Ben-Akiva, 2001)or by using, production rules adjusted from classical to multi-value logic (Mlynski and Zimmermann, 2008; Zadeh, 1965, 2012).

In our experiments, human agents involved in architectural design processes are skilled (chief architects who gather for showing their abilities in solo or duet exercises in non-intentional plans, often in a sort of intriguing joke of mastery, or young but skilled professionals who perform design tasks under commitment in intentional plans) or non-skilled (young students from schools of architecture in early training stages, who perform design tasks under commitment in intentional plans) agents acting in interaction with real (space or construction materials, drawings or other design fragments, to cite only a few) and/or abstract (architectural types, memories, normative knowledge etc.) entities which provide opportunities and constraints to their work. These human agents can be conceived as multi-agent bio-systems which function through dynamic interaction of sensors looking to the external (senses) and the internal (virtual entities as ideas, concepts, intuition, emotion etc.) world (Minsky, 1987, 2006; Papert and Minsky, 1988). As any generic task in bio-life, the architectural design process develop through bidirectional knowledge-in-action fluxes established in the dualistic reality constituted by inside and outside agents: a tentative figure for representing this knowledge-in-action mechanism when customized on the case of the architect-agent is in figure 3.

We observe architect-agents during their work by typical AI methods of knowledge elicitation (sharing observation plus ex post interpretation: chief architects, skilled professionals) (Buchanan, 1993) but also by conventional methods consisting in mere ex post interpretation of the design process (architect-agents in early stages of training). In general interviews and verbal protocols sideline observation and interpretation. Observation-recording devices and tools (camera-assisted zenithal recording, video recording, special recording pencils for geo-referencing drawings in the case of university students) etc. support experimentation. Different types of plan (for instance intentional or reactive) or skill levels deeply influence the design process. Contacts with the external reality (commissioners, places, resources, etc) are excluded from our experiments, which, consequently, suffer from strong reduction of complexity in simulation of real world design processes.

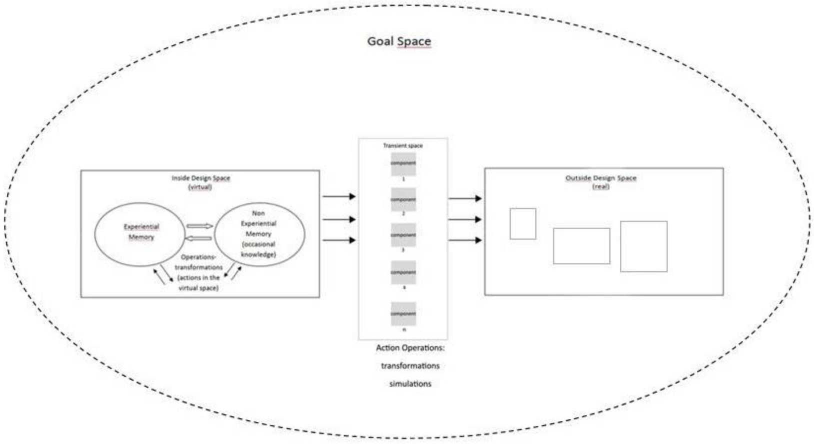

Fig. 3 From memory to design through transient objects in mental virtual space

Knowledge-in-action behaviors generating real objects (drawings) can be observed and analyzed through a conventional metric system (cardinal, nominal, ordinal, etc.) while behaviors relating to virtual objects can be managed only by hypothetical (currently at least in part supported by advancements in neurophysiology) reasoning. Architect-agents, evidently, resort to their own brain knowledge processor (internal knowledge) and to real and/or virtual interaction with reality for accomplishing a plan. In doing this, architect-agents resort to routine and non routine (creative) sub-plans depending on circumstances and constraints (for instance, non routine behaviors can be particularly time demanding but at the same time can offer solving shortcuts): but the recognition of the appearance in the process of the two instances of sub-plans is highly problematic. In some cases, apparently, professional rhetoric generate design figures whose role in the process is hardly understandable. In our experiments, architectural design multi-step processes bring some evidence of progressive reduction of uncertain choices and increasing confidence in the ongoing solution, with a sort of pruning in the space of objects and the increasing of dimensions and details of objects: navigation in design decision spaces proceeds toward design final equilibrium through continuous interaction between virtual and real figures, between a dynamic (via addition and change) cerebral repository of long term and short term memory, occasional creative combination of chunks of memory, an interaction which is strongly assisted by the cognitive benchmark provided by the real world to the virtual world (see drawings no. 1 and no. 6 (final) in the multi-step design process of designing the main entrance to a complex architectural space by a skilled professional) (figure 4).

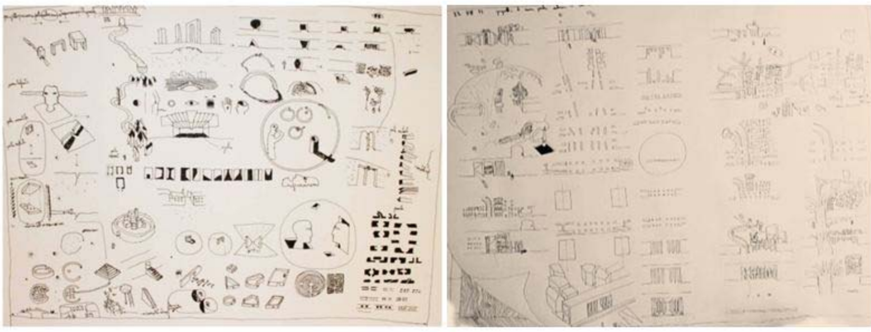

Fig. 4. Drawing n.1 and n.6 from the Urban Door design by Vincenzo D'Alba

Given the complexity (randomness, chaos, etc.) of structure and organization in the virtual vs real and vice versa cognitive relationship, experiments clearly suffer from partiality and vagueness.

To shed some light of intelligence on this intriguing complexity analytical modeling is needed. The main knowledge-in-action blocks of a plausible analytical model of the agent-based ADP can be easily imagined and represented in the following way: the agent's inside (knowledge active and dynamic repository in the brain stimulated by senses) and outside (extra-body reality sending information to available receivers) are each in front of the other and communicate through a bidirectional energy flux made by hybrid virtual-and-real cognitive chunks: these transients are progressively adapted and refined by interaction; the elements which compose the drawings in landing on these increased their reality value in the membership function à la Zadeh, being in some sense dynamic alias (oriented to a contingent and final operational equilibrium) of the real objects in full scale which will be realized through them(Zadeh, 2012).

Clearly the presence of abstract and complex elements helps understanding each type: even more, sometimes they may represent indispensable characters of each type, as, e.g., in the cases of pillars and beams. Therefore, the need of embedding a type-based axiomatization in ontological constructions is justified by such hybrid set of concepts and relations concurring in design tasks. There is apparently no debate in current literature about this subject, that nonetheless needs to be addressed for its critical importance in architectural design activities.

4. Possible extensions of the creative ontology-based approach

Aspects of creativity in the organization of space are not only related to design, particularly spatial design. In fact, if we look at the activities of organization and design as specific types of decision-making processes, we will recognize a similar bond, dependent in many ways on forms of creativity in decisionmaking.

Spatial decisions occur in a number of activities related to space, for example to space navigation. Wayfinding is one of them, and the ways in which the space is used by agents for orientation aims depends on how its characters are perceived and associated (Denis et al., 2014). Basically, they are characters whose essence is not always uniquely determined, and the features that structure, give meaning to a given space are not only physical but also formal, superstructural, ornamental (Goodman, 1951). Indeed, sometimes characters and features are only formal, such as in cases of navigation of large, unconfined, multidimensional spaces. A series of studies carried out with university students, for example, suggested a growing importance of formal features in space perception, when shifting from indoor (a university aisle) to outdoor (a urban street) spaces (Borri et al., 2014). In such experimental sessions, the role of navigating agent's creativity has proved essential in supporting the decision on the navigation route to be taken.

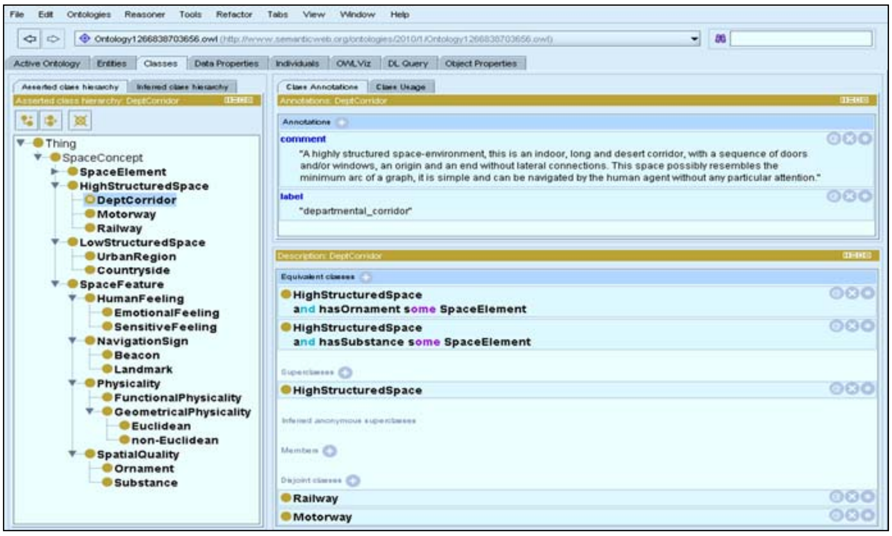

Fig. 5. Space-environment ontology in navigating an urban street (Protégé software)

The ability of the agent to associate physical elements and formal elements of the navigated environment (e.g., lights, plaques, trees in an urban space) emerges as creative interpretation that allows the agent to take effective navigations decisions. In this case, the creation of an ontology of the characters of the navigated space, accounting for the conceptual and relational (logical, algorithmic, formalized) organization of space can be a crucial element of a support architecture for wayfinding decisions (figure 5) (Borri and Camarda, 2013).

Another example of creativity in interpretative decisions of images, similarly to designers' drawings, is connected to graphical representations from remote sensing devices. Clearly, the radiation emitted by ground elements, as re-elaborated and sent back as satellite data, define images that end up being inaccurate, fuzzy, confused (figure 6) (Borri and Camarda, 2011). In this framework, image representations are comparable to the graphic-conceptual process elaborations of project designers. Just as in that case of the design action, even in this case forms and figures are linked by semantic relationships, structurally concurring to define their meaning. The analysis of such a complex layout may well benefit from an ontology-based organizational system also in this case. By founding on an ontological pattern, it is more possible for the analyzing (human or artificial) agent to build on her/his skills in the process of associative interpretative decision, towards the final decryption of the image (Frank, 2007).

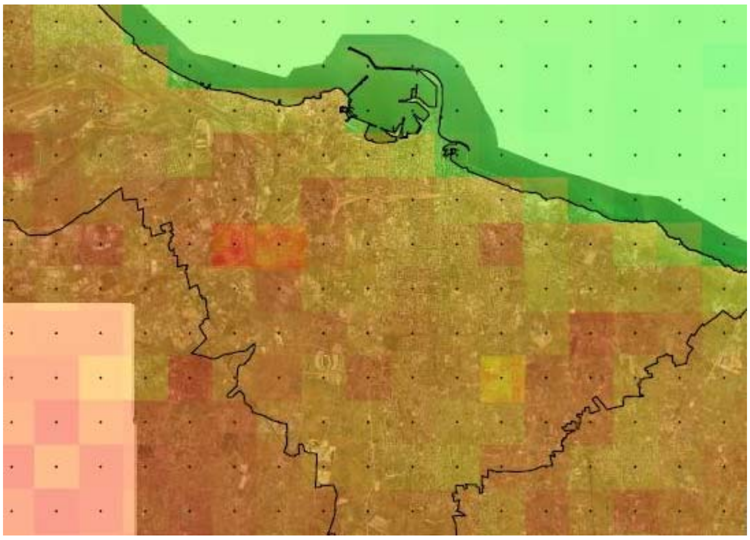

Fig. 6. Temperature survey by remote sensing (Bari district, 1000x1000m grid)

The interpretation of creativity as associating ability brings about even such kinds of extreme and apparently paradoxical results. It is however clear that different levels of abstraction, scale, operating intentional intentionality are involved, that are intrinsically self-validated.

It is nonetheless equally evident that both in the cases of design projects and interpretative analysis of space, creativity can play an important role of decision support for agents. Therefore, an important confirmation follows such framework, enhancing the possibility of building up ontology-based models toward supporting creative decision in the entire spatial-environmental domain (Brown, 2013; Freksa et al., 2005; Jarupathirun and Zahedi, 2007).

5. Conclusions

Analytical studies for ontological modeling of reality, in recent years, have focused on the management of semantic complexity in production environment.Our studies on creativity in architectural design processes as normal, memory-based function in partially structured production environments seem to demonstrate the effectiveness of a twofold approach: (i) regarding theory, looking at the role of memory in providing cognitive materials to the architectural design process, the operational dualism between virtuality and reality in the development of the design process, and the hybridization potentials between ‘universals’ and ‘locals’ in ontological classification; (ii) regarding practice, looking at building systematic experiments for observing these complex mind-and-hand-based design processes in mono- and multi-agent plans and for different kind of plans made by differently skilled agents, and classifying and interpreting parts and partial plans from process development via ‘augmented’ virtual-real ontologies.

Experiments of observation of architect-agents while they are accomplishing design tasks have showed that architectural design processes present characteristics which are difficult to be explained according to classical cognitive frames and procedures of knowledge elicitation. The interrogation of the agents about the meaning of the details of their ongoing work does not add much more to the conjectures that can be done by the observer, a part from sporadic memory- and experience-based explanations. It seems evident that architectural design is more exploration of possibilities of transforming reality by artifacts more or less constrained by the available both internal and external resources than navigation in a space of decisions toward a given goal or in a space of correlations.

For intelligent pruning and logical ordering of the very numerous and ambiguous elements of these drawings ontological classifiers seem particularly promising, in view of possible linguistic or algorithmic computation. We used the DOLCE ontology for understanding the essence of entities in the design discourse. In this way ontological computation is made easier. Statistical computation and clustering of correlation and also statistical exploration of cause-effect structural relationship can also be made by using this population of figures-entities.

Introducing the notion of architectural type as a benchmark for routine operations is valuable. The introduction of architectural types – that are universals – into currently mainstream ontological classifiers implies the operational problem of augmenting the axiomatic frames of these ontologies but this happens with a reward in terms of an augmented relational frame for understanding structure and organization of drawings and also of an augmented benchmark for distinguishing routine from non routine solutions.

Axioms specially targeted for the multi-value logic which regulates the virtual world which interacts with the real one in the design process has also to be introduced into the augmented ontological classifier.

References

Barbanente, A., Borri, D. & Pace, F. (1993). Micro-problems and micro-decisions in planning by artificial reasoners, in Klosterman R.E. and French S.P. (eds.), Proceedings of the 3rd International Conference on Computers in Urban Planning and Urban Management. Atlanta: City Planning Program Georgia Tech, pp. 17-34.

Ben-Akiva, M. (2002). Hybrid choice models: Progress and challenges. Marketing Letters, 13(3), 163-175.

Bhatt, M. (2012). Reasoning about space, actions and change: A paradigm for applications of spatial reasoning, in Hazarika S. (ed.), Qualitative Spatio-Temporal Representation and Reasoning: Trends and Future Directions. Hershey (PA): IGI Global.

Bhatt, M., Hois, J. & Kutz, O. (2009). Modular ontologies for architectural design, in Ferrario R. and Oltramari A. (eds.), Frontiers in Artificial Intelligence and Applications. Amsterdam: IOS Press, pp. 66-77.

Borgo, S. (2005). Quantificational modal logic with sequential Kripke semantics. Journal of Applied Non-Classical Logics, 15, 137-188.

Borri, D. (2002). Intelligent learning devices in planning, in Alexiou K. and Zamenopoulos T. (eds.), Seminar on Computational Models in Design and Planning Support (invited lecture, Sept. 2002). London: University College London, Centre for Advanced Spatial Analysis.

Borri, D. & Camarda, D. (2011). Planning for the environmental quality of urban microclimate: A multiagent-based approach. Lecture Notes in Computer Science, 6874, 129-136.

Borri, D. & Camarda, D. (2013). Modelling space perception in urban planning: A cognitive AI-based approach. Studies in Computational Intelligence, 489, 3-9.

Borri, D., Camarda, D. & Grassini, L. (2006). Distributed knowledge in environmental planning: Hybrid IT-based approaches in scenario-building contexts. Group Decision and Negotiation, 6, 557-580.

Borri, D., Camarda, D. & Grassini, L. 2011. Learning and sharing technology in informal contexts: A multiagent-based supporting approach. In Proceedings - IEEE International Conference on Mobile Data Management. Lulea, Sweden: IEEE.

Borri, D., Camarda, D. & Stufano, R. (2010). Memory and creativity in cooperative vs. non-cooperative spatial planning and architecture. Lecture Notes in Computer Science, 6240, 56-65.

Borri, D., Camarda, D. & Stufano, R. 2012. Spatial primitives and knowledge organization in urban planning and architecture. In 11th International Conference on Design and Decision Support Systems in Architecture and Urban Planning (DDSS 2012). Eindhoven.

Borri, D., Camarda, D. & Stufano, R. (2014). Spatial primitives and knowledge organization in planning and architecture: Some experimental notes. City, Territory and Architecture, 1(1), 1-10.

Brown, D.C. (2013). Developing computational design creativity systems. International Journal of Design Creativity and Innovation, 1(1), 43-55.

Buchanan, B.G. (1993). Readings in Knowledge Acquisition and Learning. San Francisco CA: M. Kaufmann Publishers.

Denis, M., Mores, C., Gras, D., Gyselinck, V. & Daniel, M.-P. (2014). Is memory for routes enhanced by an environment's richness in visual landmarks? Spatial Cognition & Computation, 14, 284-305.

Ferber, J. (1999). Multi-Agent Systems: An Introduction to Distributed Artificial Intelligence. London: Addison-Wesley.

Frank, A.U. (2007). Incompleteness, Error, Approximation, and Uncertainty: an Ontological Approach to Data Quality, in Morris A. and Kokhan S. (eds.), Geographic Uncertainty in Environmental Security. Dordrecht: Springer, pp. 107-131.

Freksa, C. (ed.) (2000), Spatial Cognition II. Integrating Abstract Theories, Empirical Studies, Formal Methods, and Practical Applications. Berlin:

Springer.

Freksa, C., Nebel, B., Knauff, M. & Krieg-Brückner, B. (eds) (2005), Spatial Cognition IV, Reasoning, Action, Interaction. Berlin: Springer.

Glazer, N. (1974). The schools of the minor professions. Minerva, 10(

Goodman, N. (1951). The Structure of Appearance: Cambridge: Harvard UP.

Guarino, N., Gangemi, A., Masolo, C., Oltramari, A. & Schneider, L. (2002). Sweetening Ontologies with DOLCE, in Gomez-Perez A. and Benjamins V.R. (eds.), Knowledge Engineering and Knowledge Management: Ontologies and the Semantic Web. Berlin: Springer, pp. 166-181.

Hatchuel, A. & Weil, B. 2002. La théorie C-K: Fondements et usages d'une théorie unifiée de la conception. In Colloque Sciences de la Conception. Lyon.

Ibeas, A., Borri, D., Dell'Olio, L. & Lovreglio, R. (2014). A discrete choice model based on random utilities for exit choice in emergency evacuations. Safety Science, 62, 418-426.

Jarupathirun, S. & Zahedi, F.M. (2007). Dialectic decision support systems: System design and empirical evaluation. Decision Support Systems, 43(4), 1553-1570.

Kazakci, A.O. & Tsoukias, A. (2005). Extending the C-K design theory: A theoretical background for personal design assistants. Journal of Engineering Design, 16(4), 399-411.

Le Masson, P. 2014. Towards an ontology of design: What can we learn from design theories. In Conference on Design Semantics. Bari: Technical University of Bari.

Levin, K.Z. (1947). Frontiers in group dynamics. Concept, method and reality in social science: Social equilibria and social change. Human Relations, 1, 5-41.

Lovreglio, R. (2014). Modelling Human Agents' Mobility Behaviors under Risk (PhD Thesis). Bari-Milan-Turin: Inter-Polytechnic PhD School.

Minsky, M.L. (1987). The Society of Mind. New York: Simon & Schuster.

Minsky, M.L. (2006). The Emotion Machine: Commonsense Thinking, Artificial Intelligence, and the Future of the Human Mind: New York, Simon and Schuster.

Mlynski, M.F. & Zimmermann, H.J. (2008). An efficient method to represent and process imprecise knowledge. Applied Soft Computing, 8(22), 1050-1067.

Nonaka, I. & Takeuchi, H. (1995). The Knowledge-creating Company: How Japanese Companies Create the Dynamics of Innovation. New York: OUP.

Papert, S. & Minsky, M.L. (1988). Perceptrons: An Introduction to Computational Geometry. Cambridge, MA: The MIT Press.

Petruccioli, A. (2007). After Amnesia: Learning from the Islamic Mediterranean Urban Fabric. Bari: ICAR.

Rodwin, L. (1981). Cities and City Planning. New York: Plenum.

Rossi, A. (1966). L'Architettura della Città [The Architecture of the City]. Macerata: Quodlibet.

Schön, D.A. (1983). The Reflexive Practitioner: New York: Basic Books.

Simon, H.A. (1969). The Sciences of the Artificial. Cambridge: MIT Press.

Stufano Melone, M.R. (2011). Creatività e Processo Progettuale in Architettura [Creativity and Architectural Design Process] (PhD Thesis School of Engineering). Pisa: University of Pisa.

Stufano, R., Borri, D. & Rabino, G. 2012. Creativity and planning process in architecture: A cognitive approach. In Input 2013 Conference. Cagliari: University of Cagliari.

Taylor, F.W. (1911). The Principles of Scientific Management. New York: Harper & Brothers.

Tversky, A. (1979). Prospect theory: An analysis of decision under risk. Econometrica, 47(2), 263-291.

Tversky, B. (2005). Exploring parts and wholes, in Gero G. and Maher M. (eds.), Creativity in Design. Sidney: Key Centre for Design Research.

Veloso, M.M. (1994). Planning and Learning by Analogical Reasoning. New York: Springer.

Walker, J. & Ben-Akiva, M. (2001). Extension of the Random Utility Model (Working Paper). Cambridge, MA: Massachusetts Institute of Technology.

Walker, P., Amirpour Amrai, S., Lewis, M., Chakraborty, N. & Sycara, K. 2014. Control of swarms with multiple leader agents. In International Conference on Systems, Man and Cybernetics. San Diego: Carnegie Mellon University, Pittsburgh, PA.

Zadeh, L. (1965). Fuzzy Sets. Information and Control, 8, 338-353.

Zadeh, L. (2012). Computing With Words. Principal Concepts and Ideas. Berlin: Springer.

Zumthor, P. (1998). Thinking Architecture. Baden: Zumthor and Muller Publishers.