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# Intelligent Engineering Design of Complex City: a Co-evolution Model

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**Abstract.** Engineering design and planning of the city is trans-disciplinary complex problem. City can be considered an evolving living body in complex interaction with its citizens, its artificial physical environment, and its natural physical environment. City is a multi-physic, multi-agent, multi-stratified and multi-scale object. City is also an intersecting object. It shares some of properties of two kinds of objects: empirical objects as well as theoretical objects. Based on these properties, this paper proposes a model of intelligent engineering design of a complex city. The space of problem is called Citizen Problem Space. The Citizen Problem Space is bridged to Functional Problem Space which is formulated in response to the citizen problem. The functional problem is reformulated also in response to intermediate solutions, and co-evolves with the design solutions. Design solutions belong to the Solution Space. Process Space also interacts with Solution Space. Thus the design solutions can only be dynamical consensual: satisfying both functional problem and process problem. This model depicts an evolutionary system composed of four evolutionary spaces. The evolution of each space is guided by the most recent population in the other space. It is a co-evolution model. It provides the basis for a multi-agent computational model of engineering design of the city bridged to the citizen big data extraction. It produces a multi-scale city with a holonic structure.

**Keywords.** City design, multi-scale design, holonic design, fuzzy agents.

## Introduction

The continuing unidirectional transformation of society into mass urban-industrial society shows that this process is irreversible [1]. The rapid urbanization of the world and the increasing complexity of urban systems urge to study the cities by transversal engineering sciences approaches. Climate change, urban sprawl, densification of

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present cities, as well as the inevitably conflicting demands for energy saving, better mobility, better information, environmental protection, have transformed the city into a socio-physical engineering problem of major concern [1, 2].

Today, city remains a rather unknown and poorly predictable object. City offers exceptional scope for original engineering research and applications, with critical impact for the well‑being of its citizens. Developing better strategies for the engineering design of the complex cities can be considered a global imperative [3]. The goal is to propose new models and tools either to lead to a better design and planning of cities or to give a better predictive approach for a better decision-making process. Coping with complex city in its conceptualization, in its modeling, in building up theoretical and practical new fundamentals, models and tools, implies also to enlighten the engineering modeling knowledge in the design of complex city generally hidden in the frameworks that can give birth to the these fundamentals, methods and tools [4].

Designers can engage the current challenge of complex city design applying also the “the long-term ability of a system to reproduce” criterion [1]. City design solutions should be multi-scale and consensual to be accepted [5]. The lack of data flow-driven methods for design and planning of cities, integrating and resolving multidimensional conflicts for finding creative engineering design solutions, can be identified as a research engineering problem. The multi scale design can presumably stimulate greater environmental awareness. It is believed that citizens as well as policymakers of small-scale, self-sufficient [1], self-reliance [6], self-integrative [7] regions will be aware of the causes and effects of their environmental actions.

This paper, first, analyzes the key properties of the city and then, it proposes an evolution model for the engineering design of multi-scale and holonic city.

## 1. Key properties of the city

City is a complex object. Engineering design and planning of the city is also a complex problem. This complexity results from the conjugation of a huge amount of heterogeneous data interacting with each other. Three key properties of the city can be drawn:

***Property 1****: City can be considered an evolving living body in complex interaction with its citizens, its artificial physical environment, and its natural physical environment.*

Indeed, city is a living complex geometrical and topological object, limited by its artificial physical environment, and its natural physical environment. It is lived by its citizens and therefore is constrained by sociological, societal, political and economical parameters.

***Property 2****: City is a multi‑physic, multi‑agent, multi-stratified and multi‑scale object.*

Indeed, city is a multi-physic object because it is characterized by multi-flux of energy, materials, information and human activities behavior. City is a multi-agent object because it is formed by the populations (of citizens) and different actors of the urban scenery. City is a multi-stratified object from historical, institutional and cultural context of its long evolution. Cities is a multi-scale object because it is an whole object that is part of a vaster whole, and which at the same time contains elements, of which it is composed and which provide its structural and functional meaning, interconnected by networks as well as characterized by social, cultural, political and economic aspect.

***Property 3****: City is also an intersecting object. It shares some of properties of two kinds of objects: empirical objects as well as theoretical objects.*

Indeed, we face now objects that share properties of these two kinds of objects: empirical and theoretical. They are called the *intersecting objects*. These objects are empirical entity: they are not the result of a conceptual construction. They are intersecting insofar as they are also a meeting point for several scientific disciplines and so can be studied by theoretical objects proposed by those disciplines. Intersecting objects have a double transcendence: an empirical transcendence and an epistemic one. According to the first transcendence, intersecting objects exceed any experience we may have of them. While they exist, it is not possible to circumscribe them through empirical or scientific experience. According the epistemic transcendence, intersecting objects exceed any conceptual characterization we may propose of them, which cannot even be used as a reasonable approximation to study them. Intersecting objects are then objects of special interests since they require relying on many disciplines while they exceed the sum of them. City satisfies these characteristics. Therefore, it is an intersecting engineering design object.

## 2. Intelligent designing of complex cities

Engineering design can be analyzed, synthesized and validated through dynamic engineering models. In the past, there were many attempts to draw up models to handle the complexity management of design process in systematic steps [8-13]. The goal of design engineering is the conversion of a perceived need or a technical problem into information from which a product can be built in sufficient quality and reasonable cost to meet the needs or to overcome the problem [14-15]. Design process usually starts with the identification of a need, proceeds through a sequence of activities to seek for a solution to the problem, and ends with a detailed description of the product or the technical system. Both functional modeling and structural modeling have been studied [16-23]. The development of theories of innovation [24] and their application in different design problems has been investigated [25].

Our claim is that engineering design theories and practices can be applied in the engineering design and planning of complex city [3]. However, from the properties of the city, there is a need to create and develop approaches for intelligent designing of complex cities driven by dynamic distributed data and knowledge. The question of robust or consensual key data extraction is primordial. Simulation and evolution of the dynamic solutions are also important.

### *2.1. Citizen Problem Space and Citizen Models*

The definition of the design problem in terms of what citizens like is an important part of the design process. The rapidity of densification and growth of city, changing and the evolution of different actors of the urban scenery makes the problem definition as never final. Therefore, the movement of the problem in time depends on the movement of populations (citizens) and different actors of the urban scenery. The space of problem defined from the citizens is called Citizen Problem Space.

Experimental model of citizen domain is the first model developed in this application. Understanding of “what citizens want”, its progress and advancement can be achieved by observing the dynamics of interactions between different citizens in real time. Within engineering design of a complex city like Shanghai, large quantities of information and knowledge are widely distributed across citizens.

The interaction between the citizens and different objects considering the task of citizens and roles of these objects is also carried out (Figure 1). The problem then consists in analyzing the real interactions between citizens. During interactions, citizens communicate their thoughts verbally or in writing. Experiences show that the majority of real problems appear through verbalizations and writings. Therefore, the verbal and written communication offers us a direct path to the citizen requirements. For that reason, we consider a message as being a form of the representation of a problem. It can be characterized by a set of syntactic elements with a specific semantics to a domain of knowledge. The category of these elements is called analysis entities [26].

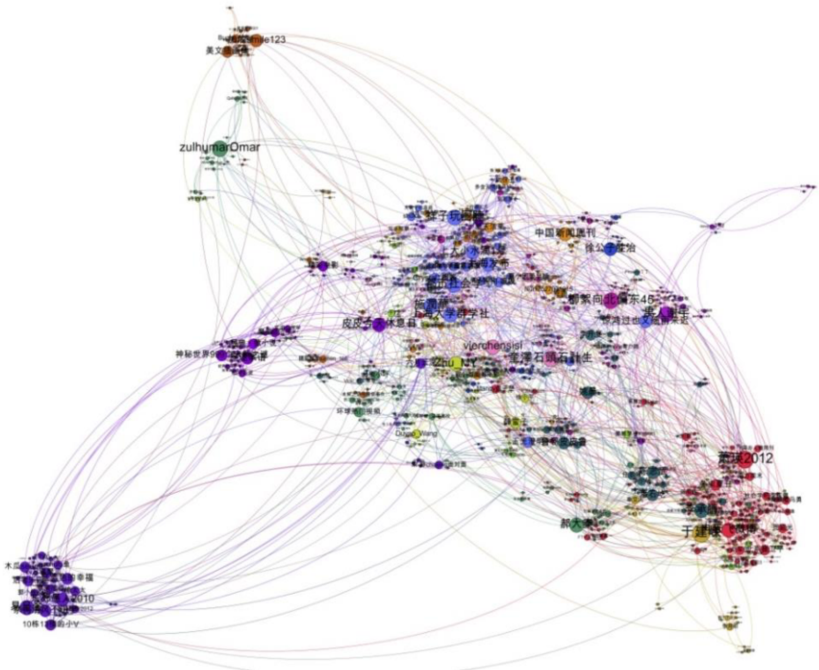


**Figure 1.** Real interactions between citizens.

*Computational model of citizen domain* and *Mathematical model of citizen domain* are used to study both citizen and automated organization as computational entities. Interactions have been viewed as inherently computational. Every interaction can be filtered by means of analysis entities. Clustering the entities of analysis can be considered a principle for *citizen-problem* discovering. Clustering permits to identify families of analysis entities (Figure 1). Mathematically, the search for interaction families and analysis entities families is a problem of search for simultaneous partitions of the two sets, the filtered interactions set and analysis entities set in correspondences or in quasi-correspondences class of partition to class of partition. Hence, this correspondence permits to characterize an interaction family by the corresponding analysis entities family that is by the corresponding *citizen problem*. If the families of state-problems are mutually exclusive, it is clear that the state-problems are completely independent. In practice, depending on the particular nature of the citizen problems, some or all of the state-problems result in either being mutually independent or not being as such. This means that interactions create "*state-problems within a state-problem*".

*Conceptual model of citizen domain* is developed from the interpretation of the results of computational model of citizen domain. Computational analysis permits a better understanding of the interactions between citizens, the nature of problems, the emergent patterns and structures of organization during interactions. The simulation of the flow of the citizens from main hospitals of Shanghai shows what are the accessible zones that the citizen reach travelling by subway or by foot during 30 minutes (Figure 2). The design for configuration of the city should consider the optimal distribution of the hospitals.

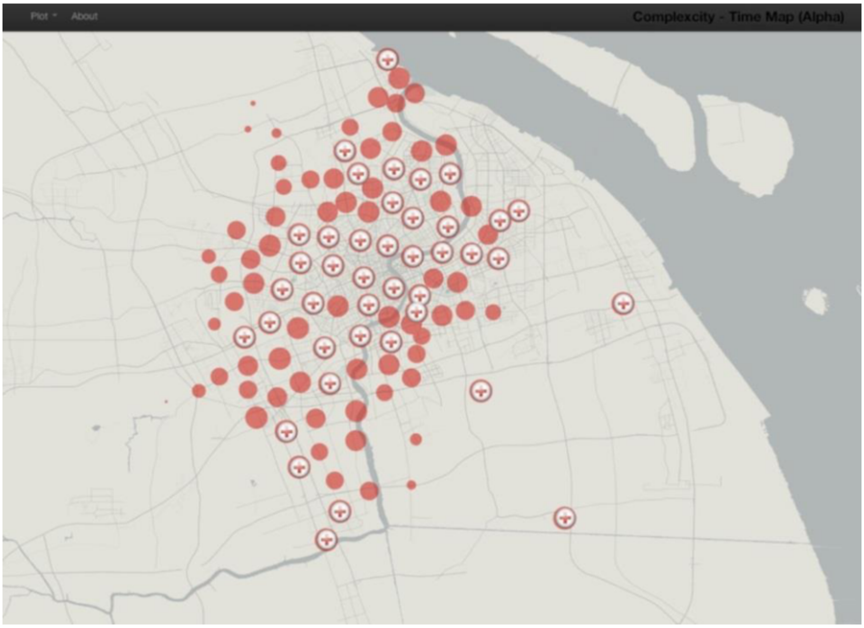


**Figure 2**. Distribution of hospitals in Shanghai.

## *2.2. Agent based computational models*

The Citizen Problem Space is bridged to Functional Problem Space. The functional problem is formulated in response to the citizen problem. The functional problem is reformulated also in response to intermediate solutions, and co-evolves with the design solution. Design solution belongs to the Solution Space. Process Space also interacts with Solution Space. The solution problem is formulated in response to the process problem (for instance, the maintenance of city). Thus the design solution can only be consensual: satisfying both functional problem and process problem.

This model of design depicts an evolutionary system composed of four evolutionary spaces. The evolution of each space is guided by the most recent population in the other space. It is a co-evolution. It provides the basis for a multi-agent computational model of engineering design of the city.

From the field of Distributed Artificial Intelligence, agent-based systems are characterized by the distribution of knowledge and information needed to solve a problem on a set of interacting agents, able to continue and reach a global goal. An agent-based system is a society of autonomous agents cooperating to achieve a global objective through interaction, communication, or transaction. Fuzzy agents emerged as a tool to model uncertain behavior problems in engineering design [27-29]. Fuzzy agents are also used in fuzzy reasoning situations, where agents interpret a situation, solve a problem, or decide with fuzzy knowledge.

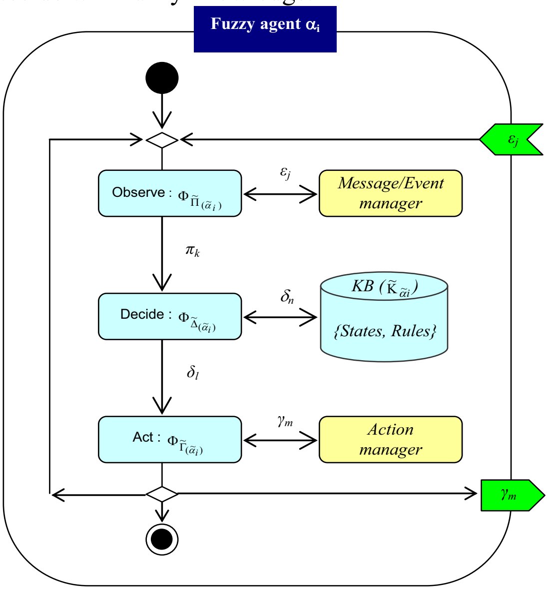


**Figure 3.** Functional architecture of fuzzy agents.

A fuzzy agent-based system $\tilde{M}_\alpha$ is defined by (1):

$$\tilde{M}_\alpha =< \tilde{A}, \tilde{I}, \tilde{P}, \tilde{O} > \quad (1)$$

where $\tilde{A}$ is the fuzzy set of fuzzy agents, $\tilde{I}$ is the fuzzy set of interactions defined in $\tilde{M}_\alpha$ , $\tilde{P}$ is the fuzzy set of roles that fuzzy agents of $\tilde{A}$ can play, and $\tilde{O}$ is the fuzzy set of organizations defined for fuzzy agents of $\tilde{A}$ .

Many agent structures are inspired by the cycle *<perceive, decide, act>* (Figure 3). Thus, a fuzzy agent $\tilde{\alpha}_i$ is described as follows (2):

$$\tilde{\alpha}_i =< \Phi_{\tilde{\Pi}(\tilde{\alpha}_i)}, \Phi_{\tilde{\Delta}(\tilde{\alpha}_i)}, \Phi_{\tilde{\Gamma}(\tilde{\alpha}_i)}, \tilde{K}_{\tilde{\alpha}_i} > \quad (2)$$

Where:

$\Phi_{\tilde{\Pi}(\tilde{\alpha}_i)}: \tilde{\Sigma} \times \tilde{\Sigma}_{\tilde{\alpha}_i} \rightarrow \tilde{\Pi}_{\tilde{\alpha}_i}$ is the function of perceptions of $\tilde{\alpha}_i$: $\tilde{\Sigma}$ is the fuzzy set of states of $\tilde{M}_\alpha$; $\tilde{\Sigma}_{\tilde{\alpha}_i} \subseteq \tilde{\Sigma}$ is the fuzzy set of states of $\tilde{M}_\alpha$ that $\tilde{\alpha}_i$ knows, $\tilde{\Pi}$ is the fuzzy set of perceptions in $\tilde{M}_\alpha$, and $\tilde{\Pi}_{\tilde{\alpha}_i} \subseteq \tilde{\Pi}$ is the fuzzy set of perceptions of $\tilde{\alpha}_i$;

$\Phi_{\tilde{\Delta}(\tilde{\alpha}_i)}: \tilde{\Pi}_{\tilde{\alpha}_i} \times \tilde{\Sigma}_{\tilde{\alpha}_i} \rightarrow \tilde{\Delta}_{\tilde{\alpha}_i}$ is the function of decisions of $\tilde{\alpha}_i$: $\tilde{\Delta}$ is the fuzzy set of fuzzy decisions defined in $\tilde{M}_\alpha$, and $\tilde{\Delta}_{\tilde{\alpha}_i} \subseteq \tilde{\Delta}$ is the fuzzy set of decisions of $\tilde{\alpha}_i$;

$\Phi_{\tilde{\Gamma}(\tilde{\alpha}_i)}: \tilde{\Delta}_{\tilde{\alpha}_i} \times \tilde{\Sigma} \rightarrow \tilde{\Gamma}_{\tilde{\alpha}_i}$ is the function of actions of $\tilde{\alpha}_i$: $\tilde{\Gamma}$ is the fuzzy set of actions which can be performed in $\tilde{M}_\alpha$, and $\tilde{\Gamma}_{\tilde{\alpha}_i} \subseteq \tilde{\Gamma}$ is the fuzzy set of actions that $\tilde{\alpha}_i$ can process;

$\tilde{K}_{\tilde{\alpha}_i} \subseteq \tilde{K}$, with $\tilde{K}_{\tilde{\alpha}_i} = \tilde{\Delta}_{\tilde{\alpha}_i} \cup \tilde{\Sigma}_{\tilde{\alpha}_i}$, is the fuzzy set of fuzzy knowledge of $\tilde{\alpha}_i$: $\tilde{K}$ is the fuzzy set of fuzzy knowledge defined in $\tilde{M}_\alpha$. Knowledge of $\tilde{\alpha}_i$ is composed of decision rules, values on the domain, acquaintances and dynamic knowledge, as observed events or internal states.

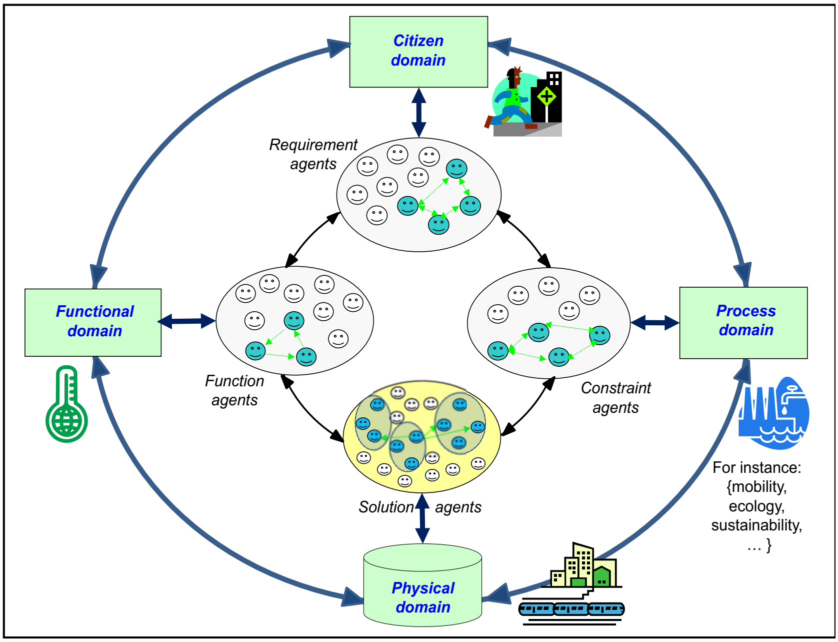


**Figure 4.** Agent-based architecture of F-ACCID platform.

The proposed platform to assist the problem of product configuration is called F-ACCID (Fuzzy Agents for Complex City Intelligent Design). This platform (Figure 4) is composed of three levels:

1) *Communication and cooperation level*. It implements services of communication and cooperation for fuzzy agents of F-ACCID (interface agents and design agents).

2) *Design fuzzy agents' level*. It is divided into four fuzzy communities of agents: (1) fuzzy community of citizen requirements agents that interact with the fuzzy community of function agents, in response to requests from the citizen requirements agents, (2) fuzzy community of function agents that interact with each other and with

fuzzy communities of citizen requirements agents and solution agents, (3) fuzzy community of solution agents that may interact with each other and with fuzzy communities of function agents and city constraints agents, and (4) fuzzy community of city constraints agents that interact with the fuzzy community of solution agents, in response to requests from the city domains agents.

3) *Interface level*. It supports the connection of different human actors of configuration (experts and customers) by use of software micro-tools (μ-tools [63]); these μ-tools communicate the orders' actors to associated city domains agents, who might transmit them to the fuzzy communities of citizen's requirement agents and fuzzy city constraints agents.

### 2.3. Multi-scale and holonic city

From the second property, the city is a multi-levelled hierarchy of semi-autonomous sub-wholes, branching into sub-wholes of a lower order, and so on to form a holon. Each sub-whole within the hierarchic tree has two properties: it is a whole relative to its own constituent parts, and at the same time a part of the larger whole above it in the hierarchy. We define a *city cell* as a holon entity.

All city functions must be performed and completed in their entirety as independently as possible. One of the essential requirements of the city cell is the capacity for independent actions. Each city cell must itself be a city cell. This means creating *"city cells within a city cell"*.

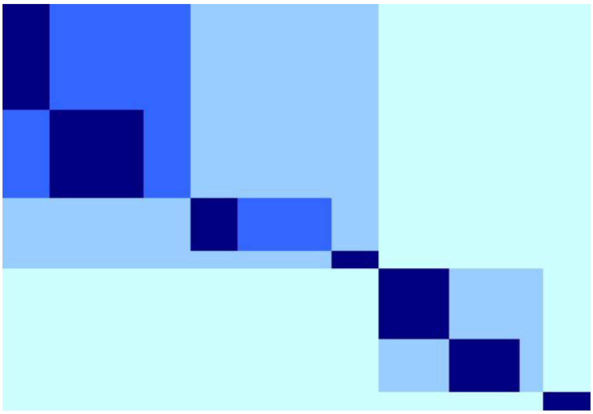

**Figure 5.** City Cell-within-City Cell.

The city cells largely structure themselves and together serve the whole system of the city. Reference can be made to the principle of regulating city functions and/or city solutions that can control the behavior of independent city cells. Thus, the internal relationships within a city are closer and more intensive than the relations with the outside. City cells are self-similar also. Here, the city functions are grouped so they are performed and completed in their entirety as independently as possible. The relationship between city solutions in different levels of the *"city cells within a city cell"* (Figure 5) allows finding regulating function or solutions that can control the behavior of autonomous city cells. Then, the city cells can largely organize themselves in consensual configurations. Figure 6 shows the fuzzy solutions agents of F-ACCID platform during the seeking the consensual configurations. From the dynamic overlapping of local behaviour of fuzzy solutions agents in different configurations emerge the consensual configurations. The consensual configurations are shown in diagonal blocks.

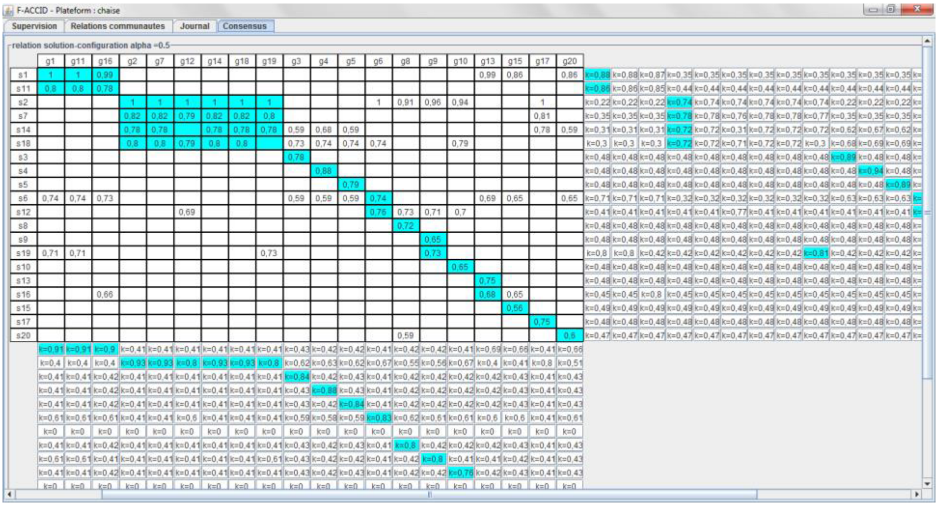


**Figure 6.** Fuzzy solutions agents of F-ACCID platform during the seeking the consensual configurations.

## 3. Conclusion

City is a complex object. City can be considered an evolving living body in complex interaction with its citizens, its artificial physical environment, and its natural physical environment. City is a multi-physic, multi-agent, multi-stratified and multi-scale object. City is also an intersecting object. It shares some of properties of two kinds of objects: empirical objects as well as theoretical objects. Based on these properties, this paper proposes an approach for intelligent designing of complex cities driven by dynamic distributed data and knowledge. The definition of the design problem in terms of what citizens like is an important part of the design process. This model of design depicts an evolutionary system composed of four evolutionary bridged spaces: Citizen Problem Space, Functional Problem Space, Solution Space and Process Space.

The rapidity of growth of city, changing and the evolution of different actors of the urban scenery makes the problem city design as never final. The citizen requirements are defined from citizen interactions. The Functional Problem Space is formulated in response to the citizen problem defined in the Citizen Problem Space. The functional problem is reformulated also in response to intermediate solutions, and co-evolves with the design solution. Process Space also interacts with Solution Space. The solution problem is formulated in response to the process problem. Thus the design solution can only be consensual: satisfying both functional problem and process problem. The evolution of each space is guided by the most recent population in the other space. It is a co-evolution design.

City can also open new ways for a trans-disciplinary research whose finality could be the elaboration of a new discipline with its own reality (city) and its own fundamental concepts.

## References


[1] S. Campbell, Green cities, Growing cities, Just cities? Urban planning and the contradictions of sustainable development, *Journal of the American Planning Association*, **62(3)** (1996), 296-312.
[2] B. Hillier, The City as a Socio-technical System: A Spatial Reformulation in the Light of the Levels Problem and the Parallel Problem, in S.M. Arisona, G. Aschwanden, J. Halatsch, P. Wonka (eds), *Digital Urban Modeling and Simulation*, Springer Berlin Heidelberg, 24-48, 2012.
[3] C. Derix, A. Gamlesæter, P. Miranda, L. Helme, K. Kropf, *Simulation Heuristics for Urban Design*. In S.M. Arisona, G. Aschwanden, J. Halatsch, P. Wonka (eds), *Digital Urban Modeling and Simulation*, Springer Berlin Heidelberg, 159-180, 2012.
[4] E. Ostrosi, F. Pfaender, D. Choulier, A.-J. Fougères and MZ. Tzen, Describing the engineering modeling knowledge for complexity management in the design of complex city , *Proceedings of the 19th International Conference on Engineering Design (ICED13)*, Seoul, Korea, 19-22 August 2013.
[5] E. Ostrosi, L. Haxhiaj and S.Fukuda, *Fuzzy modelling of consensus during design conflict resolution*, *Research in Engineering Design*, **23(1)** (2012), 53-70.
[6] D.C. Korten, Sustainable Development, *World Policy Journal*, **9(1)** (1991), 157-90.
[7] J.M. Berry and K.E. Portney, Sustainability and Interest Group Participation in City Politics, *Sustainability*, **5(5)** (2013), 2077-2097.
[8] M.J. French, *Engineering design: the conceptual stage*, Heinemann Educational Books Ltd, London, 1971.
[9] G. Pahl and W. Beitz, *Engineering Design: A Systematic Approach*, The Design Council, London, 1984.
[10] V. Hubka and W.E. Eder, *Theory of technical systems*, Springer Verlag, New York.
[11] N. Suh, *Principles of Design*, Oxford University Press, New York, 1988.
[12] K. Ulrich and S.D. Eppinger, *Product design development*, McGraw-Hill, New York, 1995.
[13] K.N. Otto and K.L. Wood, *Product Design Techniques in Reverse Engineering and New Product Development*, Prentice Hall, Upper Saddle River, NJ, 2001.
[14] D.G. Ullman, *The mechanical design process*, McGraw-Hill, New York, 1992.
[15] C. Hales, *Managing engineering design*, Longman Scientific & Technical, Harlow, England, 1993.
[16] F.J. Erens and K. Verhulst, Architectures of Product Families, *Computers in Industry*, **33(2-3)** (1997), 165-178.
[17] R.V. Welch and J.R. Dixon, *Representing function, behavior and structure during conceptual design*. In Taylor D.L. and Stauffer L.A. (eds.) Design Theory and Methodology, American Society of Mechanical Engineers, **42** (1992), 11-18.
[18] J.S. Gero and U. Kannengiesser, The situated Function Behaviour framework, *Design Studies*, **25(4)** (2002), 373-392.
[19] A. Chakrabarti and L. Blessing, Representing functionality in design, *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, **10** (1996), 251-253.
[20] B. Chandrasekaran, Representing Function: Relating Functional Representation and Functional Modeling Research Streams, *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, **19** (2005), 65–74.
[21] B. Chandrasekaran and J.R. Josephson, Function in Device Representation, *Engineering with Computers*, **16(3-4)** (2000), 162–177.
[22] M.S. Erden, H. Komoto, T.J. VanBeek, V. D'Amelio, E. Echavarria, and T. Tomiyama, A Review of Function Modeling: Approaches and Applications, *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, **22** (2008), 147–169.
[23] J. Hirtz, R.B. Stone, D.A. McAdams, S. Szykman and K.L. Wood, A Functional Basis for Engineering Design: Reconciling and Evolving Previous Efforts, *Research in Engineering Design*, **13** (2002), 65–82.
[24] G. Altshuller, *And suddenly the inventor appeared*, Technical Innovation Center, Inc. Massachusetts, 2002.
[25] D. Choulier, *Découvrir et appliquer les outils de TRIZ*, Chantier – UTBM, Belfort, France, 2011.
[26] R. Movahed-Khah, E. Ostrosi and O. Garro, Analysis of Interaction Dynamics in Collaborative and Distributed Design Process, *Computers in Industry*, **61(2)** (2010), 2-14.
[27] E. Ostrosi and A.-J. Fougères, Optimization of product configuration assisted by fuzzy agents, *International Journal on Interactive Design and Manufacturing*, **5(1)** (2011), 29-44.
[28] E. Ostrosi, A.-J. Fougères, M. Ferney and D. Klein, A fuzzy configuration multi-agent approach for product family modelling in conceptual design, *Journal of Intelligent Manufacturing*, **23(6)** (2012), 2565-2586.
[29] A.-J. Fougères and E. Ostrosi, Fuzzy agent-based approach for consensual design synthesis in product configuration, *Integrated Computer-Aided Engineering*, **20** (2013), 259–274.