Space in Socio-technical Systems: Exploring the Agent-Space Relation

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Abstract. Socio-technical systems (STS) described in literature today rely on multiple and different interaction patterns for their characterization. With the development of multi-agent systems (MAS) and formal interaction languages, the logical modeling of STS has improved. Yet these rich ongoing approaches require perspective changes and new features.

Developing within a research line on spatial urban studies, this paper takes physical space experience as a core perspective in the analysis of STS. Space experience is naturally central in human understanding and acting, and human spatial cognition provides therefore a powerful approach. This study explores the kind of knowledge that is centered on space in STS, and questions whether and how its variety can be managed and formalized.

In particular, the paper explored aspects of the configuration and relationships of the agentive and spatial components of urban environments, from an STS perspective, toward possible MAS-based prototypes of decision support architectures in urban contexts.

Keywords: Socio-technical systems · Ontological analysis · Spatial cognition · Multi-agent systems

1 Introduction

The characterization of socio-technical systems (STS) in the literature moves along these lines: "systems that involve a complex interaction between humans, machines and the environmental aspects of the work system" [7] and have five key characteristics [4, 7]: (i) have interdependent parts; (ii) adapt to and pursue goals in external environments; (iii) have an internal environment comprising separate but interdependent technical and social sub-systems; (iv) their goals can be achieved by more than one means; (v) their performance relies on the joint optimisation of the technical and social subsystems.

The first part of the STS description ("interaction between humans, machines and environmental aspects") is explicitly focusing on interactions and components, and the

The present study was carried out by the authors as a joint research work. Nonetheless, S.Borgo wrote §1, D.Camarda wrote §2 and §4, M.R.Stufano Melone wrote §3.

O. Gervasi et al. (Eds.): ICCSA 2021, LNCS 12953, pp. 489–502, 2021.
https://doi.org/10.1007/978-3-030-86976-2_33

view of STS as made of components is the center of the characterizations (i) and (iii). Points (ii) and (v) qualify the interactions as aiming to some goals (here understood as selected or desired states). Having multiple ways to achieve a goal, as stated in (iv), implies that different interaction patterns may achieve the sought state.

With the development of multi-agent systems and of formal languages for interaction [9], the logical modeling of socio-technical systems has improved. These rich approaches are still under development and require a change of perspective and thus the introduction of new features. Briefly, their potentialities today are only partially understood. To help in this endeavor, we investigate a fundamental issue that, unfortunately, has been largely disregarded in this literature: the notion of space. Of course, there is plenty of literature on space representation (geometrical and cognitive), space as environment (for navigation, perception and action), space as organization (spatial planning, decision science), and so on. Yet, socio-technical systems are complex entities with many facets, and any choice of a spatial approach from these viewpoints would look arbitrary. What we need is a holistic view of space in STS. (An analogous observation can be made about time.) Furthermore, the development of space in the listed communities presents a technical issue: these analyses developed specialized formalizations which we cannot assume are optimal, or even suitable, for a general theory of STS.

This paper falls within a research line on spatial urban studies. It takes physical space and its experience as a core perspective in the analysis of socio-technical systems. Physical space is naturally at the core of human understanding of reality and at the core of human acting in it. Moreover, the human cognitive module that deals with spatial structures is a powerful tool that humans exploit to model a variety of topics. Among the fundamental questions this research line aims to address is the kind of knowledge that is centered on space. Given the variety of roles that space takes in socio-technical systems, a further question is whether and how this variety can be integrated (managed and formalized). Of course, this also depends on the formalisms that have been explored so far and on the foreseeable developments. Finally, one wonders how one could test a general theory that tries to encompass all the space-related aspects of socio-technical system. We close this introduction noticing that the listed topics are nothing more than special cases of the following much broader research questions: I) How should we understand multi-faceted dimensions in socio-technical systems? II) How could we generate an integrated model for each dimension starting from existing formalisms? III) How could we test that the resulting theory is satisfactory and can be exploited alongside with theories for other dimensions?

The work explores particularly dimensions, instances and peculiarities of the relationships between the agentive/social element and the spatial/environmental element. These are elements that are individually endowed with intrinsic granularity, which allows them to be individually integral but also articulated, disaggregated - or possibly disaggregated.

In a socio-technical system, the possibility of maintaining a complex formalization of this organizational complexity guarantees a formidable support to aware decision-making, planning and management processes of the system itself. This is clearly a homothety (organizational complexity vs. representative complexity), desirable but also difficult to achieve operationally, based on an extended range of instances and attributes (typological, behavioral, attitudinal, dimensional, hierarchical data, etc.), even dynamically variable. However, research in the literature today increasingly reflects on the use of ontologies as a descriptor intrinsically consistent with the complexity of the sociotechnical system.

The present study is therefore placed in this ontological perspective, trying with a fine-grained approach to shed light on the relational aspects between agent and space, which seem fundamental in this perspective.

The aims of this paper within this domain is to discuss how space can and should be understood in cities here considered as a special class of socio-technical systems. The choice of cities as application case is driven by our previous analysis of these complex objects [10] and the need to make the resulting view accessible to urban planning study and modeling. The discussion remains mainly at the conceptual level with some observations into the processes of model development and formalization.

The paper is structured as follows. Section 2 deals with roles, configurations and interactions of the individual and social agents' level in spatial environments, with particular reference to decision-oriented tasks. Therefore, Sect. 3 discusses the representation of space at the knowledge level, first reasoning on a dynamic individual-collective dialectic toward space and then exploring approaches and methods toward space conceptualization. Brief remarks conclude the paper, envisioning the potentials of building formal models that seem not at our reach.

2 The Agentive/Social Level in Space

Social issues have been addressed within urban organizations and management from different points of view. Many perspectives are traditionally connected to sociological, anthropological and political aspects that have represented an indistinct magma often (mis-) interpretable only through political and sometimes even rhetorical filters [11]. Hence, for an analysis of the agentive level of space as an interactive place of connection and action, these perspectives seem logically not well objectifiable. In fact, they are vague or too aggregate to express clearly representable classes or agentive properties. Yet, especially since the middle of the last century, there is a growing interest in the field of decision theory in the individual behavioral dimension, as an essential element towards 'reasonable' rather than rational decisions in a collective arena of public interest [36]. In this context, there is an interesting articulation proposed by Forester (Fig. 1) [17] concerning the multiform limits that the relational organization between agents of a community can impose on the classic model of rational decision. This intriguing configuration, originated to operationally argue Simon's bounded rationality model, actually gives useful account of a complex system of agents, agencies and agent contexts - although mainly oriented towards an arena of institutional governance. In these arguments, space is present rather unusually as an actively determining element in accompanying, determining and sometimes participating in the relationships between the various agents that structure the decision-making dynamics. The relations between human agents and the space in this simplified world proposed by Forester are certainly of a mutually bidirectional type - whereas certain traditional domain models instead relegate space unfortunately to roles of inactive support for actions (and transformations) by agents that populate spaces. By closing doors and connecting environments, communication flows transfer information and determine relational ties between individuals, dynamically reprogramming decision-making contexts and, therefore, the activities of individuals themselves. A decision made in the solitude (or in the company) of an enclosed space is affected by knowledge limited to self-centered or self-connected relationships: only in this case (perhaps) does space take on typical features of an inactive static context. But it is a temporary and fleeting inactivity. The opening of passages immediately conveys new awareness, new arenas, new relationships and new levels of interaction. It determines new skills and new roles for the agents involved - not always and not necessarily emancipatory but also of decision-making risk and obstacle [17].

Type of Boundedness of Rationality	Conditions of Administrative/Planning Actions					
	Agent	Setting	Problem	Information	Time	Practical Strategy
Comprehensive (Unbouded)	Rational Actor	One Room (Closed System)	Well-defined Problem	Perfect Information	Infinite	Optimize/solve (algorithm, technique)
Simon: Cognitive Limits, e.g., (Bounded I)	Fallible Actor	Room Open to Environment	Ambiguous Scope, Basis of Evaluation	Imperfect	Limited	Satisfice/hedge, lower expectations
Socially Differentiated (Bounded II)	Several; Varying skills, insight; cooperative	Several rooms, phones, socially differentiated	Varying Interpretations	Varying Qualty, Location, Accessibility	Varying with Actors	Network/search and satisfice
Pluralist (Lindblom) (Bounded III)	Actors in competing interest groups	Rooms in Organizations Variable access	Multiple Problem Definitions (Senses of Value, Right, Impacts)	Contested, Withheld, Manipulated	Time is Power	Bargain/ increment, acjust/check
Structurally Distorted/ Political-Economic (Habermas) (Bounded IV)	Actors in Political-Economic Structures of Inequality	Rooms in Relations of Power: Differential resources, skill, status	Ideological Problem definitions; Structurally Skewed	(Mis)information Ideological; contingent upon participation, "consciousness"	Time Favors "Haves"	Anticipate/ counteract, organize/ democratize

Fig. 1. Rationality and practice in administration and planning [17, p.27]

The evolution of these economic studies then goes on to point out the various collective decision contexts, increasingly specifying cognitive, relational and political-structural limits and the consequent final operational viability of a purely rational approach [2, 37]. In particular, through his well-known logical-mathematical theorem, Arrow shows the impossibility of a collective multi-agent decision based on the classic axioms of rationality, unless some of them is weakened or abandoned [1]. The typical formulation of this theorem starts from five axioms, namely: universal decidability of preferences, reachability of results, inadmissibility of choices imposed authoritatively, absolute transitivity of preferences, independence from irrelevant alternatives. Indeed, the mathematical development shows that the solution attempts depend either on a relativization of the transitivity of the preferences (the outcome depends on the different order in which the preferences are expressed, the so-called Condorcet paradox) [18] or on a final decision imposed by an agent who alone determines the result (the dictator of Arrow [1]). In fact, this circumstance implies that it is impossible to devise a system that fully conforms to the axiomatics of classical rationality, meaning that no strictly rational system is able to aggregate individual preferences into social choices, unless some of the conditions are loosened. The operating model emerging from this certified substantial unattainability of a pareto-optimal decision [41] takes on the less abstract, more 'reasonable' features of a behavioural approach, which is oriented towards decidability objectives that are not rationally optimal but satisfactory for the levels of effective operations required by the decision in a collective arena [37]. The research in literature subsequently focuses on attempts to overcome the limits to the rational approach, using qualitative political analysis models such as muddling-through or mixed-scanning approaches [14, 23]. However, the level of formalization introduced by Arrow remains quite useful in an ontological analysis perspective, such as that of the present work. This also in consideration of the growing interest in pure and applied mathematics research, which have produced further interesting reflections. A particularly innovative elaboration was built starting from the field of System Theory with the possibilistic function of Zadeh [46]. Following fuzzy logic, scholars have explored solutions to Arrow's theorem by proposing the aggregability of individual preferences according to different membership degrees, ordered within the typical fuzzy range [0; 1]. Interesting results have emerged from these attempts, which are still formally viable even if not yet fully shared and consolidated [16, 19, 26].

Even with a structurally oriented approach, the reflection on decision-making contexts presents an agentive dimension that connotes space beyond its prerogative of a simple background, towards a complex interactive and proactive essence. The urban space, the theme of this contribution, is a context of extremely varied agentive decisions that characterize a real 'system' of agents [6, 31]. In a sociospatial domain this shows up as an area of mutual multidimensional and multidirectional relationships between human agents, between human agents and non-human, biotic and abiotic, natural and artificial agents, etc. In addition to a multiplicity in terms of agent's type and nature, other elements can usefully be highlighted in the characterization of agents. According to consolidated literature, a multi-agent system (MAS) is a set of agents located in a certain environment and interacting with each other through a suitable organization [15, 42, 44]. In a MAS located in a socio-spatial environment that is defined in this way, some key characterizing problems can be highlighted, useful for representing the agentive/social level in urban space [15]:

1) The action-that is, the ways in which a set of agents acts simultaneously in a multi-characterized, fragmented space, and with which the space in turn interacts in response to the agents.
2) The cognitive model available to the agent - that is, the ways in which the cognitive structure of the agent relates to space.
3) The nature of interactions - intended as a source of both opportunities and constraints, in relation to the modalities (e.g. the language/s used) and the forms (e.g. collaboration, cooperation, altruism, selfishness) of relationship between agents.
4) Adaptation dynamics - both at an individual level (for example in terms of learning) and at a collective level (in terms of evolution-or involution).
5) The implementation processes - that is, the definition of formalization rules for spatial relationships and knowledge representation.
   Further questions can be added to these ones, concerning:
6) Multiple levels of operations - that is, different level activities that can be concentrated in a single agent, for example when circumstances cause specific agents to start high level functions in addition to routine activities.

7) Types of agents. According to Jacques Ferber, a classification of agents can be made through two criteria: a typological one (cognitive/reactive agents) or a behavioral one (teleonomic/reflex behavior). The typological distinction basically concerns the agent's representation of the world. A cognitive agent is able to draw reasoning from its symbolic representation of the world, while a reactive agent can only draw perceptions, that is, subsymbolic representations. The behavioral distinction, on the other hand, discriminates between the methods of action of the agents. A teleonomic behavior is connected to intentional actions towards explicit objectives, while a reflex behavior is connected to perceptual tendencies coming from the agents themselves or from the external environment [15].
8) The environmental agent. The space-environment can play different roles in a MAS model. Intended both as an artificial computer-based infrastructure and as a natural framework for the interaction between agents, the space-environment represents an essential part of the system. As mentioned above, it is often traditionally seen as a static field with zero or merely reactive attitudes towards external stimuli. However, even if only reactive attitudes are available, it can be categorized as a type of agent within a MAS model, with relations with external agents that explicitly require further investigation and formalization (Ferber and Muller, 1996). Moreover, in recent times the environment has also been interpreted as a proactive agent in some situations, with interesting attempts at modeling transactions interacting through theories and logical rules [22, 43]. In particular, in anthropic transformation processes with an impact on natural resources, environmental characteristics tend to be enhanced and can be elevated as proxies of environmental agents, for example in an environmental conservation perspective [30].

In this context, and in a perspective of analysis or possible construction of ontological models of urban space, a final digression may therefore be useful. It concerns the outcomes that the previous analytical-taxonomic premises have induced in the traditional field of development and deepening of the MAS. We are obviously referring to the domain of computer science and artificial intelligence, which in recent decades has produced complex and advanced MAS-based operating models and architectures. A multi-agent architecture in this context consists of agents characterized in particular by some peculiar connotations, including the following [5]:

1) Agents own decision systems. Decision theory, which we discussed earlier, is the main source for a study of this field. This also happens in particular in terms of relations with the context of space-environment, with the related cognitive problems embedded in navigation and exploration tasks [12, p.45].
2) Agents need a cognitive model. One of the models often used in this field is the classic BDI model (Beliefs-Desires-Intentions) [45, p.21].
3) Agents should have a communication system. Here the problem of languages matters, which can typically be common (e.g. oral, symbolic, gestural etc.) or specialized (e.g. Knowledge Query and Manipulation Language, KQML, or the FIPA-ACL standard, Agent Communication Language) [34].

Clearly, these are key characters that inevitably and reiteratively occur. By analyzing and observing the prerogatives of these system architectures, interesting suggestions can emerge. They are important for the definition, almost from a de/reconstructive perspective, of an interpretative process of the agentive/social level, useful in the ontological perspective of spatial analysis addressed in this work.

3 A System of Representation of the Spatial Knowledge Level

3.1 Toward a 'Diffuse Individuality' or the New Individual-Collective Sight in City

This writing aims to be a hinge between the conceptualization of the city as a physical artefact immersed in material reality and a more abstract conceptualization of the city as a set of different spaces. In the last decades, the study of cities has become more and more inclusive of the immaterial aspects that, with today new consciousness of the phenomena, are clearly relevant for the city. These aspects even though not material are defined and definable and not less real than the physical aspects of the city, these are for example the dynamics of living that insist on the city, that inhabit it, animate it and shape its specific identity. In turn, these dynamics involve (and are generated by) individuals and organizations. The tension inside certain activities take place around and thanks to the spaces/places of the city. The double term of 'space/place' we use is about the definition of spaces dense and rich in lived meaning, and that is plenty of sense beyond their physical matter. These spaces/places sometimes are shaped during durable times. They are inherited through the centuries or sometimes formed in a few decades.

The city is a modified topological and geographical space in the sense of being a specific place in a physical region with geographical characteristics and affordances, and this region has embedded the physical transformations due to the activities of the city-system itself [38]. Previously we have posed and carried out an ontology-driven analysis of cities distinguishing three layers in the city: the modified place layer, the agentive layer and the knowledge layer [10].

Our aim here is to offer a way to read and interpret how space enters the layers that "make" the city through the method of ontological analysis, the aim in this paper (and more generally in our research path) is to deepen our knowledge of the city. In fact, the general aim is to make it clearer, less ambiguous and more sharable among all the actors (human and non-human agents) involved in a planning process.

In any of these cases we have to consider all the external causalities that forge the development of cities: their histories, their shapes, maybe their intrinsic tendencies towards certain types of evolution (often luckily changeable).

Intrinsic limits for planning processes are due principally to: (i) the limited rationality of the planners (a single agent or as a team, a collective agent) that are involved; (ii) the long duration needed to produce an answer and to implement a responsive tool for the city (as for an example plan, as analysis, as strategies); (iii) the almost complete lack of ad hoc monitoring and the consequent inability of reacting to plan deviations, or to rethink solutions when a previously unknown factor bursts into the scene.

External limits and external causalities to the planning process take an important part in drawing heavy limits to the effectiveness of a plan or of a strategy or a proposal for the organization of the city. These external limits deal with how our social systems are stated: (i) the political and decisional power and volition, and (ii) the economic pressure profit-oriented.

As architects and planners, we are used to conceiving the space around us as something physical, material, and metrical, even though intangible; something to model, to organize, to design, to conquer, to inhabit: a kind of void to populate with objects useful (or at least necessaire) to afford human inhabiting needs. Anyway, we have to recognize the necessity to integrate the different layered meanings that exist in the city, i.e., the abstract urban object in its wholeness, a complex and dynamic abstractness and materiality that are coexistent.

At any rate, already the philosophical reflection about space deals with the matter of the relation among parties that are there and participate in the space in different states. As an example, the nature of the relation between abstract geometry and its practical expression has been considered [20]. Space can be thought of as composed of all (actual and possible) positions of objects; pure space is space with all solid bodies removed, and distance the primitive concept we use to discuss the separation between bodies [20, 24]. The space of the city has always coexisted with a socio-technical system. Technologies have evolved in time by becoming increasingly widespread and activating dematerialized connections. The city is an increasingly dense and stratified socio-technical system. As an analogy, roads have formed one of the first infrastructure of the territory and cities, they have become more complex, larger, specialized, reaching levels of ever greater sophistication. Over time, other socio-technical networks were imposed on the environment, the territory and the city. Here, we have in mind the long evolution and stratification of various networked technological systems, from aqueducts to railways, from electrical networks, to oil and gas pipelines, telegraphic and telephone lines, radio, television, satellite transmissions, the world wide web, and all subsequent technologies.

We live in a mixed space that is increasingly growing: the digital revolution interweaves our reality with a pervasive plot of circuits that produces a material/virtual universe, expanding our consciousness to a new sense of intangible proximity [29].

Social contexts–and especially urban systems–can be seen nowadays as socio-technical systems (STSs), constituted of technical artefacts, social artefacts, and living beings (humans and not humans). As the complexity of such systems increases, their governance must be proportionally addressed, especially to face unexpected critical situations and guarantee overall system resilience [21].

The city is a complex whole made of human and non-human beings, made of physical material objects and intangible objects, the city as a unicum made of dynamics, relations, actions. But to understand the city in general, and specifically a particular one, we have to warp the weft that makes it and look inside, trying to interpret with a different sight, the individual's sight about the city and inside the city, and the individual/collective habits in the city. It is a matter of perspective and granularity too.

It is necessary to conceive that the sense of the comprehension of space, and specifically of a city is in the sight (and in the mind) of the agent who sees it, get on it, gives it a sense. In the different repetition that takes place in the making of the city developing it across space and the time it is generated as a relation, we test a tension between the city's parts, the agents, the city's knowledge itself (for each of the individual subjective knowledge and as a sum of distinct individual knowledge).

About the sight from inside of the molecular elements that form the city itself, it is useful not to forget the relationship between voids and solids that compose the city network structure. This relationship can be represented by imaging the tense flowing among spaces connecting them: they are the vectors (line) and nodes of this structure/network in some way never firm, dynamic, if not mobile. With new technologies, we deal with new model of abstract connections model a new abstract space (in and out of the city) that in some sense overlays the physical space itself. Connections made possible by computers and sensors are windows across the physical space, this re-model the relations between the material points in a new virtual space.

There is another level of space to be considered, in some sense, this is more material, and is about a kind of micro granularity of the scenario: it corresponds to the repeated gestures (lives) of every single agent, for example going back home and going out to work, to shopping, to definite places (the square, the seaside, the belvedere). Those habits trace infinite personal, individual maps that do not fit with the geographical, topological maps we usually deal with.

3.2 Exploring Theoretical and Pragmatic Methods

Cities are stratifications in time that stand side by side and overlap (Rossi, 1966). Their analysis could be an opportunity to engage in a new way to map space. But does this give an interpretation of space analogous to the one the inhabitants of that city have? And what is to be an inhabitant? Is it just being constantly present at the site? Does it make sense to talk about aggregates in the form of cities? Or must we take into account the 'n' near-infinite units (for example modules - points - nodes - trajectories) more or less mobile (with degrees of variability) that coincide with a modus of conscious and active individual identity? Does this individual identity in turn reinterpret inhabitants and models?

With the awareness of the problems posit by these questions, we begin to re-identify the aggregate spatial, agentive, relational, cognitive form of the city and reconsider it in a co-individual form of a community that inhabits a city (space-place-place).

Maybe at this point it could be useful to study more in-depth the distinction between space and place, to better affirm our interest in considering the city composed by the layer of place, that participate of space, and to better analyze what is the concept of space in the three-layer we identified (elicited) in previous contributions [10, 39].

In literature, we can find references to the multidimensionality of place and discussions about its different aspects in geography [33]. One interpretation is about the subjective and objective interpretation of both space and place. The subjective dimension embraces individualistic meanings attached to place basically in the representational level whereas the objective denotes the'naturalistic qualities of place' [33]. This reflection brought [13] to define the "betweenness of places", as a place where meanings and objective reality encounter [33]. Anyway, the reading of a space-place as proposed by Pasini [29] leads to the definition of a 'symbiotic field' that refers to space, *topos* and *chora* [25, p.99] or locus [32, p.103] and spatium [8, p.403], where anthropogenic and geogenic [3] systems intersect, producing the multilayered cognitive construct we are dealing with [29].

Cities have been and remain dynamic, polycentric systems [10, 27], new technologies populate the environment of nets, links, dynamics, that have knots in a physical place but at the same time can spread all around the world.

New technological infrastructures could implement the quality of the socio-technical system giving to decision-makers new opportunities, and giving people a chance to control the system they are in. What is needed is the ability to understand how their input relates to the relevant systemic components, which may concern structural, functional, normative, environmental, or strategic aspects, and navigate their mutual relationships [21]. Especially in a crisis, people's input may be related to a faulty component, a broken communication link, an absurd rule, an ineffective business strategy. A good model should be able to give them, at least in principle, the possibility to understand how their specific input relates to the whole system, and hopefully how they can contribute to the global resilience [21]. Here again, we can see how the ontological approach could be useful and how it is needed to develop an ontological theory of Socio-technical Systems aimed at describing the various aspects above and their complex relationships, by expanding and integrating existing foundational theories of technical, social and legal artefacts. This could integrate our 'knowledge system' about the city. To know a city, the starting point is delving into the neighborhood, the set of places around the agent begins to form a map, where interiors and exteriors flow ones into each other or stop in front of doors, private portals, walls without access to the inside.

Paradoxically, we have to consider that there will always be a more central center, although several 'centers' coexist, they could be indifferent to other centralities. Also, they could be interpreted as connected in a sort of network of centralities.

The concept of space often remains founded on its geometrical reading, which gives us back its Euclidean measurability, the rigorousness of the postulated V, which has been joined in the centuries by non-Euclidean geometries. These have revealed a new complexity of the spatial fact, albeit abstract where the parallels multiply, the 'saddles' deform the perspective. Perhaps this could be intended as a metaphor for real complexity of the urban spaces that overlapped, layered, erased in the time, which have preserved previous memories, intuitions of future space and have been structured beyond walls, squares and public halls, symbolic monuments, geographical and geological signs forfeited in functions and symbolic signs of the city, in the city. The city's space itself it is realized in a social collectivity, in collective knowledge, and expresses a knowledge extraneous to itself beyond the individuals and the single stone that articulates it.

There is a first attempt here to propose an interpretation for the reading of the shape of the city which, takes into account the fluid interaction between the inside and the outside which in their setting define the overall shape of the city in finer granularity.

Traditionally the study of the shape of the city is called morphology. Urban morphology has known an important 'scientific' development in the 1950s thanks to Saverio Muratori research and subsequently by the so-called 'Scuola Romana'. Anyway, the word morphology existed previously, in fact, it was first proposed by Johann Wolfgang Von Goethe (1749–1832). Goethe used the word morphology to designate the 'science that deals with the essence of forms' [28, p.2].

The natural context is the first condition for the establishment and organization of the different elements of urban form. The land relief, the quality and suitability of soil and subsoil, the climate, the solar and wind exposure, the type of natural landscape [28]. As an example, the Persian life, art, and architecture Tavassoli affirms to be shaped by mountainous and desert [40].

A renewed interpretation of the urban morphology comprises the study of urban forms, of agents and processes responsible for their transformation; the urban form refers to the main physical, geographical, topological elements that structure and shape the city and then by urban tissues, streets (and squares), urban plots, buildings, to name the most important [28]). Different granularities take part to the complex game of being of the city, the making of it and then transforming it.

An analysis of the city for effective support to the decision and interpretation for the city has to consider: a harmonious integration of mass and space; consideration to origin; environmental knowledge; aesthetic knowledge; aesthetic experience; development problems; principles of urban spatial organization. This is a proposal by Tavassoli derived from his attentive reading to the geographical and climate as the point of the origin of the city's shape and identity. He looks back to the origin of forms operating a confrontation between coeval cities in different geographical areas: European cities, Chinese cities, Persian cities [40]. It is interesting to point it out here the importance of 'where' the city is founded (or is born) to have an a-priori lens for the relations that shape it.

The awareness of the non-homogeneous nature of time, of how time flows with different rhythms for different individuals and social groups, for different activities and on different occasions and places has perhaps become the real problem of the twentieth-century city and its project adds new layers of analysis [35].

4 Final Remarks

This work is part of the studies for the creation of cognition-based models to support spatial decisions in urban planning and management contexts. In particular, the paper explored aspects of the configuration and relationships of the agentive and spatial components of the city, from an STS perspective.

The study analyzed the agentive dimension, aiming to capture and highlight the characters of relationship and spatial contextualization in decision-making actions. The analysis began by reflecting on the potential actions of agents in the multiformity of multi-agent decision-making contexts - of which STS are intrinsically characterized. Reflections developed in the economic and partly environmental literature were taken into consideration, proposing model layouts referable to MAS architectures with cognitive characterization. A particularly intriguing aspect of this characterization is the modeling of the 'environmental agent', whose intrinsic multidimensional complexity represents a specific topic for reflection in MAS approaches - although still debated.

The spatial dimension of the environment was therefore specifically investigated in the paper, as a complex stratification and representation of metric but also behavioral and emotional, agent-inspired features. The analysis induces to highlight aspects of the characterization of the space as aggregated entity and/or entities in the organization of the

STS. However, the analysis also emphasizes the relevance of aspects of disaggregation of the space into components and of mutual relationality between components, and between disaggregated elements towards aggregate entities. In particular, the second part of the analysis focuses on the identification of possible formal characterizations of the spatial components/elements in their aspects of individual granularity and scaling. As a result, the study seems to add a deeper and more articulated insight to these spatial entities, apparently and traditionally simple and instead of great intrinsic complexity. It seems to integrate the results of significant complexity already emerged within the previous agentive analysis, possibly exasperating the general complex layout.

However, the traditional synthetic and reductionist approach that exalts a standard stereotype of citizens and an urban environment as a passive theater of their actions is no longer suitable today. The city today appears to be more and more consciously complex and difficult to manage through aggregate and undifferentiated approaches. Today we deal with 'smart city' but the network approach included in this concept needs to embed the fine understanding of the parts, attributes, instances, nodes and relationships of the urban object, to which the network itself must adhere, in order to function and be effective. STS today can take advantage of smart supports and grid-oriented infrastructures, which allow systems to evolve towards functionalities more consistent with the organizational and relational contexts of current urban communities.

In this framework, the disaggregated analysis carried out here is able to prefigure the suitability of this approach in ontological terms, in order to investigate this complexity in an analytical and fine-tuned way. In fact, the ontological approach is also intended as a potential tool for formalizing features, instances and relationships, within this STS [21]. It is evident that these efforts are still prodromal to a real ontological modeling, oriented to investigate in advance the scope of work of an ontological analysis - which is large and articulated, and increasingly extends almost fractally after each new reflection.

However, it is an extremely useful and interesting perspective in reasoning on the smart city. In fact, in this framework the follow up of this study envisions the possibility of creating MAS-based prototypes of decision support architectures in urban contexts. Therefore, the development of this research will be oriented towards these objectives in the near future.

References

1. Arrow, K.J.: A difficulty in the concept of social welfare. J. Political Econ. **58**, 328–346 (1950)
2. Arrow, K.J.: Social Choice and Individual Values. Wiley, New York (1963)
3. Baccini, P., Brunner, P.H.: Metabolism of the Anthroposphere: Analysis, Evaluation Design. MIT Press, Cambridge (2012)
4. Badham, R., Clegg, C., Wall, T.: Socio-technical theory. In: Handbook of Ergonomics, John Wiley, New York (2000)
5. Balke, T., Gilbert, N.: How do agents make decisions? A survey. J. Artif. Soc. Soc. Simul. **17**, 13 (2014)
6. Batty, M.: Agents, cells, and cities: new representational models for simulating multiscale urban dynamics. Environ Plan A **37**, 1373–1394 (2005)
7. Baxter, G., Sommerville, I.: Socio-technical systems: from design methods to systems engineering. Interact. Comput. **23**, 4–17 (2011)

8. Böhme, G.: Atmosphere as the subject matter of architecture. In: Ursprung, P. (ed.) Natural Histories. Lars Müller, Zurich (2006)
9. Borgo, S.: An ontological view of components and interactions in behaviorally adaptive systems. J. Integr. Des. Process. Sci. **23**, 17–35 (2019)
10. Borgo, S., Borri, D., Camarda, D., Stufano Melone, M.R.: An ontological analysis of cities, smart cities and their components. In: Nagenborg, M., Stone, T., González Woge, M., Vermaas, P.E. (eds.) Technology and the City. PET, vol. 36, pp. 365–387. Springer, Cham (2021). https://doi.org/10.1007/978-3-030-52313-8_18
11. Davoudi, S.: Planning as practice of knowing. Plan. Theory **14**, 316–331 (2015)
12. Dennett, D.C.: The Intentional Stance. MIT Press, Cambridge (1989)
13. Entrikin, J.N.: The Betweenness of Place. Springer, London (1991). https://doi.org/10.1007/978-1-349-21086-2_2
14. Etzioni, A.: Mixed-scanning: a "third" approach to decision-making. Public Adm. Rev. **27**, 385–392 (1967)
15. Ferber, J.: Multi-Agent Systems: An Introduction to Distributed Artificial Intelligence. Addison-Wesley, London (1999)
16. Fono, L.A., Donfack-Kommogne, V., Gabriel Andjiga, N.: Fuzzy arrow-type results without the Pareto principle based on fuzzy pre-orders. Fuzzy Sets Syst. **160**, 2658–2672 (2009)
17. Forester, J.: Bounded rationality and the politics of muddling through. Public Adm. Rev. **44**, 23–31 (1984)
18. Gehrlein, W.V.: Condorcet's paradox. Theory Decis. **15**, 161–197 (1983)
19. Gibilisco, M.B., Gowen, A.M., Albert, K.E., Mordeson, J.N., Wierman, M.J., Clark, T.D.: Arrow and the aggregation of fuzzy preferences. In: Fuzzy Social Choice Theory. SFSC, vol. 315, pp. 53–87. Springer, Cham (2014). https://doi.org/10.1007/978-3-319-05176-5_4
20. Gray, J.: The epistemology of geometry. In: Zalta, E.N. (ed.) The Stanford Encyclopedia of Philosophy (2019). https://plato.stanford.edu/archives/fall2019/entries/epistemology-geometry//. Accessed 19 May 2021
21. Guarino, N., Bottazzi, E., Ferrario, R., Sartor, G.: Open ontology-driven sociotechnical systems: transparency as a key for business resiliency. In: De Marco, M., Te'eni, D., Albano, V., Za, S. (eds.) Information systems: crossroads for organization, management, accounting and engineering, pp. 535–542. Springer, Heidelberg (2012). https://doi.org/10.1007/978-3-7908-2789-7_58
22. Le Page, C., Becu, N., Bommel, P., Bousquet, F.: Participatory agent-based simulation for renewable resource management: the role of the Cormas simulation platform to nurture a community of practice. J. Artif. Soc. Soc. Simul. **15**, 10 (2012)
23. Lindblom, C.E.: The science of "muddling through." Public Adm. Rev. **19**, 79–88 (1959)
24. Locke, J.: An Essay Concerning Human Understanding. Penguin Books Limited, London (1997)
25. Montaner, J.M.: Espacio. In: de Solá-Morales, I. (ed.) Introducción a la arquitectura. Conceptos fundamentales. Universitat Politécnica de Catalunya, Barcelona (2000)
26. Mordeson, J.N., Clark, T.D.: Fuzzy Arrow's theorem. New Math. Nat. Comput. **05**, 371–383 (2009)
27. Okner, T., Preston, R.: Smart cities and the symbiotic relationship between smart governance and citizen engagement. smart cities: foundations, principles and applications, pp. 344–372 (2017)
28. Oliveira, V.: Urban Morphology: An Introduction to the Study of the Physical Form of Cities. Springer, Cham (2016). https://doi.org/10.1007/978-3-319-32083-0
29. Pasini, R.: Landscape Paradigms and Post-urban Spaces: A Journey Through the Regions of Landscape. Springer International Publishing, Cham (2018). https://doi.org/10.1007/978-3-319-77887-7

30. Phillips, R.A., Reichart, J.: The environment as a stakeholder? a fairness-based approach. J. Bus. Ethics **23**, 185–197 (2000)
31. Rabino, G.A.: Processi Decisionali e Territorio nella Simulazione Multi-Agente. Società Editrice Esculapio, Milano (2005)
32. Rossi, A.: The Architecture of the City. MIT Press, Cambridge (1984)
33. Saar, M., Palang, H.: The dimensions of place meanings. Living Rev. Landscape Res. **3**, 5–24 (2009)
34. Searle, J.R.: Social ontology: some basic principles. Anthropol. Theory. **6**, 12–29 (2006)
35. Secchi, B.: La città europea contemporanea e il suo progetto. Territorio. **20**, 78–92 (2002)
36. Simon, H.A.: Administrative Behavior: A Study of Decision-making Processes in Administrative Organization. Macmillan, London (1945)
37. Simon, H.A.: The Sciences of the Artificial. MIT Press, Cambridge (1969)
38. Stufano, R., Borri, D., Camarda, D., Borgo, S.: Knowledge of places: an ontological analysis of the social level in the city. In: Papa, R., Fistola, R., Gargiulo, C. (eds.) Smart Planning: Sustainability and Mobility in the Age of Change. GET, pp. 3–14. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-77682-8_1
39. Stufano, R., Borri, D., Camarda, D., Borgo, S.: Knowledge of places: an ontological analysis of the social level in the city. In: Gervasi, O., et al. (eds.) Computational Science and Its Applications – ICCSA 2017. LNCS, vol. 10407, pp. 687–694. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-62401-3_50
40. Tavassoli, M.: Form, Space and Design: From the Persian to the European Experience. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-15831-6
41. Thompson, E.A.: A Pareto optimal group decision process. Pap. Non-Market Decis. Making. **1**, 133–140 (1966)
42. Weiss, G.: Multiagent Systems: A Modern Approach to Distributed Artificial Intelligence. The MIT Press, Cambridge (2000)
43. Weyns, D., Holvoet, T.: Synchronous versus asynchronous collaboration in situated multi-agent systems. In: Proceedings of the Second International Joint Conference on Autonomous Agents and Multiagent Systems (AAMAS 2003), Melbourne, Australia. ACM (2003)
44. Wooldridge, M.: An Introduction to Multi-Agent Systems. Wiley, London (2002)
45. Wooldridge, M.: Reasoning About Rational Agents. MIT Press, Cambridge (2003)
46. Zadeh, L.: Fuzzy sets. Inf. Control **8**, 338–353 (1965)