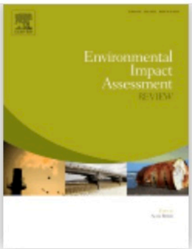

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Announcements

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Expansion of the Environmental Impact Assessment Review Editorial Team

The journal's increased profile in the community has led to a consequent increase in submissions. In order to match this expansion in submission numbers, I am pleased to have opportunity and privilege to welcome Dr. I-Shin Chang and Dr. Alberto Fonseca to join the editorial team as Associate Editors.

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Rethinking vulnerability in city-systems: A methodological proposal to assess “urban entropy”

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ABSTRACT

This paper aims at proposing a possible alternative point of view to investigate the vulnerability of urban systems. The basic ideal refers to the possibility of thinking about vulnerability as deriving by the interactions of several risks that can affect the urban system and by the interactions among them. In this sense, it is possible to refer to an “integrated territorial risk”. Considering the city as a complex and dynamic system that while evolving produce entropy is the main theoretical reference supporting this study. The loss of energy during the evolution of the system corresponds to some conditions of inefficiency that involve the whole system and, as such, this lost energy can be assumed as a “systemic entropy”. Is it possible to measure the levels of this vulnerability of the urban system when it stays in ordinary conditions, namely not during stress states that modify the state of equilibrium of the system itself? It is possible to assess the production of this “internal entropy”? In order to answer to these questions in mind, this study aims at analyzing dyscrasias that can occur within the main components of the urban system in order to individuate possible strategies able both to mitigate the fragility of the urban system and to improve its resilience.

1. Introduction

Urban systems are subject to multiple stresses that can continuously change their equilibrium. This intense exposure can generate significant damages to any human settlement and inevitably compromises the physical and spatial as well as the anthropic and functional dimensions.

Urban risks are generally attributable to the natural and anthropogenic macro-categories. For both categories it is possible to refer to a wide scientific literature and to the recognized equation:

$$R = V * E * P$$

where R is the *risk* related to the *vulnerability* (V), *exposure* (E) and *probability* (P) that a catastrophic event occurs.

In addition to the three above mentioned components, there is a further category of anthropogenic risk, which could be defined as “multiple risk”, deriving from activities that operate synchronously within the urban system and give rise to interactive relationships. The impacts generated by this risk category can be direct or indirect.

In the first case (direct risk), the impact affects the functioning of the urban system without occupying intermediate stages. In the second case (indirect risk) the impact can be mediated by elements that do not suddenly change the functioning of the urban system. The two types of impact affect urban subsystems at different levels. A definition of systemic risk may be poorly reliable if, with reference to the vulnerability of the system, the non-homogeneity of its component elements and the dynamic relationships between them are not considered. In this sense, the adoption of the systemic approach (used in urban literature since the 1960s) to study anthropic settlements can open new perspectives to figure out urban risk management and possible interactions between urban subsystems to face catastrophic events. The assessment of the propensity for damage of a dynamic and complex system must necessarily contemplate the interactions occurring between its different subsystems (Figure 1. In case of natural or anthropogenic disasters, these relationships (and the consequent negative effects) can multiply and intensify, giving rise to the so called “domino effect”. During the last twenty years the concept of resilience has taken strong consensus in urban planning theories, addressing to the capacity of the system to react to negative conditions caused by different events. More precisely, as underlined by Folke et al. (2002), resilience, for social-ecological systems, is related to three main characteristics: 1) the magnitude of shocks the system can absorb remaining in a given state; 2) the level of capability of the self-organization of the system itself; 3) the ability of

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the system to learn and to adapt itself to the transformation occurred (pag. 438). The way urban transformations are managed is crucial, as it can either destroy the system or reinforce its internal resilience (Carpenter et al., 2001; Holling, 2001). It must be considered that cities are also vulnerable to the negative consequences of overconsumption and global ecological mismanagement. At present, cities have become “entropic black holes”, as they consume energy and matter from all over the ecosphere and return all of it in degraded form back to the ecosphere (Rees and Wackernagel, 1996).

In view of the above considerations, this study proposes to consider urban vulnerability as an expression of systemic entropy (Wilson, 1970). In other words, the production of entropy during the evolution of the urban system represents a fragile condition of the system itself: in this state, in fact, the system is vulnerable to the effects deriving from unpredictable events.

The concept of entropy has its theoretical assumption in the Second Law of Thermodynamics[1] which allows for the determination of the variations of entropy, but not of its absolute value.

Thermodynamics is probably the most structured discipline to study complex systems (Ying, 2015; Bejan and Errera, 2016; Pelorosso et al., 2017) and has been widely applied to different fields, such as landscape economy (Annila and Salthe, 2009; Georgescu-Roegen, 1971; Von Schilling and Straussfogel, 2008), circular economy (Gao et al., 2020), organizational systems (Coldwell, 2016), ecology (Cushman, 2015; Ho, 2013; Naveh, 1987), sociology (Mckinney, 2012), urban planning (Fistola and La Rocca, 2014; Vandevyvere and Stremke, 2012), architecture and urban design (Braham, 2016; Vallero and Braiser, 2008).

The Second Law of Thermodynamics (Entropy Law) states that during any process of transformation useful energy is lost and irrecoverable and generates entropy in form of disorder and waste. The positive energy lost is also defined as exergy (the available energy) and it is a thermodynamic property of a system. Some scholars (Dincer et al., 2004; Valero, 2006; Gasparatos et al., 2008) defined exergy as a combination of the two thermodynamic laws since it can be assumed as a measure of both the quantity (First Law) and the quality (Second Law - Entropy Law) of different energy sources and defined only after the selection of a reference environment.

The Second Law of Thermodynamics has been recognized within the scientific context as a theoretical reference for the development of urban systems (Bristow and Kennedy, 2015; Prigogine, 1997; Rees, 2012; Rees and Wackernagel, 1996).

In a complex system, an increase in entropy leads to a decrease in available energy (Rifkin and Howard, 1980). When energy is no longer available, the highest degree of “disorder” within the system is reached (Ben-Naim, 2008; Silvestrini, 2012). Cabral et al. (2013) defined a reference framework about the main contributions of entropy theory to urban studies and pictured the main definitions of entropy within different scientific domains. Batty (2008) had already highlighted the difficulties involved in defining entropy, thus proposing a reinterpretation from a spatial analysis point of view.

Cities, like any other complex open system, are self-organizing systems that feed on consuming energy/matter coming from the biosphere (Prigogine, 1997) and, as such, they are also dissipative systems. Moreover, they cannot be self-sufficient since they continually need resources coming from the external context in order to run.

In the context of these considerations, the first part of this study, after tracing a theoretical framework, proposes an interpretative and theoretical model to understand the complexity of urban systems. The proposed model conceptualizes the city as a complex system consisting of three main subsystems: 1) the physical system (buildings, streets, houses, squares and all material but non-living components); 2) the functional system (activities, relationships and all the intangible components); 3) the socio-anthropic subsystem (citizens, users, perceptions and all those components that make up the life of the city) (Fig. 1).

In the second part, the issue of entropy has been framed in the context of urban systemic risks and considered as the result of several dyscrasias occurring within the urban system. In the third part, a first mathematical procedure to express the measure of entropy through an algorithm has been proposed.

Aware that this line of research could open innovative perspectives within the town and regional planning interests, the original contribution of this study may be probably caught in the attempt to individualize some thresholds to draw the existence field of the development trajectories for the urban system taking control of the production of entropy, in order to assure the system survival in better conditions. The individuation of the value of these thresholds can help decision makers support their choices towards more sustainable development goals.

2. Literature review

In the last decades, the theme of complexity particularly referred to complex systems has gained renewed attention within the scientific debate (McShea, 1991; Goldenfeld and Kadanoff, 1999; Lloyd, 2001; Taborsky, 2012).

Poli (2013) and Cilliers and Spurrett (1999) investigated the difference between complicated and complex, which is the starting point in understanding complexity science. According to these scholars, the main difference between complicated entities and complex objects is that the former, being aggregates of components, lack the integration and holistic nature of the latter. Other scholars (Taborsky, 2012) have longer wondered about the meaning of this difference that, in truth, is not sufficient to explain complexity. Only the concept of entropy can help effectively understand complexity. Ladyman et al. (2013) asserted that the complex systems community converges towards the acknowledgement that a measure of complexity should give the highest value to systems which are neither completely unplanned nor completely ordered.

Bar-Yam, 1997, Edmonds, 1995, Mitchell (2009) argued that the behavior of a complex system is difficult to predict for its being characterized by multidimensional and non-linear processes and structures (Allen et al., 2014).

The nexus between complexity and risks is the focus of this paper aimed at considering urban vulnerability from an alternative point of view, assuming the systemic approach as the principal theoretical reference (Gargiulo and Papa, 1993).

Johansen and Rausand (2014) provided a significant definition of complexity (referring to a sociotechnical system) within a risk assessment context. They highlighted the real sense of complexity referred to “the nature or our understanding of systems and phenomena” (pag. 272) and emphasized the existence of several definitions of complexity in literature (from general disciplines to quantitative analysis). The application of complexity to risk assessment is also debated in Jensen and Aven, 2018: the authors proposed a new definition of complexity in a risk analysis and explained that to understand the link between complexity and risks it is necessary to define the potential risks or threats inside a complex system. As known, the complexity of a system does not allow knowledge of its behavior and outputs.

A risk can be different if related to social conditions rather than to technical conditions (Vatn, 2012). For instance, risk can be associated to a terroristic attack (first case) or to an event that can interrupt the proper functioning of traffic conditions (second case).

The identification of risks and threats inside a complex system, however, is not effective immediately. Complex systems are open and nonlinear systems and as such the links among elements cause something more complicated than a simple chain of events, such as the Domino model of Heinrich (1941) which states that accidents result

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[1] The postulate of Clausius “Die Entropie der Weltstrebteinem Maximum zu” (The entropy of the world tends towards a maximum) is the basis of the Second Law of Thermodynamics.

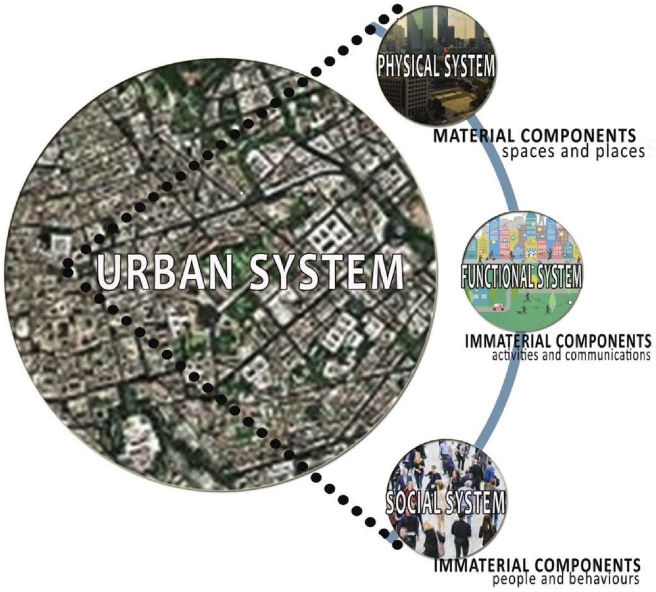

Fig. 1. Conceptual scheme of the urban system in three main subsystems. Source: Authors'elaboration.

from a chronological sequence of failures (sequential accident model) while, according to a systemic view, accidents cannot be understood individually.

The concept of complexity as a source of risk is not new. As stated by Johansen and Rausand (2014), risk can be assumed as a subjective outcome of three components based on the set of triplets of Kaplan and Garrick (1981): scenarios (s), probabilities (p) and consequences (c).

The definition of risk assumed by Kaplan & Garrick derives from an answer to the following three questions: a) what can go wrong? b) how likely is it to go wrong? c) if it does go wrong, what are the consequences? To these questions, Wall, 2011 added a fourth question referring to the decision maker preferences within the context of a managerial decision, since “there are no risks without knowledge of decision maker preference”.

The studies above mentioned, despite being strictly referred to engineering risk assessment in technical systems, are very interesting for the conceptual framework about complexity and the decision maker process to face a situation of risk.

With regard to the present study, it mainly focuses on the process of managing and planning urban transformation, considering the city as a complex system that evolves in space and time. The focus of the research is based on the attempt to look at the vulnerability of urban systems from a different point of view in order to investigate the relation between entropy and vulnerability of the city in its being a complex system.

Johansen and Rausand (2014) provided several insights about the complexity theory generated in the fields of physics, biology, cybernetics and meteorology and also involved very different disciplines, such as social science, computer science and town planning.

By applying theories of systems and control to the planning of human environments, McLaughlin (1969) opened new routes of investigation to examine how cities behave and respond to a wide variety of stimuli, even though when referring to complex systems it is not possible to achieve indisputable solutions.

The systemic vision has been the common ground for the development of town planning as a science and for the research in this field focused on monitoring the transformations occurring throughout the cities and (on a larger scale) the regions.

In this context, the reference to complexity also comes from the concept of aleatory (Poincaré, 1908) that relies on the possibility that some random effects can occur in a system, generating “chaos”. The theory of chaos is primarily based on the principle of uncertainty (Heisenberg, 1949), which underlies the unpredictability of a chaotic system that displays its high sensitivity even to the smallest action that can occur in its structure and, consequently, generates imprecision in the definition of its evolution.

The theory of dynamic systems can be considered as an indispensable reference in the elaboration of the conceptual framework for the study of chaos. Moreover, the definition of a dynamic system depends on the relations between its elements as well as on the laws that regulate its evolution and its change of state in time.

Though the definition and measurement of chaos still raise a number of questions within the scientific debate, there is consensus in recognizing entropy as a measure of chaos.

Entropy, as previously stated, has its main reference in the Second Law of Thermodynamics and represents the “price” to pay for evolution (Rifkin and Howard, 1980; Best, 1991). Actually, the second principle of thermodynamics does not refer exclusively to energy but takes into account also the importance of organization within the system (in terms of having an order): the degradation of energy generates disorder and, thus, disorganization. Referring to this principle, the organization of the system becomes a central focus in the study of complex systems (Morin, 1986; Morin, 2014). Chaotic complex systems, then, neither can be known in certain conditions, nor can be the objects of long-term predictions and this makes the check of a theory a very hard task.

In the last fifty years, research in urban and regional planning have not been extraneous to these concepts and cities have been treated as dynamic and complex systems (Allen, 1997; Batty, 2001; Coelho and Ruth, 2006; Batty, 2008; Allen, 2012; Schmitt, 2012; Li and Xu, 2015; Goh et al., 2016; Machin and Solanas, 2019).

The level of complexity achieved by modern cities, both as expressions of the collectivity and as spatial places, is so high that it is not possible to provide adequate solutions to the problems of the “city-system” which, like any other system, is subject to the process of maximization of entropy.

Von Bertanlaffy (1968) had already stated that the competition between the elements of the systems leads to the concept of antagonism, which is an essential feature of the system behavior but inevitably drives towards a potential disorganization (that is disorder). When the system lies into a state of crisis, disorder spreads out and this happens when differences turn into oppositions and complementarities into antagonisms.

Since the city can be thought as a dynamically complex system, the definition of a theoretical model to understand its evolution in time, reduce its complexity and identify its characteristics is needed.

In this regard, also Allen et al. (2014) underlined how complex systems (particularly referred to ecosystems) can be decomposed into structural and process elements defined over a fixed range of spatial and temporal scales. Inter alia, Allen et al. (2014) stated that the interactions between living and non-living elements of a system within a single domain of scale, their development, growth and decay, can be described as an adaptive cycle (Gunderson and Holling, 2002).

Holling (1986) demonstrated that in an adaptive cycle a system proceeds through four phases: growth, conservation, release and reorganization.

In the first phase (growth) the appropriation and use of resources occur. In the second phase (conservation) the system becomes more rigid; it tends to accumulate energy and its rigidity can take to a loss of resilience from the system itself. In the third phase (release), accumulated energy is released and this implies the need of a total reorganization. During the fourth phase (reorganization) the system has two possibilities: it can reorganize the initial asset (predictable trajectory) or assume a totally different structure (unpredictable trajectory).

Allen et al. (2014) tried to apply this model to the ecosystems focusing on the concept of “panarchy” and its possible application to the complex systems. Although the concept is not yet clearly defined, it can help understand how uncertain and unpredictable the evolution of a complex system could be. At the same time, it explains that a complex system, being a self-organized system, can tend towards conservativeness, substantially to preserve its initial state and resources, but its rigidity entails a loss of its resilience capacity and, thus, a fall into an entropy state.

3. Method and materials

In the present study, entropy (or the production of energy that is no longer available) is considered as a widespread negative condition of the urban system, which produces negative effects and malfunctions within the system itself. It has been assumed that this condition is due to an inappropriate use of available resources. The production of entropy is inevitable for a complex system to develop (Fistola, 2011), but what this study intends to demonstrate is that this production must be contained under the thresholds defining the limits for the system to survive (Fistola and La Rocca, 2014).

Cabral et al. (2013) masterfully debated the issue of entropy retracing the history of this concept and the main exponents who contributed to its applications. As he stated, the concept of entropy made its entrance into urban studies with Wilson (1970) who proposed a framework for constructing spatial interaction and associated location models.

Other scholars investigated the social aspect of entropy that may be interpreted as the level of resilience or adaptability of a social system to internal or external events. Very interesting in Cabral et al. (2013) is the set of definitions that contributed to the study of the relations between entropy and the issues of urban studies. The different definitions demonstrate how the concept of entropy can be heterogeneous, but, at the same time, they highlight that in different scientific domains it is unambiguously recognized that entropy is useful to measure the level of organization versus chaos (order versus disorder). Moreover, entropy addresses three big features of urban structure and behavior: the position/location, the mechanic/flow networks, and system scaling/size (Cabral et al., 2013 p. 5228).

As regards the scope of this study and considering the definition of entropy based on Shannon's information theory (1948) and the definition of Bayesian inference (Shannon, 1948; Chiandotto, 1978; Cabral et al., 2013), it is possible to refer to entropy as a subjective property of a system linked to the amount of information available for the system itself. On the other side, in thermodynamics, entropy represents a measure of the disorder in a system that - on equal amounts of energy - tends to move towards the state of maximum disorder (Rifkin and Howard, 1980).

Entropy, therefore, expresses the “degree of disorder” in a system: an increase in disorder corresponds to an increase in entropy and, conversely, a decrease in disorder results in a decrease in entropy.

As a measure of the degree of disorder or indeterminacy in a system, the concept of entropy could be extended to several application fields far from physics, such as the information theory elaborated by Shannon in the 1940s.

In an attempt to define the amount of information contained in a message and the cost related to its sending, given a transmission system and the difficulties encountered by a transmission channel (generally disturbed by noise), the intuition of Shannon was to equate the degree of ignorance with disorder. In his interpretation, the “message” is the amount of information that makes the receiver switch from a state of uncertainty to a state of order (or less uncertainty). Therefore, the amount of information - which is the negative of the amount of intrinsic uncertainty - becomes something very close to the “disorder” of statistical mechanics. Accordingly, a large amount of incongruous information leads to an increase in systemic entropy. This condition can be shifted with reference to the amount of information relating to the system state and not interpretable for the governance of urban and territorial transformations.

According to the conceptual scheme of the system, represented in Figure 1 as a set of interacting components, the “entropogenic” information (information that generates entropy) is similar to the relationships of the systemic structure, but such relationships are not processed by the system and, consequently, cannot be elaborated by the interested components.

Therefore, it is possible to state that these relationships are produced because of some dyscrasias (malfunctions) that occur within the subsystems composing the urban system.

The spread of the above mentioned relationships and of the effects of “negative interactions” between the components generates dyscrasias that increase the level of entropy, thus leading the urban system towards a structural crisis (Fistola, 2012). Structural crisis refers to the set of relationships happening between the elements of the urban subsystems: this crisis, in fact, can be mainly due to functional, economic and social failures (dysfunctions). These dyscrasias inevitably make the system more vulnerable.

Barbera and Butera (1992) proposed a procedure based on the identification of the different actors and factors involved in the urban system decision-making process and suggested quantifying entropy according to Shannon's definition. The authors considered the production of “systemic noise” (deriving from information overload) as a condition of dysfunction in the system. As the systems inherently tend to maintain their status quo, the changes entirely produced by new elements tend to undermine the system.

Likewise, changes that do not introduce new elements (but just confirm the systemic order and reduce the complexity of the system) lead the system itself towards a condition of crisis that equally produces a certain amount of entropy. In this regard and with reference to the information theory, it is possible to state that the evolution of a complex system is due to a learning process referred to the relation between alternation and equilibrium. This relation catalyzes the process of evolution. In an open system, an increase in entropy inevitably occurs when there is an increase in work and its productivity can be maintained only if the system expands. This condition points out that urban growth is necessary for the existence of the system, but, at the same time, it underlines the need to take the production of entropy under control (Yeh and Li, 2001; Fistola, 2012; Cabral et al., 2013).

4. Theoretic hypothesis: entropy as a destabilizing condition for the urban system

This study claims that entropy can be understood as the result of several dyscrasias (malfunctions) generated by the incorrect use of social, economic, geographical and territorial resources that urban subsystems need to develop and transform.

The possibility of formalizing or classifying in advance the “entropic thresholds” within the urban subsystems development trajectory allows for the identification of intervention priorities aimed at reducing the levels of risk for the whole system. Based on such individuation, the public decision-maker can be enabled to define policies and actions to prevent urban vulnerability and, consequently, make appropriate use of the economic, social, urban and territorial resources needed by the system to evolve.

It has been assumed, thus, that within the system entropy and vulnerability are correlated. Therefore, the evolution states of the system must be constantly monitored, since the production of entropy involves, on the one hand, ineffectiveness of government actions, on the other, eversion in the trajectory of evolution of the urban system from sustainable objectives.

A procedure articulated in different phases can be proposed. In a first phase it is necessary to identify the laws that determine the evolution and transformation of the urban system. In a second phase, it is essential to define the achievable rules and objectives, in order to make the urban system evolve to future states while remaining within the range of expected trajectories along which the system assumes dynamic structures (compatible with the availability of its resources) that allow

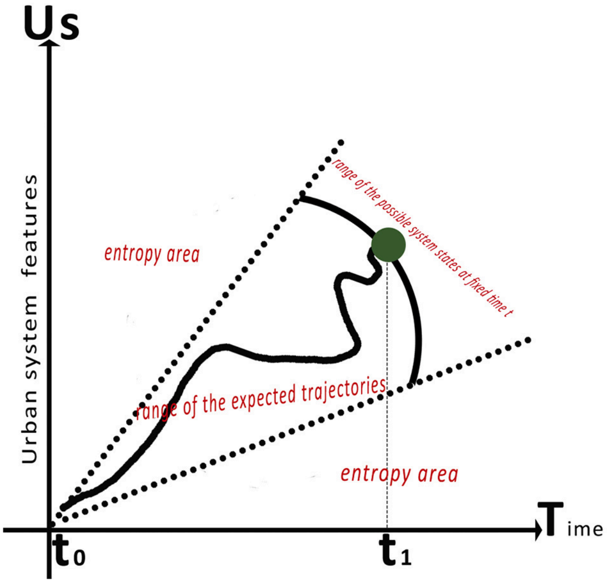

Fig. 2. The diagram illustrates the concept of evolutionary trend of the complex urban system. Projecting on the x-axis the time values and on the y-axis the features of the urban system, it is possible to suppose that the evolutionary trajectories of the urban system are included within a hypothetical area, delimited by the dotted lines. The external areas indicate entropy values. Source: Authors' elaboration.

its evolution following a “sustainable trajectory”.

The diagrammatic representation Fig. 2 explains the possible trajectory of evolution of the urban system represented on a two-dimensional plane in which the x-axis represents the time and the y-axis represents the urban system.

The point t_0 corresponds to the state of origin of the urban system that, for instance, can be the starting moment of analysis (the state of the art).

The point t_1 is the objective point towards which the urban system tends, in order to reach the “desired state” that corresponds to the targets of planning actions.

The starting point (t_0) could correspond to the beginning of the design phase of the master plan and of the objectives it wants to get in a certain time; the final goal is the point t_1.

If the city is assumed as a complex and dynamic system, it is clearly impossible to draw up the exact trajectory to shift the urban system from t_0 to t_1, but it is possible to trace a field of existence in which the planner wants to maintain the trajectory.

The control of the trajectory, thus, is one of the responsibilities of the planner, whose role is to support the decision makers.

The field of existence must be traced on the basis of the physical, social, economic and territorial resources the urban system already has (t_0) or wants to get in order to achieve the desired state (t_1). If the system is maintained within the range of compatible configurations it is possible to implement a “system control” process towards states able to guarantee its equilibrium.[2]

These configurations (or future structures/states of the system) can be considered as evolution scenarios in which the system could reach a condition of “minimum entropy”. If the primary aim of urban planning is to reduce the conditions of systemic risk, it must necessarily concern the development of policies, actions and plans able to maintain the city-system within the range of the expected trajectories. The deviation from this range and the consequent decay in the entropic areas can be determined, for example, by an incorrect definition of the development strategies and objectives, or even by an incorrect implementation of the actions necessary to pursue the development objectives set out.

When the system drops into the areas of reversible entropy, it leaves the processes of evolution (entropy-controlled) and generates anomalous development phenomena. In this case, the system produces negative external events that amplify negative conditions in the system, such as: land consumption, urban pollution, traffic congestion, excessive production of urban waste, social conflicts.

If these conditions occur, to bring the system back to the controlled evolution area (expected trajectories range) it is necessary to define appropriate actions as well as recovery, redevelopment and revitalization policies that require additional resources to be activated (Fig. 3**).**

The reasoning can be better understood by referring to a division of the entropy areas in which the system can drop without appropriate government actions.

The entropic zone (or the area in which the system is in vulnerable conditions) can be further subdivided into two parts: a zone of “reversible entropy” and a zone of “irreversible entropy” (Fig. 4).

The first zone (reversible entropy) represents a phase in the evolution of the system in which corrective actions must be taken to bring the system back to the admissible trajectory conditions.

During the evolution of the system, the zone of irreversible entropy represents a phase in which no further actions to recover the urban system can take place and consequently it drops into a condition of “heat death”.

This condition manifests itself in the presence of anthropic risk generators that have a devastating and irrecoverable impact on the urban system.

The presence of risks produced by human actions that are unplanned or incompatible with the characteristics of the urban/territorial system could be mentioned among the anthropic risk generators.

The Chernobyl disaster occurred in 1986, for instance, can represent a significant example of the decay of the system into the zone of irreversible entropy generated by the anthropic action, due to malfunctions and lack of control of the system (anthropic risk).

The derailment of a high-speed train occurred in Italy in the early morning of 6 February 2020 can be another example of the effects that an uncontrolled anthropic action can trigger on the organization of the system.

5. Results: A first proposal for “measuring” systemic entropy[3]

The objective of this part of the research is to provide an accurate and operational definition of “systemic entropy” referring to the three main subsystems which make up the urban system.

The procedure proposed is intended to show how to define an “entropy threshold”, which represents a limit value beyond which the elements composing the urban subsystems drop into vulnerable conditions.

The entropy conditions generated within the subsystems can be expressed through mathematical formulations that also consider the concatenated and synergistic effects arising among the elements of the subsystem.

On this basis and taking the systemic logic as a theoretical guide, we assume that the entropy of the physical subsystem can be expressed by eq. (1):

$$\boldsymbol{H_c = f(S, M, N)} \quad (1)$$

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[2] The equilibrium of a dynamic and complex system is a dynamic condition itself.

[3] The contents of this part have been developed by the research group coordinated by prof. R. Fistola, within the Metropolis project (Integrated and Sustainable Technologies and Methodologies for the Adaptation and Security of Urban Systems). The project was aimed at the definition of methodologies for the evaluation of natural and anthropogenic risks in urban environments.

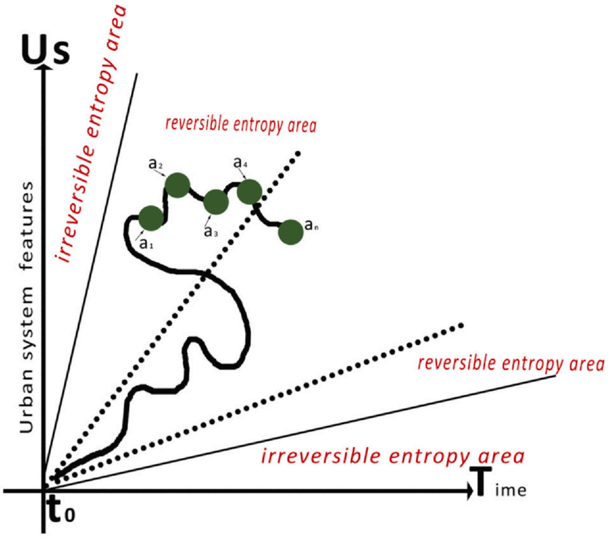

Fig. 3. Urban system recovery – lapsed in the reversible entropy area – through the implementation of actions (a1, a2, a3, … an) which envisage the use of additional resources. Source: Authors' elaboration.

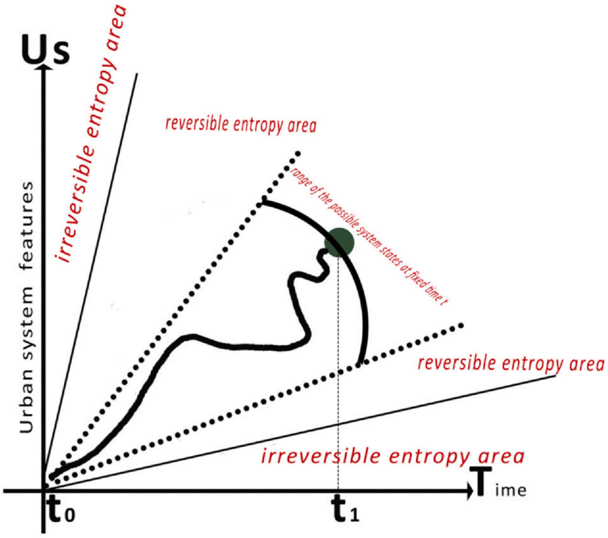

Fig. 4. Division of the entropy zones into reversible entropy area and irreversible entropy area.
Source: Authors' elaboration.

where:

H_C = entropy of the single building (physical container);

$\boldsymbol{S}$ = structural conditions of the building (physical container)*;*

$\boldsymbol{M}$ = conditions of building materials (composition of the physical container)*;*

$\boldsymbol{N}$ = conditions of communication networks inside the building (container connection).

The elements in (1) can be expressed through physical parameters (i.e. age of the structure, construction time, construction typology, presence/absence of technological networks, etc.) and qualitative and/or quantitative parameters (for example, with respect to the networks, a parameter of the infrastructural building/container could be expressed by the ratio between the length of the water network serving the building and the total water connections in the area where the building is located).

The physical entropy of the building/container is a composite indicator substantially connected to the physical conditions of the specific urban structure. It should be emphasized that the terms of the eq. (1) respect a hierarchical order in which the structural condition is prevalent if compared to the others, since the structural elements in case of discrepancy can compromise the functioning of the building/container system.

If the value of the first hierarchical variable (structural conditions) assumes a high value (corresponding to a bad condition of the structural apparatus), conditions of maximum entropy occur, which would make the evaluation of the other variables superfluous.

Following the same reasoning, the entropy of the functional system can be expressed by eq. (2):

$$\boldsymbol{H_f} = \boldsymbol{f}\ (\boldsymbol{O}, \boldsymbol{F}, \boldsymbol{A}) \tag{2}$$

where:

H_f = entropy of the activity or urban function (residence, education, safety, health, justice, etc.);

$\boldsymbol{O}$ = number of employees (subjects who carry out the specific urban function);

$\boldsymbol{A}$ = accessibility (physical and immaterial) to the function*;*

$\boldsymbol{F}$ = frequency or repetition of an activity/urban function in a set timeframe that defines the load of this activity on the urban system.

In eq. (2), the hierarchically superior variable is relative to the number of employees who legitimize the urban function and carry it out. The variable relating to frequency can be understood as a measure of the role of an urban function within the urban system. Frequency, in fact, refers to the repetitive presence of the same function in the urban system. Accessibility refers to the capacity of a hypothetical user to reach the place where the urban function is located (physical accessibility) or the time needed to connect with the service related to the function (education, health, banking, etc.), for instance by website (immaterial accessibility).

With reference to the socio-anthropic subsystem, entropy can be expressed by eq. (3):

$$\boldsymbol{H_s} = \boldsymbol{f}\ (\boldsymbol{S}, \boldsymbol{I}, \boldsymbol{C}) \tag{3}$$

where:

$\boldsymbol{H_s}$ = social entropy;

$\boldsymbol{S}$ = lifestyles expressed through parameters that can rate "urban well-being" (percentage of population with disability, old age index, birth rate, expenditure on culture, etc.).

$\boldsymbol{I}$ = intensity of use represented by the relationship between the number of "urban agents[4]" per spatial unit (for example, the crowding index expressed by the number of co-residents per room);

$\boldsymbol{C}$ = perceived comfort (for example the degree of satisfaction of the inhabitants with respect to the quality of the urban services available).

The hierarchically superior variable in eq. (3) relates to the lifestyles that can directly influence the levels of urban livability and indirectly the production of urban entropy.

The measure of intensity of use, related to the use of urban space by urban agents (for instance population density, building density, etc.) should be considered at the second level in the hierarchy of variables.

The perception of comfort occupies the third hierarchical level because of the relative reliability of a value that can vary according to the subject.

The total entropy of the city system can be formulated through a cumulative expression of the entropic value obtained by means of an "overlay verification" of the values calculated for each subsystem Fig. 5**.**

The introduction of preventive measures to mitigate vulnerability and reduce entropy values may help decision-makers identify and intervene in the subsystem that records the highest entropy value (compared to the other subsystems).

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[4] We refer to people acting in the city, namely those who perform urban activities, such as residents (main agents), city users (secondary agents), stakeholders (economic agents), tourists (occasional agents), etc.

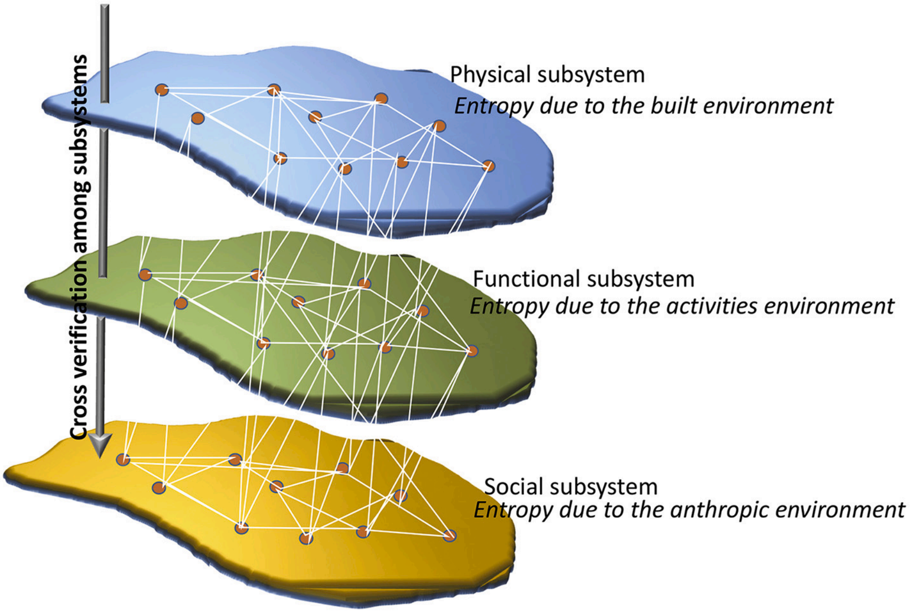

Fig. 5. The cross vertical verification of the entropy values within the three main urban subsystems for the definition of the total entropy.

The results show that the indicated procedure can represent a tool to support the decision of the urban administrators enabled to program the interventions and resources needed to mitigate the systemic risk) (Brunner and Starkl, 2004).

In the following steps,[5] the research refers primarily to the information theory and the mathematical formulation elaborated is briefly described below. It is worth recalling that the "loss of information" (regardless of the cause) has been considered as equivalent to a condition of entropy, or the loss of a quantity no longer recoverable that contributes to make the system poorly governable.

Therefore, considering "A" as "TRUE" in the logical expression, the probability $P(A|I_1)$ can occur, where I_1 is the available information referred to "A". In relation to the logical value of "A", the amount of information "lost" "H" (comparable to a certain amount of entropy produced) can be calculated:

$$H(A \mid I_1) = -log_2 P(A \mid I_1) \tag{4}$$

where H is entropy, P is probability, A is the logical expression (true or false), I is the information available.

Since there is a set of n logical expressions (exclusive and exhaustive) A_i, $(i = 1{:}n)$, where each of these expressions can assume the "true" or "false" values, the entropy (H) of the set of expressions, given I_1 as a known value, can be calculated as the expected value of the information lost in the set of expressions A_i(Shannon, 1948):

$$H(\{A_i{:}\ i = 1,\ldots,n\} \mid I_1) = -\sum_{i=1}^{n} P(A_i \mid I_1) log_2 P(A_i \mid I_1) \tag{5}$$

Furthermore, if in the set Ai (with numbers from 1 to n) a further amount of information I_2 is gained, it is possible to calculate the amount of information gained (D) related to the expression A_i:

$$D(\{A_i{:}\ i = 1,\ldots,n\} \mid I_1|I_2) = \sum_{i=1}^{n} P(A_i \mid I_1, I_2) log_2 \frac{P(A_i \mid I_1)}{P(A_i \mid I_1, I_2)} \tag{6}$$

The relative entropy (also defined as divergence or information) of the set of expressions Ai can be calculated as the expected value of the information gained I_2 with respect to I_1.

Now, let the urban system be stochastically characterized by a vector of parameters Θ that expresses all the uncertainties in the system. It is possible to hypothesize that these uncertainties are related to the general conditions of vulnerability of the urban system. The increase in the production of entropy when only the information I_1 is known – compared to when the information I_2 is also given – can be expressed by eq. (7):

$$D\langle \Theta \mid I_1 \mid I_2 \rangle = \int_{\Omega_\Theta} \log_2 \frac{p(\Theta \mid I_1)}{p(\Theta \mid I_1, I_2)} p(\Theta \mid I_1, I_2) d\Theta \tag{7}$$

It should be underlined that in eq. (7), if the parameters are expressed in a discrete (not continuous) way, the integral is replaced with a summation.

The integral in (7) could be calculated using the stochastic simulation methods. In particular, using the Markov Chain Monte Carlo Simulation scheme,[6] it is possible to simulate samples of Θ values considering the expression of the distribution $p(\Theta \mid I_1,I_2)$.

In the urban system, the vector Θ must take into account several correlated parameters; therefore, the estimate of the distribution $p(\Theta |I_1,I_2)$ is not easy to define. However, some techniques can be used to model any correlation structures between the various components of **Θ.**

For example, the groups of correlated parameters could be used and compared, in turn and individually, with parameters placed in different groups which do not have an immediate correlation with the parameters considered. An alternative technique to clustering involves the use of Bayesian networks[7] as a graphical tool to visualize and, therefore, effectively quantify the existing correlations between the various parameters.

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[5] This part has been developed also with the scientific collaboration of prof. F. Jalayer, Department of Structures for Engineering and Architecture, University of Naples Federico II.

[6] Set of algorithms that generate posterior distributions by sampling likelihood function in a representative way in parameter space.

[7] Bayesian networks are graphical models of knowledge in an uncertain domain. Based on the Bayes rule, they express conditional dependence relationships (arcs) between the variables involved (nodes). The main advantage of probabilistic reasoning compared to the logical one lies in the possibility of reaching rational descriptions even when there is not enough deterministic information on the functioning of the system.

6. Empirical framework: from indicators to case study

As already stated in this work, the concept of entropy can be useful to understand and describe the behavior of complex systems. It can be applied to the measurement of the level of organization versus chaos, uniformity versus diversity, useful versus useless, or order versus disorder in different systems and in different scientific domains (Cabral et al., 2013). Entropy, intended as a condition of crisis of urban livability, can be useful to measure the level of "unsustainability" versus sustainability, where unsustainability, according to the thesis of the present study, coincides with the entropy state of the urban system.

In this part, this study examines some reviews of sustainability indicators with the aim of individuating empirical parameters for measuring urban entropy and assumes the possibility of considering sustainability as the opposite of entropy. In this sense, sustainability corresponds to a positive state and it can be evaluated by "positive indicators" (describing positive effects). On the contrary, entropy can be assessed through "negative indicators" (describing negative impacts).

Since its definition in Brundtland et al., 1987(*Our Common Future*), the production of sustainable indicators has been considerable both within and outside the scientific context (Table 1). In a nutshell, the definition of urban sustainable indicators mainly refers to four dimensions: a) environmental, b) economic, c) social, d) governmental. Among such dimensions, the social one (mainly referring to lifestyle) is considered indispensable to measure urban sustainability. Indeed, the metrics used for the measurement of sustainability are various, but the most commonly used refer to Sustainability Reporting, Triple Bottom Line accounting, the Environmental Sustainability Index and the Environmental Performance Index. The most recent approach is the Circles of Sustainability proposed by the United Nations Global Compact International Programme as an alternative and critical approach to the Triple Bottom Line. The approach is mostly used for cities, with reference to social aspects of urban life, and proposes to measure sustainability according to a holistic vision (Magee et al., 2012). The Triple Bottom Line approach is probably the main reference in the assessment of sustainability applied to the city (Pope et al., 2004), mostly relating to environmental, social, and economic aspects. Table 1 illustrates the most known methods adopted to assess sustainability derived from literature.

In the last decade, the scientific literature has been very focused on the search for parameters to test and measure urban sustainability, leaving aside the search for urban indicators or parameters able to define entropy in urban contexts. In this regard, this study proposes to shift the attention of the scientific community and suggests possible ways of measuring urban entropy using the systems paradigm as theoretical support.

As already stated, entropy must be kept between the minimum value (below which the urban system becomes vulnerable and unstable) and the maximum value (above which the system becomes unsustainable).

The parameterization of these values is not easy but would be very useful to manage the functioning of urban systems. In order to achieve this target, in this part the study aims at defining a possible systematization of indicators able to "parameterize" entropy levels for each of the subsystems composing the urban system (Fig. 1).

Table 2 proposes a possible articulation that considers entropy indicators as descriptors of conditions opposed to sustainability.

After identifying the indicators, the city of Benevento in Southern Italy was chosen as a significant case study to test the described hypotheses, both for its being a medium-sized city and for its role of provincial capital within the Campania region.

Benevento, in fact, offers a number of metropolitan functions (university, hospital, law court, etc.).

At this stage of the research, analyses were carried out on the historical center, with the aim of focusing further research on the whole municipality.

6.1. Trying to measure urban entropy: the case study of Benevento

Benevento is a medium-sized city (about 60.000 inhabitants) situated in a regional historical zone (Sannio) characterized by the

Table 1
The most known sustainability indices/indicators (inspired by Mori and Christodoulou, 2012).

INDICES/indicators	Definition
Ecological Footprint (EF)	measures the total consumption of goods and services produced and the amount of waste assimilated by the global hectare of bioproductive lands
Dashboard of Sustainability (DS)	is a tool for considering the economic, social, and environmental conditions of development and incorporating ad hoc set indicators in order to evaluate sustainability
Environmental Sustainability Index (ESI)	assesses the sustainability of nations based on 5 major components: environmental systems, reducing environmental stresses, reducing human vulnerability, social and institutional capacity and global stewardship. The five components are composed of 21 indicators derived from 76 variables
Welfare Index (WF)	is the total volume of freshwater that is used to produce the goods and services consumed by the individual or community
Well-Being Index (WI)	is derived from a Human Well-being Index (HWI) and an Ecosystem Well-Being Index (EWI). The first considers indices of health and population, welfare, knowledge, culture and society, and equity (36 indicators). The second comprises indices for land, water, air, species and genes, and resources deployment (51 indicators).
- Genuine Progress Indicator (GPI) - Index of Sustainable Economic Welfare (ISEW) - Sustainable Net Benefit Index (SNBI)	alternative to the GDP, refer to economic welfare
City Development Index	is a single measure of the level of development in cities, which is calculated by five sub-indices: city product, infrastructure, waste, health and education
Energy/Exergy	Energy analysis is useful to investigate a system's performance and to evaluate energy use and energy efficiency. Exergy-based methods can be used to improve economic and environmental assessments. Thanks to energy and exergy analyses, multigeneration systems can be compared to traditional systems quantitatively. These analyses also help identify the sources of losses and emissions so that savings and efficiencies can be maximized while keeping the cost and emissions as low as possible.
Human Development Index (HDI)	measures the average achievements in a country in three basic dimensions: life expectancy at birth; adult literacy rate with gross enrolment ratio in education; GDP per capita in purchasing power parity (PPP) - US dollars
Environmental Vulnerability Index (EVI)	assesses the vulnerability of physical environment per unit of area
Environmental Policy Index (EPI)	is mainly composed of indicators on environmental health and environmental vitality
Living Planet Index (LPI)	assesses the impacts of human activities on ecosystems in themselves and/or ecosystem functions, referring to indicators of biodiversity
Genuine Saving (GS)	is a measure of the environmental degradation

Table 1
The systematization of entropy indicators.

Subsystem	Indicators	Parameter	Source
SOCIAL Indicators refer to conditions that can have impacts on the level of livability (healthy, social, environmental) of the system	Air quality	Air Quality Index	ARPAC; MUNICIPALITY
	Noise pollution	Acoustic Zoning Plan	MUNICIPALITY
	Electromagnetic pollution	Km of Electrical, Communication and Radio Transmission Systems/municipality surface	ARPAC
	Unemployment rate	Number of unemployed people as a percentage of the labor force	ISTAT
	Multi-ethnic composition of residential population	Number of resident foreigners/tot residents	ISTAT; MUNICIPALITY
	Safety and care of elder population	Number of voluntary associations per 1000 inhabitants	ISTAT; MUNICIPALITY
FUNCTIONAL Indicators refer to urban activities	Population density	Residents per sq. km of land area	ISTAT; MUNICIPALITY
	Presence of metropolitan functions	N of seats of metropolitan functions	MUNICIPALITY
	Percentage of Tertiary activities	Tertiary activities /total commercial activities	MUNICIPALITY
	Status of the housing stock	Age of buildings	ISTAT
	Density of Sport and recreational structures	N of sport and recreation activities / total public activities	MUNICIPALITY
	Crowding index	N of usual residents in a dwelling /number of rooms in the dwelling.	ISTAT
	Waste production	tons of waste generated per inhabitant	ARPAC; REGION
	Building obsolescence	N of old buildings / total buildings	ISTAT
	Building quality	N of new buildings / total buildings	MUNICIPALITY
	Clime characteristics	Climate zone	DPR n. 412 26th August 1993
	Density of Illegal buildings	N of illegal buildings / total buildings	MUNICIPALITY
PHYSICAL Indicators refer to negative conditions of the built environment	Percentage of Energy-efficient buildings	N of alternative energetic network for buildings	MUNICIPALITY
	Density of disused buildings	N of disused buildings per square km	MUNICIPALITY
	Roads conditions	N of not practicable roads / tot km of roads	MUNICIPALITY
	Quality of the Local Transport Network	N of urban bus lines	MUNICIPALITY
	Percentage of soft mobility lanes	Km of pedestrian routes / km of roads	MUNICIPALITY
	Density of areas subjected to flooding risk	Square km / territorial surface	BASIN AUTHORITY
	Density of areas subjected to seismic risk	Square km / territorial surface	CIVIL PROTECTION
	Density of areas subjected to hydrogeological risk	Square km / territorial surface	BASIN AUTHORITY
	Territorial utilization for agriculture	Square km / territorial surface	MUNICIPALITY
	Density of Quarries	Square km / territorial surface	MUNICIPALITY
	Density of Landfills	Square km / territorial surface	MUNICIPALITY
	Density of Brownfield	Square km / territorial surface	MUNICIPALITY
	Density of Urban green spaces and parks	Square km / territorial surface	MUNICIPALITY

presence of prestigious archeological and historic-artistic heritage.

In this first phase of the study, the analysis have been referred to the inner part of the city coinciding with its historical center, where the main urban functions (education, security, safety, law and order, commerce, residential) are located.

Analyses have been developed using GIS technologies that have required both the definition of a georeferenced map and the individuation of the territorial local unities.

The whole area of study, thus, has been subdivided into 59 census tracts comprehensive of 572 buildings. Data have been referred to the indicators illustrated in Table 2 obtained from the most recent surveys of official sources (Region, ISTAT, Municipality, Metropolitan City, Ministry of Education, etc.).

The final database consists of a matrix (59 territorial unit per 30 variables) containing the parameters able to "describe" the entropy level for each of the three subsystems composing the city (Table 2) and referred to the period 2018–2019, as for 2020 data are not yet available.

Fig. 6**illustrates the results of the GIS analysis for the social subsystems. The classification of the areas refers to five categories according to the levels of entropy elaborated.**

Urban social entropy particularly depends on the pollution generated by the density of electric sources and unemployment rate. The chromatic scale illustrates the sensitive urban zones from the highest entropy level (red) to the lowest social entropy (yellow) observed.

In the areas mainly exposed to the high levels of entropy connected with social parameters, actions to reduce negative effects should be have priority and they should concern mobility policies able to decrease urban traffic and thus the production of PM_{10} and other pollutants generated by car use. Reducing car use, in fact, could probably have positive effects also on the noise pollution levels. While electromagnetic pollution should be reduced by implementing building efficiency especially and primarily for the public buildings.

Fig. 7 **illustrates the results of GIS analysis elaborated on the basis of the entropic parameters for functional subsystem.** As for Fig. 6 the chromatic scale refers to sensitive zones in which the entropy values vary from the highest (red) to the lowest (yellow).Levels of high "functional entropy" are mainly due to the lack of urban open spaces, urban parks, and to the high population density.

The red areas also correspond to parts of the study area in which there are the highest values of the crowding index. Actions should be oriented to the lowering of these negative values, despite the inevitable difficulties related to the urban features of this part of the city, also typified by a lack of urban public services and open spaces.

Fig. 8**illustrates the entropy values referred to the physical subsystem.** Physical entropy values are particularly due to the

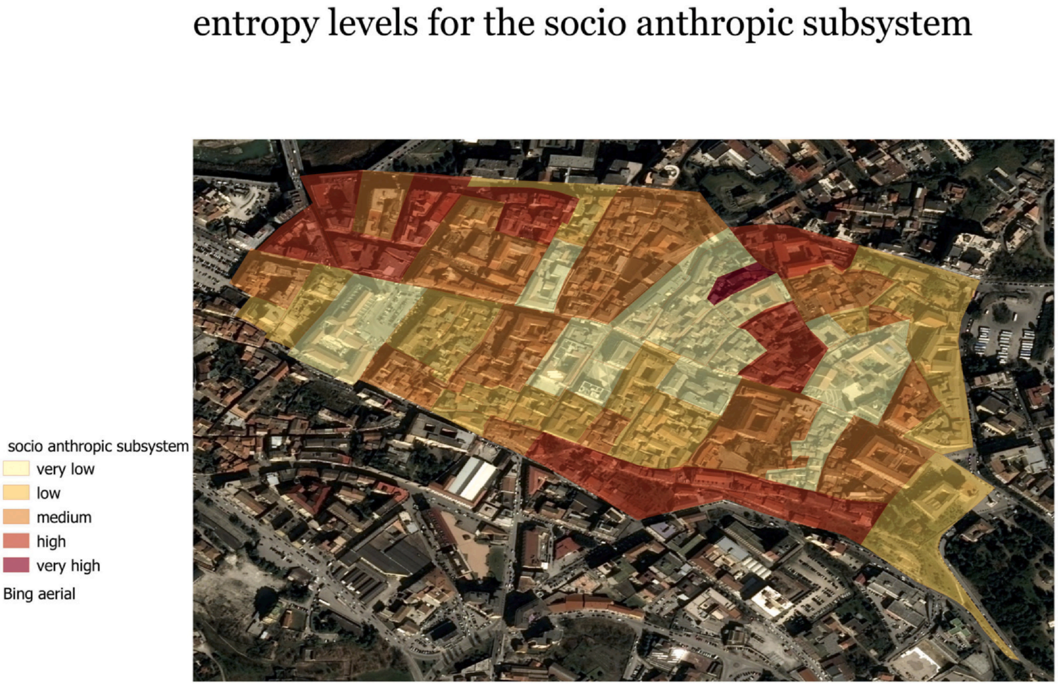

Fig. 6. Measure of urban entropy for the Social Subsystem. The red areas correspond to the highest value mainly due to noise and electromagnetic pollution and the unemployment rate.

obsolescence and the presence of disused buildings (red areas in Fig. 7) in which building energy efficiency is close to the minimum value. The overlapping of the results shows that the sensitive urban zones (identified for the three subsystems) generally coincide and represent the vulnerable areas within the urban system characterized by the worst conditions for the social, functional, and physical subsystems.

These areas are priority targets for urban policy and interventions should be implemented to face the entropy levels and switch them into sustainable conditions. As analyses have shown, the interventions should aim to the reduction of air and noise pollution, as well as to the building maintenance, and be integrated into the process of urban planning based on public-private cooperation and development agreements.

The GIS analyses carried out can be intended as a decisional support tool for the administrators and the stakeholders involved in the improvement of the quality of life for the whole urban system. The areas individuated through GIS technologies based on the algorithms elaborated in the theoretical part of this study can be seen as the vulnerable areas within the urban system. Adequate intervention strategies in this areas will take the whole system towards more sustainable conditions,

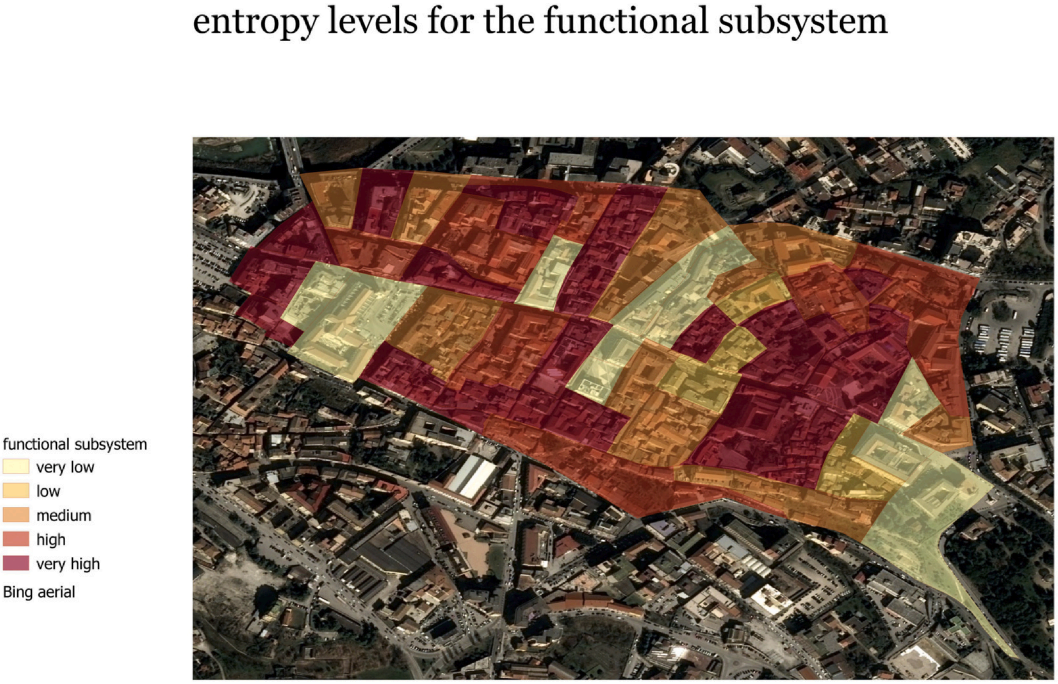

Fig. 7. Measure of urban entropy for the functional subsystem.

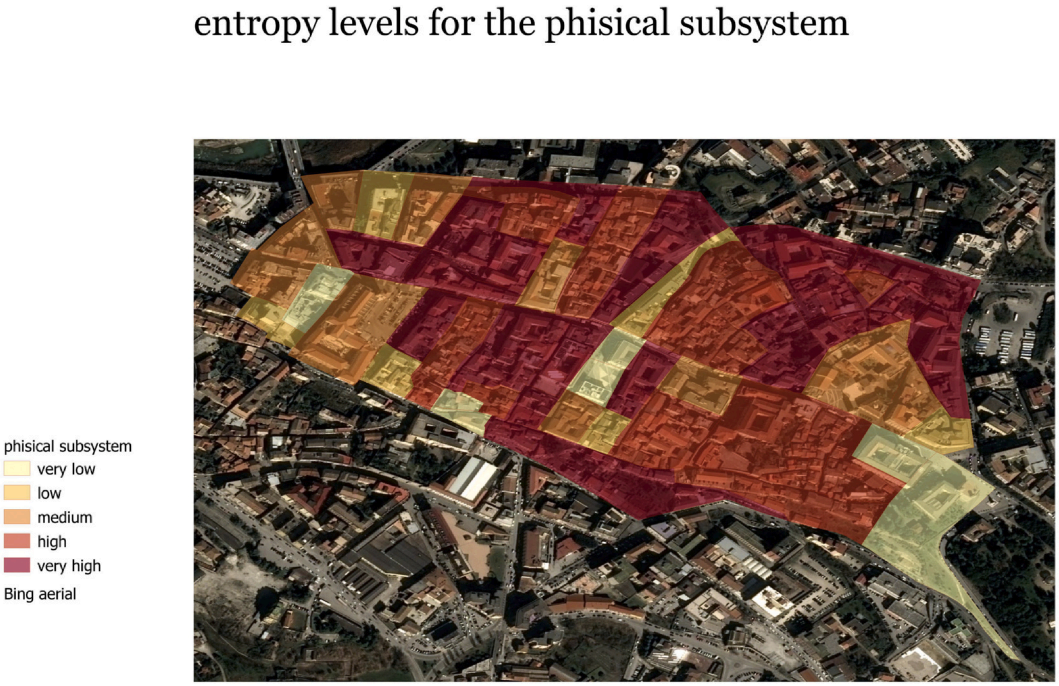

Fig. 8. Values of urban entropy for the Physical Subsystem.

reducing the production of entropy and thus the wastefulness of the resources for the right evolution of the system itself.

7. Concluding remarks

One of the objectives of this research was the attempt to show how urban risk assessment must be addressed according to a holistic vision that considers urban complexity. Based on the adoption of the systemic logic, urban vulnerability has been considered as a condition in which urban systems produce entropy.

The inevitable production of entropy in the evolution of the system has been assumed as a factor of vulnerability when there are dyscrasias within the system that slow it down or block its functioning.

The appropriately planned and well-timed intervention on such malfunctions can mitigate the production of systemic entropy, thus reducing the whole vulnerability of the urban system and increasing its resilience[8]. Within the scientific domain, the concept of resilience has gained more and more interest (Rus et al., 2018) while the belief that a wider vision is needed to investigate and especially to understand the current urban issues is not deep-seated (Rees and Wackernagel, 1996; Lee, 2014).

The search for possible mathematical formulas (algorithms) to measure systemic entropy represents one of the longer-term objectives of this research work to define the value of the threshold within which the trajectory of the urban system can assure a compatible evolution. This objective could probably contribute to implement the intuition of Cabral et al. (2013) in the definition of rapid response solutions to both control dyscrasias and plan adequate actions to reduce vulnerability.

A further objective of this research refers to the proposal of tackling the topic of risk by focusing on the need to understand and address complexity in a systemic way, which means to develop preventive measures to mitigate the effects of possible dangerous events (of natural or anthropogenic origin). Maybe, the current experience of the coronavirus pandemic should make us ponder over the need of a holistic approach to city challenges.

The system resilience, thus, could be assumed as the ability of the system itself to react to dangerous events through two possible alternatives:

- by developing a high capacity of adaptability to the conditions that occur after an event that can destabilize the trajectory of its evolution;
- by identifying preventive actions to reduce the weaknesses and vulnerability of the system.

In both cases, the essential condition consists in considering that a territory or a city behave like complex systems (components interacting with each other) and, therefore, it is not possible to examine a single process in a separate way.

Excess in entropy production within one of the urban subsystems affects the functioning of the whole system. Referring to the evolution trajectory of the urban system as shown in Fig. 4, the entropic condition corresponds to the crossing of a threshold beyond which the system can be in conditions of reversibility or irreversibility. In this regard, it is possible to intend the resilience of the urban system as a measure of the distance from the thresholds of the range of the positive trajectory of the system.

The smaller the distance the greater the resilient capacity of the system (Fig. 9**).**

Likewise, the urban resilience could be also intended in accordance with two systemic dimensions.

The first dimension can be considered as an *internal resilience* (Fig. 10**),** that consists in the ability of the city to balance the impacts determined by an endogenous or exogenous cause and, thus, to activate the processes of reorganization, that is one of the properties of the complex systems.

The second dimension refers to an *external resilience* **(**Fig. 11**),** that can be meant as the “flexibility of the city”, i.e. its elastic capacity to enlarge the breadth of the range in which evolution can stay.

Flexibility, thus, is an elastic adaptability of the city that can be achieved through an adequate planning of actions, interventions and

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[8] It is not the authors' intention to investigate about this complex and largely discussed concept (see Cai et al., 2018; Gargiulo and Zucaro, 2015); the intention is to underline that it can be integrated with a positive evolution of the urban system.

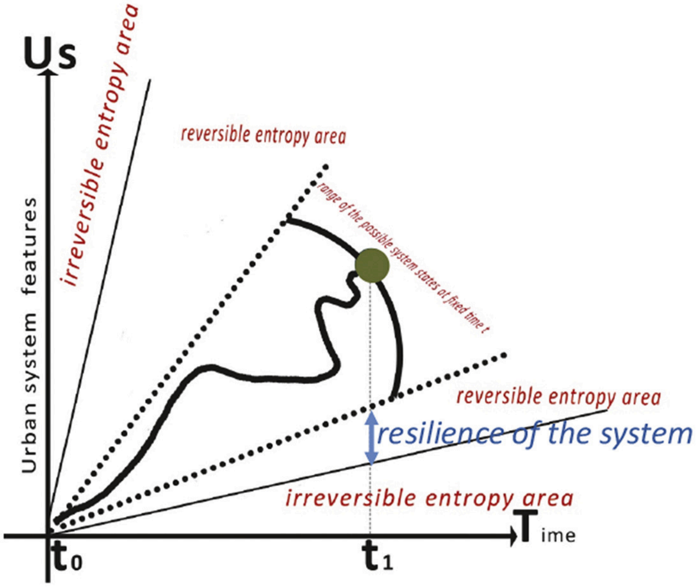

Fig. 9. Resilience can be expressed as the distance from the thresholds of the existence field of the system evolution area. Source: Authors' elaboration.

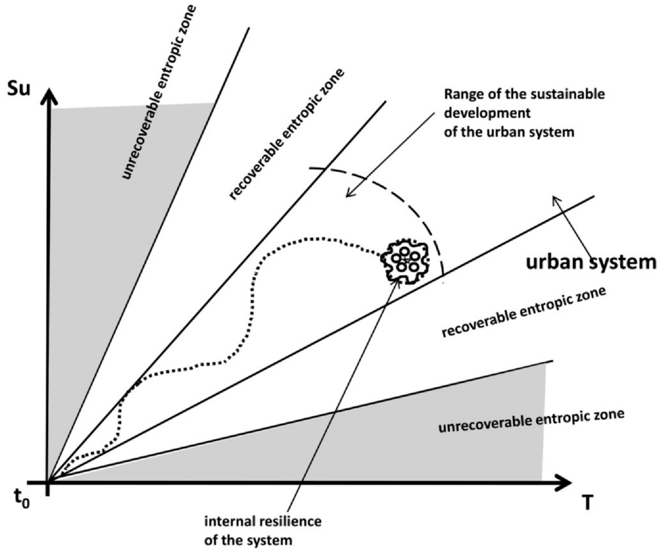

Fig. 10|. The internal resilience can be meant as the capacity of self-organization of the urban system balancing and facing at the same time the impacts that endogenous or exogenous events can generate.

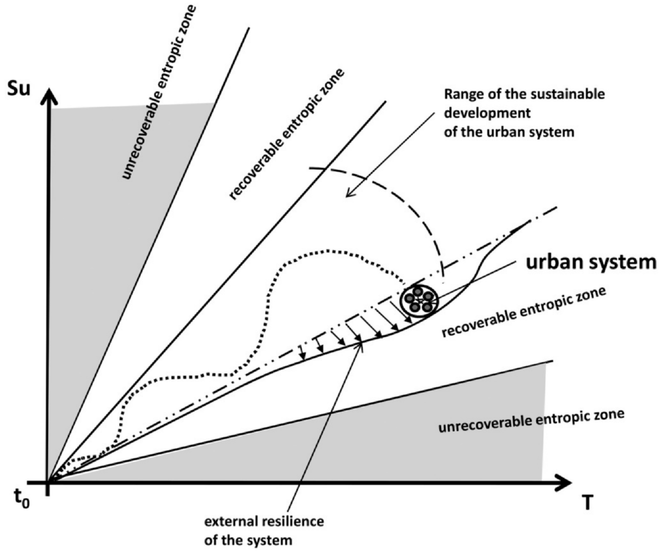

Fig. 11|. The external resilience can be meant as the elasticity of the existence limits of the urban system and it depends on the flexibility of the systems itself to face the impacts that can affect the system.

governmental policies aimed at sustainable goals. It should be noted that there is a limit that cannot be exceeded without falling into an entropy state, which would require many resources and new energies to recover from it.

The identification of the values of the thresholds and the flexibility range of the edges are currently the objects of further research.

The theoretical assumptions developed in this study represent an attempt to increase the scientific community awareness about the possibility of seeking new perspectives as a framework for the study of urban phenomena.

The need to review (and renew) the theoretical and application tools of urban planning can open new and interesting research trajectories that need to be explored, in order to contribute to the implementation of urban system resilience (Borsekova et al., 2018).

The case study proposed tried to test the methodological and theoretical hypothesis of this research. Even if at a initial state, it could represent a useful tool to support the decision makers as it allows for the individuation of sensitive areas meant as those parts of the urban system in which intervention have priority.

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Author Contribution Statement

Although the paper is the product of a jointed work the authors wants to specify that *Conceptualization*	Romano Fistola, Rosa Anna La Rocca and Carmela Gargiulo
Methodology	Romano Fistola, Rosa Anna La Rocca
Formal analysis	Romano Fistola and Rosa Anna La Rocca
Investigation	Romano Fistola

Resources	Romano Fistola and Rosa Anna La Rocca
Data Curation	Romano Fistola
Writing - Original Draft	Rosa Anna La Rocca
Writing - Review & Editing	Rosa Anna La Rocca
Visualization	Rosa Anna La Rocca
Supervision	Romano Fistola and Rosa Anna La Rocca a

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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