Proposal for a Data Visualization and Assessment System to Rebalance Landscape Quality

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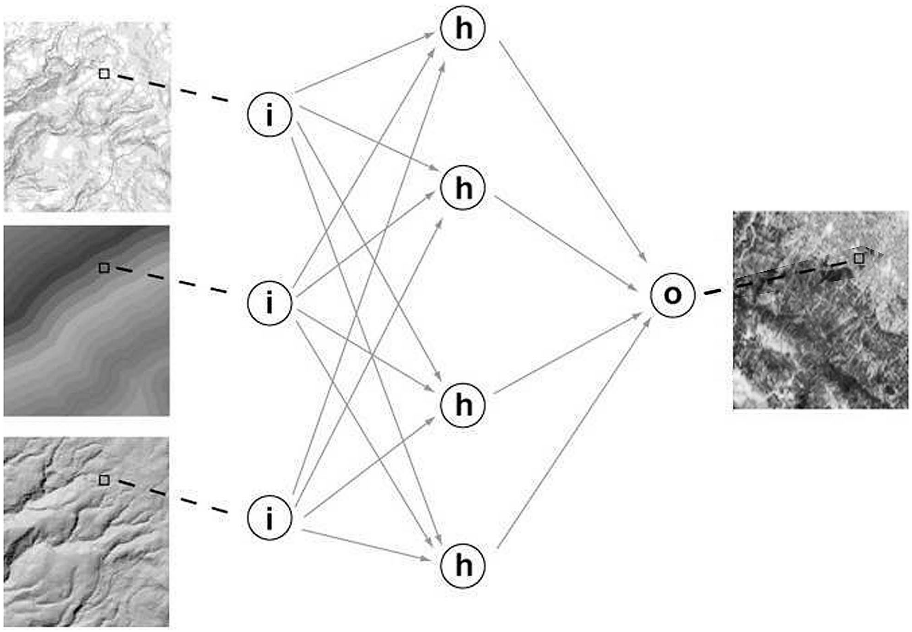
Abstract

The landscape can be considered a complex system described as a non-linear entity, organized according to the connections between the different elements that characterize its state. The latter cannot be determined a priori but emerges from the multiple interactions between assets and relationships that are no longer found when the phenomenon is traced back to the individual components. Territorial development is closely connected to social, economic, cultural and symbolic issues that determine the transformative practices of space and the territorial palimpsest. If not carefully managed, these forces can lead to the dissolution of the landscape and environmental values that have been stratified in a specific land. This paper proposes the construction of a numerical spatial model that describes the territorial settlement patterns, based on methodologies and techniques typical of AI, to develop tools for re-balancing the man-landscape relationship.

Keywords
AI, complex systems, emergent behaviours, landscape design.



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Introduction

Representing a territory pattern is an interdisciplinary research subject because it requires the detection, analysis and understanding of different and interdependent issues related to human settlement. The latter leaves visible signs, which determine specific landscape conformations, as result of the settlement stratification choices of the past.

Several research have defined the shapes of settlement meshes, traceable to patterns derived from spatial determinants (climatic factors, hydrography and land morphology, administrative structure and resource exploitation, etc.), without dwelling on possible alternative responses, which were of little significance before the development of objective assessment tools.

The landscape is, in fact, a complex system in continuous search of equilibrium, describable as a non-linear entity, organized according to the connections between the different elements that characterize its state. The latter cannot be determined a priori but emerges from the multiple interactions between assets and relationships that are no longer found when the phenomenon is traced back to the individual components. Today, Artificial Intelligence allows the evaluation of multi-factorial parametric models' development in long-term dynamics, which enables to prefigure choices in anthropic policies. However, the landscape transformation determinants are multiple and fragmented in an abnormal amount of heterogeneous information in shape and size, which makes it difficult to represent them in context and thus the necessary interpretation for the efficiency and sustainability of interventions (projects).

The emerging phenomena that arise in complex systems are highlighted using computers to explore the possibilities and limits of developing increasingly articulated models. Awareness of the complexity of urban and regional dynamics, based on spatial interaction, makes it possible to appropriately identify interventions of different scales capable of selectively intervening by rebalancing the system and contributing to the improvement of territorial quality.

Realizing predictive digital twins requires survey data representation systems to interpolate the 'visual' information stratified in the landscape with the otherwise acquired information. Beyond the description based on direct observation of places (classic cartography, geo-referenced information systems-GIS), the territory is daily digitized by thousands of photos, videos, comments and annotations processed in real-time through personal devices. In addition to this, there is a multitude of data derived from the Internet of Things, or Networks of Objects, connected to the information structure in a continuous exchange of information about the surrounding environment.

The AI makes it possible to deal with this complexity by constructing probabilistic models that identify among thousands of data those significant about a specific problem, reconstructing the patterns of optimal organization with Machine Learning techniques based on Neural Networks (Fig. on front page). These use mathematical-computational methods to extract knowledge directly from alphanumeric data, images or any other digitizable format, without the need for explicit predefined rules. Applied to spatial analysis, they can highlight hidden links between the various elements of anthropogenic space, aiding understanding of the principles that shape and evolve a given landscape and facilitating its planning and development.

So that a Neural Network could be used to solve complex problems of deterministic or stochastic order, it should be trained with a set of data significant to the understanding of the phenomenon analyzed. The study and selection of the information that correctly represents a territory is the first step for any machine learning model aimed at an outcome.

Therefore, we propose a research purpose based on construction of a numerical spatial model that describes the territorial settlement patterns, based on methodologies and techniques typical of AI, to develop tools for rebalancing the man-landscape relationship. This goal requires defining the semantic organization and methods for collecting and integrating data into a syntactic structure of predictive representation, based on three nested and interconnected levels, understood as the central dynamic components that condition the visual organization of a territory as a complex system:

– the physical level of matter and energy,
– the logical level of information and representations,
– the identity and self-referential level.

The first level concerns the resources and processes recognized and more or less regulated for their exploitation; the second involves the presence of elements referable to the population; the last qualifies the identity space through architecture, which expresses the symbols and shared social norms of a shared vision expressed through the physical signs that consolidate a specific culture.

Territory as a Complex System

The science of complex systems, which has emerged in recent decades under the computerization acceleration, renounces the assumptions of linearity in dynamical systems to investigate their real-world behaviour in greater depth. The main field of interest is the behaviour that specific systems exhibit when they are far from stability, giving rise to dynamics of self-organization and adaptation describable according to rules shared by physical-chemical, biological, social, natural or artificial phenomena. The suggestion of some theories advanced in the field of complexity has produced over the years an epistemological debate that makes it problematic to define a precise frame of reference. Complexity science [1], theory of chaos, theory of complex systems are terms often used spuriously in journalistic circles and customs with meanings that move away from the scientific context to venture into colloquial areas.

Systematics is not, as too often reported, a new branch of science but rather a different vision of the scientific method that questions the research model prevalent today. The latter can be traced back to the cultural revolution of the Renaissance, when the scholastic was gradually replaced by the empirical-rational model based on the observation of nature and logical-mathematical description. According to this paradigm, any phenomenon, however articulated, can be understood by reducing it to a sum of specific and more comprehensible parts, then assembled by unifying the individual observations into a single absolute value theory.

Nevertheless, the systemic view sees the world as an irreducible dynamic system, consisting of networks of interconnected systems, interdependent and inseparable, which also includes human action. Regardless of their natural or artificial origin, complex systems are therefore determined by relational laws, which exist as an interaction between the elements of a particular structure and not at the individual element level. From the mutual interaction of components and factors acting on the system, emergent behaviours develop, leading to organizational forms that cannot be determined a priori. A typical complexity issue is the three bodies problem [2] faced by Henri Poincaré [3]. The phenomenon does not admit an analytical solution, therefore deterministic, because, although describable by known equations, it diverges unpredictably after a certain period. In other words, with the same values and maintaining the same mathematical formulations, different results are obtained at each recalculation.

Poincaré's observation is recognized as the general theory of complex system birth, but we must wait for the studies of Ludwig von Bertalanffy (1968) and Heinz von Foerster (1981) and the advent of cybernetics, initiated by Norbert Wiener (1948) and William Ashby (1956), for the construction of a rigorous systemic approach. Wiener extends the potential of logical-mathematical models to the description of social systems, conceived as ensembles in which the interaction, continuous and changing, between matter, energy and information takes place (see Fig. 3). The morphology that a territory assumes is therefore not necessarily a consequence of prior planning: individuals, families, industries, religious groups are entities that choose and interact in non-linear ways within society, understood as the gradual result of the experience accumulated by several generations, in a process of continuous learning based on the flow between the available materials, the

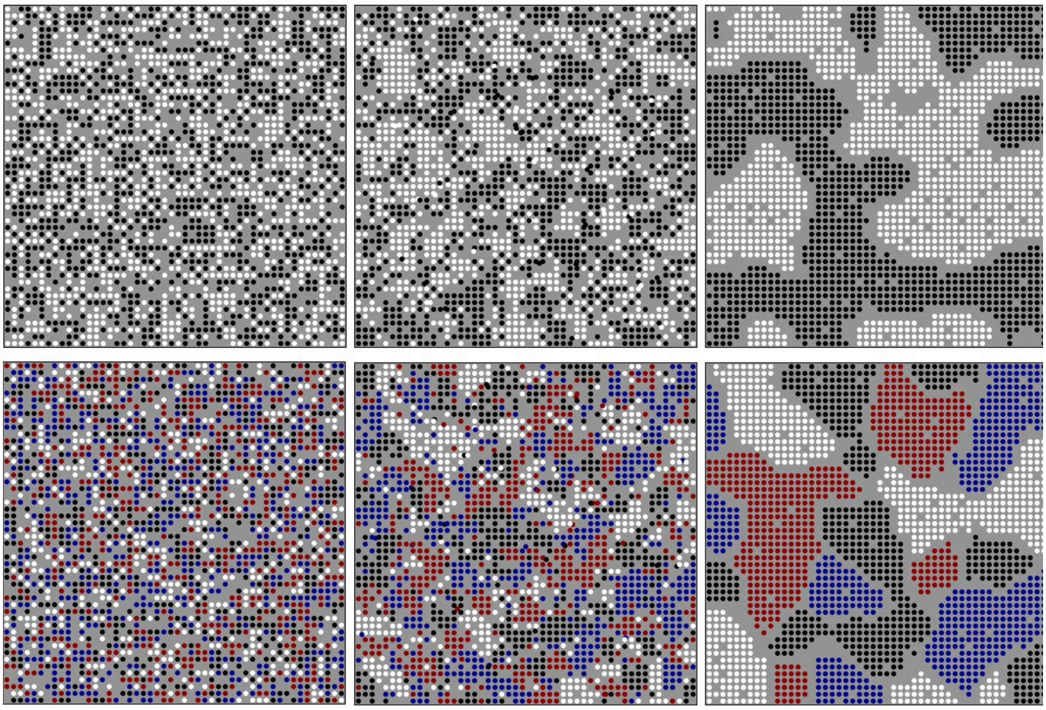

Fig. 1. The dynamics of the Schelling model: individuals of a specific type (e.g. ethnicity, religion, political view, etc.) migrate to different locations: An initially mixed population segregates, after some time, into patches of uniform type. The same behaviour is also obtained as the number of ethnic groups increases (*below*). (https://www.complexity-explorables.org/slides/t-schelling-plays-go/)

energy necessary for their transformation and the exchange of information that contributes to the evolutionary processes of the economy [Fujita, Krugman, Venables 2001]. A significant example of systemic concepts application to spatial analysis is Schelling's segregation model [Schelling 1971; Schelling 1978] based on the observation that almost all US metropolitan areas are characterized by neighbourhoods inhabited almost exclusively by whites or only by people of colour. It is not easy to find areas where both groups exceed three-fourths of the total population.

To analyze the phenomenon, Schelling developed a two-dimensional cellular automaton[4] in which the territory's surface under consideration is divided into square cells, each corresponding to an individual or a household. The cells can be vacant or identified according to a colour attributed to the individual's ethnicity occupying them. Each individual (or household) can thus have from zero (neighbouring cells all uninhabited) to eight (neighbouring cells all inhabited) neighbours. The system is then implemented through a set of rules that determine when an individual is 'happy' or 'unhappy' with his or her home, based on number and neighbourhood [5].

Suppose during the evolution of the system the condition is not respected. In that case, the occupant moves to a new dwelling in the nearest vacant cell [6], thus influencing both the habitat he leaves and the one he enters since the displacement will condition the preferences of both old and new neighbours.

Given an initial configuration of the model, in which the ethnic groups are randomly distributed over the territory, it is observed that after a few iterations, the cells aggregate into large homogeneous groups, distinct by ethnicity (Fig. 1). The system, therefore, from a disordered state, operates an actual phase transition [7] towards an ordered state of equilibrium, reached when segregation zones form.

If the ethnic groups are allocated according to a chessboard arrangement in the initial moment, the system instead maintains a state of dynamic equilibrium: all individuals remain where they are. Interestingly, the introduction of a few localized perturbations, such as changing the colour of a small number of cells at random, reactivates the dynamics of relocation that leads to segregation (Fig. 2). Despite its simplicity [8], the model reveals a form of endogenous self-organization of the territorial system, where the interaction between individual choices leads to collective results.

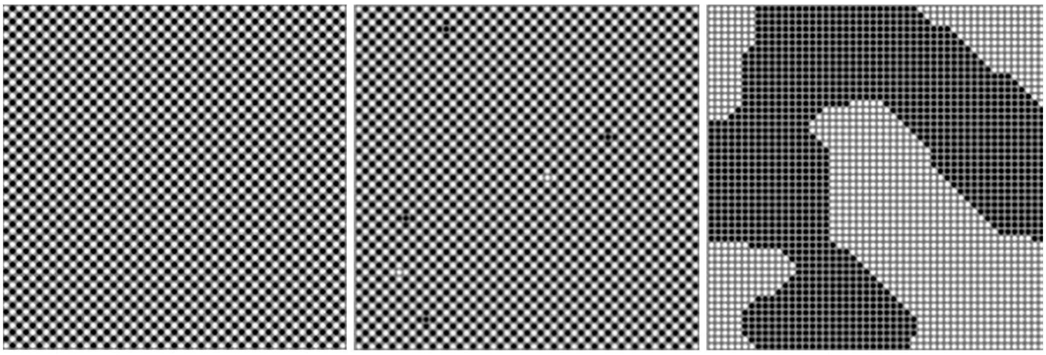

Fig. 2 Chessboard arrangement in the initial moment: the system maintains a state of dynamic equilibrium. The introduction of a few localized perturbations, changing the colour of a small number of cells at random, reactivates the dynamics of relocation that leads to segregation.

The formation of ghettos results as an emergent phenomenon due to the process of self-organization that follows the locational choices of individuals, regardless of any radical positions they may hold. In the model, no individual thinks in a dirigiste way of establishing organized segregation, so much so that the system is initially disorderly. Even when the degree of tolerance is high (37% of similar neighbours), local interest determines broad zones of separation at higher system levels. A close reciprocal relationship is implemented: people and social dynamics influence the built environment which, in turn, influences people and society.
Clearly, it cannot be assumed that the self-organization of a system, as itself, necessarily leads to a desirable outcome [9]. Leaving aside natural systems, where such evaluations are not relevant, it is a prejudice to suppose that spontaneous and self-organizing order is necessarily the best outcome in the face of the unstable equilibrium from which it originates. Considering the territory as a complex system can, however, promote a design capable of restoring the system's equilibrium, should this be broken by causes of any nature, replacing the failed managerial vision applied since the post-war period, which sees the anthropic environment as a disorganized system to be redesigned using homologated and predefined schemes.

Method and Goals

New forms of survey restitution allow an effective description in terms of dynamics models underlying the territorial evolution. According to the complexity approach, the study of appropriate modelling is based on the endogenous mechanisms, linked to agent choices, that lead to the system's configuration. Agents (individuals, households, enterprises) interact through the network that connects them to exchange information, goods and resources, to establish new partnerships, collaborations, friendships and more. A territory can thus be described as a network of connections between different socio-economic determinants, in which links are changeable and diffuse in space and evolve over time towards a hierarchical organization. Thanks to particularly effective interactions between energy, material and information with local geographical features, some of these networks are configured into particular recognizable settlement systems and reduce the various morphological occurrences to a manageable number of types. Industrial districts, for example, are specialized, organized settlements located in areas of limited size, which are characterized not only by the availability of particular materials and energy, but also by the sharing of experiences through an active communications network at a social level (so-called intangible capital) and by continuous, widespread interactions between the parties. Therefore, the resulting territorial reality is self-organizing, challenging to achieve with external dirigiste regulatory actions [Corò, Micelli 2008].
Formally representing the relationships on which the built environment depends, to model and manage the different flows to guide them towards predefined goals is not an obvious process. The problem goes beyond the morphological issue, it is closely connected to social, economic, cultural and symbolic issues that together determine the transformative

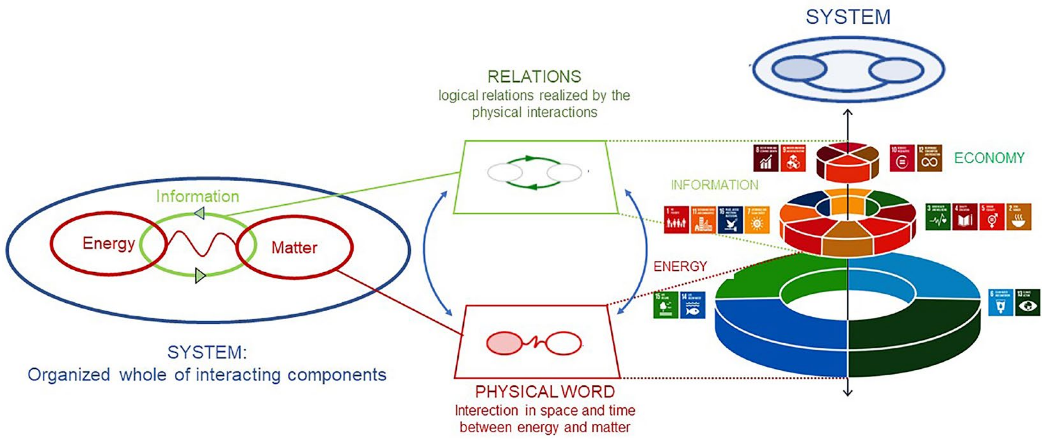

Fig. 3. Sustainable Development Goals related to the matter, energy and information scheme derived from cybernetics theories.

practices of space and how new elements modify the pre-existing configurations of the territorial palimpsest. If not carefully managed, these forces can lead to the dissolution of the landscape and environmental values that have been stratified in a specific territory.
The behaviour of these forces is parcelled out in many data and information heterogeneous in type and size, which, if examined by man, would require the commitment of a large number of people over a long time.
It is necessary to use an AI capable of sifting through this multitude, even admitting partial or incomplete data, to identify the relationships between territory, resources, and the various settlement realities. By observing and comparing the results diachronically, it would be possible to visualize the system evolution, highlighting the continuities, discontinuities and possible interruptions that characterize them, allowing the visual representation of otherwise abstract concepts.
In particular, the simulation requires a neural network model based on fuzzy logic will be configured, which can be used to solve both deterministic and stochastic problems. The process will be conditioned by moments of "training", during which data significant to the problem understanding being studied are input, followed by new data, whose possible output is unknown, to obtain effective solutions based on the previous phase.
The realization of such a large and complex synthesis model requires the achievement of secondary objectives:

a. Definition of a procedure enabling the AI to recognize spatial data, in the first instance those available in databases related to the application of geographic information systems (GIS), summarized as:

– geometric, relating to the cartographic representation of the objects represented.
– topological, referring to the mutual relationships between objects.
– informative, concerning the data (numerical, textual, etc.) associated with each object.

The GIS databases are usually in vectorial formats, more suitable for the representation of information that varies discretely (e.g. the location of waste bins in a city or the representation of roads or a land-use map), and raster formats more suitable for the representation of data with continuous variability (e.g. a digital elevation model or a slope acclivity map). These data will have to be integrated as far as possible with other sources, both of a documentary and archaeological nature. They will require the definition of symbolic schemes that make it possible to treat historical-archaeological data in numerical form.

b. Study of the energy-materials-information domain by identifying several notable areas, chosen on the basis of the United Nations Development Goals [10]. These are universally valid, i.e. all countries must contribute to achieving the goals according to their capacities and take into account the three dimensions of sustainable development, economic, social and ecological, in a balanced manner. The comparison between the different forms of settlement and these parameters, by identifying differences and similarities, within the investigated territory will make it possible to analyze spatial relations and inductively determine the possible outcomes of political and planning choices, anticipating the effects.

Attributions

Although the article must be considered a collective work, Michela Rossi was responsible for the Intro, Giorgio Buratti wrote the second paragraph (Territory as a complex system) and Giorgio Buratti and Sara Conte wrote the third paragraph (Method and goals).

Notes

[1] "Complex" descends from the Latin verb ***complector***, meaning to gird, to hold tightly, and, in a metaphorical sense, to embrace, to understand. Other meanings used in the Latin classics are bond, nexus, concatenation.

[2] The three bodies problem consists of calculating, given the initial position, mass and velocity, the system's future evolution consists of three bodies subject to mutual gravitational attraction. If in the case of two bodies, the evolution of the system is entirely determined by simple equations, if a third body is added to the system, this last is no longer describable analytically or only for particular cases, since each displacement of a body simultaneously influences the displacements of the other two. The introduction of the computer has allowed over the years a greater control of the system's evolution, which is now predictable for longer and longer periods with the adoption of simplifications. However, at the writing of this article, the problem is not yet definitively solved.

[3] In the pioneering study on the qualitative theory of differential equations, published between 1881 and 1886, Poincaré discovered that the existence of a doubly asymptotic solution led to infinite others, which intersect infinite times, forming a tangle that Poincaré did not even try to draw. Although he did not pay much attention to the disorderly behaviour he discovered, Poincaré was deeply disturbed by it; almost ten years passed before he returned to publish something new on the subject. This type of motion is now called 'chaotic'.

[4] A cellular automaton is a mathematical model used to describe the evolution of complex discrete systems, studied in the theory of computation, mathematics, physics and biology, consisting of a grid made up of cells. The grid can have any finite size; each limited portion of space must contain only a finite number of cells. Each of these cells can assume a finite set of states and, after a fixed time, changes state simultaneously with all the others, according to a fixed rule.

[5] For example, one is 'happy' if at least 37% of one's immediate neighbours are of the same ethnicity, a condition for which one does not leave the cell.

[6] The preference for similar characteristics or interests is very marked and widespread in all cultures and has a strong instinctual connotation. It is clear that the relationship between this propensity and racism or just residential segregation is very intricate and still far from being definitively clarified and agreed upon. One could, for example, observe that the difference in income may have a more significant influence, but this kind of recognition would imply a more articulated analysis, whereas ethnic distinction requires only the recognition of somatic features, clothing or eating habits.

[7] In physics and chemistry, a phase transition is the transformation of a thermodynamic system from one state of aggregation to another, with a consequent change in one or more physical properties. The best-known phase transition is the transition from the solid (ice), liquid and aeriform (vapour) state of water.

[8] The segregation/integration relationship could also depend on other variables such as: the size of the city; the percentage of free cells; a different number of neighbours; different settlement patterns; possible costs of moving (relocation) to other areas; the value of the urban rent and its variation according to the prevalence of one group rather than the other, and so on. However, studies conducted in the following years, which have considered these and other variations, align with Schelling's outcome. The only research that has so far led to different conclusions is the model of E. Bruch and R. Mare (2006), which departs from the original model in terms of a larger grid, tolerance degree diversification for different agents and allowing entities to return to occupy a cell they have already left. However, it is sufficient to eliminate the last condition for this model to return to the segregationist model too.

[9] If, for example, a group of people decide to sell stocks in the equity market, in the absence of a cause attributable to economic fundamentals that rationally justifies the decision, then the previously disorganized market, in a stable balance between requests to sell and requests to buy, organizes itself towards a continuous fall, leading to a financial collapse.

[10] In September 2015, more than 150 international leaders met at the United Nations to contribute to global development, promoting human well-being and protect the environment. The community of states endorsed the 2030 Agenda for Sustainable Development, the essential elements of which are the 17 Sustainable Development Goals (SDGs).

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