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Critical Thinking About Urban Studies Linked with Thermodynamic Terms

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Abstract. The interaction of urban science with psychology, biology, ecology, and technology creates a rich diversity. Thermodynamics and information theory are among the methods of analysis used to understand urban systems. These methods have a variety of options, and their decision-making processes are complex. Definitions related to the concept of city vary depending on the approach of social science disciplines such as urban science, sociology, geography, economy and public administration. Geographic Information System (GIS) enables the creation of interactive maps of the urban system's transformation processes. Thus, city maps have gained qualifications for the examination of the possible changes and future scenarios. The relationship between city and thermodynamics has been developed with implementations such as energy, sustainability, system approach, spatial analysis, aesthetic evaluation methodologies, urban growth, and urban models. The thermodynamic interpretation of implementations provides concrete data such as heat map of the cities, and energy potential. The interpretation of entropy at the intersection of thermodynamics and information theory gives different perspectives to the concepts such as coding, redefining aesthetics and urban growth. The studies which relates urban issues and entropy concept are very different in approach and content from each other. This situation has also created a ground for meaning shifts. The aim of this study is to critically discuss the methods, concepts, and theories of urban studies related to the thermodynamic terms. As a method, the studies on the approaches of the concepts of thermodynamics in urban planning and urban design will be evaluated with a literature review.

Introduction

The system approach, diversity, network relations, complexity are among the prominent adjectives in the definitions of a city structure. Since the emergence of the urban planning discipline, the redundancy of options and possibilities has led urban analysis to the search for integrated models. In this process, the concepts of thermodynamics and entropy have been integrated into the academic researches of the profession by an analysis of the theory and implementation characteristics. There are basically two different relationships between the city and thermodynamics. The first is related to the three basic laws of thermodynamics. Heat map and energy usage of cities can be given as examples. These features can be measured in a very tangible way and have a scientific nature. The second is associated with entropy in information theory including its re-formulation with a different interdisciplinary interpretation, depending on the second law of thermodynamics. It includes the calculation of the aesthetics and informatics-based information depending on various criteria at the plan (two dimensional) and skyline (three dimensional) scales in the urban form by using the formula developed by Shannon (1948) [1].

A source of information can be considered as a mathematical model allowing the symbols to occur randomly in a row. These symbols can be electrical quantities, computer data, image sequences, or waveforms. All these symbols are the alphabet of the model that is the result of probabilistic processes. This model includes terms that are measurable, computable and has a time concept. The calculation of these measurements is related to probability spaces and random variables. These concepts can be defined as nonnegativity (equation 1), normalization (equation 2) and countable additivity (equation 3).

$$P(F) \geq 0 \quad (1) \qquad P(\Omega) = 1 \quad (2) \qquad \mathrm{P}(\cup_{i=1}^{\infty} F_i) = \sum_{i=1}^{\infty} P(F_i) \quad (3)$$

Here is the probability space, consists of (Ω, P, B) and a probability measure P that assign a real number P(F) to every member F of the field. It is possible to expand this theorem and to apply to different areas [2].

The cities are dynamic structures, and they change according to time in terms of visual and construction techniques. These changes can be evaluated as a random process and the perception of a dynamic system. Two models can be used here. The first model is a series of random variables that are very basic. The second model is assumed that it consists of an abstract dynamic system formed by a space of probability and a transformation over space. Both models can be related to each other by taking into account a time shift as a conversion. In the mathematical description of the physical world with laws of thermodynamics, there are statistics and probability theory. Meier (1962) revealed the concept as the communication theory of urban growth [3]. Wilson (1969), in transport planning, developed entropy-maximizing spatial interaction models [4]. Batty and Mackie (1972) dealt with spatial entropy and spatial interaction models in urban systems [5]. Based on these, the spatial infrastructure of statistical physics and information theory has been developed [5,6]. There is a need to make an abstraction with coincidence and symbols in order to associate information theory with urban systems. In this way, the definition of a specific information-based entropy can be created from the definition of physical entropy. When the process is reduced to the problem of measuring the information with abstraction, the measurement of the aesthetic value with entropy is performed. The greatest support for aesthetic theory in this field was provided by the entropy formula developed by Shannon (1948) [1]. This process can be described as the aesthetic interpretation of entropy. After this stage, spatial implementations of the entropy method begin. The information entropy approach is used in areas such as urban growth, architectural facade features, urban skylines, art, and aesthetic evaluation. On the basis of each of these areas, message items and information concepts follow a similar process, but the interface models integrated with the implementations differ. In order to better interpret the subject, it has been decided that the implementations of entropy in the field of evaluation of aesthetics and urban skyline will be considered as a constraint in the information theory part of the study.

The general criticism of the studies in this area is the acquisition of partially modified data based on the interpretation of the architectural, aesthetic and environmental psychology parameters. There is a conflict in the interpretation and handling of these data.

The definition of thermodynamics in heat and energy and its meaning in information theory and a binary grouping related to the urban structure will be performed in this study.

One of the biggest challenges in urban planning studies is to be able to relate two different definitions of entropy with thermodynamic laws and its formula in information theory with urban studies. Figure 1 includes a sketch outline prepared for this relationship.

In this schematic explanation, entropy relations and the city can be seen in two different aspects. These relations are different from each other. In one side looking at entropy from the thermodynamic standpoint, urban entropy is a kind of waste (energy, heat, pollution) related to dense urbanization and urban decay. On the other hand, from the information theory viewpoint, the entropy is a kind of measure of criteria research which is related to urban aesthetics in terms of urban aesthetic values. From this approach, Table 1 is prepared to define the urban system in the context of entropy. Comprehensive information on these definitions can be found in the next section.

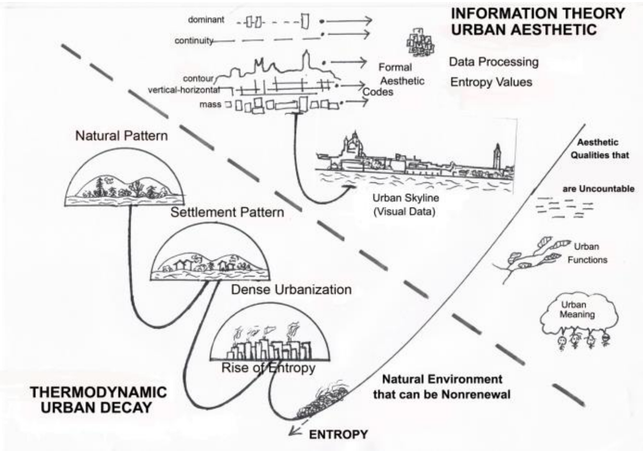

Figure 1. The binary character of the city and entropy: informational interpretation of entropy measure of urban aesthetics and thermodynamic definition of urban decay.

Table 1. Entropy concepts and their relations with urban system.

Entropy		
Thermodynamic Laws		**Statistics and Probability Theory**
Physical Entropy		Entropy Related to Information Theory
Urban Relations -Efficient use of energy and sustainability -Heat map and thermodynamic structure of the city -Strategy for designing and management of a low-entropy city -Urban metabolism concept for understanding self-organization of open thermodynamic systems		**Urban Relations** - Spatial organization as the communication theory of urban growth -Understanding urban design aesthetic criteria in the coding system, by the effects of information theory -Understanding facade aesthetic dimensions of architectural styles of the buildings -Measuring aesthetic quality of urban skylines

The main objective of the study is to draw attention to dual structure of thermodynamics and information entropy and their discrete effects to urban studies.

Thermodynamics and Urban Studies

Thermodynamics: Heat-Energy and the City Structure

Carnot, the founder of thermodynamics, found the right expression for the maximum efficiency of any heat machine operating between two given temperatures [7]. From a thermodynamic viewpoint, resources are transformed from the usable energy state into an unavailable form, and this form is defined as entropy in Thermo dynamics developed by Clausius (equation 4).

$$\Delta S \geq 0 \tag{4}$$

Within the semi-open system of the world, sources such as sun and wind are renewable energy sources. With these features, renewable energy sources have the potential to turn into clean energy, as they offer an alternative to the situation of risk of increased entropy. Its expression in thermodynamics is that the energy cycle is a partially reversible process.

Thus, if the energy-based entropy map is prepared for the city, the natural resources and mineral reserves are determined, and the energy potential of them is shown on this map when the city is first established. So, the entropy accumulation of the city from past to present and what it means for the city's future can be defined. The relationship among thermodynamics, energy and urban structure is closely related to the concept of sustainability. Fistola (2012) describes the effects of water pollution-producing activities on the soil, electromagnetic pollution, air pollution as urban entropy producing activities. Thus, it is seen that strategies should be developed to reduce urban entropy for a sustainable future [8]. In a similar approach, Fistola and La Rocca (2014) defined urban entropy as a fundamental obstacle to creating a sustainable and intelligent urban system [9]. There are several studies suggesting the reduction of urban entropy for the ecological survival of the urban system. Pelorosso et.al. (2017) defines internal entropy as socio-ecological and structural complexity and wastes as external entropy [10]. These studies show the direct meaning and implementations of entropy in thermodynamics laws.

Gandy (2006) interpreted urban entropy in a different way. “The growing presence of nature within former industrial landscapes can be conceived as a kind of urban entropy whereby the distinction between human artifice and ecological succession becomes progressively blurred” [11]. This interpretation differs from other urban entropy definitions. This information shows that there are differences in the definition of urban entropy in the thermodynamic context. Mohajeri et.al. (2016) has addressed urban entropy as a flexible indicator for urban mobility and sustainability. Measurements have been made on the solar potential of urban entropy [12]. From a thermodynamic point of view, this study is important as an urban study in which the entropy measurements are implemented in real terms and used for solar energy measurements.

The concept of low entropy city is a common denominator of urban metabolism and sustainability approaches. Organic structures of cities are human population and ecosystems. These two organic structures are seen as urban metabolism. In terms of thermodynamics, the metabolism of cities is a growing and evolving open system [10]. In the approach of urban metabolism, there is an understanding that the city has an organic system, not an autonomous system, and that this system needs external material and energy change. Identification of appropriate entropy indicators that can spatially assess the effectiveness of green interventions at different urban scales is necessary for implementations. This makes entropy suitable for use as an effective tool in sustainability studies [13].

According to Bristow and Kennedy (2013) thermodynamics has two main effects of cities and these are; “(1) the implications of the second law of thermodynamics on the efficient use of energy; and (2) the self-organization of open thermodynamic systems” [14]. Thus, it is seen that the real meaning of thermodynamics is discussed in the definition of two different processes in urban studies. Different implementations and researches can be performed with various combinations of these approaches.

The Second Law of Thermodynamics in Information Theory: Information Aesthetics in Urban Design

Entropy as the second law of thermodynamics, redefined in the information theory, has developed according to statistics and probability theory. In relation to the random processes, the logarithmic expression used by Boltzmann (1896) [15, 16], who defines the definition of statistical entropy and improves its formula, is similar to the modern concept of information theory. This equation is expressed below (equation 5).

$$S = k \log W \tag{5}$$

$$\Delta S = S_2 - S_1 = K_B \ln \frac{\Omega_2}{\Omega_1} \tag{6}$$

Schrödinger (1944) defined the negative entropy as a contribution to the statistical entropy described by Boltzmann [17, 18]. Statistical entropy is expressed by the above equations. Here; when the initial state is set to 1, S1=KBlnΩ1. Similarly, the equation S2 can also be written. In this case, ΔS is given in equation 6. (Here S is state function). Equation (7) is obtained when equation (3) is written taking into account the gas molecules (V1, V1), Avogadro number (N) and Boltzmann constant (kB).

$$\Delta S = S_2 - S_1 = N\, k_B \ln \frac{V_2}{V_1} \tag{7}$$

When the equation (7) is arranged, equation (5) is obtained. In equation (8), Boltzmann equation is considered equal to R/NA. Where R is the gas constant NA is the number of Avagadro. As the entropy changes with temperature, the temperature is assumed to be constant.

$$\Delta S = nR \ln \frac{V_2}{V_1} \tag{8}$$

$$\Delta S \geq \frac{q_{rrev}}{T} \tag{9}$$

It is understood that the entropy from the equations can be defined according to the second law of thermodynamics in an irreversible and reversible process. In this sense, entropy becomes meaningful when the entropy of the environment and the system is also taken into consideration. Consequently, the concept of entropy ΔS is expressed by equation (9). Where q (heat) is T (temperature). An entropic amount is often used to determine whether a given reaction takes place or not. This situation can be used in the development of the environment and the city [19, 20, 21]. Shannon is the person who defines the entropy concept of physical processes within the scope of information theory, he defines the statistical entropy theory as the mean information (knowledge) and constitutes it as the basis of modern communication theory [1]. The mathematical structure equation (10) of communication theory created by Shannon (1948) is known as information theory nowadays and has been a pioneer in the development of communication technologies.

$$Hs = \sum pi\ log_2\ pi \tag{10}$$

A different approach in historical development was made by Prigogine (1989), who defined entropy on the behavior of open expansionary structures [22, 23]. Considering the meaning of entropy within other mathematical structures, Renyi (1961), who demonstrated the relationship between chaotic structures and fractals, made a new definition of the fractal dimensions of entropy [24, 25].

There are recent studies on the relationship between statistical entropy with topological structures and their participation in learning structure (algorithms) [26, 27, 28]. Interpretation of entropy in interdisciplinary studies in the fields of social sciences, economics, and psychology has become a subject of criticism over time by Shannon. Shannon (1956), who published an article on this subject, stated that information theory, which started as a technical tool for communication engineering, attracted great interest in the scientific and popular press. He points out that it is possible to make real progress in the theory of communication by only maintaining a purely scientific attitude [29]. Loewenstein (2013) states that information theory has deficits in meaning when describing the message concept. He states that Shannon formula provides data about how much of a message has knowledge of but does not provide data about the meaning value of the information content [30]. This approach is similar to Shannon's criticism. Arnheim (1974) mentions that there are some misunderstandings and confusion in the use of entropy in the field of art and aesthetics. He draws attention to the disadvantages of limiting with risky and reductionist approaches and from moving away from instrumentalized meaning such as a kind of the wrong definition of entropy such as entropy is the relationship between order and disorder [31]. Sahyun (2013) mentions that in the image processing studies, entropy approach is limited in aesthetic evaluation processes and they should be supported with psychometric studies [32]. Gauvrit et.al. (2017) use in the field of aesthetic and environmental psychology, Shannon entropy as a measure of complexity as a measure of the fact that creates a meaning shift, instead of a function of density (or symbol redundancy) emphasized that it would be more accurate [33]. Bostancı (2008), in her study on the aesthetic evaluation of urban skylines, described entropy as value range in the formal aesthetic evaluation data instead of as an expression of entropy increase or decrease [27, 34].

$$H = -\sum pi\ log_2\ (pi + \varepsilon) \tag{11}$$

Bostancı (2008) by adding the epsilon to Shannon's formula, with equation (11) this modified formula, tries to find a solution for the uncertainty in the information entropy studies on urban aesthetics. Thus, an adaptation has been made that allows the probability values that cannot be measured in the aesthetic criteria of urban skylines to be calculated without going to infinity [27]. The given examples show that like the creator of the theory, the experts from interdisciplinary fields searching of this theory also try to identify the risks such as meaning shift, disconnection of the main theory. With its various debates, information aesthetics has reached a holistic dimension where art and aesthetic analyses have been predicted by measurability of aesthetic features of the cities, presented chronologically in Table 2.

Table 2. Conceptual development of information aesthetics.

Formation and Conceptual Development of Infrastructure of Information Aesthetics
Birkhoff (1933) [35,27] *Mathematical formula of formal aesthetics*: Aesthetic value = Order/Complexity (Analytical aesthetic approach)
Bense (1956) [37] created an approach to *information aesthetics* by the roots of Information Theory: Shannon (1948) [1] + Semiotic: Peirce (1934) [36] + Analytical Aesthetics Birkhoff (1933) [35] = Bense (1956) [37]
Gunzenhäuser (1962) created *a formula for information theory measurement of aesthetic value* as R: Redundancy, H: Entropy R/H: 1/H – 1/ Hmax [38, 27].
Nees (1969) from Bense's Stuttgart School developed the concept of *aesthetic complexity* by investigating Bense's theories related to philosophy, mathematics, and aesthetics [39, 40].
Moles (1966) wrote a book on *information theory and aesthetic perception* [41].
Berleyne (1971) questioned *the relationship between behavioral theory and aesthetics related to information theory* [42].
Kiemle (1967) *first used the information aesthetics for architectural facade analysis* with reference to Bense's work [43, 44].
Buttlar et al. (1973) conducted studies on architectural facade analysis and compared the late nineteenth-century buildings with modern buildings [45, 46].

After these studies, especially in the field of computerized visualization, information entropy in the measurements of cities and architectural facades entropy concept transformed into a tool that makes aesthetics measurable to a certain extent. Its implementations about the evaluation of architectural facades, [46, 47]; the numerical evaluation of form characteristics of urban skyline [48, 49, 50] are among the pioneering and inspiring researches in this field. Studies have gained new dimensions from facade analysis, including the aesthetic evaluation of urban skylines [34]. In this area, there are studies involving GIS modeling of urban skylines [51]. Stamps (2010) conveyed his experiments on the relationship between form and aesthetics which he developed due to information theory to virtual reality models of spaces. Stamps' entropy models are tested with experimental aesthetic approaches and become a model of an integrated aesthetic solution [52]. Gauvrit et.al. (2017) used entropy and algorithmic information theory-based studies of spatial aesthetics in relation to experimental aesthetic subjects to evaluate perceived beauty in random texture patterns [33]. Thus, the field of information aesthetics has managed to include the concepts of probability and mathematics next to the philosophical and psychological meanings of aesthetics with computer-aided innovative solutions, different aesthetics evolution methods and integrated approaches from the 1933s to the present.

Conclusion

Measurement of the energy potential of the city and changes in heat map according to years show great consistency with the formula, $\Delta S \geq 0$. In addition, there are more researches carried on information entropy in urban design and planning. The main problem of this field is the need for the development of a coding system in order Shannon's formula ($H_S = -\sum p_i \log_2 p_i$) to function. In the fiction of this code-probability relationship, the other studies have to follow this process after the pioneering studies. This brings out the risk of the increase in repetitive scientific publications. As Loewenstein (2013) [30], Arnheim (1974) [31] and Gauvrit et.al. (2017) [33] who are experts from different disciplines point out, the research questions how much these studies can be effective on aesthetics and the sensory system of human being. In order to come to a conclusion, many researchers state that these studies are a helpful method in urban studies. Generally, entropy is a component of the formula in the composition of different methods. Experimental aesthetics is the most common integrated method analysis in this field. In the future studies, all urban studies on the concepts of thermodynamics by using meta-data analysis method will be examined considering their scientific or theoretical background, concepts, method approaches, results, suggestions for solution, differences in interpreting and understanding, deficiencies and illusions, as a result, the concepts of thermodynamics for the city will become clear. The realization of such a work is possible with a series of international workshops where scientists from different disciplines in this field come together. Consequently, the studies dealing with urban entropy in a subject of heat and energy have acquired scientific content that brings urban planning and engineering together as a result of using thermodynamic concepts. On the other hand, despite all critical and controversial issues, the information aesthetics discussed in the evaluation of urban aesthetics has gone through the all stages (assumptions, a search for a method, historical content, criticism and updatability) that must be accepted as a theory in social sciences and has become a method approach which has a theoretical background in the urban aesthetics. In the academical studies in this field, descriptive and critical studies are needed as much as practices.

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