Traditional Settlement Morphology from the Perspective of Thermodynamic Architecture Theory: Taking Two Villages in the Iberian Peninsula as Examples

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Abstract. The form of rural settlements is not determined by a single factor, but by various factors. With a particular focus on settlement morphology and natural energy, this study introduces thermodynamic architecture theory to discuss the relationship between rural settlement morphology and environmental energy, starting from the analysis of the relationship between rural settlement morphology and building density, building order and settlement boundary dispersion, trying to provide a reference for the updated design of traditional settlements. The first part of this paper explains the research method of settlement form based on thermodynamic architecture theory from the theoretical level trying to construct the analysis framework of settlement form typology based on energy concept. The second part introduces the coupling between thermodynamic energy concept and morphology from the methodological level. The relationship between the three energy correlation factors of intensity, order and dispersion and settlement morphology is studied. In this paper, two settlement cases are quantitatively analysed by simulation and mathematical analysis. In conclusion, it proposes a new perspective for the morphological analysis of rural settlements, which provides a feasible framework for further research on energy utilization and microclimate comfort of settlements. This study also provides a preliminary concept for the integration of the buildings type and thermodynamic study of vernacular architecture in the future.

1. Introduction
The creation of an ideal environment is more embodied in a specific spatial organization (Amos Rapoport, 1969). For the general traditional vernacular settlement, many formations are through individual behaviour, that is to say, neither through government planning nor through the design of professional architects. In the long process of human history, traditional settlements have obviously formed their own unique patterns and forms.

The form of vernacular settlements is not determined by a single factor, but by various factors, including social factors, technical conditions, geography and climate factors. This paper argues that the combination of factors will vary in different climatic environments. Even Rapoport’s theory, whose theoretical framework is very similar to Semper's mathematical formula, mentioned that climate is by no means a decisive factor. Semper proposed \( Y = F (x, y, z, \text{etc}) \), in which \( Y \) represents works of art, which is determined by the constant \( F \) and the variable \( (x, y, z, \text{etc}) \). Semper regards that the constant represents functions, and the functions are differentiated according to types. The variables are materials, places, nationalities, climate, beliefs and politics, etc. As for Amos Rapoport, he regards social culture as the constant, or "the primary factor", and other material and technological factors as
variables, or "the secondary factor". However, the natural forces that human beings growing up in different regions need to overcome are different, and the demand for shelter is different as well. Therefore, "climate adaptation measure" can naturally serve as an effective concept to satisfy the demand. If this concept is expressed in diagrams, the degree of freedom of choice of the settlement form will be in the climate perspective, spanning from intolerable climatic conditions to the climatic conditions without necessity of consideration. For example, the weather condition will affect the form diversity of residential buildings to some extent as Figure 1 below, so the form selection will form a certain linear relationship [1]. Of course, in Rapoport’s framework, each form of solution is based on specific social needs and technological resources, for example, the locals' location of settlements is generally based on personal cultural awareness and needs.

![Figure 1. Diversity of Settlement Form.](image)

This paper argues that if the potential logic and correlation between the form of vernacular settlements and climate adaptation can be explored, the influence factors of the form of a settlement can be dismantled to some extent, whether directly or indirectly. Therefore, the form of vernacular settlements is varied and mysterious based on different selection factors. It is often difficult to analyse its internal causes, and its generation generally follows the mode of selection, type, imitation and improvement over time.

2. Settlement morphology research method
This paper here proposes a new framework of traditional settlement morphology research from the perspective of thermodynamic architecture theory based on many predecessors' study of vernacular architecture and environment. There are many ways to study the influence and cause of settlements’ forms and architectural forms based on climate diversity and thermodynamic theory. Firstly, based on different climatic types, we can investigate them such as hot-dry climate, hot-humid climate, continental climate, temperate climate, tropical climate, etc. and discuss the typical solutions of each region in terms of the necessary conditions of settlement morphology, spatial types and materials, which is a common method. In addition, we can discuss the geographical location and climatic conditions of various settlement forms in different climatic grades, and examine how people treat the climatic variables that lead to different climatic types, including temperature, humidity, wind, rain, radiation intensity and light. When the discussion enters micro level of natural energy, we need to introduce the concept of thermodynamic architecture to analyse the object. Because only by considering the settlements and buildings studied as an open interface system and carefully analysing the energy exchange between them and the external environment, can we understand the local settlements as a whole.

2.1. Thermodynamic architecture theory and vernacular settlement
Thermodynamics is an important part of physics. The etymology of thermodynamics is complicated. In 1849, the adjective part of the conjunction symbol appeared for the first time- thermo-dynamic. Then in 1854-1859, it was composed of its noun form thermo-dynamics to describe the subject of heat and energy movement, and hence the name Thermodynamics. Thermodynamics studies the relationship between heat, temperature, energy and work, the equilibrium and quasi-equilibrium states of matter, and the physical and chemical reactions in the interaction between the system and the outside world when changes occur [2]. It reveals the conservation relationship of energy conversion and points out the direction, conditions and limits of energy conversion process. It is of great significance to use thermodynamics to analyse and guide human creative activities [3]. When the concept of thermodynamics is introduced into architecture, it is called Thermodynamics Architecture. Thermodynamics architecture is a branch of human thermodynamics. Its research object is
architectural design theory, energy, entropy and thermodynamic law in single building and urban planning design. Alan Wilson published the first edition of Entropy in Urban and Regional Modelling in 1970, applying the method of entropy maximization in statistics to the study of urban and regional models. And describes the theory of thermodynamics architecture. He believes that the whole system theory and entropy have a positive effect on urban planning [4].

The research objects of thermodynamics architecture include natural and climate elements, architectural form and material, human body perception, etc. In this paper, three thermodynamics factors, light, wind and heat (humidity), are proposed to be introduced into the concern of vernacular settlements. "Thermodynamics Intervention in the Study of Vernacular Architectural Form" is proposed, which defines the intersection of thermodynamics, climate architecture and vernacular settlements at the level of settlement scale. This paper attempts to combine theory, technology and analysis to answer the question below: What is the significance of natural energy intervention in vernacular architecture? How do the natural energy elements interact with the form of vernacular architecture and settlement? Is there some hidden logic between them?

2.2. Research and mathematical analysis of vernacular settlement form

In this part, a framework of settlement morphology analysis based on thermodynamic energy elements will be proposed, which explains how the three energy elements of light, wind and heat interact with three indicators: density, order and interface dispersion. The framework of analysis is shown in Figure 2.

Figure 2. Settlement Form Relationship with energy elements and Three Indicators.

2.2.1. Light and settlement density. Light, which is conducive to keeping human health and creating a comfortable environment, is also one of the important climatic factors in the long history. In term of architecture, local people grasp the characteristics of light to ensure that it can be optimized in function and aesthetics, or to appropriately reduce and control excessive light in accordance with local cultural and functional needs. In term of settlement, the space and alley formed between buildings have a great influence on the light. Therefore, the minimum average distance between buildings in the settlement is taken as one of the indicators to evaluate the density of the settlement.

2.2.2. Wind and settlement order. Wind is needed by people, but sometimes it brings disaster to human beings. The relationship between settlement form and wind has been studied by many scholars, which is considered that there is a great correlation. When it’s in hot summer, cool breezes are welcomed, but in cold winter, the wind makes people feel even more bitter cold. Building orientation and architecture design can reduce the negative impact of wind to a certain extent, and can further enhance its positive impact by promoting ventilation and maintaining the stability of the building structure. Therefore, the order degree of settlement is mainly studied from the perspective of architecture.
There are sometimes many criteria for judging the order of building settlements. If each building is oriented in the same direction, then obviously such a settlement has a high sense of order. But a circular settlement around the centre of a settlement, even though the orientation of each building is different from that of the northward direction, their centripetal magnitude is similar, so we can call such a settlement highly ordered. Therefore, when we judge the order degree of the settlement by the angle, we need to consider the average angle of each building and local dominant wind direction and the average centripetal quantity of each building and settlement center at the same time. Admittedly, if the settlement has multiple centres, such as the old village of Cuenca in Spain, as we will see later, then each building should be calculated with the nearest center.

2.2.3. Hot-wet and settlement dispersion. Rural architecture based on the concept of bioclimatology has been developed and used by many civilizations in the world for centuries [5]. Thermodynamic "heat balance" often refers to the dynamic balance of heat in a space, which has become a hot topic in the world. The balance between heat supply and emission is often reflected in the planning scale and the building settlement scale, and is also of great significance in the more micro scale of human body and building scale [6-8]. Just as Inaki Abalos puts forward the "Bodily doctrine" of thermodynamics in 2015, people's judgment of comfort is both physical and sensory [9].

The theory of dissipative structure was put forward by Prigogine in his article Structure, dissipation and life in 1969 [10]. The internal organization of the thermodynamic open system of entropy flow direction is very important. When this thermodynamic viewpoint is applied to the design of buildings and settlements, the internal organization of the dissipative structure corresponds to the organization mode of energy flow, which is a generalized form of buildings and settlements. At this time, we need to first investigate the boundary state of the system. Therefore, this paper calculates the shape of the settlement by computer, and analyses the discrete degree of the ellipse which is similar to it, so as to analyze the boundary shape of the settlement.

3. Analysis and result
There have been many related studies on settlement morphology around the world, mainly from the perspective of mathematical and geometric analysis of settlement morphology and building typology [11]. This part puts forward the three indicators mentioned above and focuses on light, wind and heat (wet) in the thermodynamic vernacular settlements, and introduces them into the morphological analysis of local settlements, taking two rural settlements as examples which can be seen in figure 3. The two cases selected in this paper are the old town of Cuenca in central Spain and the old town of Gavieira in northern Portugal, both in Iberian Peninsula. They have similar latitudes and geographical conditions, but there are obvious differences in climatic conditions. For example, in terms of the annual average predominant wind direction, Portugal's case is northward, while Spain's is eastward. In addition, the Gavieira settlement is located in the low-lying valley, while the Cuenca settlement in Spain is located in the valley between the two rivers.

Figure 3. (a) Layout of Gavieira, Portugal, (b) Layout of Cuenca, Spain, (c) Wind Direction Map of Gavieira, Portugal, (d) Wind Direction Map of Cuenca, Spain, (e) Photo of Cuenca, (e) Thermal imaging of Cuenca
The following is the process of calculating the density index of settlement form. Firstly, based on Rhino-Grasshopper computer simulation technology, the boundary lines of each building unit are picked up, and the shortest distance between them is calculated, each of them has its own shortest distance. Secondly, because the distance between each building is numerically calculated, if there are n buildings in a settlement, the shortest distance per building will be n-1. Obviously, there is no basis for considering all the shortest distances in terms of density, which will lead to the inclusion of distances between two buildings that are far apart. Therefore, only the shortest distance of the first two times is considered here. Thirdly, by taking the average and standard deviation of all distances calculated and comparing the data obtained from different settlements, we can get the method of comparing the density of settlements. According to the above calculation, the average distance between each building of Cuenca settlement in Spain and Gavieira settlement in Portugal is 14.896 m and 9.241 m, respectively. The shortest distance between the settlements is 0.745 m and 0.376 m, the standard deviation is 30.10 and 17.36, and the dispersion coefficient is 2 and 1.88. That is to say, the density of Cuenca settlement in Spain is not only lower than that of Gavieira, but also the density difference of its settlements is relatively large.

Figure 4. (a) Visualization of the Shortest Distance and Density in Gavieira, Portugal (b) Visualization of the Shortest Distance and Density in Cuenca, Spain

Figure 4 above is a density visualization of Gavieira and Cuenca settlements. The buildings with smaller average distances are shown in dark while the buildings with larger average distances are shown in light. The building with the darker colours can be understood as being denser in the entire settlement.

Figure 5. (a) dispersion diagram of Gavieira village in Portugal (b) dispersion diagram of Cuenca village in Spain

This paper describes how to calculate the dispersion index of settlement form, which can also be understood as boundary integration index. In order to further consider the overall energy utilization and comfort of the settlement in future research, the boundary of the settlement needs to be defined. Generally speaking, rural settlements are greatly influenced by natural factors as above. The shape boundary of natural rural settlements is often difficult to identify unlike many artificially controlled boundary forms in urban development. Firstly, this paper uses the outline of each single building extracted before to find the outline of the settlement interface. It is assumed that each building has an attraction to the periphery so the two buildings will form the sense of place between them. Therefore, the definition of boundary is not only the hard boundary of the building, but also the “field” adjacent to each building. Finally, morphological discretization analysis is carried out between the obtained
settlement boundary and the approximate ellipse with the same aspect ratio and the same area, and the shape index and the degree of boundary discretization are obtained. Here, the shape index reflects the degree of morphological deviation between the settlement boundary and the similar ellipse with the same area. The minimum value of the shape index is 1. The closer the value is, the closer the figure is to the similar ellipse shape. According to the above calculation, the shape index of Cuenca settlement in Spain and Gavieira settlement in Portugal are 1.7 and 1.2 respectively, and the dispersion degree is 0.41 and 0.16. Figure 5 illustrates the dispersion of Gavieira and Cuenca villages. Therefore, through the calculation of the above methods, this paper finds that the boundary of Cuenca settlement is more concave and convex than Gavieira, and is more complex. The external boundary of Cuenca settlement can not only permeate with the internal buildings of the settlement, but also contact with the external environment more thoroughly.

4. Conclusion

Traditional cities and settlements can often be seen to deliberately adjust density to cope with climate. The traditional "cell-breeding" architecture and the "inward" high-density layout of small atriums in North African cities are designed to cope with the hot and dry desert climate and to withstand the hot summer wind, winter cold wind and dust accompanying the wind. Similarly, in order to obtain ventilation to cope with hot and humid climate, Dai villages in China specially make single buildings ventilated on all sides to achieve a "scattered" low-density layout.

In this paper, the thermodynamic architecture theory is introduced into the settlement morphology layout, and three methods are proposed to analyse the settlement morphology: light corresponding to density, wind corresponding to order and heat corresponding to dispersion. Firstly, the thermodynamic indexes of settlement morphology can be quantified at the level of mathematical and physical analysis. Through calculation, the density of Cuenca settlement in Spain is not only lower than that of Gavieira, but also the change of building distance is relatively large. Secondly, through the quantitative analysis of settlement morphology, the settlement morphology can be further qualitative and classified. With the help of the concept of thermodynamic open system, the calculated settlement boundary can describe the permeability of the boundary with the internal building and external environment to a certain extent, and thus can reflect the degree of its influence by external forces. Therefore, the correlation of these three indicators is helpful for the detailed description and classification of settlement morphology. It provides a feasible framework and basis for further study of settlement energy utilization and microclimate comfort.

5. Reference

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