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Article

Environmental Features of Chinese Architectural Heritage: The Standardization of Form in the Pursuit of Equilibrium with Nature

Jose-Manuel Almodovar-Melendo * and Joseph-Maria Cabeza-Lainez

School of Architecture and the Faculty of East Asian Studies, University of Seville, 41012 Sevilla, Spain; crowley@us.es

* Correspondence: jmalmodovar@us.es

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Abstract: We present a scientific discussion about Chinese historical architecture and cultural paradigms in order to analyze the formation of building patterns objectively connected to environmental features. In this regard, we will demonstrate the process of standardization from architectural modules related in different levels of composition around "voids", onto cosmological urban tissues in harmony with nature. The conclusions show that we can only understand Chinese architectural patterns in relation to *Dào* or nature, and in turn, they possess profound social and environmental values from which we receive useful lessons to advance towards sustainability in architecture and urban planning. The authors believe that it is critical for China and the world to find a new approach to the building construction industry with an ecological and philosophical background recognizable as "Chinese" and based in its own past. In order to support the information provided in the first part of the article, the authors have conducted an environmental analysis of the traditional Chinese urban layout whose results greatly confirm the initial hypotheses, i.e. the historical fashion of constructing neighborhoods improves conditions of the town in terms of comfort and is able to save energy, thus reducing pernicious change effects.

Keywords: Chinese architecture; standardization; environmental architecture; Beijing urban layout

1. Introduction

This paper discusses the formalization of Chinese architectural patterns following ancestral notions to establish a harmonious relationship between humans and nature. In this search for a balance between the way of inhabiting the world and the natural environment, the Chinese mind developed solutions that have taken on a renewed interest in the context of the current concern for global sustainability and climate change [1,2].

To understand the configuration of architectural patterns, it seems essential to discuss them in the context of Chinese millenary culture and language, due to the great differences in conceptual approaches with respect to the West. In this regard, Xinian et al. [3] state that many scholars did not consider architecture in China as a type of art despite the fact that was one of its most significant cultural manifestations. They related the concept of form or *xíng* to the execution of pre-established models, while the level of knowledge beyond formalization has been included in the field of philosophy or the arts. Moreover, *tǔmù* (literally Earth-wood) was the term used to refer to buildings, and we can obviously trace it to construction [4].

Consequently, knowledge about architecture was traditionally linked to practical manuals, such as the *Yíngzàofǎshì* or State Construction Standards. It is possible to find these concepts circa 1100 BC in the *Yìjīng* or Book of Changes, where we can read out that:

形而上者谓之道，形而下者谓之器。

"What is above form is called *Dào*, what is beneath form is called object."

According to Henderson [5], *Dào* is the term used in China to refer to nature or even natural order. Thus, formalization not only leads to construction or practice, but also to cosmological concepts. Such concepts articulate a correlative way of thinking through which architecture becomes a human creation, which must reproduce the supernatural through cosmological ideas and thus remain in balance with the natural order. This parallelism, in turn, reveals the correspondence between celestial and earthly orders ever-present in Daoist philosophy. In this sense, it was traditionally understood that "the sky is round and the Earth square", 天圆地方 [5] (p. 61). As a consequence, the composition system and traditional spatial organization in China hark back from the development of geometries based on ideas of geomancy or *fēngshuǐ* [6,7]. In this regard, cosmological schemes and numerical relations that explain the nature of the cosmos have been applied to the configuration of architectural patterns [8]. Similarly, the social order based on the Confucian tradition stems from nature and, thus, it reflects in architectural models [9]. Accordingly, the traditional spatial organization of the house reproduces the hierarchical order of the family, which is the basis of society [10]. In fact, the Chinese disyllable of country or *guójiā*, is a semantic equation that literally means country plus family, because the concept of house or *jiā* also means family and decomposes in a big sow or domestic animal protected under a sheltering roof. Consequently, both architectural and urban patterns tend to reproduce the social rules [11]. Another relevant difference in relation to the Western approach lies in the fact that Chinese architecture has pursued consistent standardization from its inception [12,13]. We have to bear in mind that economy of means has always characterized such architecture due to secular overpopulation of the country. Accordingly, Frank Lloyd Wright points out that "the Oriental artist sees in everything the pattern, the Western artist values" [14], and his mentor in oriental matters, Ernest Fenollosa, stressed that the supreme thing in the world of art is conception [15]. In this regard, China has a strong tendency towards cultural coherence that is reflected in its architecture, despite showing a considerable regional and climatological diversity [16]. Therefore, Chinese architectural evolution has been slow and has maintained a continuity in essential aspects. Similarly, Liáng Sīchéng comments that: "It is an indigenous growth that was conceived and born in the remote prehistoric past, reached its 'adolescence' in the Han dynasty, matured into full glory and vigor in the Tang Dynasty, mellowed with grace and elegance in the Song dynasty, then started to show signs of old age, feebleness, and rigidity" [17] (p. 65). Furthermore, historical Chinese architecture has not been developed through a slow process of adaptation to the natural environment by trial and error, as is common in other cultures [18]. On the contrary, architectural patterns were configured thousands of years ago from high intellectual notions about the natural order that underlie the most basic substrate of culture and whose essence has been maintained over time in building codes [19]. In this regard, an adroit correlation establishes between cosmological concepts, understood as dualities that combine in different levels of complexity, and an architectural composition system based on elements or modules aptly assembled at different levels [4]. These notions of ritual cosmology have crystallized in the production of ancient and modern cities, as we would outline below.

As the article focuses on cultural aspects for the configuration of architectural patterns of profound environmental values, we intend to promote and revitalize them in the modern world and to recognize their potential for important cities of modern China. More specifically, we have analyzed the correlation established between architectural models and cosmological ideas. Through this parallelism, we draw the articulation of architectural modules in different levels of composition from the most basic structures to the urban pattern. Moreover, the authors carry out an exploratory solar access analysis of Beijing's traditional urban layout to discuss objectively the environmental benefits of traditional patterns. We are convinced that these ancient ideas should be highly effective to avert climate change effects through building construction.

2. Cosmic Order and Harmony between Man and Nature

2.1. Bāguà *Diagram as a Representation of Space-Time*

In the basic substrate of Chinese culture lies the belief that humans may occupy nature but only in harmony with the universe, constituted by dualities or opposing and complementary elements [20]. These concepts appear more than three thousand years ago in the Book of Changes (*Yìjīng*), known as the Book of Divinations [21]. In fact, the pictogram 易 represents a reptile easily changing its color under the sun, which suggests the ancestral sacrifices held for divinatory purposes on solar events, such as equinoxes and solstices. Both Daoism and Confucianism show influences of this book, which embodies the spirit of Chinese culture. In fact, Confucius annotated the only surviving version of the *Yìjīng,* and this treatise inspired some of the terms used by Laozi. On a fundamental sentence, we find that:

> 易有太极，是生两仪，两仪生四象，四象生八卦。
>
> "There is in the Changes the Great Primal Beginning. This generates the two primary forces. The two primary forces generate the four images. The four images generate the eight trigrams."

At another fragment, Zhuāngzǐ mentions the nine divisions of the writing of Luo (see below) and states that, if disregarded, calamity and evil are inevitable (not unlike today if we refer to environmental terms).

Therefore, it is suggested that the world is composed of dualities. The first two forces mentioned in this quote would constitute the first duality, the *yīn* and *yáng*, which refer respectively to the sunset and sunrise or the west and east. Geometrical compositions that represent cosmological ideas have evolved from this polarity based on the movement of the sun.

In addition to west–east, the concepts of *yīn* and *yáng* have other meanings and applications, including female–male, night–day, odd–even, and solid–void. The *yīn–yáng* represents a duality that dissolves in a dark unity that emerges from the "mysterious female" *xuán pìn*. They would be like two sides of the same coin, since they are interrelated and at the same time interdependent.

Because of this cosmological conception, a scheme known as *bāguà* generates. *Bāguà* literally means eight directions due to the belief that orientations bias the way in which energies of the universe flow, and become decisive to achieve harmony with nature. As mentioned before, *yīn* and *yáng* refer to the solar path and therefore, they connect space (oriented according to the sun position) and time (which governs the day–night cycles and the four seasons). Consequently, Chinese architecture has traditionally occupied space by establishing a symmetry with respect to the north–south axis in order to achieve a harmonic response to the course of time and a balance between *yīn–yáng* and west–east direction.

In the *bāguà*, *Yīn* is represented by a dashed or weak line while *yáng* is identified by a continuous or strong one. Combining the two dualities *yīn–yáng* the $2^2 = 4$ images quoted in the *Yìjīng* are obtained. Therefore, west–east bilateral relationship reaches for a two-dimensional model of four directions in which the notion of north and south reveals. These four directions are associated with the seasons as follows: spring–east, summer–south, autumn–west and winter–north. If they are combined with another duality *yīn–yáng*, $2^3 = 8$ trigrams are obtained which symbolize the constitutive energies of the cosmos (Figure 1).

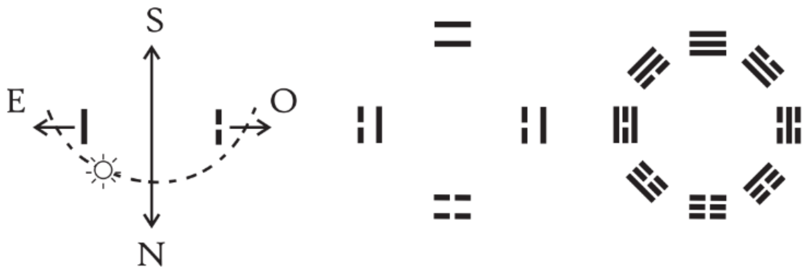

Figure 1. Configuration of the eight directions from the *yīn–yáng* duality.

2.2. The Relationship between Man and Nature. The Concept of Center

The cosmic scheme described above represents the celestial order and receives the name of Anterior-Heaven, *Bāguà* or *Xiāntiān Bāguà*. This complex two-dimensional conception of space-time implies a Cartesian and polar coordinate system. It is made up of even numbers (0, 2, 4, 8) that beckon the notion of a center. In this sense, Laozi states in the *Dào Dé Jīng* that:

道生一，一生二，二生三，三生万物。

“The course generates the one, the one generates the two, the two generates the three, the three generates all beings”. [22] (p. 113)

According to Chinese tradition, the vital energy or *qì* emerges from the vacuum spontaneously. Being it considered an indivisible unit, it implicitly constitutes a duality, or two opposing and complementary elements, the *yīn-yáng*. In order to locate the existence of human beings in relation to Nature the idea of centrality arises and subsequently the concept of one, which occupies a central place in balance with the dualities that provide for the universe. Moreover, according to an ancient belief father heaven fertilizes mother Earth with the qì, and from the harmonic relationship between them, human beings emerge. Regarding the relationship between heaven and Earth Laozi comments:

天下，万物生于有，有生于无。

“Beneath heaven, all beings emerge from being, though being emerges from nothingness”. [22] (p. 109)

Being and nothingness are considered a duality that respectively represent heaven and Earth. Harmony emerges from the union of both, and is symbolically radiated by *Shàngdì* (the Emperor of Heavens) who governs the central region of the celestial vault. Likewise, the emperor (*Shàngdì*'s son on Earth) receives the mandate from heaven, and from the center of China (literally country of the center) radiates his harmony generating order and civilization.

Therefore, the rulers of heaven and Earth occupy the center, and are always represented facing south, with left situated to the east and right to the west. To reproduce this correspondence between left–east and right–west, the *bāguà* is usually oriented with south upwards. Likewise, Chinese maps have traditionally been represented with the same orientation.

Accordingly, the center is considered in Chinese cosmology as “the space in which *yīn* and *yáng* are intertwined to produce the world, the place where the faithful is situated in his meditation and the warlock in his ritual, from and to whereby they can communicate with heaven as well as with Earth” [23] (p. 95).

As a result of combining the center with the *yīn–yáng* duality, number 3 emerges. Similarly, the number 5 was derived from addition of the center to the four cardinal orientations, constituting a “pure” number that represents the natural order. Likewise, number 9 forms by combining the eight orientations that make up the *bāguà* with the center. Therefore, 9 is considered the most relevant number on Earth. From this number, geometric representations generate to reflect the earthly order and apply to architectural patterns. There is even a cosmological representation of all the former at the reverse of bronze mirror dating from Tang (Figure 2).

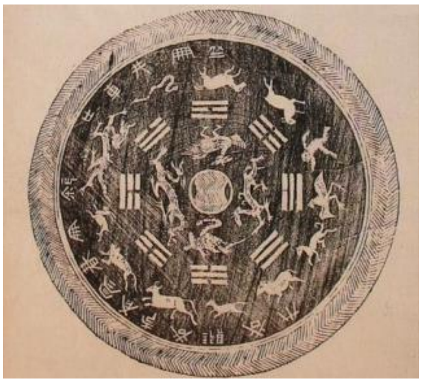

Figure 2. Cosmological representation on a mirror of the Tang dynasty (Chinese cosmological Catalogue of the Bogu Tu, from the Xuanhe era. Chinois 1114, chapter 30, page 14. Bibliothèque Nationale de France, Paris).

2.3. Parallelism between Heavenly Order and Earthly Order. Xiāntiān Bāguà *and* Hòutiān Bāguà

It is possible to obtain a three-dimensional model by virtue of a link between heavenly and earthly orders with a central axis occupied by the ruler of heaven and his son on Earth (the Emperor). In the *Yìjīng*, this model is described as follows:

> 古者包氏之王天下也，仰象於天，俯法於地。
>
> "In ancient times, when *Bāoxī shì* came to rule everything beneath the heaven, he looked up and contemplated the forms displayed in the heavens (the constellations), and looked down to contemplate the processes that were taking place on Earth."

Thus, a cosmological pattern is established in which heaven and Earth are related. In this regard, it is commented in the *Yìjīng* that:

> 在天成象，在地成形，变化见矣。
>
> "In the heavens phenomena take form, on Earth forms are configured. Thus change and transformation are manifested."

Furthermore, heaven is divided into four regions, each containing seven star formations. Mythical animals represent in this fashion the four quadrants: turquoise dragon (east), vermilion phoenix (south), white tiger (west) and a mysterious dark war between a serpent and a turtle (north). These regions have a correlation on Earth, both with natural and human structures. This correlative way of thinking between heaven and Earth is associated with *fēngshuǐ*, traditionally used to establish a cosmic structure in architectural design.

Therefore, the Anterior-Heaven *Bāguà*, which depicts the heavenly order has a reflection on Earth. As a result, from the Posterior-Heaven *Bāguà* emerged trigrams organized in a different way to represent the earthly order.

Moreover, both *baguà* schemes are associated with numerical tables that correlate natural phenomena. In particular, the *Hétú* whose round geometry symbolizes celestial principles, and the *Luòshū* with a square shape representing the earthly order. The origin of *Luòshū* and *Hétú* is still unknown but they are more than 3000 years old. In fact, we can find references to *Luòshū* in the Book of Changes and in the Zhuāngzǐ as well.

Figure 3 shows the correlation between the Anterior-Heaven (celestial order) and Posterior-Heaven (earthly order) *Bāguà* diagrams, which respectively refer to the *Hétú* and *Luòshū*. The parallelism between heaven and Earth translates into a numerical correlation for different orientations. These cosmological diagrams apply to architectural design by means of the *fēngshuǐ* to reach harmony between humans and nature.

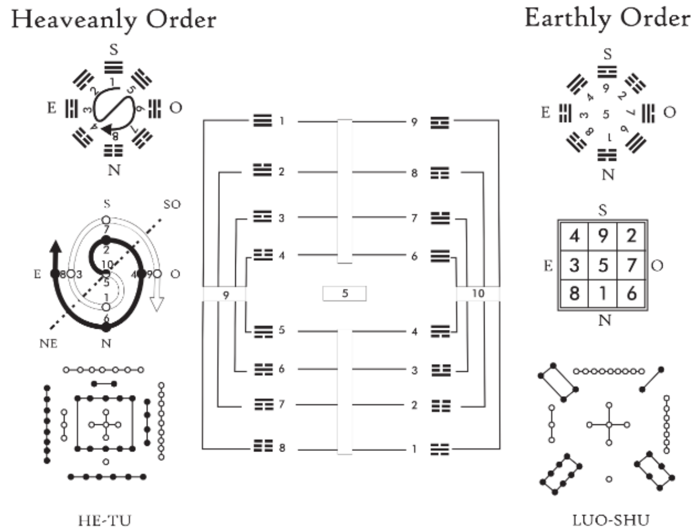

Figure 3. Relationship between the heavenly and earthly orders.

3. Cosmological Conceptions and the *Bùjú* Composition System

3.1. The Structure of the Cosmos. Relationship between the Whole and the Parts

As previously mentioned, the *bāguā* is composed of eight trigrams that represent basic principles of multiplication and permutation based on the *yīn-yáng* duality. The resulting structures are organized in space and time following cosmological principles which provide harmony between heaven, Earth and human beings.

The multiplication process from two to four and then to eight is the result of adding a *yīn–yáng* duality to the previous modules. In a higher level of organization, 64 hexagrams are generated from 8 trigrams as base modules of combination by virtue of pairing then. The *Yìjīng* uses the resulting hexagrams for divinatory purposes. In this regard, the term *shù*, used in China to refer to mathematics, justly means both calculation and destiny.

In this cosmological conception, the whole (a hexagram in this case) implicitly contains the compositional rules of the trigrams, which in turn, are constituted by *yīn–yáng* dualities. In other words, at each level of composition, the whole contains the parts and those potentially contain the whole. Consequently, relationships establish between elements or modules that derive from each other and related simultaneously beyond their hierarchy to a higher complex structure, which responds to cosmological principles providing harmony with nature [24].

Similarly, a new form of intelligibility related to the Theory of Chaos emerged in science. The latter encodes information according to a binary system. This new form of knowledge, used to understand complex systems, allows the analysis of relationships between parts and the whole by means of computer simulation methods. The language used conveys in a binary system that permits encoding the information in 8, 32 or 64 bits much in the same way as in the *Yìjīng*.

3.2. Bùjú *Duality as an Instrument for Standardization*

The manner of structuring reality described above, permit representation in the *bùjú* system (literally macro-micro). This duality suggests the existence of two complementary levels of organization. The term *bù* (warp) represents a system of division from macro to micro. In other words, from the global structure, several constraints articulate downwards to ensure that each element occupies the right place, proportion, and function as in a fabric. On the contrary, the system *jú* (organization) shows principles of growth from micro to macro. It links the rules of composition of the parts to achieve a harmonious whole. As a result, each part potentially contains the whole, which in turn, regulates the parts.

This form of architectural composition involves a large number of multiplications and permutations of interchangeable modules at different scales or hierarchical levels, which respond to prefigured constraints or limitations.

Therefore, we have been able to settle one of the main problems of the standardization of architecture. In particular, how to solve the apparent contradiction of obtaining a large number of solutions by using few modules or variations.

4. The Generation of Architectural and Urban Patterns. From the Capital to the Whole City

4.1. The Dǒugǒng and its Relation to the Space Dimension

With regard to the aforementioned compositional system, China has considered architecture as a microcosm composed of dualities organized into different levels of complexity to reproduce the macrocosm. *Dǒugǒng* (literally head-arm) is considered the most basic element of composition or modulation. A type of capital city whose outline depends on the span between pillars. Thus, it relates directly to the interior spaces' dimension.

Dǒugǒng consists of small wooden elements, which combine into a more complex structure. While longer wooden pieces are kept for pillars and beams. We can find different configurations of *dǒugǒng* standardized as a function of the distance between pillars around 1100 BC in the *Yíngzàofǎshì*.

4.2. The Concept of Architectural Space. From Jiān in China to Ma in Japan

The term *jiān* characterizes the second level of composition; it consists of a parallelepiped space limited by pillars or walls. The *jiān* pictogram (间) is composed of a representation of the Sun or Moon seeping through a door. Thus, we can deduct etymologically that thos architectural space metaphorically leads to the progress of the sun and the passage of time. Accordingly, naturally cycles are traditionally linked to human perception of space. It is interesting to note that in Chinese the netherworld received the name of *yīnjiān* or Space of the *Yīn*.

In Japan, the same pictogram is used but the Japanese write it in the traditional Chinese () and they spell it *ma.* It also means "interval" or transitional space. In fact, a succession of transitional spaces configures the indoor–outdoor sequence. From the façade, a large eave or *noki* projects towards the outside. Behind the *noki* a gallery or *engawa* is located in such a way as to be closed in winter with *shôji* panels. Finally, a succession of interior spaces follows.

This sequence of elements generates a typical gradation of light from the bright exterior to dark interiors, conditioning the way of perception and residence of the space. Inside rooms, the "void" characterized by the absence of light counterbalances with nature represented in interlocked exterior gardens. In this sense, Japanese architecture frequently uses gardens as a landscape background by means of the technique known as *shakkei* or "borrowed scenery".

Superfluous or redundant elements constitute a distraction in the meditative pursuit of the essence. Thus, the design of neutral spaces reflecting the aesthetic concepts of *wabi*, *sabi* and *shibui* is crucial to achieve a transcendent knowledge. *Wabi* refers to the elimination of everything superfluous. *Sabi* connects with the passage of time, which in Japan has an aesthetic value, and *shibui* is related to abstraction. Therefore, Japanese neutral spaces invite us to experience the mystery of emptiness, to detach ourselves from the phenomenological world, while nature becomes a catalyst to achieve *satori*. The famous master Matsuo Basho described this process in the following haiku poem:

古池や
蛙びこむ
水の音
An old pond
A frog jumps
Water undulates

In this stance, which reflects Zen principles, an analogy draws between the pond and human mind or consciousness. Consider yet another haiku of poet Basho when contemplating the ruins of the proud Royal Palaces of yore at Hiraizumi (nowadays a human heritage site).

夏草や
兵どもが
のあと
The summer grass leaves
Ruins of the dream
Of ancient warriors

To sum up, geometry works in Japan as an underlying order of architecture that can be adapted wisely to nature. In this sense, rectangular spaces conditioned by the tatami dimension refer organically to gardens.

In contrast, halls do arrange in China around empty spaces following cosmic schemes as the *bāguā* that result in an overimposed rigid geometry. Therefore, in China humans enforce their own intellectual concepts about order and harmony over nature. Such interesting discussion can be exemplified in the celebrated poem of Bái Jūyi (772–846) "Climbing Mount Incense Burner":

> "My new hut has three bays, and five columns, with stone steps and wooden pillars made of katsura tree. I put a door on the north side to let in cool breezes and to fend off oppressive heat, made the southern rafters high to admit the sunlight in case there should be severe cold. The beams were trimmed but left unpainted, the walls plastered but not given a final coat of white. I have used slabs of stone for paving and stairs, sheets of paper to cover the windows; and the bamboo blinds and hemp curtains are of a similar makeshift nature. Added four wooden benches and two screen partitions. A serene brook traverses my piece of land but it rarely splashes out. Next spring, I will thatch the side room to the east, fit it with paper panels and reed blinds for my poems of Meng Guang."

To the authors' judgment, such a delectable poem is a prelude of sustainability that harks back from the eighth century.

4.3. The Composition of Halls or Tīng. The Jiānjià System

Jiān not only means space but also refers to the span of load-bearing beams. In the *Yíngzàofǎshì* manuscript, the edge (*cái*) of a standard wooden beam represents the module of measurement from which other building dimensions are deduced. Moreover, tie beams displayed transversely to load beams receive the name of *jià*.

The interior chambers juxtapose in a longitudinal or even transverse direction to create halls or *tīng*. This type of arrangement, called *jiānjià* facilitates the standardization and structural simplification of buildings, and in turn, the speed of construction and economy of means.

Due to the high degree of standardization of *jiānjià* structures, *Yíngzàofǎshì* classifies them in different typologies, also related to the social or political status of owners. In this regard, halls or *tīng*, generally have 3 *jiān*, which represent the sum of *yīn* (identified by the number 2) and *yáng* (number 1). Thus ensuring a harmony between *yīn* and *yáng*.

On the other hand, each interior space or *jiān*, receives a name according to its position. The central space goes as illumination or *míng* 明while the contiguous rooms on both sides are known as *cì* or secondary spaces. With a few exceptions, halls have an odd number of *jiān*. Odd numbers related to *yáng*, which is hierarchically superior to *yīn* (identified with even numbers). Regarding the social status of the owners, nine or exceptionally 11 *jiān* were designed exclusively to accommodate imperial palaces.

When larger halls are required, the *jiān* size increases, although there are obvious limitations due to structural requirements and the transcendental Chinese requirement of achieving an intimate relationship with the exterior or courtyards that represent nature.

4.4. The Solid-void Duality as a Configurator of Dwellings or Fángzi

Halls or *tīng*, compose harmoniously around open spaces or courtyards following cosmological principles to achieve harmony with the natural order. Consequently, Chinese architectural patterns reflect a solid–void duality, which we can define by *yuàn* or courtyard and *jiān* or built space. As in all dualities, *yuàn–jiān* constitutes an indivisible unit. Accordingly, we assume that:

> "Functionally, a void without a solid would imply returning to a wild nebula. Visually, a solid without a void would imply the loss of the visible form. Neither of them could exist without the complement of the other". [25] (p. 56)

The chambers set the limits that allow us to identify the hollows or courtyards. Consequently, courtyards take the place of an imaginary room that symbolizes nature, in which heaven constitutes the roof, and Earth the soil. Thus, the courtyard represents the unifying element of the composition in which humans sit quietly on Earth in harmony with the cosmos [26]. In this sense, Laozi points out:

> 埏埴以为器,当其无,有器之用。
>
> 凿户牖以为室,当其无,有室之用。
>
> 故有之以为利,无之以为用。
>
> "Mud is worked out to make vessels, but in its nothingness, lies the usefulness of the vessel. We cut windows and doors to make a chamber, but in its nothingness lies the usefulness of the chamber.
>
> Being is practical, nothingness is useful". [22] (p. 51)

Thus, we surmise that emptiness is more important than being because it allows all things to complete their wholeness. Through the void occupied by nature a fluid relation is established between human beings and the movement of the heavenly bodies which determine the passage of time, the seasons, the course of day and night. In short, the experience of time and the course of life. On the other hand, Laozi comments in relation to the void that:

> 天下之至柔, 驰骋天下之至坚。
>
> 无有入无间,吾是以知无为之有益。
>
> "The softest beneath heaven, dominates the hardest beneath heaven. What does not have being penetrates what does not have interstices, that is why I know the advantage of non-action". [22] (p. 115)

Thus, the void incarnates the concept of non-action or *wúwéi*. *Wú* means nothingness or not being, but it could also be interpreted as the contrary, as not meaning nothingness or being. As a result, *wú* may become nothingness in the phenomenological world but also the whole, since the universe arises from the void, and alternately, it is the most important thing. Accordingly, the courtyard is associated with *yáng*, which is hierarchically higher than *yín*, represented by the built space.

When rooms surround the courtyard completely, more chambers are arranged around another void. In this fashion, the architectural composition focuses on open spaces and the complexity lies in the organization of halls around them to create superior structures. Thus preserving a fluent inside-outside relationship. The former entails a clear differentiation regarding Western architecture in which there is a common trend to increase the complexity of the built volume.

Furthermore, there is an ancestral credence that human beings must inhabit nature not only in harmony with nature but also with society. Accordingly, the *bāguà* establishes a relationship with Confucian concepts about social order. In particular, the eight directions correspond to eight members of a family formed by the mother and father, three sons and three daughters.

Therefore, we could establish a correspondence between the hierarchical position of each family member and their orientation and location within the house. The direction occupied by the person with the highest hierarchical level in the family is the south, followed by east, west and finally north, which is the most unfortunate orientation according to *fēngshuǐ*.

4.5. The Nonary Scheme of the City or Chéngshì *and its Relationship with the* Jǐngtián *System*

The aforementioned composition system traditionally applies to small houses, large buildings or even to whole cities or *chéngshì*. To that end, authorities enforced some urban regulations or restrictions. In China, the first written reference to an ideal urban pattern appears around 475–221 BC in the *Kǎogōngjì* or Register of the Artificers. In particular, we learn that:

> 匠人营国，方九里，旁三门，国中九经九纬，经涂九轨。
>
> "The artificers (literally carpenters) demarcated the capital as a square with sides of 9 li, each side having 3 gateways. Within the capital there were 9 longitudinal and 9 latitudinal avenues, each of the former being 9 chariot-tracks in width."

Thus, it follows that the ideal urban layout consists of a nonary system defined by three by three blocks or sides. As previously mentioned, the number nine represents the eight human orientations along with the center. Thus, it is the number that best reflects the earthly order.

Consequently, ancient Chinese developed a hierarchical composition system, consisting of a central element surrounded by eight modules. This concept of centrality also entails the design of a north–south main axis, since there is a symmetrical number of parallel streets on both sides. Thus, they achieved a harmonic balance between *yīn* and *yang*. As a result, this urban pattern combines three overlapping schemes: a cartesian scheme along with a polar system derived from a nonary pattern and at the same time a north–south main axis that articulates both schemes.

This composition system was possibly used in agricultural plantations before its application to an urban pattern [5] (p. 64). In China, agriculture being the main basis of the populace's livelihood, it was highly controlled by rulers. In particular, they used a nonary pattern called *jǐngtián*. The Chinese pictogram that represents the concept of a well (*jǐng*井) also suggests a three-by-three scheme, considered an evolution from the semantic equation of rice field 田. The annexed farmers used collectively the central plot of this nonary system to pay taxes.

In summary, a city or *chéngshì* is composed of homes or *fángzi*, which in turn consist of *tīng* or pavilions formed by rooms (*jiān*) whose dimension predetermines the *dǒugǒng* or master configuration. This compositional system, called *bùjú*, relates parts with the whole and the whole with the parts, as previously stated (Figure 4).

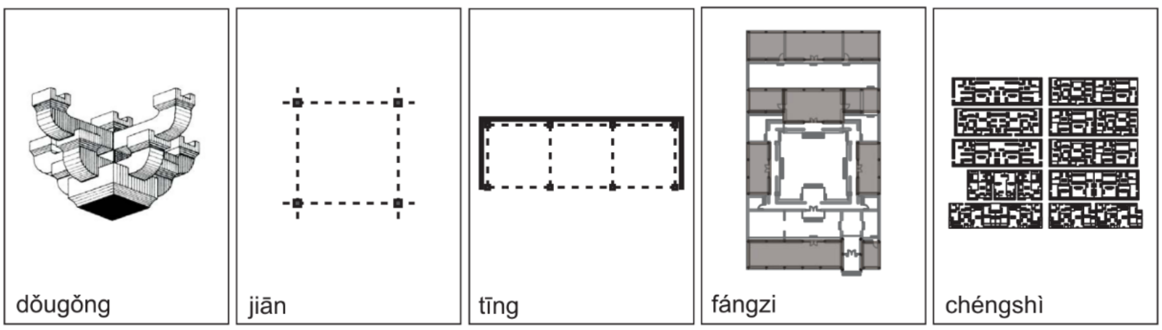

Figure 4. The composition system *bùjú*, macro-micro.

To support the information hitherto discussed, the authors have conducted a number of simulations to determine solar access and radiative transfer distribution for traditional houses and street compounds alike. Validated software like Ecotect and Envi-met has been employed in the process but mainly the author's own software, DianaX. We have corroborated the simulation data with on-site measurements that we hope to complete by further monitoring.

In the ensuing paragraphs, we will discuss from a scientific point of view, how all the former correlates at ease in the formation of the urban tissue of the capital city of Beijing. The authors consider such a city as a paradigm of imperial planning for a state that needed to ensure good government and prosperity through supreme and respectful harmony with nature. That is, to bring forth well-being and prosperity for all its inhabitants. In this regard, some 1500 years ago the ancient historian Sīmǎ Xiàngrú explained that the true beauty of a capital city does not reside in the towers and riches that we can find along its avenues but rather in the happy faces of its dwellers.

5. Environmental Analysis of the Traditional Chinese Urban Layout. The Paradigmatic Experience of Beijing

Beijing is the last representation of a millenary tradition in capital city construction. It is probably unprecedented in its time and perhaps even unique in all of urban history. Due to the *bùjú* composition system discussed in detail previously, Beijing's urban fabric consists of a grid in which residential neighborhoods are limited by main streets or *dàjiē* (37 m wide). Inner neighborhoods are designed as a fish-bone shaped layout of streets. Roads are hierarchized from main streets or *jiē* (running north–south, width of 18 m) to small alleys or *hútòng* (from east to west and 9 to 5 m wide), and finally to courtyard houses or *sìhéyuàn*, literally courtyards surrounded by buildings on all four sides [27].

This plan is extremely consistent and has interesting values in terms of harnessing solar energy and environmental urban quality. The Beijing urban layout is oriented according to the cardinal points so that the main spaces or halls are facing south. Moreover, the courtyards of the *sìhéyuàn* provide solar access to interior spaces during the winter, while perimeter passageways surrounding them reduce solar gains in summer. Therefore, artificially open spaces became the focus of design providing the necessary environmental benefits [28].

5.1. Beijing Climatic Conditions

The Chinese climate divides into five mayor climatic zones and nine geographical regions based mainly on the average temperatures in the coldest and hottest months of the year [29]. Accordingly, Beijing (latitude of 39.8° N) has been included in the cold zone since it has ATCM = 0–10 °C and NDAT5 = 90–145 days. Where ATCM = average temperature in the coldest month, and NDAT5 = number of days in which average temperature is below 5 °C.

In order to discuss the climatic conditions of Beijing, we obtain a psychrometric chart using the software Climate Consultant, developed by the Energy Design Tools Group of University of California, Los Angeles (UCLA). Different climatic zones appear on the chart to analyze the impact of some design strategies to indoor environment (Figure 5). The climatic control strategy zone concept was developed by Milne and Givoni [30]. It provides information on the ranges of outdoor conditions, within which some climatic control design strategies would have the potential to achieve comfort.

The chart shows that Beijing has a predominantly cold climate. The potential of achieving comfort by internal heat gains is 23.1%. However, the summer months can be hot and humid. Most of the time between June and August, the outside conditions fall beyond the comfort zone and lie within sun shading of windows and natural ventilation climatic zones. Consequently, the conflict between seasonal requirements is a key aspect that we must consider in the particular case of Beijing.

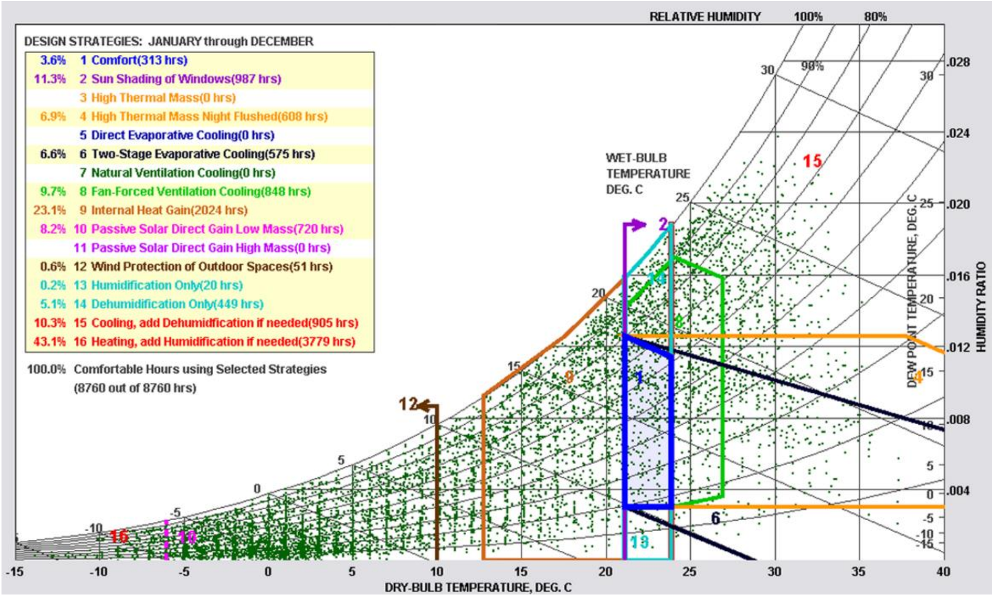

Figure 5. Psychrometric chart for Beijing plotted using the software Climate Consultant.

5.2. Exploratory Solar Access Analysis

Urban geometry, specifically the width-to-height ratio (W/H) of streets and their orientation, has a great impact on the thermal urban environment for both summer and winter [31–33]. An effective passive solar design assumes that the urban fabric is orientated to receive as much solar radiation as possible in winter when heating is required, whilst rejecting as much solar gains as possible in summer when it is not. Moreover, narrow streets tend to reduce solar penetration but may also result in trapped radiation or a heat island effect [34]. Therefore, the necessary protection from the sun in summer and the need for solar access in winter imply a concern for compactness and openness to the sky, respectively.

In order to make a preliminary study on the radiative environment of Beijing's traditional urban fabric we have used the Ecotect software and have contrasted the results with authors' own software DianaX [35] (Figure 6). We provide the hourly-recorded direct and diffuse radiation data from a TMY (typical meteorological year) data file of Beijing provided in Energy Plus and derived from Chinese Standard Weather Data (CSWD) [36].

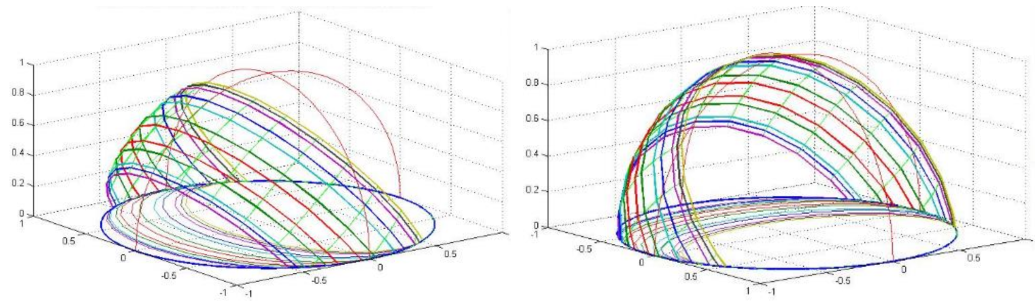

Figure 6. Beijing's solar chart (latitude 39.9° N), DianaX software.

The daily average solar radiation on the surfaces which delimit the urban space in the four cardinal directions has been assessed (Figure 7). In addition, the effect of the W/H ratio of streets has been analyzed due to its large impact on the amount of both incoming and outgoing radiation.

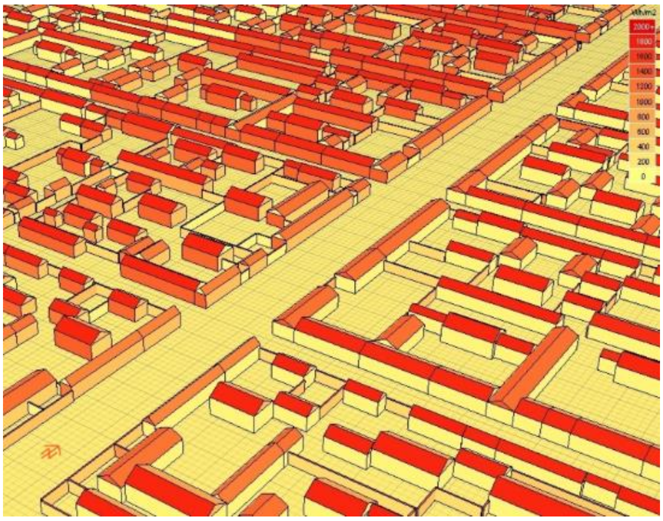

Figure 7. Beijing's traditional urban layout. Average daily radiation during the winter.

We have created comparative tables to visualize the results. Figure 8 compares the daily average solar radiation on the four possible directions: north, south, east, and west. The hottest months of the year appear in red and the coldest ones in blue to clarify the results. In addition, for each orientation we have displayed the impact of the W/H ratio in decreasing solar gains, from the widest street (W/H = 2.5) to the narrowest one (W/H = 0.5), in intervals of 0.5.

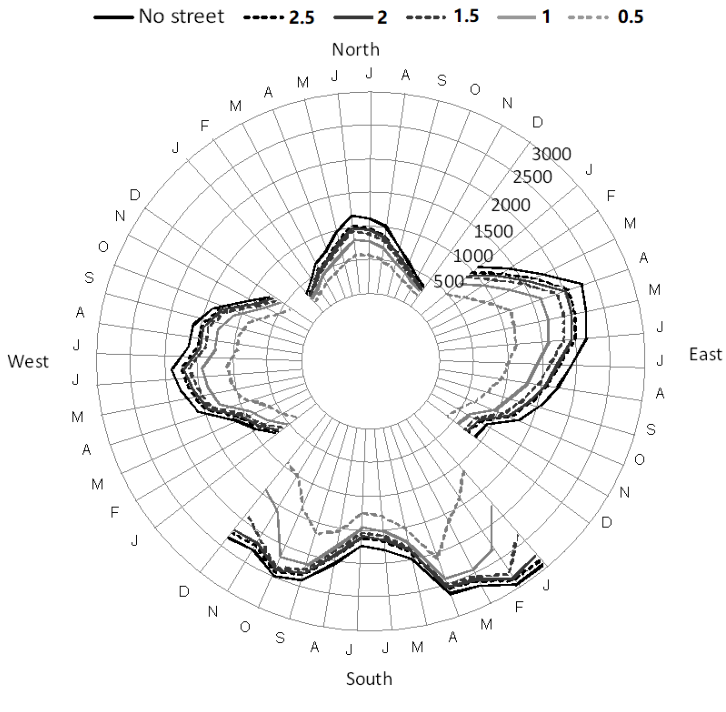

Figure 8. Effect of orientation and width-to-height ratio (W/H) of streets on the average daily radiation (Wh/m2).

Results show that south is the only orientation that has the advantage of receiving more solar gains in winter than in summer. Moreover, the daily average solar radiation on the south during the winter is higher than on the other three orientations. In addition, the potential problem of overheating in summer can be mitigated by horizontal solar protections or overhangs, since the angle of solar radiation incidence on the south facade is higher in summer than in winter. In this regard, the traditional passageways around courtyards contribute to reduce solar gains in summer. Thus, the southern orientation has the highest potential for passive use of solar energy. Accordingly, the south has occupied the highest hierarchical level of all orientations in the Chinese building codes.

On the other hand, the solar gains received in the north orientation during the winter are negligible and, therefore, have little potential of achieving comfort by internal heat gains. Consequently, the Chinese notions of geomancy or *fēngshuǐ* considered north-facing orientations as inauspicious.

In the east and west orientations, solar gains are unfortunately much higher in summer than in winter. Although in winter they receive less than half of the radiation that impinges on the south, they represent more than two-times the solar gains obtained in the north. Therefore, east and west orientations possess a higher passive solar heating potential than the north facade in winter. In contrast, the solar radiation incident in both orientations during the summer is able to produce overheating. In this regard, the east-facing halls have better performance since they receive most of the solar gains in the morning when the ambient temperature is lower. Conversely, the highest thermal gains impinge on the west during the afternoon when outside temperature is higher. Thus, we can establish a correlation between the orientation's hierarchical order and its environmental benefits, since the Chinese historically consider the east orientation as superior to the west orientation.

In addition, results show that the W/H ratio of streets has a high impact on solar gains. This influence is particularly relevant in the south during the winter due to its high passive solar heating potential. A critical situation takes place in the hutongs, the narrowest streets of the urban fabric that run east–west (facing north–south). The width of hutongs varies from 5 to 9 m. Assuming an average height of 5 m (single-story buildings), the W/H ratio is usually higher than 1 and generally superior to 1.5. Results show that from a W/H ratio higher than 2, the decrease in solar gains is negligible. Therefore, the breadth of hutongs can be considered slightly smaller than the advisable limit to take advantage of the solar gains potential of the south orientation. However, the hutongs' direction (running east–west) allows houses to be displayed along a north-south axis following a solid-void duality because the house entrance is usually facing the hutongs. Due to this configuration, the most important spaces or halls can be oriented to the south following both the highest Chinese hierarchical position and optimal environmental performance.

Additionally, we have used Ecotect to calculate the most efficient orientation taking into account the daily average solar radiation measured over the three coldest months and over the three warmest months. Both values have been plotted on a polar graph (the coldest months in blue and the warmest in red), where the radius of any point from the center represents the incident radiation value (Figure 9). The optimal orientation takes place where the amount of incident radiation during the winter is greater than that incident in summer, where the blue line extends out beyond the red line. The graph suggests that the most favorable orientation is not exactly south, but slightly to the east due to the hot afternoon sun in summer.

In short, the hierarchical level traditionally associated with the four main orientations (from high to low: south, east, west and north) has a correlation with its objectively assessed environmental benefits. In this regard, a popular saying is:

> 有钱不住东南房，冬不暖来夏不凉。
>
> "If I had money I would not live in eastern or southern chambers, they are not warm in winter nor cool in summer."

In this quote, the chambers located in the east and south correspond to those respectively oriented to the west and north. Thus, the chambers occupied by lower hierarchical inhabitants of the house. It should be clarified that house owners rented rooms to other families in certain circumstances, although they always tried to stay in the south-facing rooms.

On the other hand, the Chinese term used to define ridgepole (*dòng* 栋) etymologically represent a tree or trunk facing east and it is very similar to the character meaning coolness. Due to this direction, the longer façades are facing south, the best orientation in Chinese tradition.

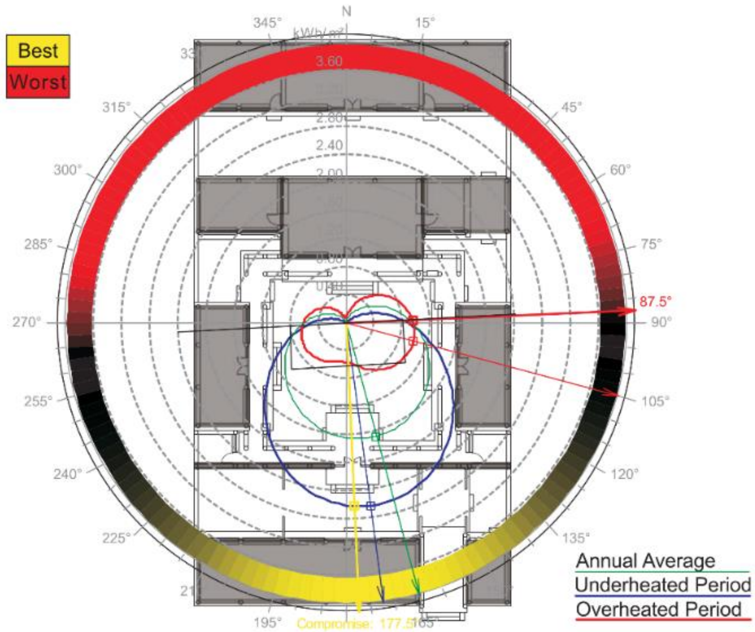

Figure 9. Optimal orientation angles in Beijing according to solar radiation received in the coldest three months (blue) and the warmest three months (red).

5.3. Microclimate at Street Level

We have used the three-dimensional microclimatic modelling system ENVI-met (version 4.1.0) to analyze the thermal comfort in the Beijing traditional urban fabric. This model was developed by Bruse and Fleer [37]. Thapar and Yannas [38] have compared experimental and simulated data obtained by ENVI-met, and other studies have used ENVI-met to assess microclimate and thermal comfort conditions in different urban layouts [39,40].

This software simulates microclimatic interactions of the urban environment, providing several thermal comfort indexes that have been developed to standardize comfort appreciations. Among these, we opted for the predicted mean vote (PMV) based on Leo Fanger's model, extended for outdoor conditions, that relates the energy balance of the human body to the personal feeling of persons exposed to the corresponding climates [41].

The simulation by ENVI-met has required the introduction of climate data that have been obtained from a TMY data file of Beijing (Table 1). We have simulated the Beijing urban fabric during the summer and winter solstices in a period of 24 hours starting at 6 am Due to the fact that the simulation takes only 24 hours, it is known that the model has limitations for the initial hours. Therefore, we have analyzed results from 9 am to 5 am.

Table 1. Simulation configuration settings.

Simulation Date	06/21	12/21
Beginning of the simulation	06:00 h	06:00 h
Air temperature (°C)	18.4	−4
Relative humidity (%)	88	71
Wind speed at 10 m to the ground (m/s)	2.5	3.5
Wind direction	SE	N

We have assessed microclimatic factors and comfort conditions in four street types that characterize Beijing's urban layout: *hútòng* (facing north–south), *jiē* (facing east–west), and *dàjiē* facing north–south and east–west. As in the previous solar analysis, we have assumed an average building height of 5 m. Figure 10 compares the temperature evolution in the selected streets during the winter and summer solstices.

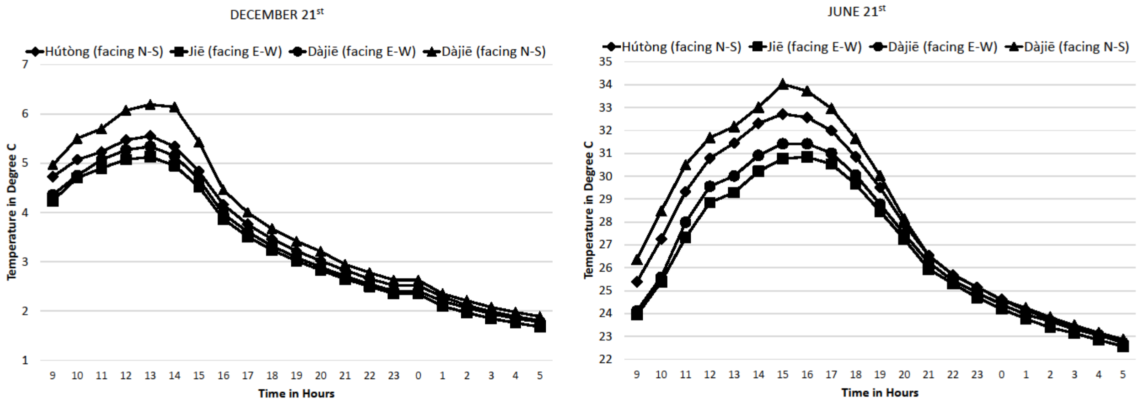

Figure 10. Temperature variations in both winter and summer solstices.

We note that in winter, temperatures are very cold, particularly during the night time. North-south facing streets are slightly warmer than those facing east-west. As we discussed in the previous section, solar gains in winter are much higher in streets facing north–south. During the summer, north–south oriented streets are also warmer if sun protection is not provided. For each orientation, *dàjiē* streets are hotter, since they have a higher W/H ratio, and therefore, receive more solar gains.

We have used the PMV index to evaluate the outdoor thermal comfort in the selected streets. The following climatic factors are considered for the evaluation of the PMV: air temperature, mean radiant temperature, wind speed and specific humidity. ISO international standard (International Standards 7730/1994) are selected for personal human parameters (clothing, gender, age, etc.). According to the aforementioned ISO 7730, the recommended values are $-0.5 < \text{PMV} < +0.5$. Generally, the PMV range is defined from -3 (cold) to +3 (hot). Figure 11 shows the evolution of the PMV values during the winter and summer solstices.

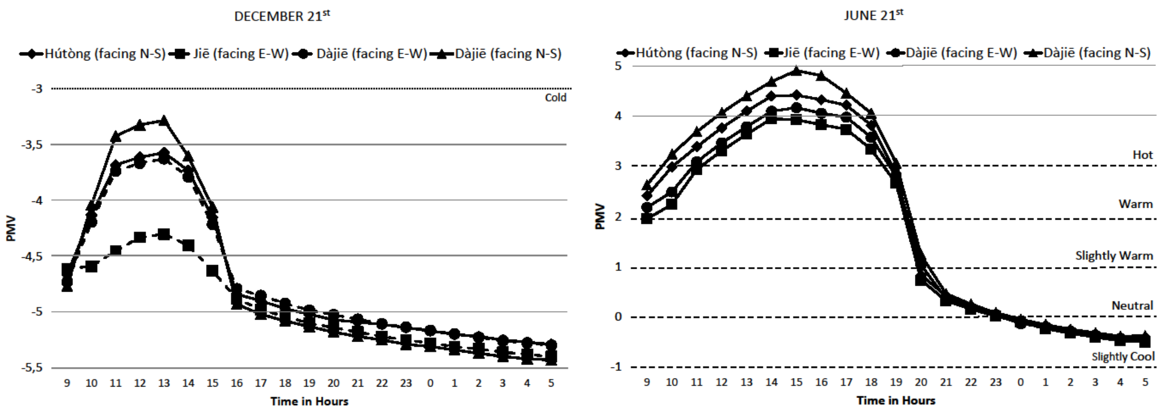

Figure 11. Daily variations of predicted mean vote (PMV) in the selected street types.

In winter all the streets present values of PMV below -3, and, therefore, they are extremely cold. During the central portion of the day, streets facing east–west (running north–south) are less comfortable because the predominant wind from the north increases the thermal sensations of cold. In summer, the comfort level is reached during the night time. However, during the central hours of the day the comfort limit is exceeded. Streets running north–south are slightly more comfortable, particularly the *jiē* streets since the W/H ratio is lower.

6. Conclusions

We have amply shown that Chinese historical architecture entwines with profound cosmological concepts from which we can draw a parallel between the heavenly order and earthly patterns. Within the framework of this correlative way of thinking lies an empirical wisdom that crystalizes in the belief that human beings must inhabit nature always in harmony with cosmological ideas. Consequently, we can understand Chinese architecture as a microcosm that must reproduce the macrocosm.

According to the process described in the *Yìjīng*, architectural patterns are configured by simple elements which are assembled according to cosmic principles to create more complex structures, which in turn multiply and permute each other following the same principles to generate a higher level of structures.

This composition system relates to the *bùjú* concept, which represents the macro-micro duality. The combination of both procedures results in a harmonic relationship of the parts with the whole, and vice versa. Thus, traditional Chinese architecture has solved one of the great objectives sought by the standardization of architecture. In particular, how to obtain a large number of solutions from a few modules or elements.

In this complex and highly intellectual architectural composition system, the focus of design lies in the void or courtyards to which rooms are harmoniously tied following the four cardinal points, along with cosmological concepts represented in the *baguà* and collected in *fēngshuǐ*. Due to this search for an intimate and harmonic relation between interior spaces and courtyards which represent nature, the basis of Chinese architecture lies in multiplicity, or quantity of simple modules or halls, more than on complex interior spaces. In other words, we can only understand Chinese architecture in relation to nature and, thus, it is naturally sustainable.

The former notions indeed offer a kind of proto-scientific knowledge, lore or wisdom. In order to attain proof of these notions, we have simulated Beijing's traditional urban layout to present objective proof of how the harmonious interaction between climate and cultural traditions is able to generate urban solutions with positive environmental values like energy saving and eventually sustainability. Based on the former we recommend urban design guidelines governing street dimensions and orientations. The outcome of a preliminary solar access analysis also shows a correlation between the hierarchical order established for each orientation and its environmental benefits.

Finally, we should emphasize that China has an ancient culture that during long periods of history has had a level of development comparable or even superior to Western cultures. Since the economic reforms of the late 1970s, China has experienced an astonishing process of urban growth and socio-cultural transformation unprecedented in history. In this regard, more floor area has been built in China in recent decades than in the whole world combined. Thus, the problems of the real estate bubble, climate change and global warming are catastrophic, not merely for China but for the whole world. In this article, we have tried to provide strategies and notions able to cope with the problem in a scientific and philosophical manner and to avert climate change.

In this way, China should be able to rebuild its unique identity while achieving high levels of sustainability attuned to an ailing planet. A lesson worth learning, we believe.

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