 doi:10.20944/preprints201804.0050.v1

Article

Environmental Features of Chinese Architectural Heritage. The Standardization of Form in a Pursuit for Equilibrium with Nature

Jose Manuel Almodovar Melendo

University of Seville; jmalmodovar@us.es; Tel.: +34-667647456

Abstract: A correlation between Chinese traditional architecture and cultural concepts has been established to analyze the formalization of architectural and urban patterns in relation to environmental features. In this regard, we have discussed the process of standardization from architectural elements or modules related in different levels of composition and articulated around empty spaces following ancient cosmic concepts to achieve harmony with nature. The conclusions show that Chinese architectural patterns can only be understood in relation to nature, and in turn have profound environmental values from which lessons can be learned to advance towards a more sustainable architecture.

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

1. Introduction

This paper discusses the formalization of Chinese architectural patterns following ancestral cultural concepts to establish a harmonious relationship between man and nature. In this search for a balance between the way of inhabiting the world and the environment, solutions have been developed that have taken on a renewed interest in the context of the current concern for global sustainability.

To understand the configuration of architectural patterns it seems essential to discuss them in the context of Chinese millenary culture, due to the great differences in conceptual approaches with respect to the West. In this regard, Xinian et al. [1] state that architecture has not traditionally been considered in China as a type of art despite the fact that is one of its most significant cultural manifestations. The concept of form or *xíng* 形 has been related 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* 土木 (literally earth-wood) was the term used to refer to buildings, and was obviously related to construction [2].

Consequently, knowledge about architecture was traditionally linked to practical manuals, such as the *Yíngzàofǎshì* 營造 法式 or State Construction Standards. These concepts can already be found around 1100 BC in the *Yìjīng* 易经 or Book of Changes, where it is pointed out that:

形而上者谓之道，形而下者谓之器。

"What is above form is called Tao, what is beneath form is called object."

 doi:10.20944/preprints201804.0050.v1

According to Henerson [3], *dào* 道 is the term that was used in China to refer to natural order. Thus, formalization was not only linked to construction or practice, but also to cosmological concepts. A correlative way of thinking was therefore articulated through which architecture was considered as a human creation which must reproduce cosmic ideas to be in balance with the natural order. This parallelism has been linked in turn to the conception that there is a correspondence between celestial and earthly orders. In this sense, it was traditionally understood that "the sky is round and the earth square", 天圆地方 [3] (p. 61).

As a consequence, the composition system and traditional spatial organization in China have been linked to the development of geometries based on ideas of geomancy or *fēngshuǐ* [4,5]. In this regard, cosmic schemes and numerical relations that explain the nature of the cosmos have been applied to the configuration of architectural patterns [6]. Similarly, the social order based on the Confucian tradition has been related to the natural order, and therefore, has also been reflected in architectural models [7]. Accordingly, the traditional spatial organization of the house reproduces the hierarchical order of the family, which is the basis of society [8]. In fact, the Chinese disyllable of country or *guójiā* 国家, literally means country-family, and the concept of house or *jiā* 家 also means family. Consequently, both architectural and urban patterns reproduce the social order [9].

Generally speaking, another relevant difference in relation to the Western approach is that Chinese architecture has deeply tended towards standardization from its origin [10,11]. We have to bear in mind that economy of means has always characterized Chinese architecture due to the historic overpopulation of the country. Accordingly, Frank Lloyd Wright points out that “the Oriental artist sees in everything the pattern, the Western artist values" [12].

In this regard, China has a strong tendency towards cultural coherence that is reflected in its architecture, despite having a considerable regional and ethnic diversity. Therefore, Chinese architectural evolution has been slow and has maintained a continuity in essential aspects. Accordingly, Liang Sicheng 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 sign of old age, feebleness, and rigidity” [13] (p. 65).

Furthermore, Chinese vernacular 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 [14]. On the contrary, architectural patterns were configured thousands of years ago from high intellectual concepts about the natural order that underlie the most basic substrate of Chinese culture and whose essence has been maintained over time [15]. In this regard an ancestral correlation has been established between cosmic concepts, understood as dualities that are combined in different levels of complexity, and an architectural composition system based on elements or modules that are assembled and combined in different levels [2].

This article focuses on the discussion of cultural aspects that have influenced the configuration of architectural patterns of profound environmental values to promote and revitalize them in the modern world. More specifically, we have analyzed the correlation established between architectural models and cosmological ideas. Through this parallelism, we have discussed the articulation of architectural modules or elements in different levels of composition from the most basic structures to urban patterns. Moreover, an exploratory solar access analysis of Beijing’s traditional urban layout has been carried out to objectively discuss the environmental benefits of traditional patterns.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 4 April 2018 doi:10.20944/preprints201804.0050.v1

In short, this paper explores the way in which traditional Chinese architecture has been articulated from architectural patterns following an ancestral pursuit to reproduce the cosmic order and thus inhabit the world in harmony with nature.

2. Cosmic order and harmony between man and nature

2.1. Bāguà 八卦 diagram as a representation of space-time

In the basic substrate of Chinese culture lies the belief that man must occupy nature in harmony with the universe, constituted by dualities or opposing and complementary elements [16]. These ideas were already collected more than three thousand years ago in the Book of Changes (*Yìjīng* 易), also known as the Book of Divinations [17]. In fact, the pictogram 易 represents an animal under the sun, which suggests the ancestral realization of animal sacrifices for divinatory purposes on solar events, such as equinoxes and solstices. Both Taoism and Confucianism were influenced in some way by this book, which embodies the spirit of Chinese culture. In fact, the version of the *Yìjīng* that has survived to this day was annotated by Confucius. In addition, some of the terms used by Laozi were inspired by the *Yìjīng*. In this classic of Chinese literature, it is argued 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."

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 been developed 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 yin-yang represent a duality that in turn expresses an implicit unity. They would be like two sides of the same coin, since they are interrelated and at the same time interdependent.

As a result of this cosmological conception a scheme known as *bāguà* 八卦 was generated. *Bāguà* literally means eight directions due to the belief that orientations condition the way in which energies of the universe flow, and in turn have a decisive influence to achieve harmony with nature. As mentioned before, *yīn* and *yáng* are linked to the solar path and therefore, they are also connected to space (oriented according to the sun position) and time (which governs the day-night cycles and the four seasons). Accordingly, Chinese architecture has traditionally occupied the space 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* or west-east.

In the *bāguà*, *Yīn* is represented by a dashed or weak line while *yáng* is identified by a continuous or strong one. Combining two dualities *yīn-yáng* the $2^2 = 4$ images quoted in the *Yìjīng* are obtained. Therefore, west-east bilateral relationship extends to a two-dimensional model of four directions in which a notion of north and south is represented. These four directions are associated with the four 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).

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 4 April 2018 doi:10.20944/preprints201804.0050.v1

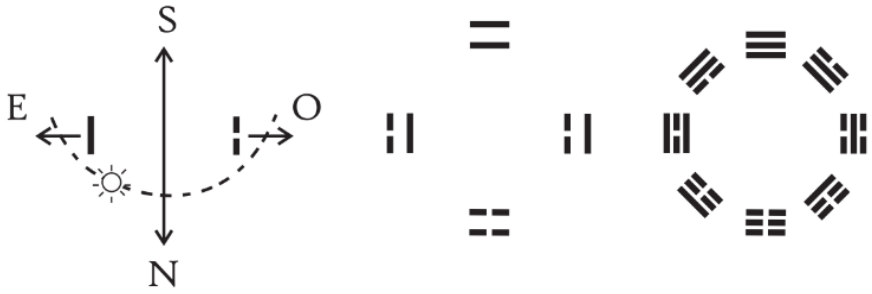

Figure 1. Configuration of the eight directions from the yīn-yáng duality.

2.2. The relationship between man and nature. The concept of center

The cosmic scheme described above represents the celestial order and has been called Pre-Heaven *Bāguà* or *Xiāntiān Bāguà* 先天 八卦. 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 imply the notion of a center. In this sense, Laozi states in the *Dào Dé Jīng* 道德 经 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" [18] (p. 113).

According to Chinese tradition, the vital energy or *qì* 气 (氣 in traditional Chinese) emerges from the vacuum spontaneously. Due to being considered an indivisible unit, it implicitly constitutes a duality, or two opposing and complementary elements, the *yīn-yáng*. In order to situate the existence of human beings in relation to nature the idea of centrality arises, and in turn, also the concept of one which occupies a central place in balance with the dualities that make up 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, being emerges from nothingness" [18] (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* 上帝 (the god of heaven) 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 中国 or 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 yin and yang are intertwined to produce the world, the place where the faithful is situated in his meditation and the priest in his ritual, from and to whereby they can communicate with Heaven as well as with Earth" [19] (p. 95).

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 4 April 2018 doi:10.20944/preprints201804.0050.v1

As a result of combining the center with the *yīn-yáng* duality, number 3 emerges. Similarly, the 5 was derived from adding the center to the four main orientations, constituting a "pure" number that represents the natural order. Likewise, number 9 has been formed by combining the eight orientations that make up the *bāguà* with the center. Therefore, 9 is considered the most relevant number on earth. From number 9, geometric representations have been generated that reflect the earthly order and have been applied to architectural patterns.

2.3. Parallelism between heavenly order and earthly order. Xiāntiān Bāguà 先天八卦 and Hòutiān Bāguà 后天八卦

A three-dimensional model is obtained by linking the heaven 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:

古者包犧氏之王天下也，仰則觀象於天，俯則觀法於地。

"In ancient times, when *Bāoxī shì* 包犧 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. The four quadrants are represented by symbolic animals: turquoise dragon (east), vermilion bird (south), white tiger (west) and black turtle in continuous struggle with a snake (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* 风水 which has been traditionally used to establish a cosmic structure in architectural design.

Therefore, the Pre-Heaven *Bāguà* which represents the heavenly order has a reflection on earth. As a result, the Post-Heaven *Bāguà* was developed, in which trigrams are 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* 河图 whose round geometry symbolizes celestial principles, and the *Luòshū* 洛書 with a square shape representing the earthly order. The *Luòshū* and *Hétú* origin is still unknown but they are more than 3000 years old. In fact, references to *Luòshū* can be found in the Book of Changes.

Figure 2 shows the relationship between the Pre-Heaven (celestial order) and Post-Heaven (earthly order) *Bāguà* diagrams which are also respectively linked to the *Hétú* and *Luòshū*. The parallelism between heaven and earth is translated into a numerical correlation between different orientations. These cosmological diagrams are applied in architectural design through the *fēngshuǐ* to reach harmony between man and nature.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 4 April 2018 doi:10.20944/preprints201804.0050.v1

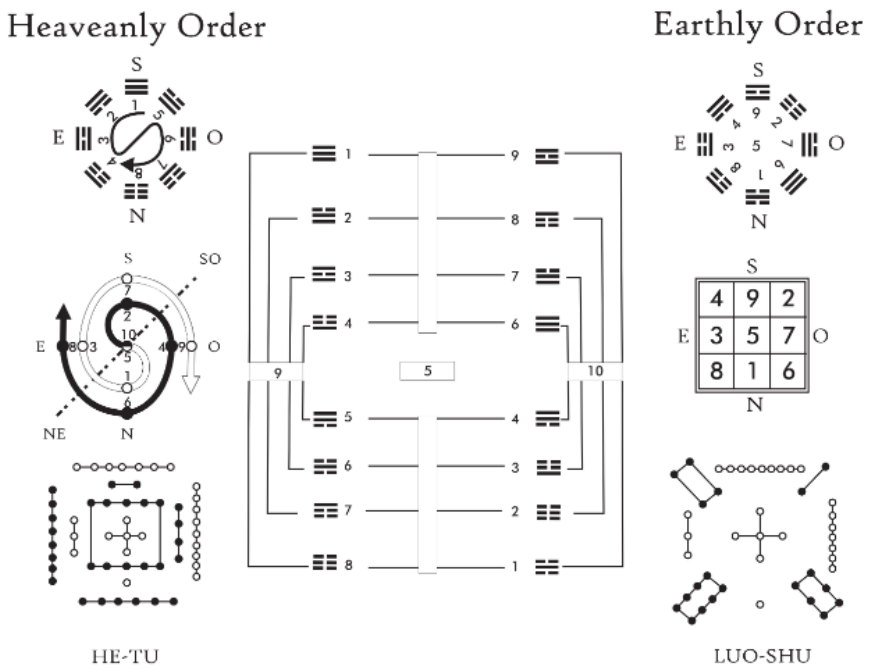

Figure 2. Relationship between the heavenly and earthly orders.

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 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 and associating them in pairs. The resulting hexagrams have been analyzed and used in the *Yìjīng* for divinatory purposes. In this regard, the term *shù* 数, used in China to refer to the number concept, also means calculate or destination.

In this cosmological conception, the whole (a hexagram in this case) implicitly contains the composition rules of the trigrams, which in turn, are constituted by *yīn-yáng* dualities. In other words, in each level of composition the whole contains the parts which at the same time potentially contain the whole. Consequently, relationships are established between elements or modules that are derived from each other and related simultaneously beyond their hierarchy to build a complex structure which responds to cosmological principles providing harmony with nature [20].

Similarly, a new form of intelligibility related to the Theory of Chaos is recently being used in science, which 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 is also articulated in a binary system that permits encoding the information in 8, 32 or 64 bits.

3.2. Bùjú duality as an instrument for standardization

The latter way of structuring reality can also be represented by the *bùjú* 布 局 system (literally macro-micro). This duality suggests the existence of two complementary levels of organization. The

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 4 April 2018 doi:10.20944/preprints201804.0050.v1

term *bù* 布 represents a system of division from macro to micro. In other worlds, from the global structure constraints are articulated downwards to ensure that each element occupies the right place, proportion, and function. On the contrary, the system *jú* 局 shows principles of growth from micro to macro. It is articulated through 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 pre-established regulations or limitations.

Therefore, one of the main problems of the standardization of architecture has been settled. 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 dougǒng 斗栱 and its relation to the space dimension

In regards to the aforementioned composition system, architecture has been considered in China as a microcosm composed of dualities organized into different levels of complexity to reproduce the macrocosm. *Dǒugǒng* 斗栱 (literally head-arm) is considered the most basic element of composition or modulation. It is a type of capital whose design depends on the span between pillars. Thus, it is directly related to the interior spaces' dimension.

Dǒugǒng is made up of small wooden elements that are combined into more complex structures, while longer wooden pieces are reserved for pillars and beams. Different configurations of *dǒugǒng* as a function of the distance between pillars were already detailed and standardized around 1100 BC in the *Yíngzàofǎshì*.

4.2. The concept of architectural space. From jiān 间 in China to ma 間 in Japan

The second level of composition is characterized by *jiān*, which consists of a parallelepiped space limited by pillars or walls. The *jiān* pictogram (间) is composed of a representation of the sun and a door. Thus, it can be etymologically deduced that the architectural space was metaphorically tied to the movement of the sun and the passage of time. Accordingly, human perception of space has been traditionally linked to natural cycles.

In Japan, the same pictogram is used but written in traditional Chinese (間) and known as *ma.* It also means "between" or transitional space. In fact, the indoor-outdoor relationship was traditionally made through a succession of transitional spaces. From the facade a large eave or *noki* 軒 is projected towards the outside. Behind the *noki* a gallery or *engawa* 縁 is located which is closed in winter with *shôji* 所持 panels. Finally, a succession of interior spaces is arranged.

This sequence of elements generates a gradation of light from the bright exterior to dark interiors, conditioning the way of perceiving and inhabiting the space. Inside rooms the "vacuum" characterized by the absence of light is counterbalanced by nature represented in exterior gardens to which indoor spaces are closely tied. In this sense, gardens were frequently used as a landscape backdrop be means of a technique known as *shakkei* 借景 or "borrowed scenery".

It should be pointed out that contemplation of nature is considered in Zen Buddhism as a valuable pillar to achieve "enlightenment" (*wù* 悟 in Chinese and *satori* 悟り in Japanese). Accordingly, Zen is the Japanese pronunciation of *Chán* 禅 Buddhism, which in turn, is derived from the Sanskrit word *dhiana*, that means meditation.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 4 April 2018 doi:10.20944/preprints201804.0050.v1

Superfluous or redundant elements are considered as a distraction in the meditative pursuit for the essence. As a consequence, the design of neutral spaces reflecting the aesthetic concepts of *wabi* 侘び, *sabi* 寂 and *shibui* 渋い is crucial to achieve a transcendent knowledge. *Wabi* refers to the elimination of everything superfluous. *Sabi* is connected 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 is used as a catalyst to achieve the satori. The famous master Matsuo Basho described this process in the following haiku:

古池や
蛙飛びこむ
水の音

An old pond
A frog jumps
Water noise

In this haiku which reflects in itself Zen principles, an analogy is established between the pond and human consciousness.

In short, geometry has been understood in Japan as an underlying order of architecture that can be adapted to nature. In this sense, rectangular spaces conditioned by the tatami dimension is organically related to gardens. In contrast, halls are arranged in China around empty spaces following cosmic schemes as the *bāguā* that result in imposed rigid geometry. Therefore, in China man enforces his own intellectual concepts about order and harmony on nature.

4.3. The composition of halls or tīng 厅. The jiānjià 间架 system

Jiān not only means space but also refers to the span of load beams. In the *Yíngzàofǎshì* manuscript, the edge (*cái* 材) of a standard wooden beam is considered the base unit of measurement from which other building dimensions are deduced. Moreover, tie beams that are placed transversely to load beams are called *jià* 架.

The interior spaces or chambers are juxtaposed in a longitudinal or even transverse direction to create halls or *tīng* 厅. 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, a harmony between *yīn* and *yáng* is ensured.

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

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

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 4 April 2018 doi:10.20944/preprints201804.0050.v1

4.4. The solid-void duality as a configurator of dwellings or fángzi 房子

Halls or *tīng* are harmoniously composed around open spaces or courtyards following cosmological principles to achieve harmony with the natural order. Consequently, Chinese architectural patterns reflect a solid-void duality, represented by *yuàn* 院 or patio and *jiān* or built space. Like all dualities, *yuàn- jiān* constitutes an indivisible unit. Accordingly, it is assumed that:

> Functionally, a vacuum without a solid would mean returning to a wild nebula. Visually, a solid without a vacuum would imply the loss of the visible form. Neither of them could exist without the complement of the other [21] (p. 56).

Halls establish the limits that allow us to identify the vacuum or patios. Consequently, courtyards can be understood as an imaginary room that symbolizes nature, in which heaven constitutes the roof, and earth the soil. As a consequence, the courtyard is conceived as the unifying element of the composition in which man is situated on earth in harmony with the cosmos [22]. 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 to make vessels, but in its nothingness, lies the usefulness of the vessel.
> Windows and doors are made to make a chamber, but in its nothingness lies the usefulness of the chamber.
> Being is practical, nothingness is useful" [18] (p. 51).

It therefore implies that emptiness is more important than being because it allows all things to be completed to reach their wholeness. Through the vacuum occupied by nature a fluid relation is established between man 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 vacuum 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" [18] (p. 115).

Thus, the vacuum is related to the concept of non-action or *wúwéi* 无 为 (無 為 in traditional Chinese). *Wú* means nothingness or not being, but could also be interpreted to the contrary, as not meaning nothingness or being. As a result, *wú* can be understood as nothingness in the phenomenological world but also as the whole, since the universe arises from the vacuum, and in turn, is the most important thing. Accordingly, the vacuum or patio is associated with *yáng*, which is hierarchically higher than *yín*, represented by the built space.

When a patio is fully surrounded, more halls are arranged around another void. Therefore, the architectural composition is focused on open spaces and the complexity lies in the organization of halls around them to create superior structures. Thus, a fluent inside-outside relationship can be preserved. This entails a clear differentiation regarding Western architecture in which there is a tendency to increase the complexity of the built volume.

Furthermore, there is an ancestral belief that man must inhabit nature not only in harmony with

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 4 April 2018 doi:10.20944/preprints201804.0050.v1

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, a correspondence is established 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 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 城市 and its relationship with the jǐngtián 井田 system

The aforementioned composition system has been traditionally applied to small houses, large buildings or even to whole cities or *chéngshì* 城市. To that end, some urban regulations or restriction were taken into account. In China, the first written reference to an ideal urban pattern appears around 475-221 BC in the *Kǎogōngjì* 考 工记 or Register of the Artificers. In particular, it is mentioned 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 meridional and 9 latitudinal avenues, each of the former being 9 chariot-tracks in width."

It therefore follows that the ideal urban layout is configured by a nonary system consisting of three by three sides. As previously mentioned, the number 9 represents the eight main orientations along with the center. Thus, it is the number that best reflects the earthly order.

Consequently, a hierarchical composition system is created, consisting of a central element surrounded by eight modules. This concept of centrality also underlies the design of a north-south main axis, since there is a symmetrical number of parallel streets on both sides. Thus, a harmonic balance between *yīn* and *yáng* is achieved. As a result, this urban pattern combines three overlapping schemes: a Cartesian scheme along with a polar system derived from a nonary pattern, as well as a north-south main axis that articulates both previous schemes.

This composition system was possibly used in agricultural plantations before its application as an urban pattern [3] (p. 64). In China, agriculture has been the main basis of the population's livelihood; and therefore, was highly controlled by rulers. In particular, a nonary pattern called *jǐngtián* 井 田 was used. The Chinese pictogram that represents the concept of a well (*jǐng* 井) also suggests a three-by-three scheme. The central plot of this nonary system was collectively used by the farmers of the 8 surrounding plots to pay taxes.

In summary, a city or *chéngshì* is composed of homes or *fángzi*, which in turn are composed of *tīng* or pavilions formed by rooms (*jiān*) whose dimension predetermines the *dǒugǒng* or capitals configuration. This composition system, called *bùjú*, relates parts with the whole and the whole with the parts, following cosmological principles in order to achieve harmony between man and nature (Figure 3).

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 4 April 2018 doi:10.20944/preprints201804.0050.v1

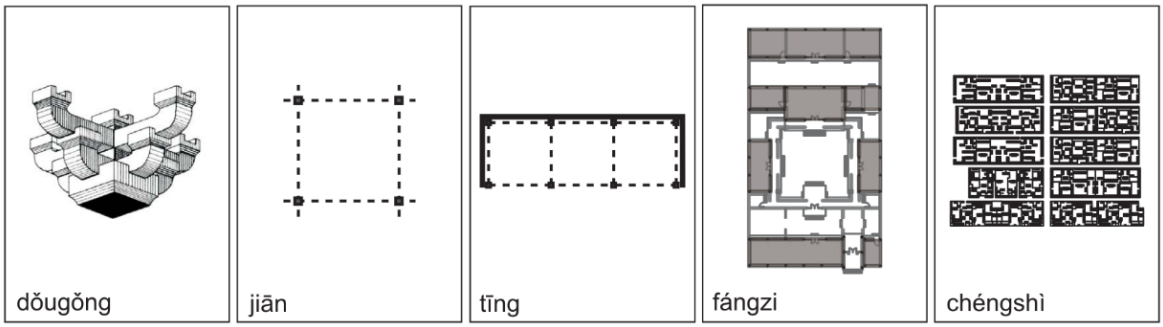

Figure 3. The composition system *bùjú* 布局, macro-micro.

5. Solar access in traditional Chinese urban layout. The paradigmatic case 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 above, Beijing urban fabric consists of a grid in which residential neighborhoods are limited by main streets or *dàjiē* 大街 (37 m). Inside neighborhoods, a fish-bone shaped layout of streets is designed. Roads are hierarchized from main streets or *jiē* 街 (running north-south, 18 m wide) to small alleys or *hútòng* 胡同 (running east-west, 9 -5 m wide), and finally to courtyard houses or *sìhéyuàn* 四合院, literally courtyard surrounded by buildings on all four sides [23].

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, landscaped open spaces that became the focus of design provide interesting environmental benefits [24].

5.1. Beijing climatic conditions

China has been divided into five mayor climatic zones and nine geographical regions based mainly on the average temperatures in the coldest and hottest months of the year [25]. Accordingly, Beijing (latitude of 39.8º N) has been included in the cold zone since it has ATCM = 0 – 10 ºC 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 ºC.

In order to discuss the climatic conditions of Beijing, a psychrometric chart has been obtained by using the software Climate Consultant, developed by the Energy Design Tools Group of UCLA. Different climatic zones have been plotted on the chart to analyze the impact of some design strategies in indoor comfort (Figure 4). The climatic control strategy zone concept was developed by Milne and Givoni [26]. It provides information on the ranges of outdoor conditions, within which some climatic control design strategies would have the potential to achieve comfort.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 4 April 2018 doi:10.20944/preprints201804.0050.v1

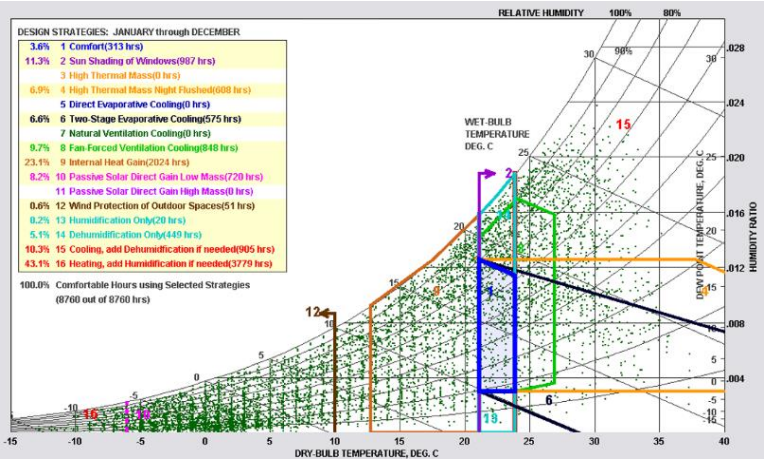

Figure 4. Psychometric chart for Beijing plotted using the software Climate Consultant.

The chart shows that Beijing has a cold dominated climate. The potential of achieving comfort by internal heat gains is 23.1 %. However, 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 must be considered in the case of Beijing.

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 in both summer and winter [27,28]. 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 as possible in summer when it is not. Moreover, narrow streets tend to reduce solar penetration but may also result in trapping long-wave radiation [29]. Therefore, the necessary protection from the sun in summer and the need for solar access in winter imply a need for compactness and openness to the sky, respectively.

In order to make a preliminary study on the radiative environment of Beijing's traditional urban pattern we have used the Ecotect software (Figure 5). The hourly recorded direct and diffuse radiation data has been obtained from a TMY data file of Beijing (*.epw). The daily average solar radiation on the surfaces which delimit the urban space in the four cardinal directions has been assessed. 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.

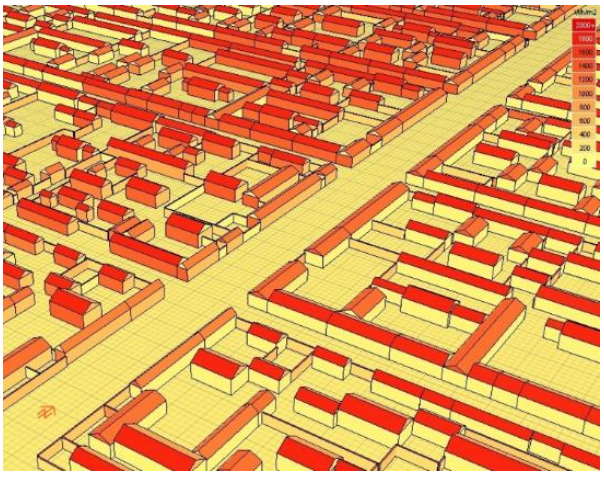

Figure 5. Beijing's traditional urban layout. Average daily radiation during the winter.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 4 April 2018 doi:10.20944/preprints201804.0050.v1

Comparative tables were created to visualize the results. Figure 6 compares the daily average solar radiation on the four possible directions: north, south, east, and west. The hottest months of the year are indicated 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.

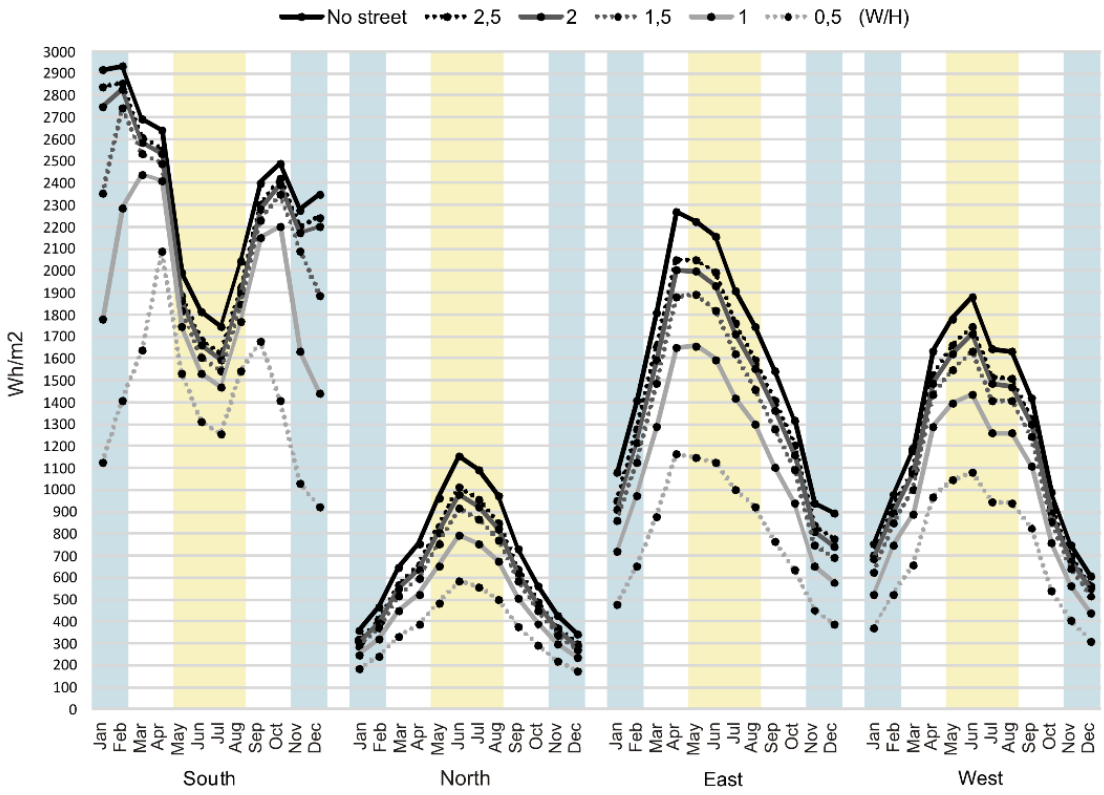

Figure 6. Effect of orientation and width-to-height ratio (W/H) of streets on the average daily radiation.

5.3. Discussion of the results

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. As a consequence, the south 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 tradition.

On the other hand, the solar gains received in the north orientation during the winter are negligible, and therefore, has no potential of achieving comfort by internal heat gains. Consequently, north facing orientation has been considered fateful in the Chinese ideas of geomancy or *fēngshuǐ*.

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 can be captured in the south, it is more than double the solar gains received in the north. Therefore, east and west orientations have a higher passive solar heating potential than the north facade in winter. In contrast, the solar radiation incident in both orientations during the summer can produce overheating. In this regard, the east-facing halls have better performance since they receive most of the solar gains in the

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 4 April 2018 doi:10.20944/preprints201804.0050.v1

morning when the ambient temperature is lower. Conversely, the highest thermal gains are received in the west during the afternoon when outside temperature is higher. Therefore, a correlation is also established between the orientation's hierarchical order and its environmental benefits, since the east has traditionally been considered in China superior to the west.

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 width 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 arranged 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 coldest 3 months and over the warmest 3 months. Both values have been plotted on a polar graph where the radius of any point from the center represents the incident radiation value (Figure 7). The suggested optimal orientation is not exactly south, but slightly to the east due to the hot afternoon sun in summer.

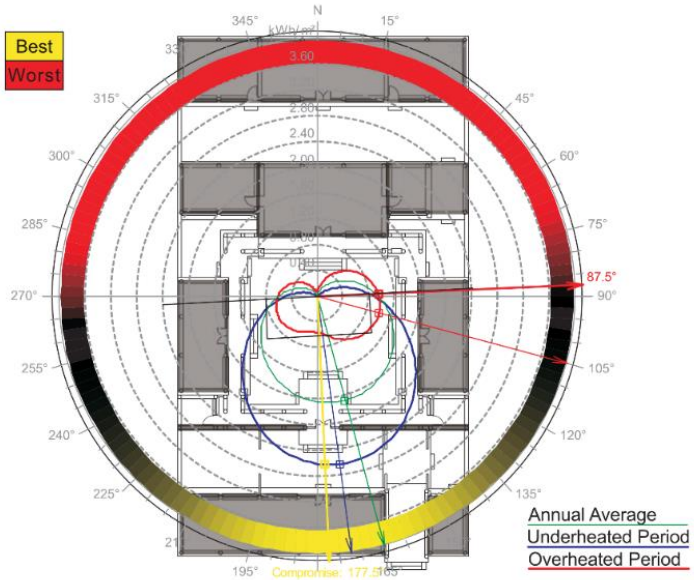

Figure 7. Optimal orientation angles in Beijing according to solar radiation received in the coldest 3 months (blue) and the warmest 3 months (red).

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 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."

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 4 April 2018 doi:10.20944/preprints201804.0050.v1

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) can be etymologically interpreted as a tree or trunk facing east. Due to this direction, the longer façades are facing south, the best orientation in Chinese tradition.

6. Conclusions

Chinese architecture has been traditionally related to cosmological concepts from which a parallelism was established between the heavenly order and earthly patterns. Within the framework of this correlative way of thinking lies the belief that human beings must inhabit nature in harmony with cosmological ideas. Consequently, Chinese architecture has been understood as a microcosm that must reproduce the macrocosm.

In the *Yìjīng*, a classic book that had a great influence on Chinese thought, the universe was built from the first duality (*yīn-yáng*) in different levels of complexity. These ideas are represented in the *bāguà*, a diagram that defines the position that man must occupy as an integral part of nature to be in harmony with the cosmos.

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, and so on. Consistent with this way of understanding architectural composition in relation to cosmological concepts, *dǒugǒng* duality is considered to be the first level of composition. It is a structural support whose arrangement is tied to the dimension of *jiān* or rooms whose combination generate halls or *tīng*. Halls are arranged around courtyards generating houses or *fángzi*, whose combination in a higher level of composition articulates cities or *chéngshì*.

This composition system is related to the *bùjú* concept, which represents the macro-micro duality. *Bùjú* suggests the existence of two complementary levels of composition, one being the reverse of the other. *Bù* refers to the division system from macro to micro, while *jú* shows the principles of expansion from micro to macro. 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 symbolizing nature, Chinese architecture is based on multiplicity, or quantity of simple modules or halls, more than on complex interior spaces. Therefore, Chinese architecture can only be understood in relation to nature.

Furthermore, Beijing's traditional urban layout is a good example of how the harmonious interaction between climate and cultural traditions can generate urban solutions with positive environmental values from which lessons can be learned in the present to formulate urban design guidelines governing street dimensions and orientations. Results of a preliminary solar access analysis show 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 on par with 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 square meters have been built in China in recent decades than in any other country and probably the world combined.

In this rapid process of transformation and opening to the world, China is rebuilding its identity while the rest of the globe is showing an unusual interest in its ancient culture. In this regard, Chinese traditional architecture has interesting environmental values from which lessons can be learned both in China and in the West to move towards a more sustainable architecture.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Xinian, F.; Daiheng, G.; Xujie, L.; Guxi, P.; Yun, Q.; Dazhang, S. *Chinese Architecture*; Yale University Press: New Haven, CT, USA, 2002.
2. Xiaodong, L.; Qinghua, Z. *Form-making in traditional Chinese architecture;* Chinese construction industry Press: Beijing, China, 2009 (in English and Chinese).
3. Henderson, J.B. *The development and decline of Chinese cosmology*; Windstone Press: Corvallis, OR, USA, 2011.
4. Madeddu, M.; Zhang, X. Harmonious spaces: the influence of Feng Shui on urban form and design**.** *Journal of Urban Design* **2017**, *22:6, 709-725.*
5. Mak, M.Y.; Thomas Ng, S. Feng shui: an alternative framework for complexity in design. *Architectural Engineering and Design Management* **2008**, *4:1, 58-72.*
6. Xu, P. Feng-shui models structured traditional Beijing courtyard houses. *Architectural and Planning Research* **1998**, *15:4, 271-282.*
7. Slote, W.H. *Psychocultural dynamics within the Confucian family*; State University of New York Press: New York, USA, 1998.
8. Hu, X. Boundaries and openings: spatial strategies in the Chinese dwelling. *Hous. and the Built. Environ.* **2008**, *23,353–366*.
9. Xu, Y. Form types and social functions in traditional Chinese architecture. *Architectural Theory Review* **1997**, 2:2, 67-82.
10. Liu, Z. *Typology and Structure of Chinese Architecture*; China Architecture and Building Press: Beijing, China, 2000.
11. Rowe, P.G; Seng, J. *Architectural Encounters with Essence and Form in Modern China*; The MIT Press: Cambridge, MA, USA, 2002.
12. James, G. *Frank Lloyd Wright's Imperial Hotel*; Dover Publications: New York, USA, 1968.
13. Sicheng, L. *A Pictorical History of Chinese Architecture*; SDX Publishing House: Beijing, China, 2010.
14. Lawrence, R.J. The Interpretation of Vernacular Architecture. *Vernacular Architecture* **1983**, *14:1, 19-28.*
15. Yi, J. Reflections on philosophy of culture in China. *Social Sciences in China* **2008**, 29:4, 131-142.
16. Dainian, Z. Chinese culture and Chinese philosophy. *Chinese studies in philosophy* **1988**, *19:3, 69-95.*
17. Wilhelm, H; Baynes, C.F. *Change: Eight Lectures on the "I Ching"*; Princeton University Press: Princeton, NJ, USA, 1960.
18. Suarez, A.H. *Tao te King*, 5th ed.; Siruela: Madrid, Spain, 2009.
19. Robinet, I. *Lao zi et le Tao*; Bayard Jeunesse: Paris, France, 1999.
20. Sypniewski, B.P. China and universals: Leibniz, binary mathematics, and the Yijing hexagrams. *Monumenta Serica* **2005**, *53:1, 287-314.*
21. Cabeza, J.M. *El Dao de la Arquitectura*; Comares: Granada, Spain, 2007.
22. Zhang, W. The influence of Lao Tzu's "solid and void" on the Spatial Theories of Chinese Architecture. *Journal of Tibet Nationalities Institute* **2004**, *25:3, 62-64.*
23. Liangyong, W. *Rehabilitating the old city of Beijing: a project in the Ju'er hutong neighbourhood*; University of British Columbia Press: Vancouver, Canada, 2000.
24. Dong, W.; Mackee, J.; Mak, M. Exploratory analysis of the traditional philosophy underpinned urban sustainability model for Chinese cities. *Procedia Engineering* **2011**, *21, 838-845.*

 doi:10.20944/preprints201804.0050.v1

679 25. Lam, J.C.; Yang, L.; Liu, J. Development of passive design zones in China using bioclimatic approach.
680 *Energy Conversion and Management* **2006**, *47, 746–762.*
681 26. Milne, M.; Givoni, B. Architectural design based on climate. In *Energy Conservation through building design*;
682 McGraw Hill Book Company: New York, NJ, USA, 1979.
683 27. Oke, T.R. *Boundary layer climates*; Routledge: London, UK, 1987.
684 28. Stromann, J.; Sattrup, P.A. The urban canyon and building energy use: Urban density versus daylight and
685 passive solar gains. *Energy and Buildings* **2011**, *43, 2011-2020.*
686 29. Voogt, J.A.; Oke, T.A. Validation of an urban canyon radiation model for nocturnal long-wave fluxes.
687 *Boundary-Layer Meteorology* **1991**, *543, 347-61.*