Chinese Vernacular Architecture
Lessons to learn for sustainable architecture in China

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Abstract
Due to a great technological development it became possible to build without any concern regarding the exterior environment. The use of air conditioning systems has become more and more frequent in order to solve the interior discomfort, caused by inadequate designs. This resulted in a higher energy demand in buildings, which is today one of the biggest contributors to the pollution problem in China. The objective today is to build an architecture that allows for interior comfort, using the least amount of energy and resources, replacing non renewable energy by renewable energy sources. This thesis intends to answer the following question: How can vernacular architecture inform contemporary architecture? To answer this question, China is used as an example. A country with a vast territory with many different climates, topographies, cultures and beliefs.

Firstly the history and religion in China are analyzed through bibliographic and field research. The climate and topography are also analyzed in order to have a better understanding on the most relevant factors that will influence vernacular architecture. After this, seven case studies were selected to demonstrate the relationship between architecture and climate. Their most relevant characteristics were analyzed regarding their thermal performance. The case studies are distributed in China according to the different climatic zones. In order to have a global understanding of the Chinese territory all of the climatic zones were analyzed: Severe cold zone; Cold zone; Temperate zone; Hot summer and cold winter zone; Hot summer and warm winter zone.

In order to identify the climatic patterns that influence the building design, the specific climate where each example is found is studied. Through the analysis of the building and its characteristics we can then verify the importance of interior comfort, that is often the driver of a design. The need to develop projects that can adapt to the specific climate and culture has resulted in a great deal of passive solutions of environmental design. These strategies were then analyzed using adequate software in order to understand their importance and thermal performance.

The relation between vernacular architecture and climate is quite evident, specifically in the Chinese study. The need for comfort is something that has always been of great importance for the inhabitants, and in severe climates this necessity is aggravated. It is curious to observe how the different case studies adapt to the local climate without losing their identity and sense of community. Nowadays, the building models do not adapt to either the local climate or culture where they are found. Vernacular architecture can and should be used as an example of sustainable architecture, due to the adaptation to the climate that results in better energy performances, but also due to the cultural adaptation.

Keywords: Chinese vernacular architecture, Bioclimatic architecture, Sustainable development, Interior comfort, Passive design, Sustainability


0. Introduction

China has the largest population in the world, and through industrialization it has experienced astonishing economic development that resulted in rapid urbanization. Because of this the construction of residential buildings increased exponentially, with millions of residential units being built every year, which resulted in a number of problems: The adoption of Western models that do not adapt to the specific context; Repetition of these models in excess, which results in a loss of identity; Poor quality of construction; Negative environmental impact; and many others.

Because these buildings do not adapt to the specific context, and the quality of construction is very poor, the interior comfort is often inadequate. This results in the installation of air conditioning units in most of the contemporary buildings, in order to increase comfort. However some people can not afford to install these systems, or to pay the electricity required, forcing them to live in uncomfortable houses.

Associated with this problem is the abandonment and destruction of vernacular architecture, as people move from rural areas into cities. People leave behind the houses that have been in their families for generations, and at the same time, vernacular dwellings found in cities are destroyed to make room for contemporary high-rises. If no attention is paid to the preservation and study of Chinese vernacular architecture, its unwritten information will be forever lost.

Through the study of vernacular architecture, this dissertation intends to understand how people have adapted their homes to their customs and culture in order to ensure interior comfort. To learn how people develop different design strategies to different climates, and how these strategies perform in this contexts. The main goal is to understand the way in which the strategies used by people throughout time contribute to the interior comfort, in a specific climate. Also, it intends to understand in which way contemporary buildings can learn with vernacular architecture, to better adapt to the context where they are found.

1. Historical background

Most of China’s imperial period was notably unstable, with periods of great prosperity and periods of war and instability. This resulted in great differences of economic power and social security which strongly affected vernacular architecture. With less economic power and greater need for security, the war periods led to specific typologies that address these problems. An example of this is the Tulou building. Due to great insecurity, this large complex building has extremely thick and high walls with almost no fenestration. The materials used are

Figure 1. Chinese vernacular architecture.
found in abundance in the region, making it economically viable. In times of prosperity people were still strongly constricted by sumptuary regulations\(^1\). However, they still found numerous ways of designing their dwellings in such a way that increased interior comfort and fulfilled religious belief.

Different religions and beliefs are very important in people’s lives, by shaping behaviors and the way that they see the world. It is common to see temples in China that portrait multiple teachings of different philosophers. In the same way, it is also common to see the expression of different religions and beliefs in people’s houses. A great example of this is the Courtyard house in Beijing. With a clear hierarchical position of volumes and division of space, this dwelling is strongly influenced by the Confucian school. However, the position and division of spaces is also done according to Taoism and Fengshui. The overall organization of these dwellings promotes contact with nature, even in a dense city, such as Beijing. The courtyard enabled the presence of some trees and the direct contact with the sky above, which is strongly related with Taoism views of life.

2. Climatic context

The climate is extremely complex in the Chinese territory. This is mainly because of the air currents that come from Mongolia and from the oceans. From September to April, dry and cold winds come from Mongolia to the north of China. These become gradually weaker as they move south and are the main reason for cold and dry winters and the great differences in temperatures found in the north. From May to October a warm and moist monsoon occurs from the ocean and brings abundant rainfall and high temperature through the south and southeastern coastal parts of China.

Even though climate in China is quite complex it is possible to understand some patterns that relate the air currents with the different topographies and patterns of precipitation. Climate zoning was developed in order to allow the study of the different challenges that each type of climate faces.

The definition of climate zones, that divide China into areas that share some common features, has been attempted by many. If this division is too broad, with only a few climate regions, the information is too general to be useful, but if there is too much information this often becomes inaccessible. The considered climatic zones in China are: severe cold, cold, hot summer & cold winter, hot summer & warm winter and temperate. These are the generally accepted climatic zones for building design in China and were defined according to the ASHRAE standards. The major shortcoming of this system is the fact that it does not consider all aspects of the climate, it only considers air temperature. This system was chosen not only because of its simplicity but also because its set of rules are directly related to the building design.

3. Analysis of case studies

Vernacular architecture varies widely throughout the world and it contains inherent, unwritten information about how to optimize the building. In conditions of low technology, the climate often plays the main role and becomes the dominant force in the design process. It is very interesting to observe the plurality of design solutions that are limited by the same climatic constraints. At the same time, it is intriguing that we can observe practically identical architectural models in completely different regions of the world, that share similar climatic conditions. However, an immense number of dwellings found throughout the world shows us that this is not a correct assumption. Strong climate profiles can lead to similar building typologies. However, vernacular architecture

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\(^1\) Sumptuary laws existed in China since the Qin dynasty onwards. The Confucian virtue of restraint was embodied in the scholarly system central to China’s bureaucracy and became encoded in its laws.
shows great flexibility and adaptability of solutions due to different economies, cultures, technologies and many other aspects.

Because China has such rich history and culture, the different dwellings found in its territory are far beyond this research's reach. In order to have a better understanding of the different climatic regions and the way that climate is addressed, some case studies were selected to represent each climate. Each dwelling is located in a climate zone, and even though this division is very important when looking at China as a whole, it gets too broad for design purposes. Because of this, data was collected from the nearest meteorological station for each dwelling using Meteonorm V7 and Climate Consultant 5.5.

Firstly a climatic analysis of the region is made, regarding its baseline characteristics, such as: temperature, sunshine, humidity, precipitation and winds. After this there was the need to have a better understanding of what this climate characteristics mean for the human experience. Using Climate Consultant 5.5 and the psychrometric charts of each region, the comfort analysis is done.

After the climate analysis is done and the strategies are delineated, it is important to study the dwelling in order to understand how it is designed. The qualitative analysis focus is to understand how people designed their homes, the materials they used, special techniques and the overall main features of a certain house type. By doing this we expect to understand whether or not people used the natural elements of nature to increase the interior comfort of the house, and how they did it.

After the qualitative analysis is done it is important to ensure the viability of the strategies used in this dwelling through a quantitative evaluation. In order to assess the interior comfort, a BIM model was created for each case study, using Revit 2018, and taking advantage of the Insight 360 plug-in that allows the creation of an energy model. The case studies that are represented here have the standard characteristics and dimensions found throughout China. These values and information were found through investigation, local visits and are mostly based on bibliography.

The goal of this study is to understand how the applied strategies contribute to the overall comfort of the dwelling. In order to understand how the strategies used in these vernacular dwellings behave in a certain climate, we took the most important features of each case study and analyzed how these affect the interior comfort, and natural lighting. By doing this we expect to understand whether or not the design strategies used in these dwellings contribute to the interior comfort, and how they will influence it.

3.1. Single story rectangular farm house in Harbin

This dwelling is found in the severe cold climate, one of the most challenging climates in China. The main features of this climate are: the big annual temperature range, due to extremely low temperatures in winter; significantly more precipitation during the warmer months, increasing the discomfort. The design priorities are focused on the winter's low temperatures, and less importantly, summer overheating and humidity. This dwelling has a rectangular shape, double slope roof with gabled end walls and only presents windows on the south facade. All the exterior walls of the dwelling are made out of rammed earth, and the northern, eastern and western walls are 0.5 meters thick to create a tighter envelope.
The main features that contribute to the interior comfort are: great thickness of the surrounding walls, lack of windows on the east, west and north walls; window to wall ratio on the south facade. All these feature were analyzed in this study, and contribute to the interior comfort of the dwelling. The great thickness of the surrounding walls is an important feature of this dwelling since it is used to ensure insulation and airtightness. In Figure 3 we can see that the heating load is higher for values of wall thickness lower and higher than 0.5 meters. On the right, we can see that the cooling loads are significantly higher for wall thickness of 0.125, 0.75 and 1.0 meters, but they are slightly lower for 0.25 meters. The total loads are optimized for a wall thickness of 0.5 meters, the wall thickness found in these dwellings.

3.2. Quadrangular courtyard house in Beijing

This dwelling is found in the cold climate region, in Beijing. The main features of this climate are: the big annual temperature range; significantly more precipitation and humidity during the warmer months. The design priorities are focused on the winter’s low temperatures, and summer overheating combined with high humidity. This dwelling has an approximately square shape, with a square interior courtyard that occupies roughly 40% of the building total area.

The main features that contribute to the interior comfort are: the lack of windows on the exterior walls; the dimensions of the central courtyard. These were analyzes, and both contribute to the interior comfort of the dwelling. On Figure 4 we can see that by varying the size of this courtyard we can understand the implications of increasing or decreasing its size. On the first graph we can see the cooling loads, which are not too variable with the different courtyard sizes but decrease slowly for bigger percentages. The second graph shows the heating loads. These are significantly higher for values of courtyard to building ratio higher than 40% and lower than 50%. From this analysis we can conclude that regarding the cooling and heating loads the ideal solution would be a courtyard with a ratio bigger than 50% and lower than 80%. The Beijing courtyard, even though it does not have the ideal measurements for this specific climate, it still shows good values of heating and cooling loads.

![Figure 3. Wall thickness analysis.](image)

![Figure 4. Courtyard to building ratio with correspondent cooling and heating loads.](image)
3.3. Subterranean houses in Yulin

This dwelling is found in the cold climate region, in a dry location. The main features of this climate are: big diurnal temperature range, due to lack of humidity; big annual temperature range; less humidity in the colder months; more precipitation during the warmer months. The design strategies are focused on winter's low temperatures, and less importantly, but still relevant, summer overheating. In this climate it is also very important to look at the difference of temperatures during the day and night. This dwelling is completely subterranean with a square courtyard that occupies 81 square meters. The living quarters are dug into the sides of the courtyard with the exception of the south side where the stairs are found.

The main feature of this dwelling is the fact that this building is subterranean. It is a very important feature since it ensures the airtightness of the envelope as well and insulation, as well as natural heating and cooling. When looking at this, one can think of it as only massive construction. However there is also the fact that the soil can act as a heat sink in summer and allow for free cooling, since the earth temperature at deeper levels is lower. In winter the deep soil temperature is much higher than the outdoor air temperature, allowing for free heating. To understand this factor, five cases where studied where the building is buried progressively at lower levels, from 6 to 3 meters deep, and finally when the building is not subterranean. As we can see in Figure 5 the heating and cooling loads are very low and quite similar for all the subterranean cases, however, for the above ground case this situation changes drastically increasing exponentially.

3.4. Han-influenced dwellings in Lijiang

This dwelling is found in the temperate climate, the most pleasant climate in all China. The main feature of this climate is the increased precipitation during the warmer months, resulting in less sunshine and more humidity, during this time of the year. The design strategies focus on the winter's low temperatures. The dwelling is composed of three buildings facing a square courtyard. These buildings are two stories high with double sloped roofs and gabled end walls. Each building is divided into three bays, and brick walls surround the whole structure with no fenestration.

This model was adapted from the quadrangular courtyard house in Beijing. Because of this, it is interesting to see how this dwelling would behave in Lijiang's climate, and why people changed it. To do this, the quadrangular courtyard house from Beijing was analyzed, in Lijiang's climate. Table 1 summarizes the heating and cooling loads of this type of dwelling both in Beijing and Lijiang's climate. As we can see the cooling and heating loads are much higher in Beijing than in Lijiang. This is mainly due to the fact that Beijing as a much more severe climate than Lijiang, so even though this building is designed for Beijing's climate it preforms much better in Lijiang. One of the biggest changes, in comparison to the Beijing courtyard house, is the fact that this building has two stories instead of one. In order to understand why people chose to change this, and the implication that it has on the interior comfort, two situations were considered. Table 2 shows the different heating and cooling loads in a single story Han-influenced dwelling and in the two stories case study. Although the heating loads are slightly higher for the single story dwelling, we can see that the total loads are lower for the
original case study, indicating that this adaptation contributes positively to the interior comfort of this dwelling. When comparing the Beijing courtyard dwelling, which has a total load of 162.64 W/m², and the Han-influenced dwelling, with a total load of 121.94 W/m², both in Lijiang’s climate, the second has better thermal performance.

<table>
<thead>
<tr>
<th>Quadrangular courtyard</th>
<th>In Beijing</th>
<th>In Lijiang</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling loads (W/m²)</td>
<td>220.36</td>
<td>116.12</td>
</tr>
<tr>
<td>Heating loads (W/m²)</td>
<td>247.58</td>
<td>46.52</td>
</tr>
<tr>
<td>Total loads (W/m²)</td>
<td>467.94</td>
<td>162.64</td>
</tr>
</tbody>
</table>

Table 1. Courtyard house in Beijing and Lijiang.

<table>
<thead>
<tr>
<th>Single story</th>
<th>Two stories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling loads (W/m²)</td>
<td>39.49</td>
</tr>
<tr>
<td>Heating loads (W/m²)</td>
<td>80.05</td>
</tr>
<tr>
<td>Total loads (W/m²)</td>
<td>128.54</td>
</tr>
</tbody>
</table>

Table 2. Single story and two story building in Lijiang.

3.5. Huizhou’s enclosed multi story Tianjing houses in Anqing

This building is located in the hot summer and cold winter climate region. The main features of this climate are: high humidity throughout the year; more sunshine during the warmer months, which add to the discomfort; low diurnal temperature range. The design strategies are focused on winter’s low temperatures, summer’s high temperatures, and high levels of humidity. This dwelling is composed of three buildings and two sky wells. The sky wells occupy roughly 20% of the built area and are the main source of light and ventilation. The surrounding walls are high and do not allow for the double sloped roof to show from the outside.

The main features of these dwelling are: lack of windows on the east and west walls; the use of a sky well instead of a courtyard. These features were analyzed and contribute to the interior comfort. The lack of windows on the east and west facades and the longer sides of this building are things that immediately strikes the attention. This can be a good feature for the interior comfort in winter and summer, creating a tighter envelope. In Figure 6 we can see that in both these facades, the higher the window-to-wall ratio, the bigger the EUI value. Therefore the lack of windows on the east and west facades contributes to the interior comfort.

3.6. Bamboo stilt houses in Mengla

This dwelling is found in the hot summer and warm winter climate. The main features of this climate are: small annual temperature range; high levels of humidity throughout the year; increased precipitation during the wet season. Therefore, the design strategies focus on the high levels of humidity, the need for heating during the dry season, and the need for cooling in the wet season. This dwelling is elevated 2 meters above the ground by 36 columns that support not only the flooring but also the heavy roofs.

Because this dwelling has no walls or ceiling, it is not possible to generate an energy model. Insight 360 creates the energy model using the surrounding surfaces of a room: roofs, ceilings, walls and floors. Because this dwelling is focused in the amplification of ventilation, the interior room is considered exterior in this software, since it has no clear distinction between inside and outside.
3.7. Tulou earthen houses in Fujian

Tulou earthen houses are found in the hot summer and warm winter climate zone. The main features of this climate are: Small annual temperature range, of high temperatures; high levels of humidity throughout the year; significantly more precipitation during the wet season. With a square floor plan, this dwelling has an approximate area of 848 m$^2$, with an interior square courtyard with 196 m$^2$. Its walls are 2 meters thick at the bottom and gradually decrease to 1 meter thick at the top.

The main features of this dwelling that were analyzed are: the height of the building; the thickness of the surrounding walls. This building is four levels high, with 12 meters in total. Its verticality ensures a compact interior space that is not too affected by outside phenomenon. Figure 7 shows how the cooling and heating loads vary with the height of each story of the building. As we can see both loads increase with a lower level, indicating that the higher the building is, the better it performs thermally. We can also see in these graphs that from levels 4 to 6, the cooling and heating loads are practically the same, indicating the number of levels in this dwelling is a positive attribute to the interior comfort.

4. Looking at the future

Vernacular architecture is generally marked by good thermal responses. However it also presents some challenges when it comes to interior comfort and sustainability. The lack of interior lighting is a problem that is found in every dwelling that was studied. The fact that most buildings relied on airtightness of the envelope to keep the interior temperature comfortable, strongly contributed to this. The presence of glass was often at the expense of airtightness and low insulation. With the technology that we have today, this situation could have been easily resolved. Besides allowing for good insulation and airtightness of the envelope, a double or triple pane window would also increase the passive solar heat gains.

Another always present problem in vernacular architecture is the burning of biomass for heating. Nowadays we know that this is not the most efficient way of heating our homes, and it may even be dangerous for our health due to the inhalation of toxic gases and particles.

Although it is relatively simple to see that vernacular architecture has a much better thermal response than the contemporary examples in China today, it is also clear that contemporary architecture is subject to many more challenges. The increased urban density, lack of qualified professionals, exterior influences, along with the rapid building pace, are only a few of the most difficult challenges that contemporary architecture in China faces today. The lessons that we learn from vernacular architecture may indeed be applicable to contemporary designs, after all they fulfill most of the climatic, cultural, social and religious needs. However, one must be careful in this transition. China today is very different from a few years ago, both culturally and socially, and it presents many new environmental concerns.
The development of new technologies has also greatly changed the building sector. Nowadays, with increased living standards, people can not live in an energy-free house, as was done many years ago. Even if we can heat and cool our dwelling naturally for every hour of the year, there will still be an energy demand for all the contemporary appliances and hot water. This is why it is important to understand that the use of technologies are a very important characteristic of contemporary architecture. It should not be, however, an amend to a poorly designed project, as it is currently in so many cases.

Although vernacular dwellings have a good thermal response, it is not reasonable to think that they have the potential to house the growing population of the northern Chinese cities. These buildings do not take the most advantage of land use, and are quite expansive in their disposition. The materials used were relevant for that time. However, today there are materials that are more environmentally friendly and that can improve the thermal response. All in all for each climate the most important features to have in mind are still the same as they were many years ago. They should achieve their full potential when informed by vernacular architecture and executed with contemporary building methods and technologies.

As we previously studied, the design strategies are strongly dependent on the climate in which they are found. Table 3 shows the summarized project recommendations for the Chinese climates, based on the information in the vernacular case studies.

<table>
<thead>
<tr>
<th>Airtightness</th>
<th>Insulation</th>
<th>Southern exposure of windows</th>
<th>Horizontal shading</th>
<th>Natural ventilation</th>
<th>Heat source</th>
<th>Underground temperature</th>
<th>Thermal mass</th>
<th>Shading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold and humid</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
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<tr>
<td>Cold and dry</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Temperate</td>
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<td>Hot and humid</td>
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<tr>
<td>Hot summer and cold winter</td>
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</tr>
</tbody>
</table>

Table 3. Project recommendations according to climate

5. Conclusions

The global purpose of this thesis was to explore the relation between Chinese vernacular architecture and the context in which it is found. To understand how the strategies applied in these dwellings contribute to the interior comfort, in a specific climate. This study consisted of the analysis of design strategies found in Chinese vernacular architecture that contribute to the interior comfort, and the assessment of their performance in the climate where they are found.

Most of the design strategies studied in these dwellings are quite relevant, and should be taken into consideration in contemporary architecture. However, it is also important to consider contemporary materials and technologies that can improve their performance. The relevance of these dwellings resides in the concepts that they teach us, and not necessarily on the specific ways they are applied.

Generally this thesis contributed to spread the present knowledge regarding Chinese vernacular architecture, and to increase consciousness regarding its cultural and technical value. To increase the body of knowledge, and to promote the implementation of vernacular architectural concepts in contemporary architecture.If the lessons learned from this are applied in Chinese contemporary architecture, we expect to increase interior comfort for everyone, as well as improve the air quality in China, by reducing CO₂ emissions.

With such a vast territory and rich culture, China has many more vernacular dwellings than those analyzed in this research. Due to the time frame in which this thesis was elaborated, it was not possible to study all vernacular dwellings, and the different design strategies that are found within them. The main limitation of this
research is the language barrier. Although some people in China understand English, communication is often problematic. Also, the bibliographical research was limited to either English or Chinese translated books and papers, which was also quite problematic since the existing research on this topic is already quite narrow.

This project can serve as an inspiration and a base for future investigations in this field, such as the study of other examples of vernacular architecture in China. Also, the study of multiple examples in the same climate would allow to see the different nuances of bioclimatic design on the building environment. This should also be an inspiration for other developing countries, that are facing similar problems today. Countries like India are now having to deal with urbanization and massive construction rates. They have the opportunity to learn with China's development and to adapt in order to prevent the same catastrophic consequences that China is facing today.

The logical next step of this research would be the application of the design strategies in contemporary architecture, according to their climate. An analysis should be made in order to understand the implications of these strategies in real case studies of new buildings, as well as the renovation of inadequate designs. This study would be particularly interesting in the specific case of the high rise typology, since it is becoming more and more common throughout China.

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