Energy-Concious and Sustainable Architectural Principles for Cold Environments

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Abstract: - The present paper is the summary of the results of an extensive research on energy-conscious architectural elements and principles in different climates, used throughout the history, but in this paper the results of the cold climate will be presented. The methodology used to investigate the selected case studies is a comparative method, and the cases are cross-referenced to each other. This is to derive the strategies and elements of climate-conscious design or for the purpose of comparison to the architectural aspects in other environments. The analysis of the cases demonstrates similarity and some contrast in elements and principles, differing in history and culture but being similar in climate.

Key-Words: - Sustainable Architecture, Energy, History, Culture, Climate, Cold Environment.

1 Introduction

In recent years world has set many initiatives in motion in order to ensure sustainable development. The goal is to have sustainable environment, and the architecture is at the forefront in terms of fulfilling the set of goals which the Rio agreement in 1992 stipulated as necessary for sustainable development in the 21st century. One of the most significant means to achieving sustainable development is green building. “... the most effective actions to effect reduction of CO₂ emission lie in the building sector, largely because buildings, in use or construction, are the biggest single indirect source of carbon emissions generated by burning fossil fuels.” [1] The plan is to reduce overall consumption of energy, water and heat, and it is ends and means regarding all relevant environmental factors.

The influence of climate on man's evolution, on one hand, has affected the evolution of architectural form indirectly, and on the other hand, climate has affected the architectural configuration directly. The ancient settlers, in all regions, discovered these conditions and they became factors, which affected the way they planned their buildings. Once these factors were clear and understood, then the principles were deduced and their designs were based upon them. For contemporary designers these principles, which were established on the basis of natural conditions and factors, and were supported by trial and error over thousands of years, could become significant decision-making constituents.

The solutions to the constraints that have been imposed on the inhabitants by the harsh condition of the cold climate have led to some of the most ingenious solutions to climatic architecture. Minimal exterior urban and architectural surfaces for minimum heat loss and minimal volume for minimising the heating requirements caused the cold climate settlements to be compact with good sun access. “The heating season is long and the temperature difference between the heated buildings and the outdoors is large. ... the main concern is to minimize the heat loss from the building.” [2]

Morphology, Density, Arrangement, Circulation, Roof form, Surface, Openings, Shading Device and Material are selected as the main topics for design principle and building elements. The purpose is to identify strategies that created more bioclimatically comfortable indoor spaces for the inhabitants in cold climate. Each elements and principles according to its culture and history is unique, however, many of their physical patterns are similar to each other, specifically patterns of elements and strategies influenced by the physical environment in cold region. The results from the above process are the pieces which will be put together in this paper to provide guidelines for architectural configuration in cold environments.
2 Selection Criteria
Architectural meanings are ultimately always set in history, advancement of knowledge and environmental context. Therefore, the three criteria that will define the entity of an urban centre are history, culture and climate.

Each element and principles according to its criteria is unique, however, many physical patterns are similar to each other, specifically patterns of elements and strategies influenced by the physical environment. These criteria have been considered in order to include fairly representative examples of architecture from various historic periods, climatic zones and cultures, or to have a homogeneous and balanced distribution of the selected buildings, to achieve broad results and in making recommendations.

The following are the types of climate, which were considered in the selection of the cases. These climates can be regarded as ‘habitable climatic zones’, since most civilisations and land occupied by human beings have been located within these areas. For the purpose of generalisation, these buildings were divided into the four major climatic regions with some variation. These regions are abbreviated according to Köppen’s generally accepted classification of the climate, and they are:

A: Hot-Humid / Tropical rainy
B: Dry / Hot-Arid
C: Temperate / Warm-Humid
D: Cold/ Semi-polar

Cold Climate or microthermal regions that have few humid seasons are mainly concentrated in the east-central and northern Asia, northern Europe, on the north of North America and some other higher altitude and upper middle-latitude parts of the world. The investigation of morphological and architectural form of the urban centers within the cold region can be useful, because many developed and developing countries are located within this region. The existing historic settlements in this region, such as Ch'ang-an (China), Masule (Iran) and others, and the results of the strategies and elements employed in their architectural planning and morphology is studied, and the findings is classified and presented.

2.1 Climate
Climate has played and should play a significant role in determining the overall architectural form and fabric of the future architecture and living style. The purpose is to observe the continuity or discontinuity by considering the climatic influence on the architectural form in the course of history. It is important to emphasis, as the findings of the study that indigenous architectural styles are defined less by national frontiers and more by environmental considerations. The evidence for this can be found in all continents.

The people had learned to establish their settlements according to the limitations that the cold climate imposed. The severe conditions sometimes provoked the inhabitants to relocate from their established settlements to a more climatically appropriate location or orientation for more physical comfort, e.g. Masule. The urgency for comfort also necessitated new architectural inventions; the chimney was one of them.

[Fig.1: The On-going Process of Urban Life Entity [3]

[Fig.2: Cold Regions of the World (the shaded areas) [4]

2.2 History
The historical periods that are most appropriate for the objectives of this study are those in which urban civilisations were already established and whose progress could be manifested in the culture, innovations and works of art of their people. This study is not a review of the architectural history, but history is used as a conveyer of climatic influence upon the morphology of urban centers and their vernacular architecture.

The following are the periods from which climate-oriented buildings were selected. They are not necessarily categorised according to the divisions or the denominations used by historians. Rather these periods are divided and named by their characteristics as a turning point in the history of climate-sensitive design. They are:
- Prehistoric (~5500 to ~3500BC)
- Ancient Time (~350BC to 422AD)
- Pre-industrial Era (422AD to 1735)
- Modern Era (Industrial) (1735 to 1970s)
- Sustainability Era (1970 onward)

2.3 Culture
Cultural impacts on the formation and configuration of architectural elements have been extensively researched, with various intentions. The importance of cultural influence on architectural form need not be re-examined or re-emphasised in this study, since it is beyond the scope, and there is already a large body of evidence and research in this area for further studies. However, it is important to mention that cultures have been considered to be influenced by climate itself.

There are many different and advanced cultures that could be considered in the selection of architectural samples, and for the diversity of the study, most major cultures were included. Many cultures or civilisations were not considered, but their impression can be found in the selected buildings.

Some cultures existed in close physical or climatic proximity to each other, and had many common influences on the spatial characteristics of each other’s architectural form. There are buildings in different climatic regions but built by the same or similar culture. The study of this type of buildings will be an important aspect of the research in order to investigate how their morphology in the same culture was transformed and modified as different locations and/or climates were selected for the placement of settlements. Some Near Eastern or Roman cultures can be considered as such.

East, Near-east, West, and Mesoamerica are the four major cultures selected with regard to all the above considerations, from the beginning of urban civilisation up to the present time. They have been chosen to be fully representative of most major and influential cultures for the climatic study of architecture. Based on the selection criteria the following two urban centers were selected out of many, and their architectural merits will be presented.

3 Ch’ang-an
The Chinese city of Ch’ang-an, which now is named Xi-an (shean), marks the start of the Silk Road and has its roots in the early years of the Han dynasty as the capital. It lays at latitude 34º N and 950 km south west of Beijing. The foundation of new Ch’ang-an was based during the Sui dynasty. It became the richest, grandest and largest city in the world during the T’ang dynasty between 618 and 907 AD. Ch’ang-an was planned and built on a grand scale covering an area of about 3,000 hectares. This area included 292 hectares of the palace complex, and at its peak had an estimated population of one million people.

Fig.3: Architectural Elements Mo-ni Hall, China [5]

The central blocks for administrative buildings were divided making oblong and better building lots in order to capture the sun and daylight. The residential areas were divided into four equal parts by north-south and east-west alleys for better access to the structures and also better exposure to solar radiation. These elaborate sub-divisions of Bo and the selection of a medium density planning is thought to have been implemented to allow every building to have a good exposure to the sun in this cold winter
climate, and to provide better ventilation by the northerly wind prevailing in the warm seasons.

Ch’ang-an is a valuable historic city, for the purposes of this study, being one of the oldest urban centres of the east with a cold climate. The existing evidence demonstrates many of the city’s features to be in accordance with climate-responsive urban planning. The overall conclusion is that this urban centre had enough implemented climatic strategies and elements to be considered in this study for its climatic merits.

4 Masule
This present-day summer resort is located in a mountainous area on the most western point of the Gelan province in northern Iran. Masule has a very cold winter, a mild summer which seldom becomes hot. It has a steep, slope setting, oriented towards the south to southeast, and is in a close-end valley. This valley has dimensions about 30 km east-west and 12 km north-south, at a height of about 1050 m above sea level, and centre of the settlement is about 250 m above the river bed. Its vegetation cover is diverse, which has significantly affected traditional methods of construction.

It is speculated that old Masule, which is located within 4 km of the new Masule was built in about the 9th century. The relocation to the present area is speculated to have been due to unsuitable climatic orientation and/or destruction by earthquake. 1583 AD has been considered as the date of construction and establishment of the present Masule.

The urban morphology and fabric of Masule was significantly affected by its southeast to southwest slope and direction, particularly its general orientation. The selection of the above natural setting increases the utilisation of insolation for the long underheated period, and it indicates that the need for solar orientation was recognised. Another reason for selecting such a slope could not only be to have a higher urban density for less heat loss and reduction of wind-exposed surfaces, but also to have less shadow and composite-shadow on the structures and arteries at the same time. Also, snow-cover on the arteries and roofs usually melts with the first rays of the sun during the winter. The overall urban setting and orientation provides excellent opportunity for earth-sheltering.

The indoor spaces and buildings are not endogenous, they have south to southeast and sometimes southwest orientation and usually follow the topography, and are well-oriented to capture the insolation. There are many dwellings with up to three stories, and most buildings and their windows are usually towards the south or southeast. This building orientation is to capture maximum sunlight, particularly during the underheated period. The above architectural characteristics, together with higher density, and Masule’s general configuration are to protect against the heat loss for indoor spaces.

![Fig.4: Architectural Configuration of Masule, Iran](image)

The building materials for traditional structures are wood, stone and adobe, and this has affected the construction method. The elaborate methods used for different building functions, have not only resisted earthquakes, but have also helped to retain the internal as well as the external heat gains.

Masule could be a symbolic climatic urban centre where the cold climate has been well-restrained, which is environmentally integrated, where its tradition is sustained and its beauty preserved. Even though this town in the past had more significant importance it is still alive and functioning after at least 450 years. This may be for its good economic base, its social cohesiveness, and finally because of its consideration of the natural setting and selection of well-suited climatic orientation.
5 Design Strategies
The following is the main architectural strategies, building configuration and design elements, and the reasons and the basis for more comfortable indoor and outdoor spaces for the inhabitants of the regions for thousands of years. They are the architectural aspects in the cold climate, which include the most important design strategies that were driven from the analysis:

a. Introverted building morphology in a cube-like form was preferred: To minimise external heat loss and to retain the internal heat.

b. Maximum compact configuration was an important strategy: To minimise the structure’s exterior surfaces in proportion to the interior volume, for reduction of the contact with the prevailing cold air movement.

c. Compressed arrangement with some earth-sheltering was intended: To take advantage of the earth’s heat when the temperature was lower.

d. The most spatially efficient spaces and minimum circulation between them was implemented: To reduce the internal circulation and volume, and to reduce the volume and therefore minimise the need for heating.

e. Roof cover, primarily in a high pitched or flat form, was used: To increase the melting of ice and snow by insolation.

f. Smooth building surfaces were applied: To decrease the contact with air movement and freezing winter winds, to decrease heat loss, and to maximise sun exposure.

g. Maximum window areas on the south, moderate on the east and some on the west were adopted: To control and take advantage of insolation for internal heat gain.

h. Minimum window areas on the north facing facades were employed: To reduce the heat loss of contact with the colder northern winds.

i. Short horizontal shading devices for south facing windows were applied: To control the heat gain in the short overheated period.

j. Heavy construction materials for some interiors elements or surfaces were used: To retain heat for underheated hours.

k. Non-porous building materials were used: To decrease heat dissipation.

l. Heavy weight materials for exterior elements were employed: To maximise heat storage.

6 The Results
The results from the above aspects are the pieces which is put together to provide a guideline indicating the effect of climate on architectural configuration. The buildings in all of the four climatic zones may be hundreds of kilometres apart, but in the same types of climate similar architectural morphology, climatic design principles and physical appearance, with variable depth, are evident and transparent. The selected structures might differ in size, texture and scale, and might have different culture, but their spatial climatic organisation binds them together. The investigated buildings were a few samples from the vast and rich variety and represent a good spectrum of the culture, history and climate.

Table 1: Summary of the Results for Cold Regions

<table>
<thead>
<tr>
<th>Arch. Elements</th>
<th>Design Principles</th>
</tr>
</thead>
<tbody>
<tr>
<td>MORPHOLOGY</td>
<td>Introverted building morphology in a cube-like form was preferred.</td>
</tr>
<tr>
<td>DENSITY</td>
<td>Maximum compact configuration was an important strategy.</td>
</tr>
<tr>
<td>ARRANGEMENT</td>
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</tr>
<tr>
<td>CIRCULATION</td>
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</tr>
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<td>ROOF FORM</td>
<td>Roof cover, primarily in a high pitched or flat form, was used.</td>
</tr>
<tr>
<td>SURFACE</td>
<td>Smooth building surfaces were applied.</td>
</tr>
<tr>
<td>OPENINGS</td>
<td>Maximum window areas on the south, moderate on the east and some on the west were adopted. Minimum window areas on the north facing facades were employed.</td>
</tr>
<tr>
<td>SHADING DEVICE</td>
<td>Short horizontal shading devices for south facing windows were applied.</td>
</tr>
<tr>
<td>MATERIAL</td>
<td>Heavy construction materials for some interiors elements or surfaces were used. Some degree of porosity in building material was essential. Non-porous building materials were used. Heavy weight materials for exterior elements were employed.</td>
</tr>
</tbody>
</table>
Table 1 is a summary of ‘the results’ from analysis of the architectural aspects. This summary is the findings for each of the climatic zones, categorised by the nine principles and elements. They are presented in such a format as to provide and facilitate a comparative study of the results.

High humidity in A, high temperature in B, and low temperature in D climates have been the main climatic elements causing anxiety in their inhabitants. However, the presence of these elements did not impose limitations for the development of their architecture. It has been demonstrated that many urban centres in the above climates were the first to establish urban civilisation and some were the most progressive and made extraordinary achievements. [6]

In the present paper, the systematic organisation of the outcomes and their overall conclusion was the main goal, in order to extract the strategies and elements which would be beneficial for establishing the final recommendations. Some of the strategies, in certain climates, played a more significant role than others, and some elements were not as substantial. However, the evidence of the expansive effect of climate on the architectural configurations was illustrated, their design crystallised, but with a different degree of intensity for various regions.

7 Conclusion
Climate and energy have not made man, but without controlling and utilising them, he would not have evolved as much as he has. However, the influence of climate on man's evolution, on one hand, has affected the evolution of architectural form indirectly, and on the other hand, climate has affected the architectural configuration directly.

The main purpose and scope of this study is to recommend design based principles useful for architects, but there are some other approaches regarding sustainable architecture, e.g.; one of the most recent books on the subject has taken the insights from energy consultants and building physicists, as well as marketing specialist and even banker [7]. This paper is trying to observe the continuity or discontinuity by considering the influence of cold climate on the architectural principles in the course of history. It is important to emphasize, as the findings of the research, that indigenous architectural styles are defined less by national frontiers and more by environmental considerations. The evidence for this can be found in all continents. In other words, indigenous and vernacular architecture is mainly born out of the climatic conditions. The followings are the main concluding notes:

- The empirical accomplishment of the past and what we scientifically know now about climatic design are similar and complement each other. The regional recommendations in the study confirm the similarities and contrasts of architectural elements and principles for habitable climatic zones.
- The investigation of buildings in the same type of climate or geographical proximity but of different cultures suggests that the same pattern of architectural elements and strategies was developed, and that they were planned with similar configuration and design, and very similar forms and elements. Conversely, in many of the expansive and known civilisations around the world, although the same culture or even religion was practised, different architectural forms evolved or were implemented in different climates.

References: