Ecological Structures with Hyperbolic Geometries in Public Spaces

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Abstract. Nowadays, in central urban areas, the social activities are generally materialized into passive interactions. Although the built environment has no direct influence on the quality, the content and the intensity of social interactions, the architects and planners can at least influence the potential for physical, visual and auditory contact among people – the so-called active interactions – usually, one of the most important characteristics of public spaces. The built framework of public urban spaces can provide a wide range of opportunities for the development of human relationships, so that the architectural design and the social processes are supporting one another. The perspective of sustainability for the design of public spaces refers to three major aspects (eco-system, economy and society) and can be achieved with various temporary or permanent structures that separate and organize public spaces, giving them different social connotations (landscape design components, ecological structures with optimal geometries, etc.). Therefore, the use of hyperbolic geometries (for which the curvature is negative and the space created is open) seems appropriate because of the structural optimization that leads to a minimum material consumption. The hyperbolic structures can also help improve the overall image of public spaces, generating atypical areas with a significant impact (both visual and auditory) on the receiving public. The present paper illustrates several types of hyperbolic geometries optimized for different ecological structures (wood, bamboo, textiles, etc.) located in public spaces (public squares, parks, gardens). Our primary focus will be on the analysis of the main principles of sustainable development, their degree of compliance and on the active interactions between people - created by the implementation of such structures in public green areas.

Keywords: eco structures, sustainability, urban rehabilitation, architectural pattern, hyperbolic geometries

INTRODUCTION

To begin with, we should take a closer look at the design and development process involving the urban public spaces from the last decades. The transition from lively residential areas towards the absence of urban social activity (the industrialization era) and the functional segregation have made the urban life to become static and monotonous. Therefore, the need for incentive or social stimulation has increased dramatically over the years and urban planning has begun to acknowledge the intertwined relation between architecture and social processes.

The main function of urban spaces is to provide a background for life between buildings (Gehl, 2011) and for daily activities of the social participants. Thus, the quality of urban areas depends on the degree of compliance with certain requirements that relate to basic and specific activities, such as: walking, standing, talking, etc. These so-called active interactions are the basis for establishing human relationships. The built space is what brings us together, and at the same time, is what separates us from each other, being the essential feature of a fundamental and universal form of communication. The spatial image of our existence may be reduced to essential elements which are represented by simple geometric shapes. Each geometric shape has its own specific vibration that, to some extent, influences
the space and the people within. Thanks to new technologies, especially computer-aided design, new spatial models begin to emerge.

From a historical standpoint, artists have always created spatial patterns on flat surfaces and spheres. Lately, the hyperbolic plane began to be used more often for artistic purposes, although mathematicians have been developing hyperbolic models for over 100 years.

From an architectural standpoint, the hyperbolic structures are highly convenient, generating atypical urban spaces with a significant impact (both visual and auditory) on the receiving public.

In terms of sustainability, the planning of public urban spaces is an integrated process, in which internal components within the system and also external interactions between the system in question (e.g., the urban water system) and other social systems (e.g., financial and health systems) are considered (Heasom, 2005). Considering thus the sustainability criterion, the implementation of hyperbolic geometries brings into discussion the structural optimization that leads to a minimum material consumption. Also, the use of sustainable building materials, such as wood, bamboo, textiles, is to be considered as an important aspect in eco-design.

The aim of this paper is to acknowledge and classify several types of hyperbolic geometries optimized for different ecological structures. The focus will be on the analysis of the main principles of sustainable development, their degree of compliance and on the active interactions generated between people. Also, the implementation of such structures in public green areas creates a specific framework for social events, aspect to be analyzed from several points of view (social, historical, economical, architectural, etc.).

SUSTAINABILITY CRITERIA

The notion of sustainable is defined in the Sustainable Building Technical Manual (1996) as „the condition of being able to meet the needs of present generations without compromising those needs for future generations. Achieving a balance among extraction and renewal and environmental inputs and outputs, as to cause no overall net environmental burden or deficit. To be truly sustainable, a human community must not decrease biodiversity, must not consume resources faster than they are renewed, must recycle and reuse virtually all materials, and must rely primarily on resources of its own region.”

Currently, the scientific literature offers numerous definitions concerning the sustainable development concept and its active components. All these iterations have been perfected over time, the ongoing improvements and additions providing us with a better understanding of sustainability as a process. When we refer to the relation between architecture and sustainability, we can safely argue that there is a bidirectional exchange of information. The conceptual phase of any architectural approach should take into account certain characteristics that promote the idea of a sustainable system (Lepadatu et al., 2011).

There have been conducted various studies world-wide concerning the classification of the existing sustainable development criteria, with a direct focus upon the necessary tools for making initial decisions for the project. For example, the paper Sustainability Criteria as a Helping Tool for Developing Architectural Projects (Triana et al., 2006) presents a study carried through in Florianopolis, Brazil. The five-standpoint perspective is the basis for a global approach that captures the following aspects:

a. The choice of a sustainable surrounding;

b. Natural resources;

c. Internal environmental quality;
d. Project characteristics;
e. Social economic aspects.

In order to achieve this classification, were consulted important references such as Agenda 21 (global and local), Agenda 21 for the sustainable construction-CIB (Agenda 21, 2000), ISO 14000, the life cycle analysis concept, the environmental legislation of Brazil and the environmental certification systems for buildings. In addition, we should mention the use of the LEED® system (USGBC, 2002) and the GB Tool (Cole et al., 2002). These last references are mainly used because, in Brazil, there is a lack of certification systems. This study is very thorough and could become an important helping tool for architects and planners.

BUILDING WITH RESPONSIBLE MATERIALS IN PUBLIC SPACES

For a responsible architectural design in public areas that maintain a cultural and social component, the key elements that should be taken into account are: preserving our planet’s natural resources, increasing the living standards and developing smart technologies that meet the ecological criteria. An ecological design should be able to resort to skills and resources available in the nearby areas (local contingencies and opportunities). Therefore, a responsible ecological project has two main goals: preservation and further development of the cultural heritage of public space, and a better energy efficiency of the existing and new infrastructure(http://ecosistemaurbano.org/english/ecological-design-fundamentals responsible-materials-and-construction-practices/).

Lately, the construction materials are evaluated through the influence of the greenhouse gases (CO$_2$ emissions), the acidity (SO$_2$), and the embedded grey energy ratio (Schunck et al., 2003). We will focus our survey especially upon some of the natural materials that are relevant to contemporary architecture and have the potential to support growing responsible uses in the built environment (Fernández, 2006): wood, wood composites, natural fibres, biopolymers and earthen materials.

Historically speaking, timber (wood) is one of the oldest materials used for both fuel and as a construction material, characterized by the fibrous tissue found in many trees. It is an organic material, a natural composite of cellulose fibres (which are strong in tension) embedded in a matrix of lignin which resists to compression.

From a structural standpoint, wood has many advantages, such as renewability, a good strength-to-weight ratio, does not corrode and is aesthetically pleasing. The use of wood has been a fundamental component of the structural frame (Fernández, 2006). Over the past decades, the concept of green building has brought attention to other important qualities of wood, for example its environmental benefits, including low embodied energy, low carbon impact and sustainability. On the other hand, the disadvantages of wood include the following: it is combustible, it can decay or rot and insects such as termites, for example, can attack it. In addition, high levels of air moisture can accelerate the degree of decay and rottenness. Wood’s property of retaining moisture makes it susceptible to volumetric instability. All these characteristics are highly variable and can differ between species and even between trees of the same species. There is also variation in strength within a tree log’s cross section.

An important innovation of the last 50 years regarding wooden structures is the use of wood-based materials. Wood-based elements have the advantage of being produced in a large variety of shapes and sizes. A wide range of sources can be used in wood-based materials, for example low-quality wood (wood with localized flaws, timber recovered from
demolished constructions, residual waste from industrial processes, small diameter timber, forestry residues, exotic or invasive species, etc.).

As a fast-grown forest resource, bamboo attracts more and more the attention of architects and engineers. Bamboo could be a substitute for wood and steel in some cases. Making good use of bamboo can not only solve the shortage of construction materials but also play an important role in the protection of the ecological environment. Bamboo is a renewable resource, being cultivated in relatively poor soils, helping to control erosion by water and wind. The growth rate ranges from 30 to 100 cm per day in the growing season and bamboo plants can reach a height of 36m with a diameter of 1-30cm (Zhou et al., 2005). While bamboo structures have long been common in Asia and the South Pacific, they are only just gaining prominence in the rest of the world.

The aesthetic interest in emerging materials for novel fibres and textiles has experienced a significant increase over the past two decades, so there are various design projects that have experimented with textiles, films and fibres. Textile is a flexible woven material consisting of a network of natural or artificial fibres often referred to as thread or yarn. Textiles are formed by weaving, knitting, crocheting, knotting, or pressing fibres together (felt).

Since the mid-1960s, industrial fabrics have made rapid advances. The use of fabrics, knits or nonwovens instead of classic building materials is steadily increasing. By embedding natural fibres e.g. flax, hemp, ramie, etc. into a bio polymeric matrix made of derivatives from cellulose, starch, lactic acid, etc., the new fibre reinforced materials (bio composites) were created. As far as the mechanical properties are concerned, bio composites are comparable to the well-known glass fibre reinforced compounds. Therefore, the new construction materials are very well suited to be used for anisotropic and specially tailored lightweight structural parts.

The real sustainability of a material has to be assessed during all its life cycle. For this purpose, are usually used the Life Cycle Assessment (LCA) procedures, which analyze the potential impacts deriving from the entire life history of a product. Material extraction, production, transport, construction, operating and management de-construction, disposal, recycling, and reuse have therefore to be taken into account.

**ECOLOGICAL STRUCTURES WITH HYPERBOLIC GEOMETRIES**

In the last decades we have witnessed the infusion of digital technologies in architecture. They have changed the way we perceive space, using concepts from biology, mathematics or philosophy, reinterpreted and implemented via computation. The contemporary discourse seems to be invaded by evolutionary systems, topological geometry and is characterized by seeking the continuity through diversity and non-linearity.

Therefore, the digital generating process opens new perspectives for a space architecture focused on the emergent and adaptive properties of the geometric shape. The following examples try to establish new patterns for ecological structures located in public areas.

The Hyperbolic Embroidery Project (Loom Hyperbolic, 2012), conducted at Marrakech, was inspired by local Moroccan traditional technique, the weaving with cotton, on a structurally rigid wood frame (Fig. 1).
The Barkow Leibinger Architects tried to apply the Moroccan model at an architectural scale in order to produce three-dimensional volumes on a series of fixed wooden frames, instead of two-dimensional surfaces. To create these hyperbolic spaces, the structures were located on the site of the Koutoubia Mosque ruins.

The columns in ruins establish a grid of 5x5 meters, which will be the future base for the hyperbolic network’s installation (2.5 x 2.5 m). The network allows a height of 2.5 meters, visitors being able to perceive the complex structure both from inside and outside (Fig. 2). In order to build such a light, ephemeral and transparent structure, the architects have used the following materials: 3-4mm cotton yarn, 100mm hand cut wood (pine) poles, welded steel joints of plate and tubing (all materials and fabrication are on-site or local).

As some experience unfolds, we can observe if we have previous knowledge of it, based on our ability to predict (the familiarity of a place or a situation). In general, spatial languages resort to past models, in order to provide a sense of order and recognition in the present. For example, the recognition of certain specific urban patterns is an essential tool used by architects and planners, for whom the project must be specific to the place.

The Barkow Leibinger Architects followed this particular aspect, considering the collision of traditional patterns and techniques with new computer generated shapes: “…The question for us became: what techniques, which form of knowledge, can be brought to this situation that could start to mediate those that we find on-site and as-found? What effects can we produce by considering geometrical form as found in the architecture of Marrakech and as constructed by using current algorithm software programming (Grasshopper, Rhino for example) and then begin to speculate how these forms might be rendered (made physical) by local craft techniques and materials?...” (Fig. 3).
The final structure is comprised of light hand-peeled pine poles attached to steel plates and tubes (which establish and fix the geometry), as shown in Fig. 4. The yarn is tightly secured over the frames that alternate in their positions and tie them off.

Another example of an ecological structure with a hyperbolic geometry, created in a public space, is The Bird-Like Amphitheater in Hanoi, Vietnam, designed by architect Vo Trong Nghia (Fig. 5).

This structure was completed in 2010 and is currently used for fashion shows, live music, conferences and other public activities. Surrounded by a pond, the wing-inspired design of the amphitheater was made only from bamboo and rope, with no metal or other types of wood used in the construction (Fig. 6). The architect took into consideration the ecological criteria by shaping the roof as bird wings. This form helps at capturing the wind inside the built space thus minimizing the use of air conditioner. The overall image of the amphitheater integrates perfectly in the surrounding environment, mediating the relation between outdoors and indoors.
This entirely bamboo made structure allows people to experience a 12 meter open space, without any vertical columns. Here, the hyperbolic component can be found less in the structural side and more in the physical and philosophical perception of the open space.

The Price & Myers’ Hy-Pavilion was designed for the London Festival of Architecture, in 2010. The efficient and transportable structure was made of lengths of black cord strung between timber edge beams that defined the shape of two intersecting hyperbolic paraboloids (hypars) at right angles to each other, as shown in Fig. 7.

When confronted with the question regarding the construction of the Hy Pavilion, Tim Lucas (a partner at Price & Myers and founder of its Geometrics team) asserts: “I wanted to create a pavilion for the festival that was made out of a very basic element -a straight line - put together in an interesting way; elegant and exciting but simple to build. (...) Hyperbolic paraboloid is a really beautiful piece of geometry that allows complex structures to be achieved in a simple way. Geometry and maths are used to resolve its form which results in a very pure solution”.

The space defined by the erection of the Hy Pavilion has a height of 9m and provides a 360-degree stage and shelter for events. The materials used are Kerto-engineered timber (12m long Kerto beams - 75mm thick and 400mm deep in the middle), a fabric made by Millimetre, that has been stretched across the timber beams, together with 56 pre-stressed bungee ropes (each 12mm in diameter). The bungees form the hyperbolic paraboloid shape, while the canvas has its own double-curved shape to keep it taut. The entire structure is secured on the ground with concrete paving slabs.

One of the great advantages of timber as a structural material is the ease with which parts can be connected with a wide variety of metallic pieces (hinges). In this case, the
elasticity of the joints plays a key role. The possibility of leaving exposed the structural system, and not having to close the structure, for visual effect or thermal insulation, is an important economic and aesthetic aspect, that enables us to recognize and admire the spatial geometry of wooden structures.

CONCLUSION

In the last decade the concept of green buildings has become mainstream, the consumers becoming aware of the potential benefits of this new alternative to traditional constructions. In this regard, the choice of construction materials that have ecological attributes is a major focus of the environmental concerns. From this perspective, wood, wood composites, natural fibres, biopolymers and earthen materials have many positive features, including low embodied energy, carbon low impact and sustainability. In addition, another important attribute of the previously mentioned materials, which ensure the sustainability, is the renewability.

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REFERENCES

http://www.bustler.net/index.php/article_image/barkow_leibinger_installation_at_marrakech_biennale_higher_atlas/