Architectural Structures
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Beijing Olympic Stadium 2008 as Biomimicry of a Bird's Nest

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Table of Contents

List of Figures

1.0 Introduction

Beijing National Stadium, designed by Swiss architects Herzog & de Meuron, is an excellent example of the use biometrics in modern architecture. Still under construction, the project is not scheduled to be completed before the end of 2007; and yet, due to its innovative design, the “Bird’s Nest” is already capturing the attention of the local and international architecture community.

As implied by its nickname, the stadium rises out of the landscape in the shape of a giant upturned bird’s nest (Figure 1). Drawing from the structural strength and beauty of natural objects is a growing trend as architects and designers become increasingly interested in the efficient use of energy and materials. According to Janine Benyus this movement is known as biomimicry; “a new science that studies nature’s models and then imitates or takes inspiration from these designs and processes to solve human problems.” (Benyus, 1997)

The concept of biomimicry in itself is nothing new. Human structures have borrowed from nature throughout history. Our first shelters, for example, were little more than upturned bird’s nests; formed of branches and insulated against the elements by whatever materials were readily available. In fact, it could be argued that biomimicry is not a new movement, but a return to our earliest inspirations. New technologies, however, have allowed us to investigate and replicate systems that our ancestors were unable to exploit on a grand scale.

Figure 1: Rendering of exterior view of Beijing National Stadium: "Bird's Nest" ("Presentation," 2002)

2.0 Stadium Design

In 2002, the Beijing Municipal Planning Commission held an international competition for the design of the main stadium for the 29th Olympic Games. As the building is intended to house the opening and closing ceremonies, as well as the track and field events, the original competition program included the following main criteria (Beijing, 2002):

- A stadium capacity of approximately 100 000 people during the games (to be reduced to approximately 80 000 afterwards),
- A retractable roof,
- A multi-functional design, to efficiently incorporate a range of uses in the future; and
- An emphasis on green building and advanced technology.

After passing through two rounds of adjudication, Herzog and de Meuron's proposal emerged as the winning entry (Lubow, 2006).
The stadium consists of an inner bowl of concrete seating surrounded by a façade of twisted steel, with a public concourse area sandwiched between the two (Figure 2). The elliptical building footprint is dictated by "the constraints of seating 100 000 people around an athletics track and field." ("National", 2004) Meanwhile, the variation in the height of the stands between the major and minor axes of the ellipse allows for the majority of spectators to be seated along the longest length of the track, and "ensures that all spectators are within the same radius of view from the corners of the field."("National", 2004) In all, the structure encloses a volume approximately 333 meters long by 284 meters wide and 69 meters tall. ("Steel", 2006)

2.1 Structural Modelling

The building's distinctive façade was conceived in order to disguise the large parallel steel girders required to support the retractable roof that was specified in the original design program. (Lubow, 2006) The geometry of the seemingly random elements was defined using the geometrical constraints dictated by the usage and capacity of the structure (as outlined in section 2.0) and formalized using modeling software designed by Arupsport. ("Beijing," 2006)

In defining the geometry of the structure, lines representing members were extended outward from the projected plan of the athletic field, along the roof and wall surfaces to the ground in one continuous gesture (Figure 3, blue lines). The angles of these lines were planned so that they intersect at ground level in 24 points spaced at regular intervals around the elliptical building footprint. This allows the vertical components of the structural members to be prefabricated in truss-columns of a roughly pyramidal shape (Figures 4 and 5). Conversely, the diagonal lines created by the staircases placed around the perimeter are traced continuously from the ground, along the roof, and down the other side (Figure 3, yellow lines). The remaining infill members balance the aesthetic of the façade (Figure 3, red lines). (Stacey, 2004)

2.2 Use of Steel

As the continuity of the members from the ground across the roof surface was essential to the aesthetic desired by the architects, steel HSS sections were chosen to allow each 'stick' to twist over the curved intersection of the wall and roof to "maintain its outer edge parallel to the façade." ("National", 2004) Hollow structural sections (HSS) are strong in torsion, a property essential to members that are subjected to the eccentric loading experienced at the rounded intersection of the roof and wall.

Using computer software, Arup designed the structure to be assembled in prefabricated segments of multiple intertwined HSS components, which were connected on site using welded joints (Figure 6). On-site welding always poses a challenge, as gaining full strength in the joint requires rigorous attention to on-site conditions. The welders faced two main challenges. "One is the rigorous temperature requirement: it should be 19 plus or minus 4 degrees Celsius. The other is that the welding joints amount to as many as 128 with a combined seam length of some 600 meters. ("Steel", 2006) However, the welded joints provide a smooth appearance, creating the illusion of continuity between all the prefabricated segments.

Steel's high strength-to-weight ratio provides further advantages due to the large spans inherent in the construction of a sports arena, as the roof structure must be cantilevered from the exterior walls to avoid interior columns which obstruct spectator views. This issue was magnified in the case of the National Stadium, as the retractable roof placed a very large load at the center of the roof structure (i.e. at the far end of the roof cantilever) which is located in an earthquake zone. Ironically, the retractable roof was eliminated from the project scope due to budget cuts. This, however, created a structure that is much more efficient in its material use. In all, approximately 40 000 tons of steel were used, a reduction from the approximately 80 000 tons estimated for the original design. (Lubow, 2006)

2.3 Green Features

Aside from the structural advantages provided by steel, it has the added benefit of being easily recyclable, and thus ties in with the Beijing Olympic organizers' focus on sustainable design, and the driving principles of biometric design. Beijing's Olympic Stadium draws directly from nature, as elements of the bird nest are exposed as its major aesthetic motif, with little material wasted to disguise the structure.

In keeping with the bird's nest analogy, the façade is in-filled with translucent ETFE panels in much the same way that a nest is insulated by stuffing small pieces of material between the twigs that make up the structure. The ETFE panels serve to protect spectators from the elements and provide acoustic insulation, while allowing sunlight to filter through to feed the natural grass field (Lubow, 2006). Furthermore, the panels are lighter than either glass or aluminium panels would be, reducing the dead load supported by the roof. The panels are also self-cleaning and durable, reducing costly maintenance. Openings in the façade allow natural ventilation as air filters through the public concourse, into the stadium, and eventually vents through the central opening in the roof structure. ("Uncover", 2006)

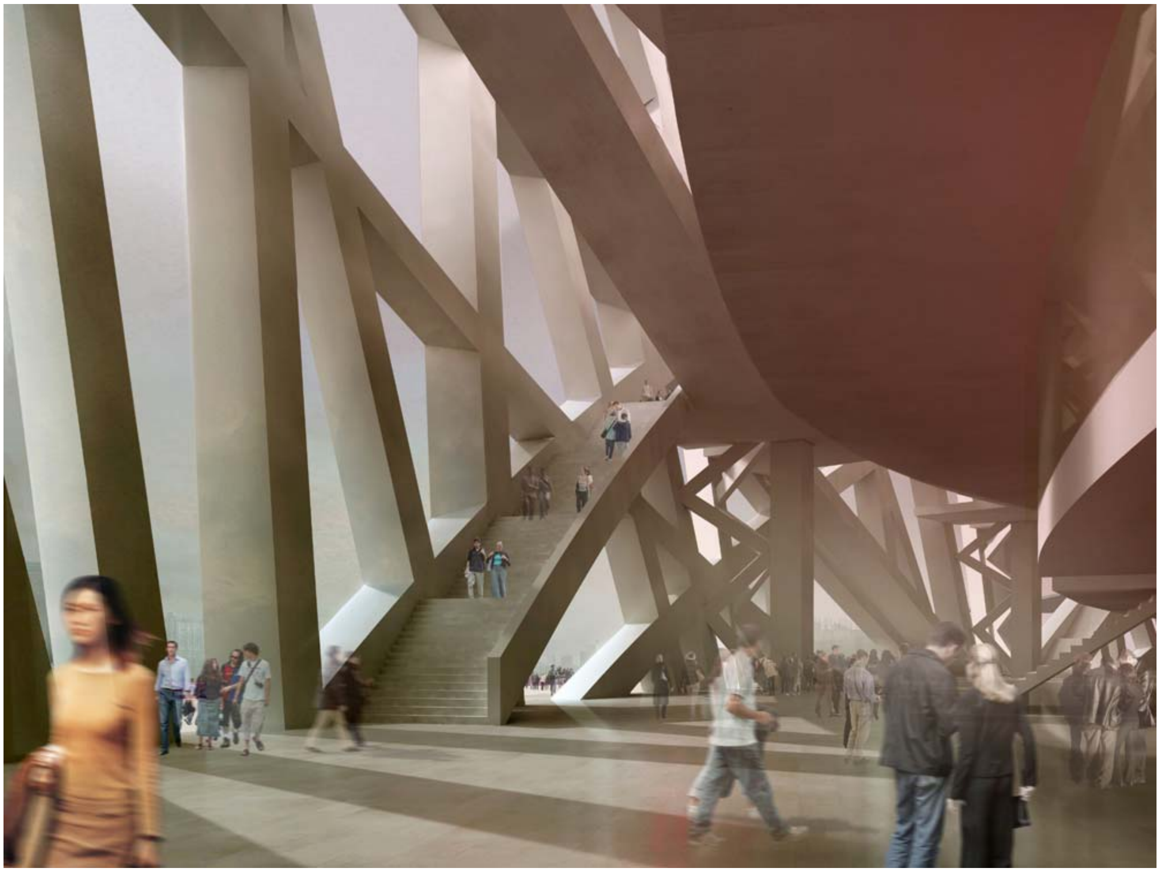

Figure 2: Rendering of interior concourse - Beijing National Stadium
("Presentation," 2002)

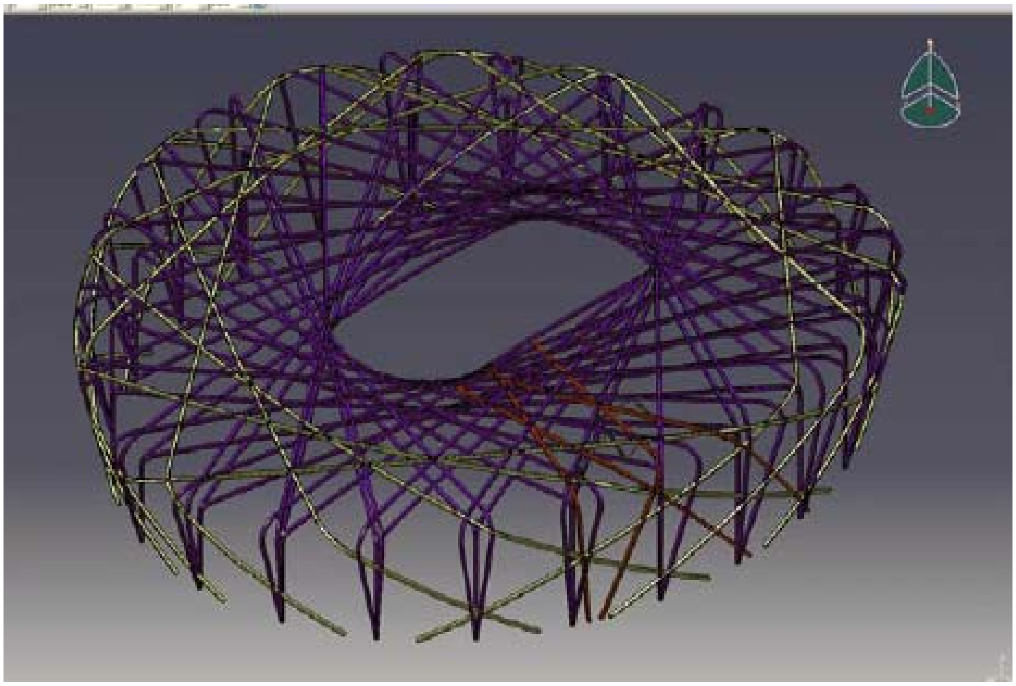

Figure 3: CAD model of stadium structure
(Stacey, 2004)

Figure 4: Truss-Column
("Olympic," 2006)

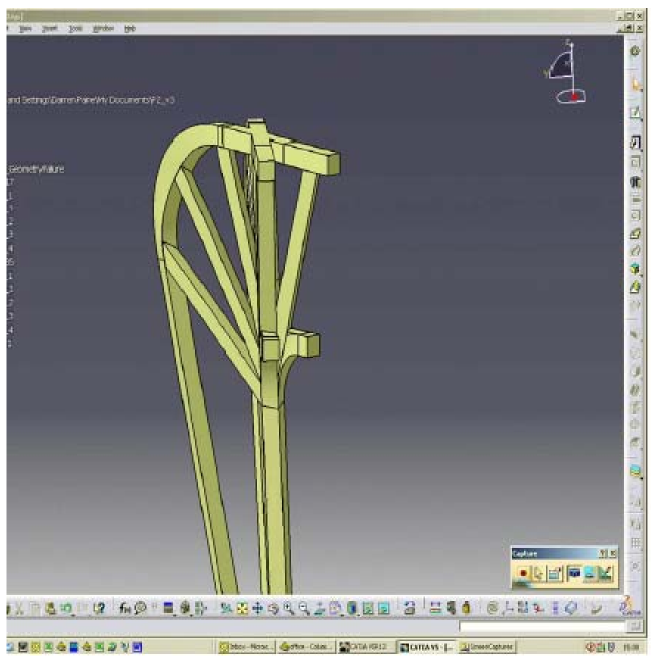

Figure 5: CAD model of truss-column
(Stacey, 2004)

Figure 6: Workers finish welding of steel structure of the Bird's Nest (Steel, 2006)

3.0 Historical Context – Past to Present

The development of architectural structures can be described as a spiral ascent of discoveries and innovation in materials. For example, weaving has been discovered and used extensively in many cultures as the main structural form. (Mainstone, 1983) Though profound in its effectiveness in providing shelter, it is a very simple way of weaving sticks in a lattice framework, insulating it with mud and clay, and sometimes waterproofing it with animal dung.(Sijpkes:2006) Weaving, in principle, is not different from the way a bird's nest is built, and the way it works and feels (Figure 7). (Mainstone, 1983) Perhaps a more recent interpretation of the hut is the timber framework insulated with wattle and daub, demonstrating the continuation of parallels between human and natural structures. (Sijpkes, 2006)

There are many other cases where nature has directly inspired human structures. The intertwining growth of ivies that hang in the form of a catenary arch inspired the rope suspension bridge.(Sijpkes, 2006) This bridge is constructed by weaving fibres that work together in a most efficient form of tension.(Mainstone,1983) In addition to the mimicry of the natural form, the rope bridge even uses a similar construction material.

As there was growth in societies from villages to cites, there was a need for larger and more enduring structures than the structural capacities organic materials are able to provide. This encouraged the development in stone and metal construction, and investigation of efficient uses for them such as the post and lintel, column and arches, and pendentives and domes. In this excitement of human ingenuity, there has been a departure from our connection to nature. Perhaps the permanence of the materials further lessens the importance of local and site specific considerations. Prefabricated buildings are a perfect example of how a building, by itself, no longer suggests the location of the site. Perhaps the permanence of the materials further lessens the importance of local and site specific considerations.

Today, building technology has advanced to give much more flexibility in its form and assurance in material strength. (Mainstone, 1983) Modern technology has resulted in such advanced materials as reinforced concrete, engineered wood that can compete with steel, and glass can span over nearly endless areas of space. (Tardif, 2006) These improved materials permit us to erect all sorts of "structural absurdities," but they also allow structures to, once again, imitate and emulate nature.(Mainstone, 1983) The challenge of construction no longer lies in overcoming the limits of materials, but rather in managing the economy, efficiency, sustainability, and ecological footprint of the entire process of construction, use, and deconstruction. Hence there is a movement toward re-establishing a mutual relationship with nature.

Figure 7: Maasai woman of Kenya plasters dung over her home ("Design," 2006)

Figure 8: WeeHouse, a Prefab home by Alchemy Architects, can be placed anywhere in the world ("WeeHouse, 2006)

4.0 Future Trends in Biomimicry

Most cities built in the near past seem to separate man from nature. An office building in Tokyo may look like and office building in Munich or in Chicago despite the fact that these cities have different cultures, climates and topographies. Thanks to growing interest in sustainability, and the growing trend of biomimicry, there is hope that in the future, buildings will be better adapted to their environmental and cultural context. (Berkebile and McLennan, 2000). They may not necessarily look like flowers and trees, but try to operate like them instead. Buildings in hot, dry climates may focus on ways of recycling water while buildings in cold climates would try to find ways to conserve heat. (Berkebile and McLennan, 2000).

Beijing National Stadium is only one contemporary example of the use of biomimicry in Architecture. The Swiss Re Headquarters, for example, is remarkably similar in its structure to the skeleton of a sea creature known as a "glass sponge." The structure has no exterior covering and is composed of an exposed exoskeleton in-filled with glass panels. Using a series of triangulations on the exterior similar to those of a glass sponge makes the structure stiff enough to resist lateral structural loads without extra reinforcements. Moreover, in the same way that the glass sponge filters nutrients from the water by sucking water from its base and expelling it through the holes at its top, the building ventilates air in a similar fashion (Barker, 2005).

More and more architects see the benefits of using biomimicry in architecture and plans for buildings are being made that incorporate this science. The national swimming center, also being built for the 2008 Olympic Games in Beijing, is further example of sustainable architecture using biomimetic design. Known as the "water cube", its design is based on the way soap bubbles form naturally, giving it an organic appearance. It will use solar energy to heat the pools and the backwash water will be filtered and returned to the pools ("The Water Cube", 2006).

5.0 Conclusion

In conclusion, the National Olympic stadium in Beijing is an innovative building in terms of its design and the way it functions through its use of biomimicry. There is a hope and likelihood that this building known as the "birds nest" will influence future buildings (especially stadia) to exploit biomimicry to create safer, healthier, economically and environmentally responsible structures.

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