Morphology and Urban Planning of a Pedestrian Bridge

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Summary

The aim of the paper is to discuss a practical application in bridge architecture of a non-standard structural system derived from a geometrical generative process. Through the rotation of a rectangle along a given path over a gap a tube like structure is formed. The pseudo-shell of the tube is shaped by connecting corners of the consecutive iterations of the rotated rectangle directly and diagonally. The strengths of the concept are analyzed and proven from a geometrical, urban, structural, economical and ecological points of view

Keywords: *pedestrian bridge; Grasshopper script; arch-like shape.*

1. About the Context

The bridge (Figure 1) was developed as a proposal for an international architecture contest named Archetypes 2011. The promoters of the contest called architects and designers from all over the world to build responsive pavilions in certain urban situations in 15 cities all over Romania.

The paper presents a polyvalent solution for spanning a lightweight structure over a body of water. Before anything else, it should be mentioned that the framework of the concept was developed in, which is basic the idea behind the morphology.

Figure 1: General view of the bridge by night

2. Initial Location

The site is located in the heart of Romania's capital city Bucharest, near Unirii Square (see Figure 2). For more than two centuries the crossing over the Dambovita river had a particular importance at this very point. Calicilor Bridge was an important element in the circulatory system of the city. Still, the economic realities have changed dramatically over the past decades and the bridge, later named Rahova, was demolished in the late 1930's and never rebuilt. Nowadays, the city, in need to reaffirm its history, looks for a way to reconnect several important cultural routes. Thus, rebuilding the Calicilor Bridge as a 30m pedestrian walkway over the river has become more than a simple desire.

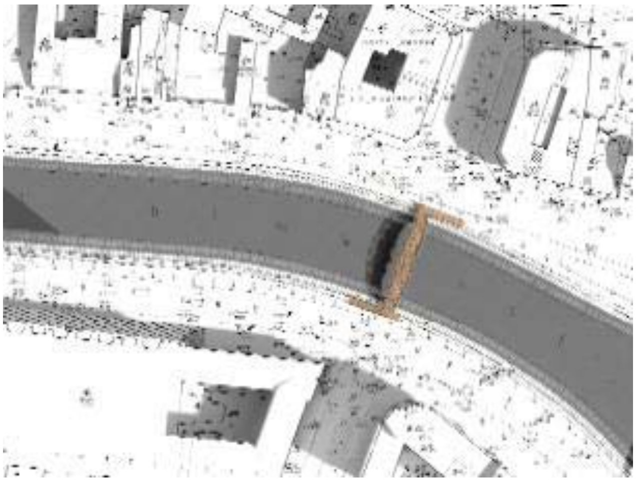

Figure 2: Site plan

Figure 3: Tipical view from the south

The Archetypes Contest framework proved a very good starting point to develop a bridge at the location. The contest theme stated that the design had to be: a public space activator, novel, sustainable, reusable, recyclable and interesting. Added to the mixture, the obvious functional value of a bridge and all the qualities an urban pavilion could posses were already a must.

In order to better understand the proposed design, first the process should be investigated. Because the answer to the contest theme and the place had to be plenary from the beginning, thinking should address to all angles. Four major criteria were identified, all of them hybrids between the classical Vitruvian qualities of architecture and modern necessities. For each of the criteria a concept was developed that later contributed to the whole design. Their explanation is presented in the following paragraphs.

3. Urban/Geometric Concept

The concept connects the requirements and the relevant studies of the site with the abstract geometry derived from the particularity of such a special location. The most important aspect of the site is the river (e.g., hence the need for a bridge). The two parts of the Splaiul Independentei Boulevard running parallel to the river (north and south shores) are also very important, as they are part of a major artery of the city. Third, there are the two perpendicular streets Selari and Sf. Apostoli. Their position marks create two junctions that will become one after the bridge is constructed. Last, but not least, comes the street fronts and the interesting relation between various (old an new) buildings and the river banks.

The geometric concept is the key to the whole design. Every operation and every line drawn is the direct result of a geometrical equation calculated through a parametric Grasshopper script [1].

The script's data inputs are the exact position of the bridge – a line perpendicular to the river banks as the shortest route in between two points, and the specific arch-like shape of most bridges. Another input is the specific movement translated into rotation going on each bank. The car and predominant pedestrian movement on the south bank is from west to east, and on the north bank is from east to west. This specificity shaped the roto-translation movement that creates the unique shape. Briefly, a 3 by 4 meters virtual rectangle is rotated starting from underneath the banks from a horizontal position into a vertical one in a few steps, and moved with a fixed distance in the same time. Then, the same rectangle is rotated starting from both banks along an arch and moved towards the opposing bank until the movements started from both banks connect in the middle of the river.

The rotation is constant 20 degrees and the movement also (3.3 m) for each step. The resulting shape looks like continuous rotational movement from start to finish and resembles a traditional twisted rope (one reason for the name of the project) .

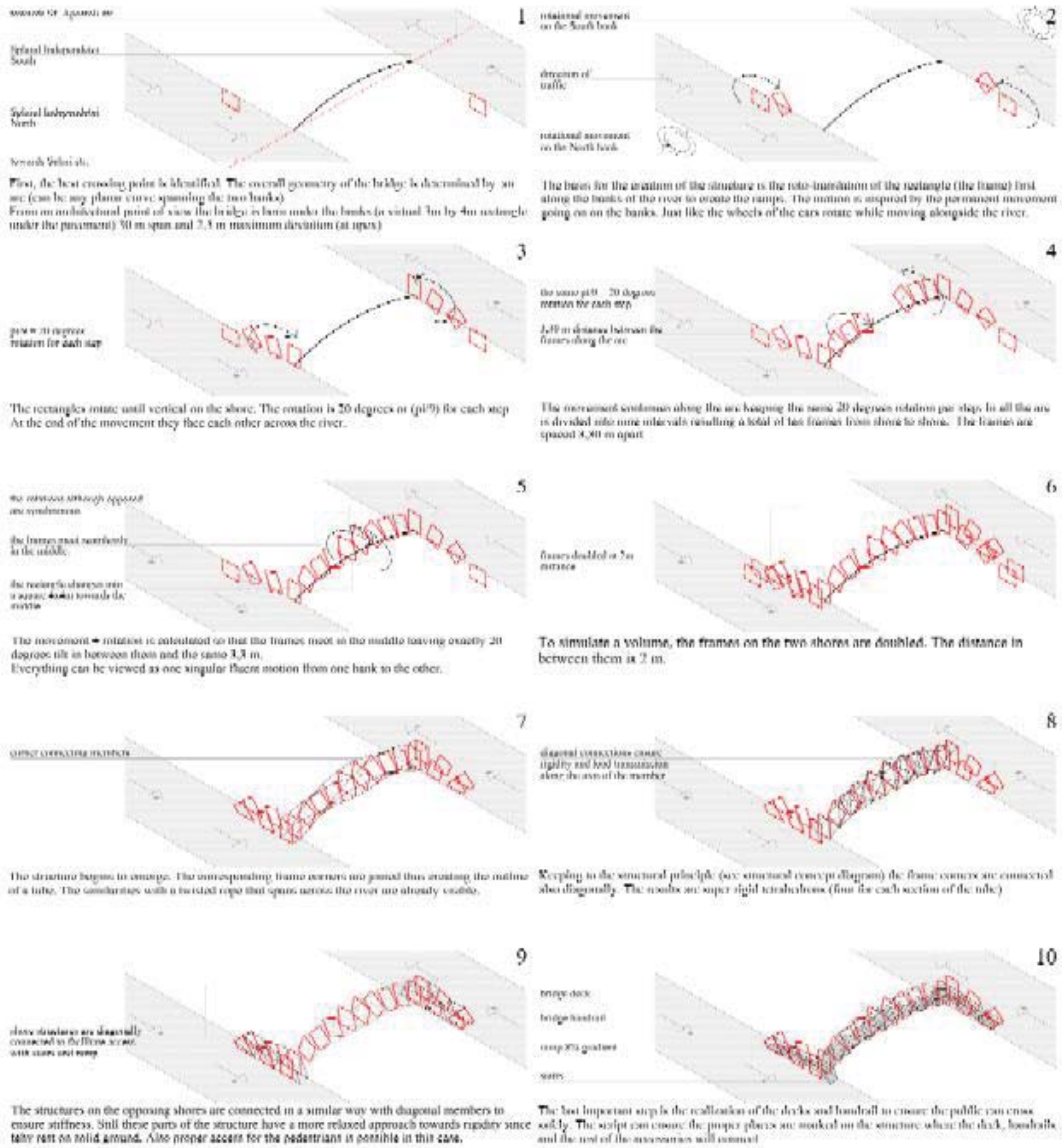

Figure 4: Development of the geometrical concept

The geometry shown above *(Figure 4)* is calculated by the script and the definition is automatically adapted to accommodate any shape and dimensions of the curve spanning the banks. This is the reason why the project is highly adaptable to any given situation. The project is actually a code that produces a result according to a number of variables.

The final shape of the structure for the bridge is achieved through connecting the corresponding rectangle corners directly and diagonally from one frame to the next.

The walking surface is the intersection of the structure with the offset of the initial curve crossing the river.

Thus, the adaptability of the construction is the direct result of the large number of variables the project takes into account and can accommodate for. All in all, the definition allows the change of the span, height, number of interpolated rectangles, rotation of each rectangle, starting dimensions of the rectangles, amount of deformation of the characteristic rectangle, shape of the traffic collectors on the banks and many others. The key parameters can be changed as easily as the most unimportant details.

4. Structural Concept

If the geometrical concept of the bridge is the key to the whole design, the structural concept is definitely the lock. It keeps everything in place. The two are the direct result of each other. From the geometrical point of view, the rotational movement along the arc across the river coupled with the diagonal connection of the consecutive frames (i.e., rectangles) produces tetrahedrons, the only rigid platonic solid. These tetrahedrons create a pseudo-shell for the bridge all the way across the gap. The beauty of the concept is that since only axial forces travel through the elements, the sections can be fairly small and the material consumptions minimal (see Figure 5).

This is, somehow, a further development of the basic tensegrity 4-prism [2] like the ones developed by the artist Kenneth Snelson [3], and the inventor engineer and architect Richard Buckminster Fuller [4].

A similar structure, but through a full tensegrity concept, was proposed by Motro [5] by using cables for the tensioned ties. The difference in this case is the extra rigid diagonal on every face and the use of the rigid members for all structural lines, compressed or tensioned. This virtually reduces the flexibility of the structure under external loads.

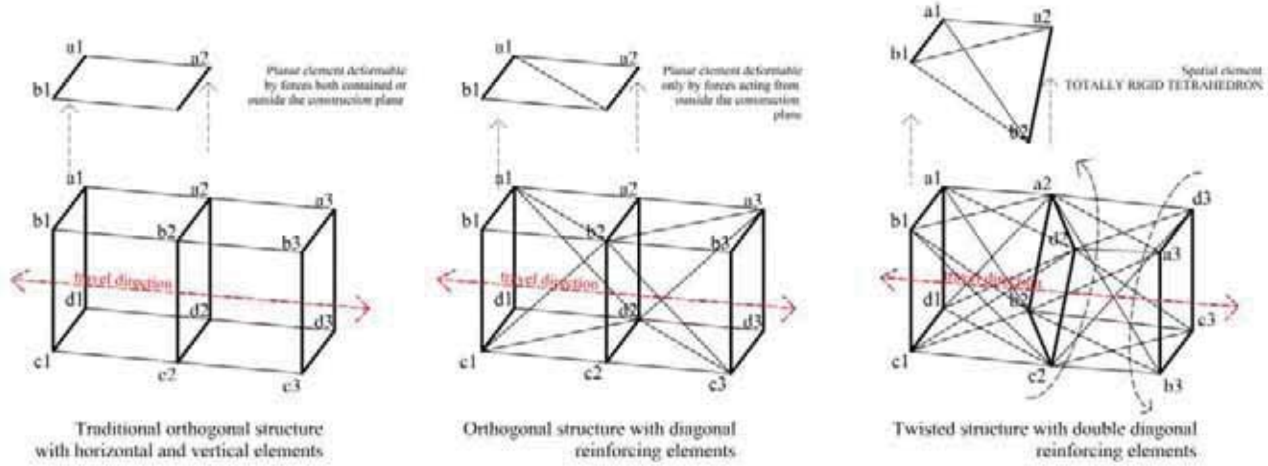

Figure 5: Main structural concept

The bridge main structural material is glue laminated white wood. The wooden elements are connected by special metal joints custom made for the project. The connectors consist in a central steel sphere with welded cruciform profiles that lead to a plate (i.e., stopper) connected to the elements through metal insertions and bolts. The connection angles (Figure 6) are calculated for each connector and each member and are extracted as three planar angles: heading, tilt and banking.

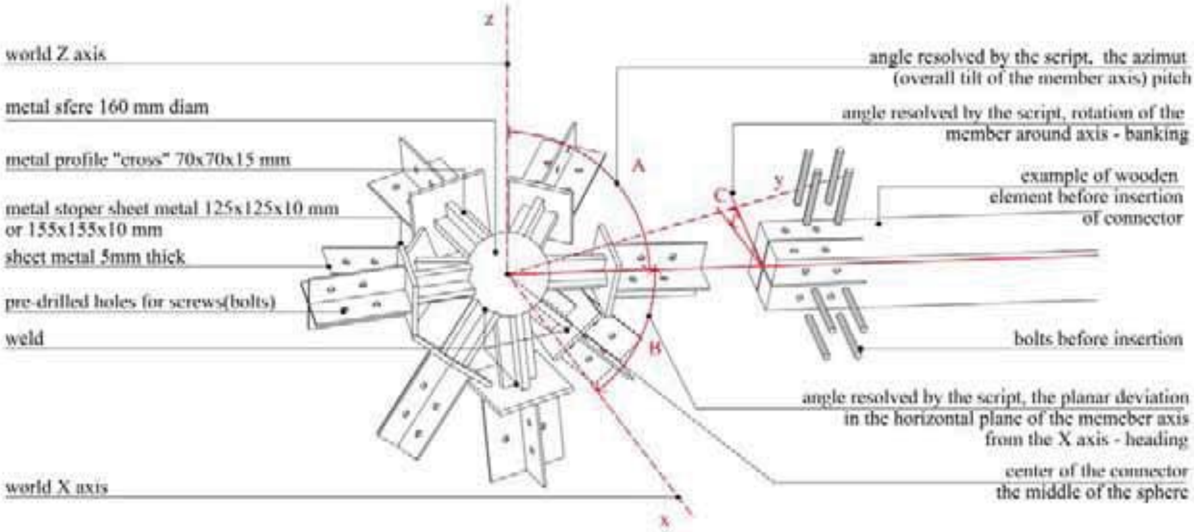

Figure 6: Typical joint

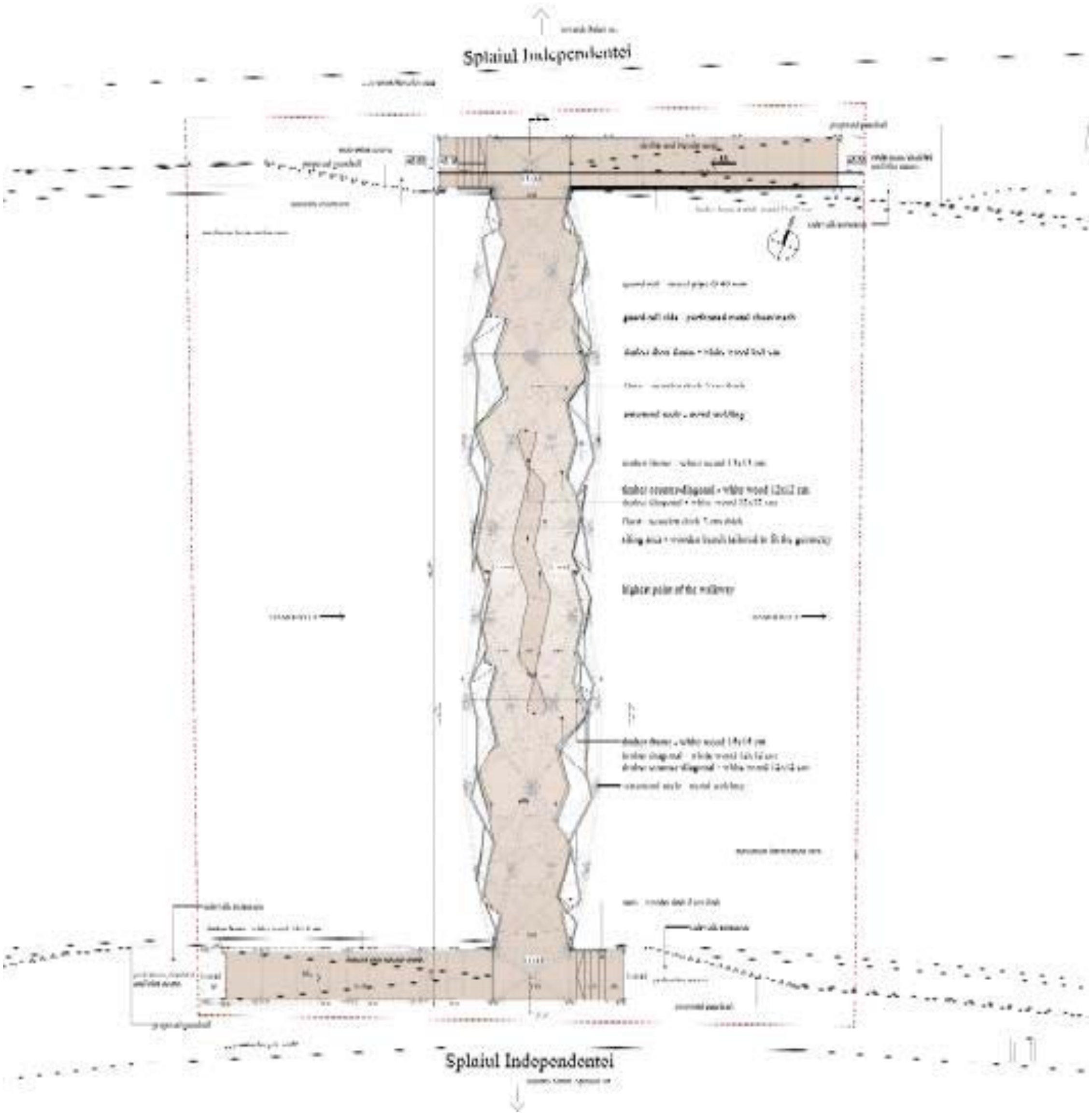

Figure 7: General plan of the bridge

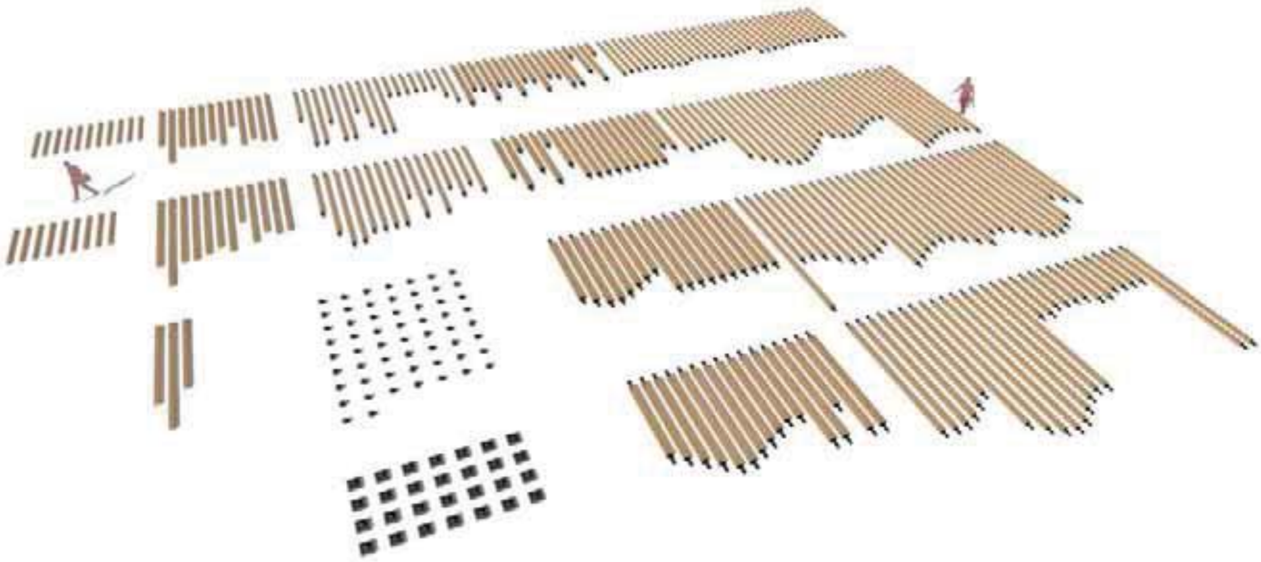

Figure 8: General view of the components before assembly

The walkway itself, made of wood planks, is created inside a contour of points calculated on the structural members and rests on the knots of the structural system. The guardrail made of metal piping connects all the exterior members of the structure exactly at 1 m above the deck add further stiffens the structure. Figure 7 presents the general shape of the walkway and guardrail in the architecture of the bridge.

5. Economics and Feasibility

One of the criteria for evaluating the projects was the ability to fit the whole construction inside a reasonable budget provided by the promoters of the competition. The bridge had also to be constructed from the logistics point of view. More than 95% of the building material required for the construction is locally produced and currently available. All in all, the costs, labor and material including transport and maintenance, were about 80% the proposed budget (including the dismantling costs).

The feasibility is also a high point of the project. Because the construction is modular, it can be pre-assembled at a specialized manufacturer and transported in larger parts at the building site, reducing the erection time and avoiding problems with traffic or residents in the area. Fabrication can be a problem only for the joints if precise machinery is not used for the correct evaluation of the welding position and angle.

Small cranes are only required briefly for loading/unloading and erection of the pre-assembled parts on site. The latter can be done in one day on site. The structure can be tested in parts or as a whole off-site for optimum results then disassembled and transported on site. Aside for the metal joints, there is no need for skilled labor during the assembly and all the parts will be labeled from the factory/shop. Thus, the final assembly will just be a big puzzle.

All the other parts (the finishes) are standard mundane materials (e.g., metal pipe, perforated sheet-metal, wooden decking, nuts and bolts. The real challenge is producing the exact dimensions in the project to fit everything together. Maintenance costs over the 12 month period, without lighting, are null.

6. Ecology an sustainability

If in the previous part it was affirmed that the project was created to be economically feasible, it should be mentioned that the sustainability of the whole construction was even more important in the general design process. From the raw materials to the end result and then back to the raw materials or alternate uses, the cradle to cradle assessment follows all the parts through the life cycle of the bridge.

In the first phase, in order to minimize the carbon footprint of the embodied materials reclaimed wood and metal are proposed for the beams and for the joints.

The second phase covers the fabrication and erection of the bridge, the energy and material consumption can be minimized by a careful planning.

The third phase is the actual after-life of the bridge, when the structure can be either totally dismantled down to the raw materials, or reused as a whole or in parts in a different location and with a different function. Even if the embedded materials are 100% recyclable, and in their vast majority can be reused as building materials, the other alternative is far more appealing. Using parts of the bridge as exterior pavilions or as an observation tower can significantly offset the carbon emissions resulted through the previous phases of the construction.

The typical morphology of the bridge can prove a challenge in rethinking new possibilities for the structure. Figure 9 shows several new configurations imagined using the same elements and connectors.

Figure 9: Alternate uses of the bridge structure

7. Conclusions

At the first glance, the approach towards building a bridge might seem pretentious and somewhat formal. After a more in depth study, the solution proves a valuable alternative to the traditional post and beam, or arch way of crossing a river. This is especially true for pedestrian walkways, where the functional weight is not such a big part of the total.

Of course the aesthetic part should not be forgotten even if we are discussing a bridge where the functional and the structural vastly outweigh the image. Still, it is an added bonus that no ornament is needed here to produce an interesting design and in the term all the parts of the construction are contributing in equal measure towards function, structure and form.

Figure 10: Different views of the bridge

References

[1] *Scripting plug-in for the popular nurbs modeling program Rhino*, www.grasshopper3d.com

[2] *Tensional integrity or floating compression, is a structural principle based on the use of isolated components in compression inside a net of continuous tension*, http://en.wikipedia.org/wiki/Tensegrity

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[4] Buckminster R., "*Bucky" Fuller (July 12, 1895 – July 1, 1983)[1] was an American systems theorist, architect, engineer, author, designer, inventor, and futurist*, http://en.wikipedia.org/wiki/Buckminster_Fuller

[5] Motro R, Tensegrity: *Structural Systems for the Future*, Kogan Page Science, London, 2003, p. 204-205.