Deployable Structures: Elegant Kinematics for Social Sustainability

"Our design medium is behavior itself. Elegance and economy remain the pre-eminent values of good design. An elegant mechanism translates a simple push or pull into rich and complex behavior."

-Chuck Hoberman, Hoberman Associates[1]

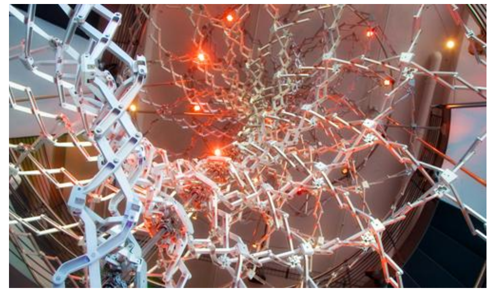

Figure 1. Expanding Hellicoid.[2]

1 Introduction and Motivation

Designers of deployable structures have a unique opportunity for aesthetic expression through elegant design in a static position and through developing exciting, kinematic experiences as the structure transforms. David P. Billington defined structural art as designs that are efficient, economic, and elegant.[3] As Hoberman noted in the quote above, elegance for deployable structures is also about the transformation of the structure and the "rich and complex" behavior that can result. Deployable structures (including movable bridges, retractable roofs, and works of art – as shown in Figure 1) offer the viewer a changing perspective and the thrill of seeing a once static structure come to life. Designers can create innovative designs that are both an aesthetically striking static structure and an exciting, dynamic experience.

One genre of deployable structure – rapidly expandable bridges and shelter for disaster relief – provides structural engineers with the opportunity to improve social sustainability through infrastructure related relief efforts. Environmental disasters often result in the need to quickly provide shelters for large numbers of displaced people. Rapidly expandable shelters and bridges that are light-weight, inexpensive, and easy to deploy are critical to an effective humanitarian response. These structures can provide shelter and transportation infrastructure for displaced families as well as create an environment suitable for dispensing essential needs such as food and water. They can have an immediate impact on mortality and morbidity rates and foster an environment for healthy hygiene thus limiting the spread of infectious diseases. Need for such shelters and bridges has been apparent in events both within the United States (Hurricane Katrina in 2005) and in events abroad (2010 earthquake in Haiti).

[1] "Insights," Hoberman Associates, accessed January 26, 2011, http://www.hoberman.com/insights.html
[2] "Expanding Hellicoid," Hoberman Associates, accessed January 26, 2011, http://www.hoberman.com/portfolio.php
[3] David P. Billington, *The Tower and the Bridge* (Princeton: Princeton University Press, 1983), 3-6.

Structural engineers must investigate this type of research to promote innovative solutions for disaster relief. By designing these structures with aesthetic intentions, the engineer also has the capability of providing a feeling of security and a sense of home that would be critical to the recovery of survivors.

If awarded the SOM Traveling Fellowship, I would study deployable structures with the intent of understanding the structural and kinematic system, the economic factors related to construction, and the aesthetic appeal from both a stationary and kinematic perspective. My objective would be to gain insight into the efficient, economic, and aesthetic design of rapidly expandable shelters and bridges for disaster relief. My long-term goal is to build a deployable structures laboratory devoted to this cause.

2 Extension of and Contribution to Prior Research and Professional Activities

The focus of my doctoral research has been on improving the sustainability of movable bridges by finding new forms that integrate structural and mechanical systems. Traditionally, designers of movable bridges have treated structural and mechanical systems as separate problems. However, by considering both problems simultaneously, a designer can reduce the environmental impact of a structure by minimizing the amount of material used and reducing power requirements for bridge operation. This can be achieved through structural integration – incorporating members which serve both structural and mechanical purposes.[4] My research methodology has included using physical form-finding techniques to develop new conceptual designs. I then optimize the geometry of each design and the section profiles of each element using a multi-objective optimization code (that I developed for this application) to simultaneously minimize the use of materials and the power for operation. My dissertation includes three case studies that demonstrate this methodology. This fellowship would enable me to explore how this research could be applied to the design of rapidly expandable bridges and shelters for disaster relief.

3 Research Methodology

My investigation of elegant, deployable structures will include: 1) visiting the site of a recent disaster, 2) meeting designers at research centers and design firms, and 3) evaluating deployable structures through site visits.

[4] Laurent Ney and Sigrid Adriaenssens, “The Piston-Stayed Bridge: A Novel Typology for a Mobile Bridge at Tervate, Belgium,” *Structural Engineering International* 4 (2007): 302-305.

To fully understand the needs and applications of rapidly expandable shelters and bridges for disaster relief, it is essential to visit a disaster site in which they could be used. Toward this end, I propose visiting Port-au-Prince, Haiti where need for shelters remains even a year after the earthquake that destroyed much of the infrastructure of the city. This phase of the research will include 1) interviewing survivors, 2) surveying make-shift tent cities built by survivors, and 3) investigating the use of tents provided by international disaster relief organizations, such as ShelterBox (Figure 2). This experience will serve to ground this research and provide focus for the chief challenges related to the design of rapidly expandable structures.

Several research centers and design firms in Europe and the United States specialize in deployable structures. With this fellowship, I would intend to visit these centers and firms to learn about their form-finding methodology, their approach to analysis, and practical considerations related to the construction. For example, the Motion Structures Laboratory at the University of Oxford led by Dr. Zhong You specializes in kinematic structures and has designed rapidly expandable shelters (Figure 3).

Figure 2. Tent City[5]*(left) and SelterBox Relief Tents*[6] *(right) in Port-au-Prince.*

Figure 3. Prototype of Shelter Design Closed (left) and Deployed (right) [7].

[5] "Tent City beside Matthew, Port au Prince," Haiti Response Coalition, accessed January 24, 2011, http://www.haitiresponsecoalition.org/pre-planning-guide-for-your-tent-for-haiti-drive/tent-city-beside-matthew-25-port-au-prince-3/

[6] "It's All About the Box," ShelterBox, accessed January 24, 2011. http://shelterbox.org/news.php?id=575

[7] "Motion Structures," Zhong You, accessed January 24, 2011. http://www.civil.eng.ox.ac.uk/people/zy/research/shelters.html

The fundamental element of this research plan will be visiting deployable structures to gain inspiration for the design of rapidly expandable shelters and bridges. The dynamic nature of these structures cannot be captured in photographs, making site visits even more essential to understand the full elegance of the static structure and the excitement of the kinematics. The Footbridge Stalhille – a 30m movable, pedestrian bridge completed in 2008 by Ney and Partners (Figure 4) – is one particularly striking example. Ney and Partners designed the bridge so that the span is simply supported when closed, moving, and open. This is efficient from a structural viewpoint since the span does not need to be designed for different static systems. This also leads to an exciting opportunity for aesthetic expression. More specifically, the span is designed as a U-beam where the webs are the railings, thereby exemplifying integrated design. The mesh spacing and thickness of these railings have been optimized to minimize the weight of the structure.[8] For example, toward either end of the bridge, where the shear is the greatest, the mesh is thicker and more closely spaced. This serves both a structural purpose in providing adequate resistance to shear and an aesthetic purpose as it shows the viewer where the forces are the greatest. The kinematic motion of the bridge swinging upward would be a thrilling and dramatic event to witness. It evokes childhood memories of playing on a swing and would undoubtedly inspire awe in the viewer. The aesthetic intentions of the designers are clear as Adriaenssens et al write that, "The resulting design is highly integrated and innovative, yet traditional and classical in appearance."[9] The efficiency of the design, the elegance of the static structure, the excitement of the innovative kinematics, and the aesthetic motivation of the designer make this structure stand out as a great work that must be visited. This would be one of many structures that could serve as inspiration for the design rapidly expandable bridges and shelters for disaster relief.

Figure 4. Footbridge Stalhille: Closed (left), Open (middle), and Close-up (right).[10]

[8] Sigrid Adriaenssens, Stefan Devoldere, Laurent Ney, and Iwan Struaven, *Shaping Forces: Laurent Ney (*Brussels: A+ Editions, 2010), 70-75.
[9] Adriaenssens et al. *Shaping Forces*, 70
[10] "Footbridge Stalhille," Ney and Partners, accessed January 24, 2011.http:// www.ney.be/en/projects_details/258.html.