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Benefits of using haptic devices in textile architecture

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Abstract

The aim of this paper is to introduce the use of haptic technologies in the design of tensile membranes structures. In the last years, haptic devices have become very popular and have been used in many applied fields as product design, medicine, architecture or art between others. By means of haptic devices, the user can interact with virtual objects via the sense of touch. The benefits of using haptics in the design of tensile membrane structures are explained in this paper. Using this technology, the designer can easily define complex equilibrium shapes and try different design alternatives in a very short time. An application has been developed to test the benefits of using haptics in textile architecture.

Keywords: form finding, tensile membrane structures, architecture design, haptics.

1. Introduction to haptics

Haptic technology allows users to physically interact with a virtual or remote environment via the sense of touch. A computer-controlled device is used as interface between the user and the virtual world.

(a) (b) (c)

Figure 1. Haptic devices: (a) PHANTOM Premiun (b) PHANTOM Omni (c) Novint Falcon.

A haptic system can apply forces, vibrations or add motion to the user, adding useful extra tactile information, which helps the user to interact with the virtual environment (Hayward and MacLean [1], MacLean and Hayward [2]).

Although some force-feedback devices were developed for teleoperation in robotics between 1950's and 1980's, the break-through occurs between 1990 and 1995, thanks to the PHANTOM haptic device (see Fig. 1a) from Sensable Technologies (Massie and Salisbury [3]).

A great variety of haptic interfaces have been developed for different purposes, being the most popular the desktop pen-based devices, with 6 degrees-of-freedom positional sensing and 3 active degrees-of-freedom force-feedback (see Fig. 1a & Fig.1b).

The possibility of touching, feeling, and manipulating objects in a virtual environment, in addition to seeing (and/or hearing) them, gives a sense of immersion in the environment that is otherwise not possible (Hannaford and Okamura [4]).

2. Tensile membrane structure design process

The main objective of this paper is to show the benefits of using haptic devices during the conceptual design of tensile membrane structures. A description of the tensile membranes design process is shown in Figure 2, from the preliminary sketches to the realization of the structure.

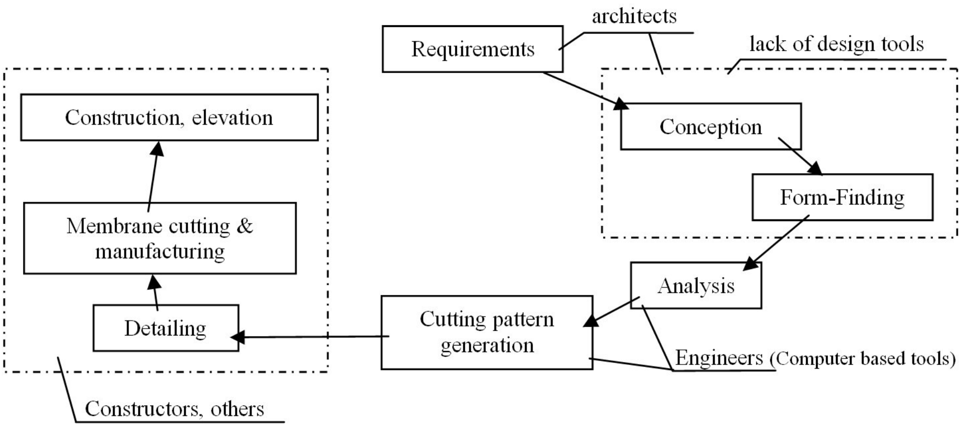


Figure 2. Tensile membrane structure design process.

Architects and engineers are involved in the study of tensile membranes structures (Mollaert et al.[5-6] and Berger [7]). Broadly speaking, architects tend to focus on the geometric shape and external appearance of the membrane, while engineers are more concerned with the internal stress distribution of the membrane and the viability of manufacturing it. Both approaches are directly related, since the geometric shape of the membrane depends on the given initial pre-stress of the membrane.

- The initial steps of the design process are defined by the architect or by the designer, with initial ideas and sketches being drawn to comply with shape and space requirements. This conceptual design stage is really the most important of the entire design process because the initial conditions are defined and will be the basis of the rest of the project. Once the project has started, any change in these initial specifications affects the whole project.

- *Form-finding* consist of obtaining the equilibrium shape of a tensile membrane structure. Many techniques exist to find the shape of a particular membrane (Otto [8] and Wakefield [9]).
  Form-finding methods are based on linearization techniques like the force density method (Scheck [10] and Linkwitz [11-12]), the surface stress density method (Maurin and Motro [13]) or the dynamic relaxation method (Barnes [14-15]).
  In the force density method, the membrane is modelled as a cable-net structure in which each element has a given force-density value, which is used to linearize the geometrically non-linear problem. This force-density value is an adimensional value that relates the force and the length of each element of the cable-net.
  There are different computer tools based on these techniques, which help the designer to obtain the desired shape. Some of them require advanced structural skills, and others need to complete too many tasks before achieving the final shape.
  The aim of this paper is to show the benefits of using haptic devices at this conceptual stage of the design process (form-finding), where the preliminary shape of the structure is defined. The designer needs a flexible tool to define easily complex equilibrium shapes and try different design alternatives in a very short time. This requires a system in which the user interacts with the virtual model in real time.
- Once the *conception* stage has been completed using form-finding techniques, a non-linear *static analysis* of the structure is carried out. Material properties are assigned to the membrane, and the stress distribution is obtained under different loads and boundary conditions to validate the initial shape of the membrane. At this moment, it is not the intention of the authors to use haptics devices to assist the user during the static analysis of the structure.
- The next step in the design process is called *cutting pattern generation*. This method allows the optimum way of cutting the membrane to be calculated. Based on a geometrical process, flat strips are obtained to comply with the desired shape. Some computer-based tools covering *static analysis* and *pattern generation* can be found, but specialized users are required to complete each task.
- Finally, detailing of the structure is carried out. Those details concerning foundation, structure supports, masts, connections, clamps, cable diameter selection, drawings and many others are defined at this stage.
- After detailing is completed, *membrane cutting* is carried out, according to the cutting pattern referred to in the previous step. Once the strips are joined, the completed membrane is prepared for the *construction* of the structure and the *elevation* of the membrane.

3. Designing tensile membranes structures using haptic devices

The introduction of haptic devices in the conceptual design of membrane structures is a great benefit to architects and designers. By means of adding the force feedback sensations to the 3D visual scenario, the user can interact in a very intuitive way with the model, which facilitates the definition of equilibrium shapes during the design process.

In this section are explained some features that would help the designer during the conceptual design stage of tensile membrane structures.

The first benefit, shown in Fig 3a, is that the designer uses a 3D device to interact directly with the 3D environment and the model. It gives the user the possibility of navigating easily through the virtual 3D environment. At this stage, the membrane is being defined by adding or deleting vertex to the model.

One of the main advantages of using haptic devices is that the user can touch the virtual model at any moment while moving around the scene. The designer can touch the double curvature of the membrane and feel when a vertex is reached, as he approaches to it.

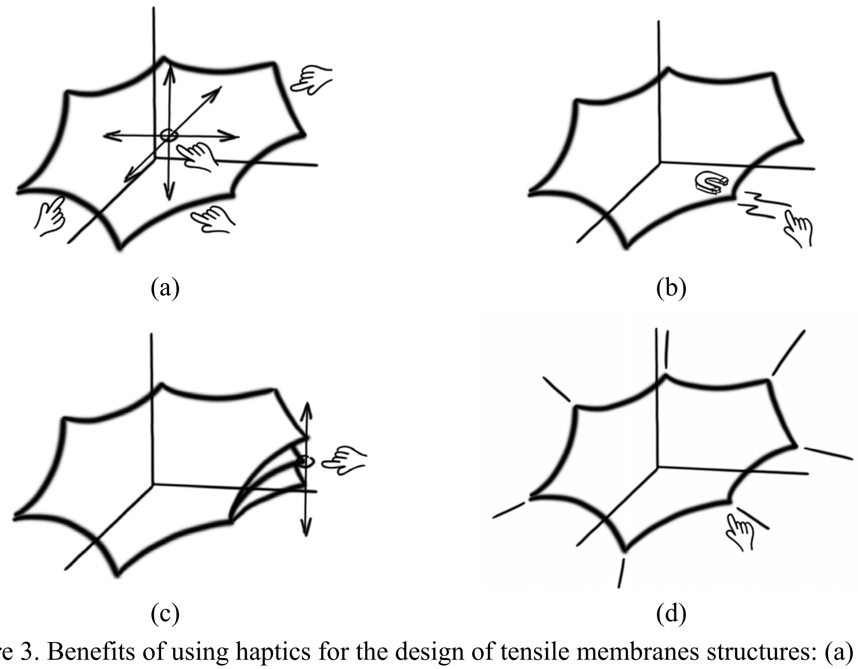


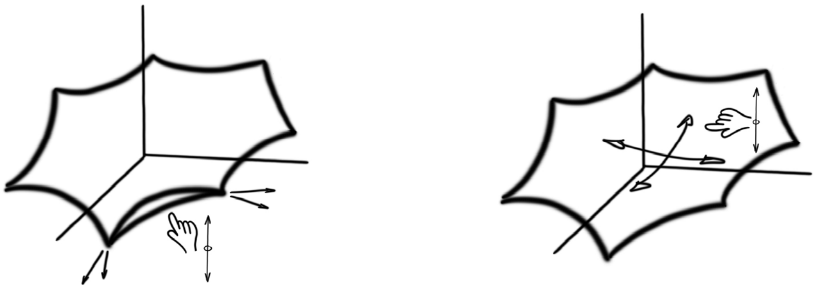
Figure 3. Benefits of using haptics for the design of tensile membranes structures: (a) 3D space navigation, touch (b) snap to vertex (c) movements restrictions (d) reaction forces.

As shown in Fig 3b, a force appears as the user approaches to a vertex. This attraction force gives the user the feeling of capturing the vertex. This "snap to geometry" feature is a common practice in most of the traditional CAD systems, helping the user to select geometry entities of the model. Once the user has selected a vertex, it is possible to move it in the 3D space according to some given constraints. Figure 3c shows how a vertical constraint is assigned to the movement of a membrane vertex. The designer can easily choose the constraints needed depending on his design intention. Some other restraints would limit the movement of a vertex to the XY plane or along the X axis. A combination of buttons can be used to switch easily between different constraint modes.

Another interesting use of the force feedback feature while the user is dragging a vertex, would be to introduction of a controlled vibration when the Z position of the vertex coincides with the Z position of any other vertex of the model. This technique facilitates the quick alignment of the different vertex of the membrane model.

It is also possible to add another force to the user while dragging the vertex, related to the direction of the reaction force of the tensile membrane at that vertex. Figure 3d shows how the user can feel the direction of the reaction forces while dragging a vertex.

The values of the force-density values used for the form-finding method can be handle directly in a very intuitive way thanks to the force feedback properties of haptics. Figure 4a shows how the user can interact with a boundary of the membrane to change the internal force-density value of the edge elements. Once a boundary is selected, the user can easily increase or decrease the force-density values of the edge elements by moving the haptic stylus vertically. The user can feel a variation on the force feedback that is related to the variation of the force-density value assigned. Upward movements increase the force feedback and downward movements decrease the force feedback. Multiple boundary selections can be made to apply the same values to different boundaries of the membrane.



(a) (b)

Figure 4. Benefits of using haptics for the design of tensile membranes structures: (a) boundary force-density values (b) internal force-density values

The same procedure can be translated to the designation of the force-density values inside the tensile membrane. As the user approaches to the membrane and touches it (see figure 4b), the force-density values of the membrane can be increased or decreased by moving the pointer upward or downward respectively. The force feedback given by the haptic device facilitates the definition of the internal force-density values. Different values would be given to each wrap and weft directions if needed, using some keyboard combination while dragging the haptic stylus.

These are the main features introduced in the design of membrane structures using haptic devices. As the user receives forces from the haptic system, it is important to include the possibility of calibrating the range of forces and scale them, depending on the level of interaction needed.

4. System implementation

A Novint Falcon haptic device has been used (see Fig. 1c) and an application has been developed to test the benefits of using haptic devices in the design of tensile membrane structures. It is a low cost haptic device which provides force-feedback in 3 translational degrees-of-freedom and increases the interaction between the user and the virtual model if it is compared with a traditional 2 passive degrees of freedom of a mouse. The device can be seen as a 3D mouse with force feedback.

The application has been initially built with the aim of being used at the conceptual design stage, in which multiple shapes need to be generated in an easy way. At this moment, it is not the intention to use this application as an analysis tool, in which the internal membrane stresses are evaluated.

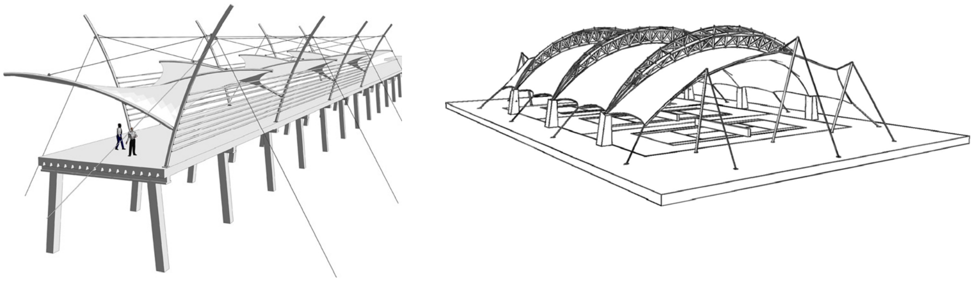


Figure 5: Examples of some tensile membranes designed using the developed system.

The force-density method has been used to generate the equilibrium shapes. It is a fast and robust method that allows the designer to obtain equilibrium shapes and visualize the model in real time. This facilitates the total interaction between the user and the virtual model, creating and manipulating easily shapes in a very short time. Figure 5 shows examples of tensile membrane structures, which have been designed using these haptics techniques.

5. Conclusions

The development of new haptic devices and its low cost has helped the introduction of this technology into many different fields, as textile architecture.

The use of haptic devices in the design of tensile membrane structures is a great benefit to architects and designers. The introduction of the sense of touch facilitates the interaction between the user and the model that is being defined. Thanks to this, the designer can easily define complex equilibrium shapes and try different design alternatives in a very short time. Real time force-feedback and graphics renderization are important issues in order to create a complete interaction between the designer and the virtual model.

An application has been built to evaluate the advantages of using haptics to assist the designers in the definition of shapes. Some features have been implemented to bring the user new intuitive ways of interacting with the model.

Future lines of work will consist on the inclusion of these techniques as a plug-in in some existing commercial architecture software.

References

[1] Hayward V. and MacLean V., Do it yourself haptics: Part I. *IEEE Robotics and Automation Magazine,* 2007, **14** (4), 88-104.

[2] MacLean K. and Hayward V., Do It Yourself Haptics: Part II. *IEEE Robotics & Automation Magazine,* 2008,**5** (1), 104-119.

[3] Massie T. and Salisbury J., The phantom haptic interface: A device for probing virtual objects, in *Proceedings of the ASME Winter Annual Meeting*, 1994

[4] Hannaford B. and Okamura A., *Springer Handbook of Robotics. Haptics*. Springer 2008, 719-739

[5] Mollaert M. and Forster B., *European Design Guide for Tensile Surface Structures*. Tensinet, 2004

[6] Mollaert M., Haase J. and Hebbelinck S., *The Design of Membrane and Lightweight Structures*. VUB BRUSSELS, University Press, 2002

[7] Berger H. Form and Function of Tensile Structures for Permanent Buildings. *Engineering Structures*, 1999; **21**(8), 669-679.

[8] Otto F. *Tensile Structures; design, structure, and calculation*. The MIT Press,1967

[9] Wakefield D.S., Engineering Analysis of tension structures: theory and practice. *Engineering Structures*, 1999; **21**(8), 680-690.

[10] Scheck H.J., The Force Density Method for Form Finding and Computation of General Networks. *Computer methods in applied mechanics and engineering*, 1974, **3**(1), 11-134.

[11] Linkwitz K., Form finding by the "Direct Approach" and Pertinent Strategies for the Conceptual Design of Prestressed and Hanging Structures. *International Journal of Space Structures*, 1999, **14**(2), 73-87.

[12] Linkwitz K., About formfinding of double-curved structures. *Engineering Structures*, 1999, **21**(8), 709-718.

[13] Maurin B., Motro R., The surface stress density method as a form-finding tool for tensile membranes. *Engineering Structures*, 1998, **20**(8), 712-719.

[14] Barnes M.R., Form-finding and analysis of prestressed nets and membranes. *Computers & Structures* 1988, **30**(3), 685–95.

[15] Barnes M.R., Form Finding and Analysis of Tension Structures by Dynamic Relaxation. *International Journal of Space Structures*, 1999; **14**(2), 89-104.