

6.837  
Computer Graphics  
Final Project Proposal

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## **CatenaryCAD: An Architectural Design Tool**

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Tools are an essential part of production in any field. Even tool-building itself relies on other tools, with the most basic of all tools being the human hands. Those with the ability to create their own tools are limited in what they can do only by their imaginations. Meanwhile, those that are not tool-builders are limited in what they can accomplish not merely by their imaginations, but also by the tools available to them.

In computer graphics, it seems that many of the tools built are meant to service other computer graphics tasks. With the exception of the movie industry, research in computer graphics rarely impacts fields other than the CG field itself. For example, faster rendering techniques and other advances in computer graphics are interesting, but researchers should address how these techniques can be used in new contexts and outside the exclusively visual domain. There are many fields that could benefit from tools that use the state-of-the-art in computer graphics.

We have chosen to create an design tool for architects that differs in its approach to form-finding from current tools likes AutoCad, Rhino, SoftImage, or Maya. CAD packages take drafting and add in the power of computation to make more complex and interesting buildings possible. Computer tools allow designers to experiment with other shapes, merging computational power with form finding methods and resulting in much more interesting architecture. Maya and the other programs are modelling tools rather than generative tools.

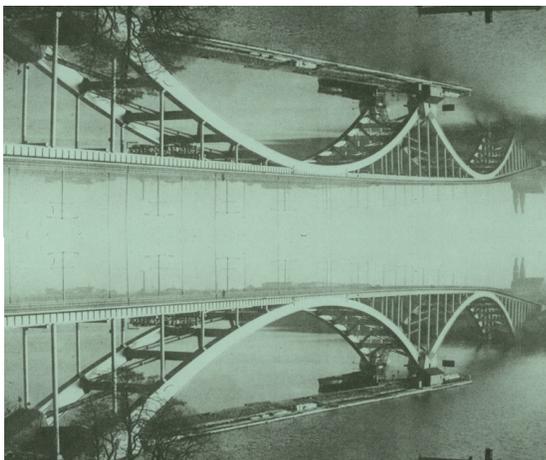
A design technique created by Antonio Gaudi allows an architect to design complex structures based Catenary systems, whose curves are formed by perfectly flexible, uniformly dense strings suspended from their endpoints and weighted under gravity. He created many amazing structures with pieces of string that architects would be at a loss to reproduce using today's most advanced design tools. We aim to provide a computationally enhanced version of Gaudi's atelier. Rather than simply allow an architect to arrange geometric primitives as in AutoCad, instead we provide an environment in which strings responding to gravity can be arranged to form structures that are far more organic and beautiful.

Catenary systems have been used for construction in Catalan areas of Spain for a long time. For example, if a Catalan stair has to be constructed it is not detailed by the planners or architects. Instead, the masons on site hang a rope between the point of departure and the point to be reached, trace the shape and flip the curve over to use as the guide for constructing the masonry arch that carries the stairs. The rope is in pure tension, as it can not take any compression due to its flexibility. Therefore the form it finds contains the pure tensile force within the envelope of the string. If one inverts the parabola, one gets a pure compression arch which is necessary for brick construction, which cannot take any tensile forces.

Antonio Gaudi developed the system of catenary string statics into a spatial design system. He constructed scaled models of his design ideas by developing forms through a weighted string form-finding method. In his case, the models are spatial and are

### Steel bridge

When inverted, the arches can be identified as catenary shapes (approximately) with the vertical members in pure compression. This bridge is not a design by Gaudi, rather an illustration of the principle of catenary systems.





**Colònia Güell model**  
Hanging and inverted.



much more complex than the catenary staircase example. Gaudi achieved the desired forms through the control of three variables - anchor points of the strings, the length of the strings, and the weights attached to them. By designing his forms this way, Gaudi knew that the resulting geometry would act purely in compression when inverted. He also had a pretty precise estimate of the loads necessary

on the different members of his construction. Beyond structural form finding, Gaudi also used this method for rendering the interior and exterior shapes of the buildings. He imagined them by painting and tracing over the “wire frame” models of lines in photos.

We hope the creation of our catenary design tool will help contemporary architects realize these beautiful shapes and methods through computational methods rather than physically sitting at their desks tying strings together. Computer-aided catenary designs will be quicker and provide room for playing, trial and error, and potentially provide a means to create more complex designs than imagined in the physical world. In addition, we hope our tool will help expand the reach of computer graphics to outside fields, and if successful, perhaps others will begin applying complex computer graphics to other fields as well.

**Gaudi's rendering technique**

He used photographs of the string models literally as wire-frame models, filling in the surfaces with paint to create an impression of the spaces that would be created.

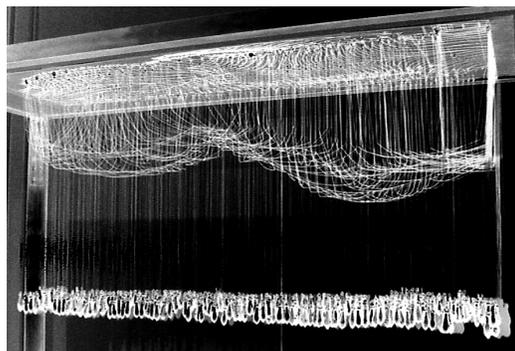


**Weiser- Umemoto model**

Their exploration of catenary systems in physical and digital models (1996).



We have divided the project into three components in order to evenly distribute the work amongst the three team members. The first component is the construction of the User Interface (UI) black box. The designer for this component will be concerned with the interactions between the program and the user, in particular with the experience of the user. They will create an intuitive and powerful way to navigate through the program, to allow the user to work within the string-gravity spaces, and to provide the user with the means to save, load, or create new files and thus new designs. Part of the navigational design means this team member will design the layout of the screen and all the elements that interface between human input and execution of the program.



The second component of the project is the visual graphics/rendering component. This team member will build how the strings look (either realistically or intentionally unrealistically) through the use of visual elements like lighting, color, shading, and texture. They will determine how to visually model the string when it is affected by external and internal forces, stresses, and strains, twists, or pulls. Finally, they will devise one or more secondary modes for the user to toggle between when viewing their string constructions, which might let the user learn about particular information about the design. One example is a mode where the

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string color changes throughout, depending on the stress applied at each point.



**Interiors and exteriors**  
Sagrada familia still currently under construction.



The third component is the physics computation, data structure design, and general back-end program design. This team member will design the methods for passing information between the three components, they will construct the data structures for storing information such as a string's placement, length and thickness, or the forces applied to it, or general information about the user's design, such as the number of strings in the scene, their adjacency and connectedness, etc. The team member working on this component will use an accurate physics model in order to compute data about the strings as gravity and applied weights deform their shape and lengths.

In addition, as a team we will decide whether to create the strings using a particle system or other approach. We will also determine what features we want our tool to have, what assumptions our tool should be using, and what data abstractions and methods we must build in order to construct the program through effective levels of abstraction, transparency, and opaqueness.

## Timeline

- November 4** Choose software to build the project with (OpenNurbs versus other libraries)  
Design the System and all intentions/expectations, such as the features it offers, what it should assume or be told, etc.  
Set up CVS or other repository to share code (i.e. SourceForge)
- November 18** Construct the technical back-end  
Construct the Graphics engine  
Construct the UI black box
- November 25** Sew it all together - placement of strings, connection between strings, etc.  
Add additional features if desired  
User-test
- December 2** Write the written report  
Create the presentation  
Create the artifact

Ultimately it is not the goal to just provide a catenary environment but to create tools that are easily expandable and adjustable. It is not about recreating an accurate, historical simulation of Gaudi's techniques, but rather to take his inspiring form-finding techniques and use them as a starting point for building a modeling tool that operates around the principles he used.