FOLLOWING A THREAD: A TREE COLUMN FOR A TREE HOUSE

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ABSTRACT

Tree columns and branching structures have been known for many years and have found increasing application in both architecture and civil engineering structures. This article reviews some earlier work with these structures and describes techniques which have been used for form finding. Using a specific design example of a tree house which was build for handicapped children, results of form finding techniques with thread models are shown.

The design, fabrication and erection of the Treehouse at Fowler Center, Michigan USA, is shown as an example. The structure was built for the University of Michigan's C.S. Mott Children's Hospital, which runs a summer camp for pediatric, ventilator patients, about half of whom need wheelchairs. Special criteria for this project made a branching column particularly appropriate. The example also shows the use of some unique details in the continuous radius bend pipe sections and the asymmetric cantilever form of the structure. In conclusion some comments are made regarding the effectiveness of the thread models for form finding, and other possible approaches are suggested.

BACKGROUND

Branching structures are distinguished from closed cell trusses and frames in that the members divide at nodes but do not come back together to form enclosed cells. Like trees they continue instead to branch outward in a series of 'generations'[1]. Numerous tree column topologies have been explored in particular with a program written by Matthias Neureither at the University of Stuttgart, IAGB which uses something like shape grammar to explore pattern variations (see Figure 1.) [2].

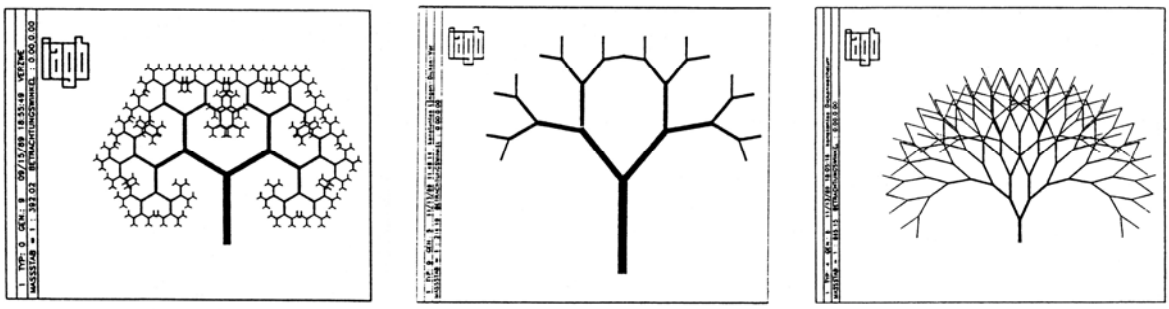

Abb. 4: konstantes Längen-Dicken-Verhaltnis (Baumtyp 2) / Verzweigungswinkel 120° / 9 Generationen

Abb. 5: konstantes Längen-Dicken-Verhältnis (Baumtyp 2) / Verzweigungswinkel 90° / 5 Generationen

Abb. 6: konstanter Dickenzuwachs (Baumtyp 3) / Verzweigungswinkel 50° / 8 Generationen

Figure 1. Examples of branching structure topologies generated with Neureither's program [2].

In terms of structural loading and behavior, however, these structures are very different from natural trees. Tree columns are generally used as compression structures which carry distributed gravity loads down to a foundation. The forms have also been used as tensile systems, inverted to gather loads up to an anchor point. Bletzinger has shown that branching tree columns are efficient load carrying systems particularly for less dense, distributed load patterns [3]. Also, Otto demonstrated the efficiency of branching columns over regular columns by use of his BIC efficiency quotient [1].

Although examples can be found in aboriginal structures as well as column and ribbed vaulted systems of the gothic period, Frei Otto is primarily responsible for exposing tree columns as a structural type. From early work at Yale University to later investigations carried out at his own Institute for Lightweight Structures (IL now ILEK), Otto explored fundamental principals governing the form development of branching systems [4]. Jürgen Hennicke, with other members of the IL task group "Biology and Building" (Biologie und Bauen), studied branching systems and developed several techniques for form finding. One method uses strings or chains

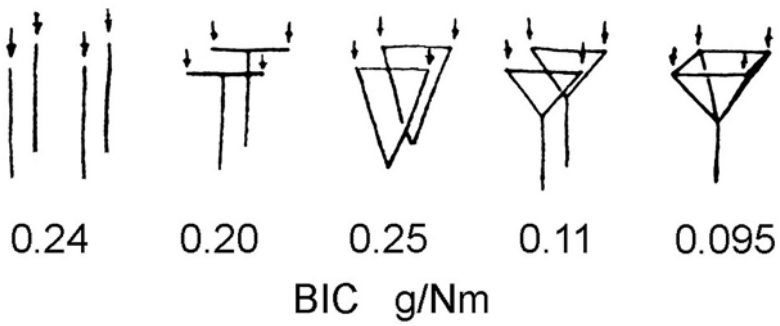

Figure 2. Comparison of BIC efficiency quotient for four systems based on the same load/path configuration [1].

connected to springs to measure force levels [1]. The models are built inverted with weights hung beneath. A second method is to use loosely loomed threads, dipped in water to explore branching patterns. As the thread models are removed from the water, surface tension pulls the threads together to form branching networks. Marek Kolodziejczyk demonstrated this procedure at the IASS Conceptual Design of Structures Symposium in 1996 in Stuttgart. Figure 3 shows patterns generated with this technique.

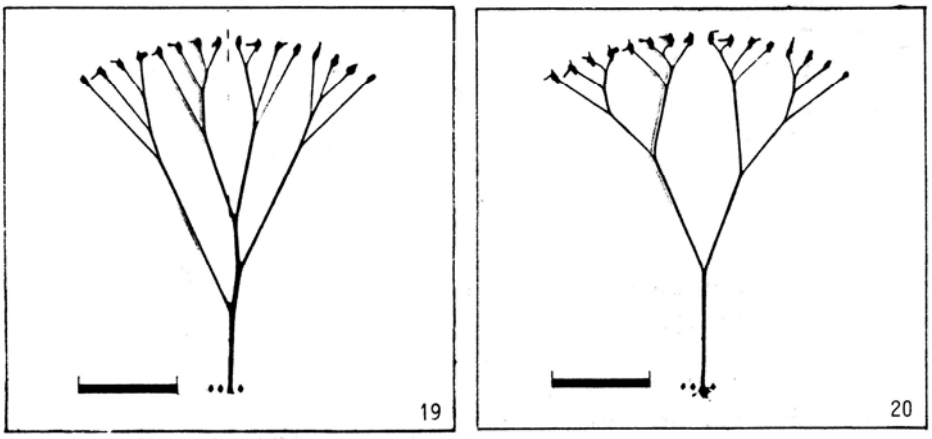

Figure 3. Examples of 2 dimensional thread models by Marek Kolodziejczyk [5]

INVESTIGATION USING THREAD MODELS

In the design exploration for the Treehouse branching column, several string models were produced. These were dipped in water to study branching forms. The technique does not produce a singularly unique form, but is useful in seeing general patterns of forms. It was found that lighter cotton threads worked better. In an attempt to increase cohesion sugar was tried (making it more sticky), but as the mixture added weight, the result did not work as well as just plain water.

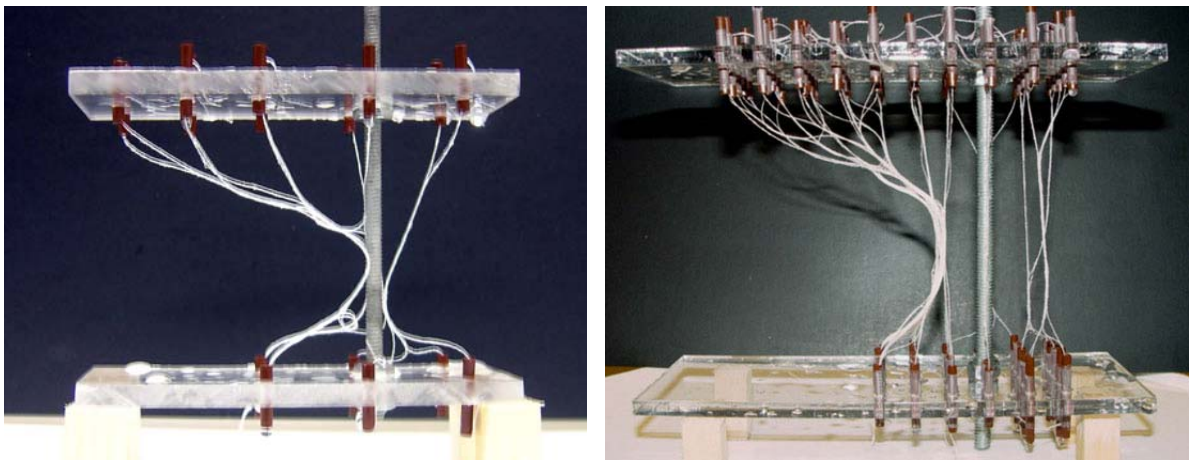

Figure 4. Left – 1:100 model with 5 threads on long side. Right – 1:50 model with 10 threads.

Three model scales, 1:100, 1:50 and 1:20 were used and different string densities. Figure 4. compares the 1:100 model with the 1:50 model. Both models were made with sewing thread, although the number of threads on the long side is doubled in the lager model from 5 to 10. The smaller scales seemed to produce better results. At the larger 1:20 scale, the weight of the model caused excessive droop. Since there is no form giving load in this technique, only cohesion of the threads, excess weight gives a distorted (sagging) shape. Figure 5 shows the top section of the 1:20 scale model (inverted). This model used 17 strings on the long side in an attempt to enhance bundling effect and cohesion.

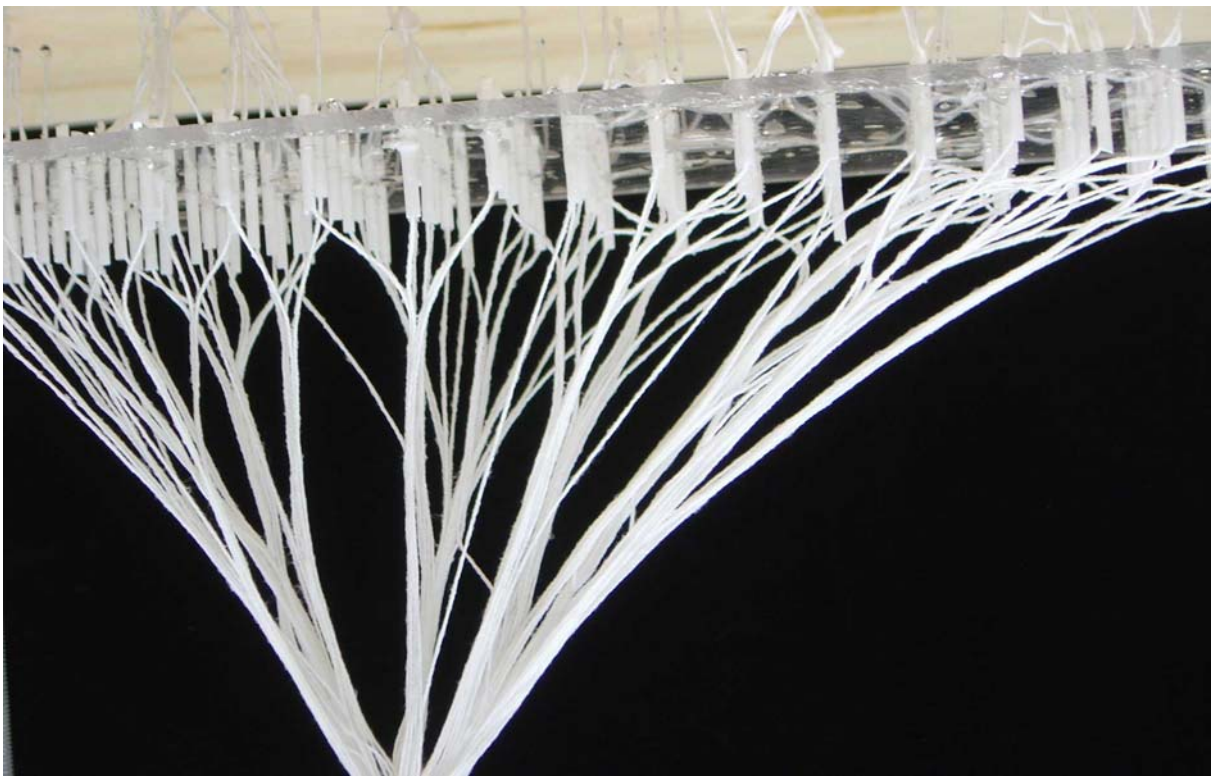

Figure 5. Top section of the 1:20 model using string. Photographed in inverted position.

DESIGN CONCEPT FOR THE TREEHOUSE

The Treehouse at the Fowler Center near Mayville, Michigan was built for the University of Michigan's C.S. Mott Children's Hospital summer camp for pediatric, ventilator patients, about half of whom need wheelchairs. For many of these children, this is the only opportunity they have during the year to venture beyond the confines of their home or hospital. Architect Kristine Synnes conceived of an imaginative ship, nestled in a treetop, where the children could have an adventure well beyond anything they would normally be able to experience. In order to support this ship of dreams 7 meters in the air, a steel tree column was chosen. There were several parameters that impacted the design. One, the superstructure needed to pass between the branches without actually hitting the tree. At the same time the foundations needed to be far enough removed from the tree's root system as to prevent damage. There needed to be a second cantilever away from the tree to allow for hoisted access. Above this there needed to be a hoisting point capable of carrying 680 kg (personnel and equipment). Environmental loads included 145 km/hr wind load and a 1.68 kN/m^2 ground snow load. Finally the size of the ship needed to accommodate several children and adult aids at a time (about 30 m^2). A more detailed discussion of the design of the Treehouse can be found in an earlier article by the author [6].

Originally the joint details were to be cast in a manner similar to tree columns used as pedestrian bridge supports by Jörg Schlaich [7]. Because the casting proved impractical for the single use, and also with so many different joints, it was decided to use continuous pipe from base to top. This is similar in concept to the branching design proposed by Frei Otto for the KOCOMMAS at Riyahdh [8]. Figure 6 shows an isometric view of the form of the steel pipe branching column. The continuous sections are radius bent, with branching pieces welded in place. Connections at top and base are pinned.

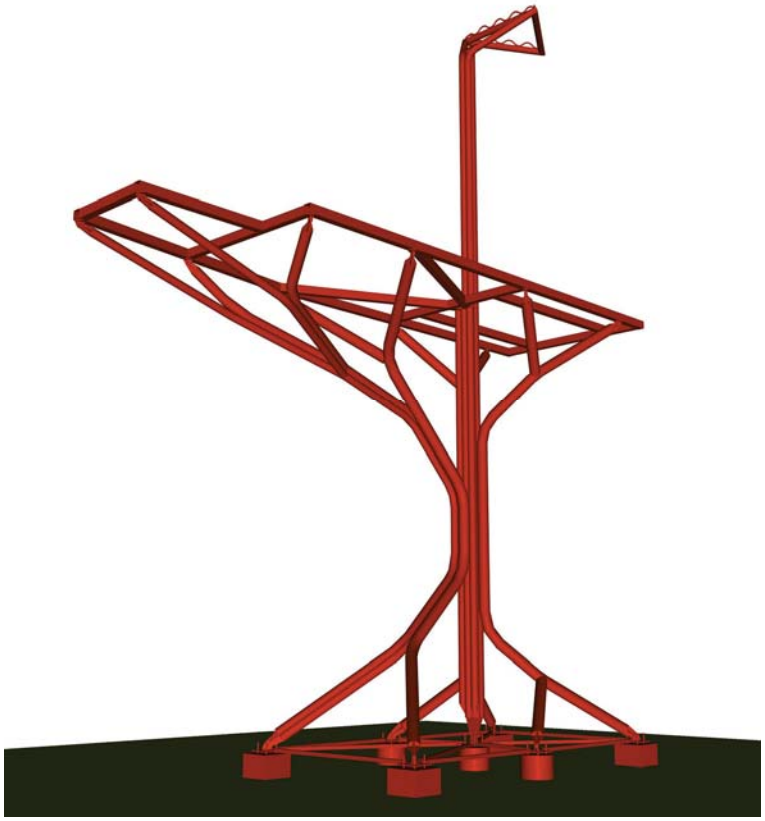

Figure 6. Isometric drawing showing the form of the steel pipe branching column.

CONSTRUCTION

The branching column was fabricated using hollow structural sections (HSS pipe) in 3 sizes to accommodate the capabilities of the fabricator. Joined sections were sleeved, and all contact points on the pipes, in section and longitudinally, were continuous welded. The tree column itself was fabricated in two sections, top and base, with a staggered, sleeved joint about mid height. The hoisting mast formed a third section. The overall height is 11.7 m. Figure 7. shows the fabrication and a detail from an upper branch connection.

Figure 7. Fabrication (left to right): the base section, the top section (inverted), detail of pinned connection on upper branch.

The three sections were transported to the site as complete units. Once the base section was secured to the foundation piers, the top section was lifted into place with a mobile crane, aligned and welded. Finally the hoisting mast (complete with topping out tree) was set it place and welded. The steel erection was thus completed in one day. Using the hoist point, materials for the wooden superstructure were later lifted into place.

Figure 8. Field erection of the column, mating the halves together and placing the mast.

To make the tree house accessible to immobile children, a special gondola chair was designed which could allow 360° rotation while moving laterally through the tree house and out onto the open balcony using an overhead track system. The chairs are padded and adjustable to accommodate people with spinal injuries. The system is shown in Figure 10.

Figure 9. Finished structure from front and rear. Temporary ladder placed though the hoisting hatch was for construction use only.

CONCLUSION

The use of a branching column in the design of the Treehouse was very successful. The visual allusion to a tree was particularly appropriate in this case. The system allowed the structure to be projected through the branches of the existing tree and avoid damage to the root system by using pier supports. The system was able to carry the design loads with adequate stiffness.

Although the thread models dipped in water did produce branching forms, it was difficult to get consistent results with the 3 dimensional models. The 2 smaller scales did seem to work better, with less distortion from

gravity, than the larger 1:20 model. For 2 dimensional models, the system works better, but even here, how the model is made tends predetermine the topology. The string (or chain) and spring models used by Frei Otto are also useful in determining geometries that provide even stress distribution among members of the same generation. However, here again, topology explorations are tedious and require new models. In the thread models used for the design of the Treehouse, the topology was fixed with sliding nodes for geometry tuning. The stress levels in members were compared using a FEA program. Other mathematical methods such as Genetic Algorithms or homogeneous analysis techniques might offer better results in exploring different topologies. It is anticipated that continued efforts will proceed in that direction.

Figure 10. Interior views of the tree house showing gondola chairs and track. From left to right:
a) Young girl with cystic fibrosis just hoisted into chair. The box is a portable respirator.
b) Interior of tree house showing track system. c) View off of the balcony.

ACKNOWLEGEMENTS

The author would like to gratefully acknowledge the support of TCAUP and the two graduate students, Salome' Reeves and Ross Olson for their help in constructing and photographing the thread models.

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