The Case for Catenary Roofs

An interview with Theodore Thoeny by JNIBS

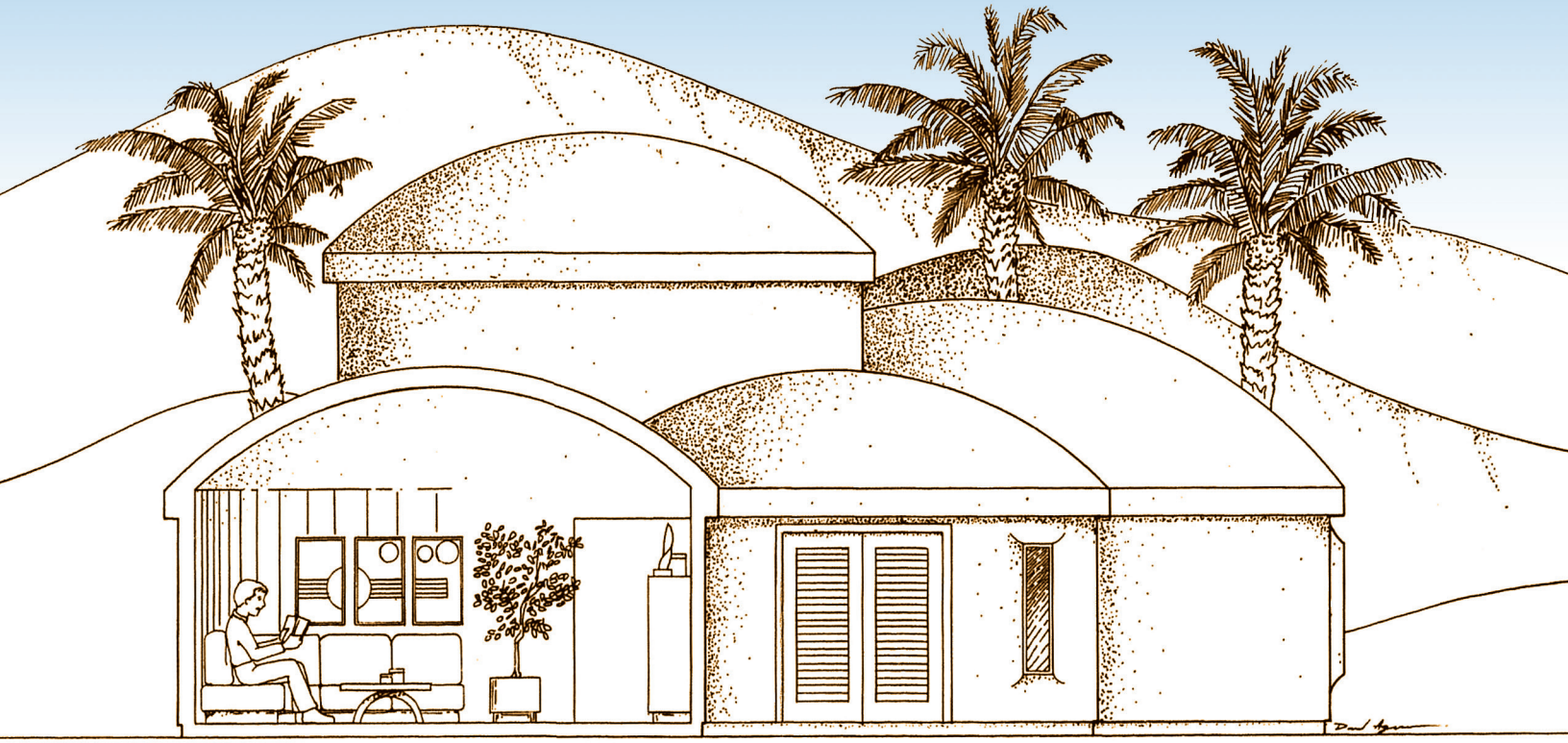

Illustration by Ted Thoeny, PE.

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The Swiss civil engineer and contractor Heinz Isler (1926-2009) is regarded as one of the pioneers of shell structures. He gained renown for his experimental, physical methods of form-finding and the resulting expressive shell structures produced in thin-walled concrete,[1] and first triggered his lifelong fascination and professional work with such structures by draping a saturated bed sheet in freezing weather to form a catenary shell (see the "Defining Catenary" sidebar on page 45) before inverting it. He proved that what gravity forms when inverted is resistant to the forces of gravity.

As a civil engineer, Theodore "Ted" Thoeny, PE, principal at San Juan Bautista, California-based Thoni Thermal Homes,[2] has been interested in fabric structures for the past 55 years, and has experimented with different fabrics, from burlap and fiberglass to geo-fabrics. "Using fabrics to form roofs is very simple and efficient, especially when gravity is allowed to form the shapes," he says. "Such lightweight roofs may answer the need in areas that lack more traditional resources (such as third-world countries), plus address both life-safety and energy concerns in modern settings."

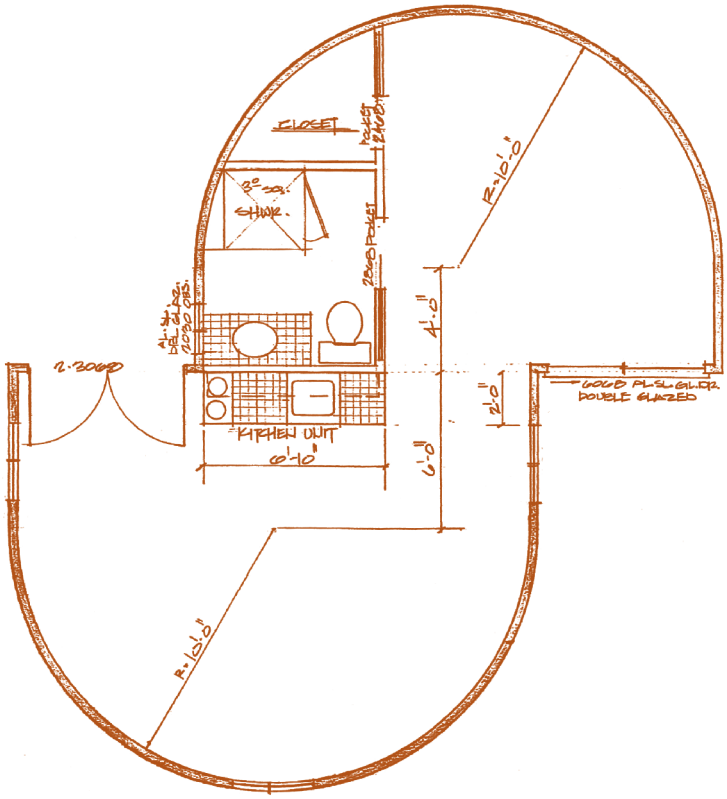
In this article, the *Journal of the National Institute of Building Sciences (JNIBS*) talks with Thoeny to gain an understanding of catenary roofs. When considering alternative construction techniques and materials, such as those used in catenary roof structures, this discussion may provide additional insight.

JNIBS: HOW DOES A CATENARY ROOF STRUCTURE WORK, AND WHAT ARE THE COMPONENTS?

Thoeny: Components of a catenary roof structure are a flexible fabric that drapes in a smooth curve without wrinkles and is relatively strong in tension when stiffened or loaded with a polymer (whether a chemical or natural stiffening product). The resulting shape is formed by gravity and, when inverted, it will be stronger and more resistant to gravity.

JNIBS: WHERE IS SUCH A ROOF MOST APPROPRIATE TO USE?

Thoeny: Catenary structures are appropriate for roofs on homes, especially where resistance to high winds and earthquakes is desired. The shape permits a minimum use of materials in protecting occupants from the weather. The only limitation is building size and the ability to invert and place the roof structure on the building. Draping the roof fabric over an inflatable form offers an alternative method to placing catenary roofs over larger buildings or edifices. Other ideal building applications are for schools, clinics, and agricultural buildings.



Floor plan by Ted Thoeny, PE.

JNIBS: WHAT ARE THE BENEFITS OF A CATENARY ROOF STRUCTURE IN AN APPROPRIATE APPLICATION?

Thoeny: First, a catenary fabric roof is lighter weight and less expensive than a standard roof, because a minimum amount of material is needed. The lighter weight reduces the hazard of collapse and injury to building occupants because the shape is resistant to wind and snow loads. Its life cycle depends on the materials used. If fiber cement is properly used, the roof could remain intact for many years. In fact, a polyurethane foam roof with an elastomeric coating, which I constructed 33 years ago, is still weathertight.

JNIBS: WHO CAN PROVIDE/CONSTRUCT A CATENARY ROOF?

Thoeny: A homeowner can erect one on his or her own, or a journeyman trained in the material can erect the desired structure.

JNIBS: WHEN DID YOU BEGIN USING CATENARY STRUCTURES IN APPLICATIONS?

Thoeny: My first attempt was using a weather balloon as a form for fiberglass fabric. The glass fabric cut the balloon, so I draped the shape and sprayed it with polyester resin, which resulted in a very strong dome. My inspiration came from an architect named Lloyd Turner.[3] In the late 1950s, he built a dome of fabric and inflated it, spraying the interior with polyurethane foam. Since then, he has designed and built several

Double dome illustration by Jonathan Zimmerman, Monolithic Dome Institute.

homes using this technique and now lives in a multi-domed home in Boulder Creek, California.

As for my own real-world applications, I was involved in creating a catenary roof for the Seaside Wastewater Treatment Plant in Monterey County, California, in the 1970s. We built the walls for the building, which needed to incorporate a round sludge-thickener tank, and formed a top plate for the building, inverting the plate and draping burlap inside the plate. We added glass mat for reinforcement and sprayed the fabric with polyester resin. When it had cured, we inverted the roof and placed it on top of the walls. The project was a success and served its use for many years.

My second prototype was a thermal home, built in 1982. Again, the process was very simple. For the roof, we draped uncut and unshaped needle-punched, geo-synthetic fabric[4] to the top of the walls. The drape was smooth, without wrinkles. Through an opened window, we blew air into the building, inflating the roof into multiple domes. We sprayed the fabric-domed roof with a three-pound density, closed-cell polyurethane foam; used an elastomeric coating on the roof exterior; and plastered the interior with a fire barrier. As noted earlier, this 30-plus-year-old thermal home is still weathertight.

JNIBS: WHO ELSE IS BUILDING CATENARY STRUCTURES?

Thoeny: I admire other practitioners who work with catenary structures, including:

- Steve Kornher, the principal of Flyingconcrete, who constructs his concrete domes using fiber concrete on welded-wire fabric (www.flying-concrete.com).
- David South of Monolithic and Monolithic Constructors, Inc., who builds large domes, including schools, and for agricultural bulk-storage.
- Mark West, a professor at the University of Manitoba's Department of Architecture and founding director of the Centre for Architectural Structures and Technology (C.A.S.T.), who has been experimenting with alternative construction and design methods, including the use of flexible fabric formwork for the production of reinforced concrete structures (http://umanitoba.ca/faculties/architecture/facilities/cast.html).

DEFINING CATENARY

Wikipedia, the free encyclopedia, defines "catenary" as a mathematical curve. "In physics and geometry, a catenary is the curve that an idealized hanging chain or cable assumes under its own weight when supported only at its ends. The curve has a U-like shape, superficially similar in appearance to a parabola, but it is not a parabola; rather, it is a (scaled, rotated) graph of the hyperbolic cosine. The curve appears in the design of certain types of arches and as a cross section of the catenoid—the shape assumed by a soap film bounded by two parallel circular rings. ...Catenaries and related curves are used in architecture and engineering, in the design of bridges and arches, so that forces do not result in bending moments."

JNIBS: WHAT KIND OF CATENARY RESEARCH IS GOING ON CURRENTLY?

Thoeny: Fabric-formed roof structures are being built all over the world, with many schools of architecture conducting research in alternative methods. Among them are:

- North Dakota State University in Fargo, where students and faculty are studying the use of bio-based (natural) fibers as composite reinforcement in polymer structures.
- The University of Michigan, in which textile composite materials are being used in new industrial knitting methods. The program has been funded by pharmaceutical giant Upjohn, which provides grants through its Research Initiative Program.
- In Belgium, at the Belgium Building Research Institute (and in cooperation with Princeton University),

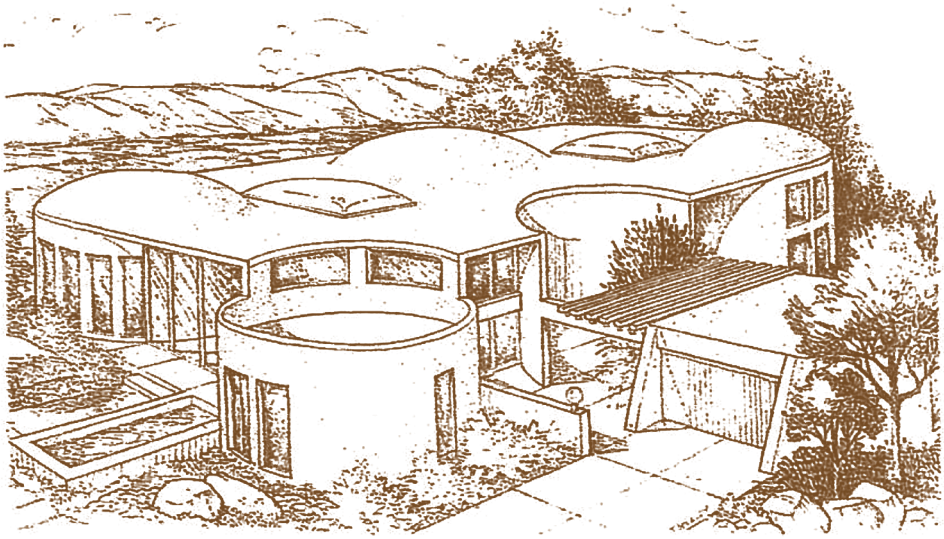


Illustration by Ted Thoeny, PE.

Niki Cauberg and fellow researchers are working with flexible fabric as a replacement for stiff traditional formwork to create double-curved, thin-shell elements.

JNIBS: LOOKING AHEAD, WHERE DO YOU SEE THE USE OF CATENARY STRUCTURES?

Thoeny: The future for catenary structures is unlimited, in that housing is not a luxury, but a necessity. The catenary roof is simple, inexpensive, and safer than many other forms of construction. Components range from jute to geo-fabrics, natural polymers to the latest manmade plastics. With continuing interest from product manufacturers, these structures are a roofing alternative that offers life safety, as well as reductions in material use and energy costs.

REFERENCES

1. J.F. Abel and J.C. Chilton. "Heinz Isler—50 Years of 'New' Shapes for Shells." *Journal of the International Association for Shell and Spatial Structures*, (52)3. 2011. www.schwartz.arch.ethz.ch/Publikationen/Dokumente/Isler.pdf.
2. Theodore "Ted" Thoeny, PE can be contacted at thoni@basicisp.net.
3. Lloyd Turner, architect, https://twitter.com/ahaaaa.
4. The geo-synthetic textile used was Mirafi® by TenCate, www.tencate.com/amer/geosynthetics/products/geotextiles/default.aspx.

RCI TO HOLD CANADIAN BES; SPEAKERS SOUGHT

RCI will hold its first Canadian Building Envelope Symposium September 13-14, 2018, at the Hilton Mississauga/Meadowvale in Mississauga, Ontario.

A call for abstracts has been issued seeking speakers for the event. Potential topics include information on curtainwalls, roofing, façades, wall technology, air-barrier systems, construction processes, sealants, hygrothermal analysis, and unique design solutions for the building envelope. Abstracts should be received at RCI headquarters by April 13. Papers will be due for peer review on May 25.

Contact Tina Hughes, thughes@rci-online.org for a copy of the Abstract Submittal Form and RCI Guidelines for Presentations.

INTERIM GRENFELL INQUIRY FALLS SHORT OF BAN ON COMBUSTIBLE CLADDINGS ON HIGH-RISE BUILDINGS

The interim report from the building regulations review ordered by the British Parliament following the deadly Grenfell Tower fire has fallen short of taking a stance on banning combustible clad dings on high-rise buildings. "This means we continue with this grey-area in regards to fire-safety," said Jane Duncan, immediate past president of the Royal Institute of British Architects and chair of RIBAs Expert Advisory Group on Fire Safety.

Dame Judith Hackitt, a chemical engineer, led the review and issued her report on December 18. She did call for a complete overhaul of the construction industry, finding that the system is "not fit for purpose." The report called for an end to cost-cutting on materials—the practice in which the building designed is not the one that's built, which is thought to have been a major factor in the fatal fire's rapid spread.

RIBA is calling for the final report, which is due in the spring, to require a named person or organization to be held accountable for the oversight of fire safety in the design and construction of a build ing project. It also has called for introduction of immediate changes to Approved Document B, the current fire safety guidelines, to ban flammable claddings on high-rise buildings. In the U.S., such alumi num composite panels as were installed on the Grenfell Tower are illegal in buildings over 40 feet in height.

— NY Times, Guamsite.com, and Durability and Design