An Introduction to Fabric-Formed Concrete for Architectural Structures – Part 1
Is There a Future for Fabric-Formed concrete Structures? – Part 2

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An Introduction to Fabric-Formed Concrete for Architectural Structures - PART 1

Fabric formwork is a unique method of forming concrete and there are benefits to the contractor using it successfully.

Figure 1. Juan Zurita residence.

Photo Credit: Studio Miguel Fisac

Throughout the 20th century, a number of innovators experimented with fabric as a flexible membrane for the support of fluid concrete, forming structural members. Significant among the early innovators were James H. de W. Waller (1884-1968) who in 1934 patented a fabric-formed system using hessian (burlap) fabric for numerous building components and in 1948, along with Kurt Billig, built corrugated concrete shell roof structures utilizing hessian fabric. In 1949, Felix Candela one of the most prolific of the shell builders and influenced by Waller began to experiment with fabric by utilizing burlap sacks stretched over wooden arches to form corrugated shell roofs. In the years following, Candela in turn influenced other visionaries including Pier Luigi Nervi (1891-1979) and Heinz Isler (1926-2009). Besides Nervi and Isler a few of the architects and engineers who used the forming materials at hand to create expressive forms out of concrete and masonry were Antoni Gaudi (1852-1926), Robert Maillart (1872-1940), Eladio Dieste (1917-2000) and Miguel Fisac (1913-2006).

FORMWORK APPLICATIONS

Alan Chandler in fabric formwork[1] notes "…for Felix Candela and Christopher Alexander fabric acted as a permanent shutter (formwork)…". Chandler speaks of the family of fabric construction that includes:

- Tensile structures
- Pneumatic structures
- Hydrostatic structures
- Shell structures derived from membrane form-finding

From this family of fabric construction what potentially practical applications exist? Fabric forming applications include:

- Walls - Cast-in-place, precast, Shotcrete thin-shell curtain wall systems.
- Beam and floor system - Trusses
- Columns
- Shells and vaults - Prefabrication of thin-shell funicular compression vaults, pneumatically fabric-formed thin-shell domes, molds for stay-in-place concrete formwork pans, pneumatically formed concrete impregnated fabric shells.
- Foundations - Continuous and spread footings.
- Civil engineering works - Revetments, underwater pile jacket, coastal and river structures.

While it is true that a flexible fabric formwork may be used nearly anywhere a rigid formwork is used, a significant amount of research remains to be done to bring these systems into everyday practical use by the construction industry. Standards and guidelines for using flexible fabric formworks need to be developed for the design community to take full advantage of this unique method of forming concrete members and feel comfortable using it. It should also be recognized that wood and/or metal used for forming is not totally eliminated by using fabric but can be reduced to essential components thereby saving natural resources. So what is the current state-of-the-art? Following are several architectural examples.

STATE-OF-THE-ART: ARCHITECTURAL FORMWORKS

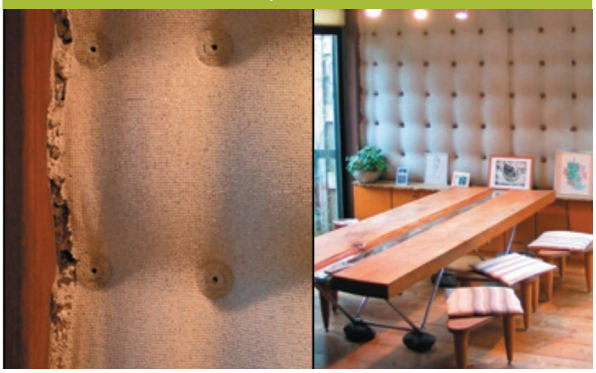
One of the first architects to use a flexible formwork in an architectural application was the late Spanish architect Miguel Fisac with his 1970's design of the Juan Zurita residence in Madrid, Spain, see **Figure 1**. His use of rope and plastic sheeting to create these precast panels imparts a sense of "warmth and softness" to an otherwise cold and hard substance. Fisac used this method throughout the 1970's to form the cladding of a number of structures.[2]

Another architect whose work has softened up concrete is Japanese architect Kenzo Unno. Working independently of Fisac he has developed several cast-in-place (CIP) fabric-formed wall systems since the mid-1990's. The Kobe earthquake on January 17, 1995 provided the motivation for Unno to create residential designs that are intended to provide safe housing using simple methods of construction with as little construction waste as possible. Using standard wall ties and the wall's reinforcement for support of the fabric membrane his quilt-point restraint method, for example, creates a pattern reminiscent of a quilt for the Eiji Hoshino Residence, **Figure 2.**

For the Susae Nakashima "Stone Renaissance" house a "frame" restraint method was employed using pipes at a slight angle to restrain the fabric and give these walls their own distinct character, see **Figure 3**.

Another practitioner that comes to mind is Sandy Lawton, a Vermont, USA design-builder. Lawton used geotextiles to form the columns, walls and floors for a nontraditional "treehouse" which was completed in 2007, see **Figure 4**.

Figure 2. Quilt-like formwork pattern used for the Eiji Hoshino Residence.
Photo Credit: Mark West photos



FOUNDATIONS

Industries are sometimes slow to embrace new technologies and industries utilizing fabric formworks are few. Since 1993 Richard Fearn, owner and founder of Fab-Form Industries, Ltd., has developed and marketed several fabric forming products including; Fastfoot for continuous and spread footings; Fastbag for spread footings and Fast-Tube for piers and columns.

PNEUMATIC FORMWORKS

Several methods of construction using inflated forms have been available since the early 1940's but it was only recently that American Concrete Institute (ACI) Committee 334 introduced a standard guide for the construction of thin-shells using inflated forms.[3]

David South, president and founder of Monolithic is the co-inventor of the Monolithic Dome and has been constructing thin-shell domes for more than 40 years. Monolithic's basic steps for constructing a dome are inflating an airform fixed to a foundation, applying a layer of polyurethane foam, hanging reinforcement and applying up to five layers of shotcrete. The inherent tensile strength of the PVC-coated or polyester fabric used for the airform allows it to be inflated to a sufficient strength to support all the applied construction materials until the concrete has cured to the point where the dome is self-supporting. Monolithic's use of fabric allowed the construction of thin-shell domes to once again be done economically.

Figure 3: Susae Nakashima "Stone Renaissance" house.
Photo Credit: Kenzo Unno

CONCLUSIONS

By utilizing a flexible fabric formwork, such as a geotextile, several advantages have been noted:

- The possibility to form very complex shapes.
- Geotextile fabric is strong, lightweight, inexpensive and is reusable.
- Improved surface finish and durability—due to its filtering action.
- A more efficient and sustainable design is possible since material is placed only where it is needed —"form follows function".
- Flexible fabric formwork increases freedom of design expression and can spark the imagination of architects and designers to think beyond the simple prismatic shape.
- The development of a fabric formwork system has the potential to significantly reduce man's impact on the environment in terms of materials and energy usage. **CC**

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Robert P. Schmitz, P.E. is a registered professional engineer in the State of Wisconsin, with more than thirty-five years experience in architecture and structural engineering. His research interest in fabric formwork comes as a result of work he completed for his Master's degree and his desire to see this unique method of forming concrete brought into mainstream construction practice. He is a member of ASCE and ACI. He can be reached via e-mail at rpschmitz@rpschmitz.com

Figure 4: "Treehouse" for Chuck and Wendy Black.
Photo Credit: Sandy Lawton

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Readers interested in additional information are encouraged to visit the following websites:

- Author's research dedicated website: http://www.fabwiki.fabric-formedconcrete.com/
- The International Society of Fabric Forming (ISOFF): http://www.fabricforming.org/
- See Umi Architectural Atelier website: http://www.umi-aa.com/architecture-en/
- See Sandy Lawton ARRODESIGN website: http://www.arrodesign.org/

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Is There a Future for Fabric-Formed Concrete Structures?

PART 2

This is Part 2 of a two-part article on the use of flexible formworks for forming concrete structures. Part 1 appeared in the February/March 2016 issue of Concrete Contractor and introduced this unique method of forming concrete. This article will focus on some of the obstacles to its use as practitioners: architects, engineers and contractors have yet to embrace this forming method as a replacement for or an addition to their conventional formwork systems.

Figure 1. Exterior view of the Schultz Residence .
Photo Credit: Sandy Lawton

A paper by D. Veenendaal et al.,[1] gives a detailed historical perspective of innovators who have proceeded us using fabric as part of their building forming systems, as hydraulic and geotechnical structures, as form liners and as the membrane in their pneumatic formed structures. Most influential were those innovators who used woven geotextiles for their civil engineering works such as revetments, underwater pile jackets, pond liners and coastal and river structures. Their research found that geotextiles offered superior concrete finish and durability, had exceptional strength and were a very economical way for containing concrete.[2] Additionally were those applications where fabrics, used as form liners, were also shown to improve the surface

quality and finish of the cast concrete member. They set the stage for today's researchers. Throughout the 20th century, a number of innovators experimented with fabric as a flexible membrane for the support of fluid concrete, forming structural members.

Despite decades since visionaries such as Heinz Isler and Antoni Gaudi used hanging chains and fabrics to visualize their shell structures, computational analysis still presents a challenge for structural members cast directly into a flexible membrane.[3, 4, 5] The author and several others have explored the analysis of these complex forms.[6, 7, 8] My research involved the development of an FEM (finite element method) procedure to design a fabric cast wall panel.[9, 10] Straightforward methods of analysis and design are available for the conventionally cast concrete wall or floor panel. This is not the case for the wall panel cast in a flexible fabric formwork.

It bears worth repeating that while it is true that a flexible fabric formwork may be used nearly anywhere a rigid formwork is used, a significant amount of research remains to be done to bring these systems into everyday practical use by the construction industry. Standards and guidelines for using flexible fabric formworks need to be developed for the design community to take full advantage of this unique method of forming concrete members and feel comfortable using it. We recognize that wood and/or metal used for forming will not be eliminated by using fabric but can be reduced to essential components thereby saving natural resources.

There are a number of issues and hurdles to be overcome before architects, engineers and especially concrete contractors are accepting of this unique method of forming concrete. While geotextile fabric as a formwork has a number of distinct advantages including:

- The possibility to form very complex shapes.
- It is strong, lightweight, inexpensive, reusable and will not propagate a tear.
- Less concrete and reinforcing are required resulting in a conservation of materials.
- Filtering action of the fabric improves the surface finish and member durability.[2, 11, 12]

It also has several disadvantages including:

- Relaxation can occur due to the pre-stress forces in the membrane.
- The potential for creep in the geotextile material, which can

be accelerated by an increase in temperature as might occur during hydration of the concrete as it cures.

- The concrete must be placed carefully and the fabric formwork not jostled while the concrete is in a plastic state.

However, until new fabrics are developed the benefits of using geotextiles far outweighs any disadvantages. In addition, unless standards and guidelines for use in precast and cast-in-place forming systems are developed this method of forming concrete will remain a niche market exploited only by those brave and bold enough to challenge the status quo. To be of practical use to the design community some standardization of systems and guidance are needed for contractors to feel comfortable using flexible formworks.

After reviewing recent e-mail correspondence from three of the leading proponents of fabric formwork regarding their thoughts on the future of fabric-formed concrete, Richard Fearn of Fab-Form Industries and Professors Remo Pedreschi and Mark West I get the impression that making an immediate and significant industry impact is indeed difficult. All three indicate that the very nature of the marketplace is complex and that for the builder, who may be selected solely based on his/her low bid, he/she may be reluctant to take on an unknown system. There is a risk involved when pursuing new means of construction. However, Professor Pedreschi says we should not see fabric formwork as a replacement but a new "disruptive technology" that offers us the opportunity to design formwork in a new way.

CONCLUSIONS

To date, three fabric-formed concrete conferences have been held. From these dedicated conferences have come more than 75 papers and presentations on this topic. Therefore, it would appear, from at least the international scene, the movement, if it can be called that, is alive and well.

Is there a future for fabric-formed concrete structures? Given the current level of research and enthusiasm that was expressed at the most recent conference; the answer is **maybe**. Practitioners: architects, engineers and contractors have yet to embrace this forming method as a replacement for or an addition to their conventional formwork systems. The current disconnect between academia and industry needs to be overcome. From a practical point of view, the answer may be one where fabric formworks do not replace but supplement

conventional forming methods.

This fabric forming concrete method has special properties, structural advantages unique to its use as outlined above and we fully expect to see it grow beyond the "niche" or novelty forming method marketplace it currently occupies. It will just take collaboration with industry and time. CC

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Figure 2. View of stripped formwork (left) and insulation cavity (right).
Photo Credit: Sandy Lawton

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