Frank Lloyd Wright's Textile Block System: The Inspiration for a Sustainable Future

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Abstract:

Frank Lloyd Wright had a vision for an inexpensive, aesthetically pleasing precast concrete modular block system, locally-produced and assembled without the use of a mason. His vision never took hold, in large part due to the technological limitations of the period. It is possible that, 88 years later, these limitations can be overcome by using architectural precast techniques, realizing Frank Lloyd Wright's original idea of replacing masonry with something better.

Keywords: Frank Lloyd Wright, modular, textile block, wall, residential

(All photographs are by the author unless noted otherwise)

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Introduction

When Frank Lloyd Wright (Wright 1992a, 242) devised his "textile block" system, he envisioned it as a mono-material – one material that would have integrity, serve as both the inner and outer finished surfaces of a wall, support floor or roof loads, and provide insulation and protection from the weather. To be successful, it would have to be inexpensive yet aesthetically pleasing, locally-produced from local materials, and assembled without special skills or equipment. As he wrote in his autobiography, concrete block was "the cheapest (and ugliest) thing in the building world... Why not see what could be done with that gutter-rat?" (Wright 1998, 235)

In the early 1920's, Wright designed a series of homes that incorporated a reinforced precast concrete load-bearing modular block system. The first of these homes were built in the dry, wooded hills around Los Angeles—areas prone to wildfires.

The wall system for these homes consisted of a dry-cast double precast concrete block wall with an air gap between the outer and inner wythes. The outer wythe was optionally stamped with a decorative pattern. The 16 in. square site-cast blocks were stacked and reinforced horizontally and vertically with a "fabric" or mesh of grouted reinforcing bars, 16 in. on center. Although the existing homes have exhibited serious problems over time, a case can be made for resurrecting the system using new technology. In this paper, design possibilities will be explored.

The Storer House - 1923

Wright first used the textile-block system on the John Storer house in Hollywood in 1923, with Wright's son, Lloyd Wright, supervising construction. According to the original specifications, the blocks were to be made from one part portland cement to four parts sand or decomposed granite. Consistency was to be such that the mix would hold its shape when squeezed by hand, and it was to be used within a half hour. Blocks were to be formed by pressure into machined metal molds, then removed immediately and kept moist for at least 10 days (Sweeney 1994, 59, 62).

The actual block dimensions were exactly 16 in. by 16 in. with no tolerance, hence the need for precision-machined molds. There was no mortar joint between the blocks. A formed reveal was used instead, which gave the appearance of a tooled joint.

Figs. 1-2 Storer house, built 1923. Note the tight rustications

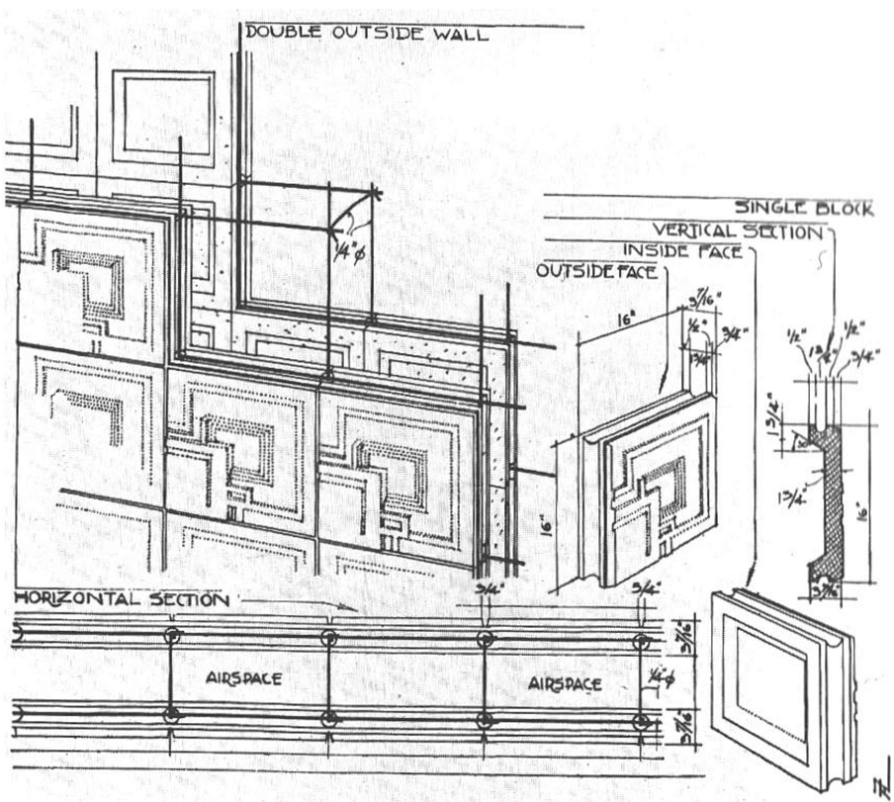


Fig. 3 Richard Neutra sketch (Sweeney 1994, 231)

The Freeman House, - 1923

Later that year Wright was commissioned to design a home for Samuel and Harriet Freeman in the Hollywood Hills neighborhood. This was to be a relatively small house for a client of modest means. Wright undoubtedly felt that this would be a good test case for his new textile block system. It used inexpensive materials and could theoretically be assembled using unskilled labor.

Unfortunately, the cost of completion was almost two and one half times Wright’s original estimate. There are many possible reasons for this. It could have been due in part to excessive labor costs resulting from not having a cement mixer on site (Sweeney 1994, 73) or Wright’s penchant to embellish his designs and refuse compromise, or delayed communications with the contractor (Lloyd Wright) when Wright returned to Wisconsin, or a combination of the above. Wright’s original estimate assumed 9000 blocks would be required at a cost of 30 cents each, totaling $2700. The 11,000 blocks actually used cost 66 cents each, for a total of $7260. (Chusid 1989, 49) That represents a $4560 increase, just for the blocks. Harriet Freeman never forgave Wright for the cost overruns and continued to complain about it 60 years later (Freeman 1983). Regardless, the Freemans loved the house and remained the only owners and occupants until the house was bequeathed by Harriet Freeman to the University of Southern California School of Architecture in 1986.

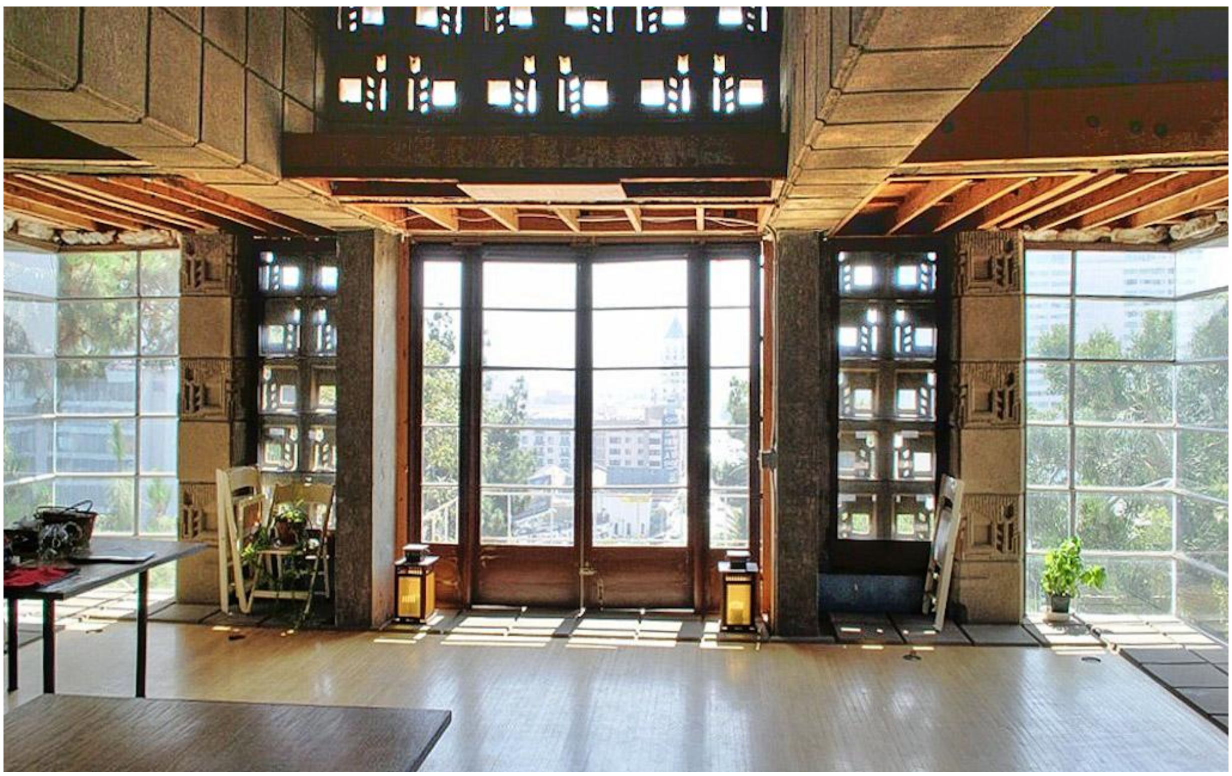


Fig. 4 Freeman House living room

The Ennis House - 1923

Later in 1923, Wright had the opportunity to further test the limits of the textile block system when he received a commission from Charles and Mabel Ennis to build a home in the Los Feliz area of Los Angeles. The Ennis’ had the resources for a large house on a grand scale. Wright’s budget would not be as constrained as it was with the Freeman house, and he took advantage of that fact to further flesh out his mono-material concept. Inspired by Mayan ruins, He used offset blocks to form battered walls. Plus there was extensive use of textile block on floors and ceilings. The ceiling blocks served as stay-in-place forms for a reinforced concrete structural slab. Reinforced concrete posts and beams have textile block facings.

Visually, the house is monumental in scale and posture – uncharacteristic for Wright. It's no exaggeration to say that it dominates the hillside in an almost brutal fashion. Unfortunately, the Ennis' were not of the same mind with Wright and made changes to the design that eventually led Wright to resign from the project (Sweeney 1994, 90-91). Even so, the Ennis house arguably stands as one of the most complete built examples of Wright's modular, mono-material, machine-age vision.

Fig. 5 The Ennis house

Strengths and weaknesses of the original textile block system:

The total number of textile block buildings actually constructed is small, only 42 at 22 different sites, by the author's count. Why didn't this revolutionary building system sweep the nation, as Wright had undoubtedly hoped? If his vision was sound, there must have been flaws with the execution. Was Wright limited by the technology of his day? He endeavored to re-invent concrete masonry and turn it into something else altogether. The first task was to overcome the limitations of traditional masonry. Some of these are:

It's labor-intensive: The process of constructing a masonry wall using mortared joints is slow, and requires specialized, skilled labor. The finished result is highly dependent on the skill of the craftsman. In fact, building codes require inspection of a wall before it can be used in a structural capacity.

Wright tried to change that by devising a connection system for the blocks which eliminated mortar joints. The blocks were to be cast to precise dimensions so that they would fit tight. Alignment would not be necessary as long as the joints were snug. In actuality, the lack of tolerance made it difficult to correct for any errors in alignment – there was no "fudge factor". Grout was also required to fill the channels which held the reinforcing bars that "knit" the units together. The blind nature of the connection made it hard to tell when a channel was fully grouted, and, in practice, many weren't. (Fidler 2007, 25) In some cases, the only grout found in some joints were at the block corners (Chusid 1989, 177). Therefore, in practice, the walls did not go up any faster than with traditional masonry and may have been slower, based on the reports of construction delays with some of the Los Angeles textile block houses. (Sweeney 1994, 75)

It's non-insulating: Concrete is not a good insulator. The "R" value of concrete is only 0.08 per inch. Hollow concrete block performs a bit better, due to the air voids. Still, an 8" hollow block has an R rating of only 1.1. Lightweight concrete and cinder block have a higher R than normal weight concrete. What works to concrete's advantage however is its mass. It takes a long time for heat to be absorbed by the wall. This works well in warm dry climates, where the wall can absorb heat during the day and release it at night when it's cool.

Wright was probably aware of this beneficial thermal characteristic of concrete walls when he specified them for the four Los Angeles textile block houses. The main reason for using a double wall with a 3" air gap was likely not for the insulating value of the air gap, but to provide a path for infiltrated water, so that the inner wythe would remain dry -- which leads to the next point:

Water and air infiltration is a problem: Dry-cast concrete can be porous. Untreated, it may absorb water. In cold climates, this is deleterious because absorbed water will expand as it freezes and potentially cause spalling. In addition, in any climate the water can bring salts (chlorides) with it that can corrode reinforcing. That can also cause spalling, as the corroded reinforcing expands.

Wright's solution for preventing water penetration was not new. He used an air gap between the walls. The intent was that any water that penetrated the outer wythe through capillary action would trickle harmlessly down the air gap and exit at the foundation. Unfortunately, metal wire ties were used to connect the wythes and keep them together. Water could travel along the wires to the inner wythe and enter the finished space, which it did frequently. (Chusid 1989) A vapor barrier or a sloped joint or a block that was moisture-resistant would have helped.

It's heavy: Block size was limited by what a person could lift. According to Wright:

> *"A unit-mass of concrete, size and shape determined by the work intended to be done and what weight a man can be reasonably be expected to lift and set in a wall, is fixed upon. This in order to avoid the expensive larger molds—say, the slab block we make 16" x 16" x 2½" thick."* (Wright 1992a, 242)

The smaller the block, the more joints and labor involved for installation. Assuming a unit weight of 140 pcf and an average thickness of 2¼", a 16" square Freeman house block would have weighed around 45 lbs. A 16" width worked well within a 4 ft. module and resulted in a block size that a man could lift.

Another important reason to keep the weight down was to reduce the load induced by a seismic event. The weight of a structure works against it in an earthquake. It's best to use lighter materials and keep the weight close to the ground. Unreinforced masonry performs the poorest of any wall type, due to its weight and brittle structure. The California legislature outlawed unreinforced masonry construction after the 1933 Long Beach quake. Many unreinforced brick buildings collapsed, including some schools, while wood, steel and reinforced concrete structures suffered much less damage.

Although state-wide code requirements for earthquake resistant construction did not exist until 1927, Wright was well aware of the danger by 1923, having just finished the Imperial Hotel in Tokyo. To "reinforce" the point, the hotel successfully weathered the Great Tokyo earthquake of 1923 just as construction was starting on his first textile block house, the Storer house in Hollywood. His idea for the system was to weave vertical and horizontal ¼" reinforcing bars every 16" on center. Grouted solid, he expected the walls to act as a monolithic reinforced concrete wall:

> *"Grooves are provided in the edges of the slab-blocks so a lacing of continuous steel rods may be laid in the vertical and horizontal joints of the block slabs for tensile strength. The grooves are as large as possible so they may be poured full of concrete after each course of blocks is set up, girding and locking the whole into one firm slab. Here ultimately we will have another monolith fabricated instead of poured into special wooden molds. The molds in this case are metal, good for many buildings, and take the impress of any detail in any scheme of pattern or texture imagination conceives. The whole building "precast" in a mold a man can lift."*

The American Concrete Institute specifies a minimum reinforcing ratio for reinforced concrete walls of 0.002. This minimum is a serviceability requirement intended to control cracking and would not necessarily be adequate to resist applied loads. The textile block system has a reinforcing ratio of 0.0021, slightly better than the current minimum requirement. Unfortunately, the uneven coverage of the bars by grout weakened the system. In addition, the ravages of time, weathering, spalling and corrosion further weakened walls on the Freeman and Ennis houses to the point where they were significantly damaged by the 1994 Northridge quake.

There were additional problems unique to the textile-block system:

As noted earlier, Wright was taken by the romantic ideal that a building should be a part of its site. He meant this literally. He liked to think that one could build a house by bringing in bags of cement, rebar and a couple of molds in the back of a Ford pickup. In Wright's words:

> *"Several mechanical molds may be thrown into a Ford and taken where gravel and sand abound. Cement is all else needed, except a few tons of ¼" commercial steel bars, to complete a beautiful building. This—and an organization of workmen trained to do one thing well."* (Wright 1992a, 243)

The site would supply the sand and aggregate. To take it even further, for the Freeman and Ennis houses, earth from the site may have been added to the mix to give the blocks a buff color. (Chusid 1989, 224) A petrographic analysis of an Ennis house block adds credence to this speculation:

> *"The aggregate used in the concrete might be partly responsible for the weakening of the textile blocks near to their surfaces. It includes two forms of clay that can cause micro-stresses by shrinking and expanding in response to changing moisture conditions, as well as feldspar which can decay and disintegrate in the presence of water."* (Fidler 2007, 25)

According to a 2007 report on the condition of the Ennis house undertaken by Simpson Gumpertz & Heger:

> *"The original site manufacturing conditions and processes associated with the textile blocks were apparently rudimentary with no effective batched mixing, no true compaction of the wet concrete, and limitations in site curing. Combined with the choice of aggregate, they are all contributing factors that may have resulted in poorly consolidated surfaces lacking cement paste, that have been further affected by carbonation, leaching and the dissolution of the binder. The surfaces thus act like a sponge and take up moisture with great rapidity."* (Fidler 2007, 25)

In addition to the problems encountered trying to fully grout the reinforcing located in the channels, the concrete mix was of poor quality, containing clay and decomposed granite (feldspar), and curing was deficient. This made the blocks porous, and they absorbed water quickly, furthering the deterioration.

These problems likely could have been avoided by commercially producing the concrete block. A commercial plant would have used aggregate and sand from approved sources and the ratio of cement and water would have been controlled by careful batching. In addition, the curing process would have been more consistent.

Benefits provided by the original textile block system:

The question has to be asked: If there were so many problems with Wright's original textile block system, what value would there be in resurrecting it?

It's made from inexpensive, local materials: Around 80% of the dry volume of a textile block consists of sand and fine gravel. These materials are ubiquitous practically anywhere on the planet. An "organic" building should certainly make use of the most abundant solid material on the face of the earth.

The second major ingredient is portland cement, consisting of around 20% of the dry volume of a mix. Cement is easily obtained locally, and is inexpensive. In fact, concrete is the single most widely used material in the world. One concern is that cement production is estimated to contribute 5% of total man-made carbon dioxide emissions. Currently about 800 lbs of CO_2 is released for every 1000 lbs of cement produced. (Crow 2008, 64) The industry is working to reduce this number, and cement replacements are coming on the market which are carbon neutral. Even as-is, concrete has lower embodied energy than glass and steel. Precast concrete block production reduces waste, because very little material is wasted in the process.

Water is also used—water cement ratios typically range from 0.4 to 0.55 by weight. Taking the weight of portland cement to be 94 pcf and the weight of water to be 62 pcf, the volume of water required per cubic foot of concrete would be around 0.15, or 15% of its total volume. Around half of that water permanently chemically binds to the concrete, and another 25% remains as moisture content, depending on the humidity. (Kosmatka, Kerkhoff, and Panarese 2008) The remaining 25% evaporates. The water used can be non-potable.

That's not a lot of water, when compared to the amount of fresh water required to make many other products. For example, according to the Water Footprint Network, 10 liters of water are required to make one sheet of letter paper. (WaterFootprint.org) Therefore, save some water and do not print this document!

The last major ingredient to consider is the steel reinforcing. Quarter inch diameter bars were used at the perimeter of the 16" square blocks. A single bar area is 0.05 in^2. For a single wythe wall, that works out to 1.6 in^3 per block. Block volume is estimated at 576 cubic inches, so the reinforcing accounts for less than 0.28 percent of the volume of material. 0.9 cubic inches of steel is used per square foot of wall area, or 4 ounces worth. Steel requires a lot of energy to fabricate, but very little of it is required for the textile block. Plus, steel is highly recyclable. According to CRSI, reinforcing steel typically contains at least 97% recycled content. As of 2008, around 70% of reinforcing steel is recycled. (www.Recycle-Steel.org)

Based on the above qualities, the original textile block system would contribute toward LEED points for Construction Waste Management (MR-2), Recycled Content (MR-4) and Regional Materials (MR-5).

It provides a thermal mass benefit: In warm, dry climates, the mass of the blocks will tend to moderate indoor temperatures. Wright would have been aware of the tendency for concrete buildings to stay relatively cool during the day. The material acts as a heat sink, absorbing heat during the day, and releasing it at night when it is cooler. He exposed the concrete block walls to the interior partly to take advantage of this characteristic. *"...a building permanent and safe, dry and cool in summer, dry and warm in winter."* (Wright 1992a, 243)

An energy simulation of the Freeman House reveals limitations to the thermal mass benefit if insulation is not added between the concrete wythes (HEED analysis by the author). Without insulation, the warmth can radiate to the outside as well as the inside, so at least half of the stored energy is lost.

In cool climates, solar orientation is very important. One needs south facing windows with overhangs and a concrete floor or mass wall to store the direct solar gain through the windows. On the Freeman house, Wright used south windows, overhangs (at least on the upper level), and earth sheltering for the lower level. With proper insulation and glazing, the energy savings would have been significant, according to the author's HEED energy simulation.

Fire resistance: The textile block would be suitable for use as a fire wall under current codes. The first textile block homes were built in the dry hills around Los Angeles. Forest fires were a concern. Concrete construction provides excellent resistance to heat transmission during a fire. A homeowner may be able to receive a lower insurance rate for using this type of construction.

Insect / Pest resistance: Termites and carpenter ants don't like concrete and rodents would have a very hard time chewing through it.

Durability – lasts longer than wood frame construction: Properly produced concrete can last for centuries. Wood needs to be protected or it deteriorates rapidly. Modern concrete can provide a zero-maintenance exterior and interior finish.

Security: Reinforced concrete wall construction is preferred—required, actually—for secure facilities. It can't be easily cut through or damaged by impact. That is why it is specified for prisons and other secure facilities. According to a Canadian study of the bullet-resistance of wall assemblies, only the brick and concrete block walls were able to stop all but the largest 50 caliber rounds. (Kashuba 2001)

Resistance to severe storms, such as hurricanes and tornados has also been documented. On March 17, 2008, Jim Cantore from the Weather Channel tested a concrete sandwich wall with a thickness similar to the textile block live on national TV. Wood 2x4's were shot out of an air cannon at EF-5 tornado speeds (240 mph) at various standard wall assemblies. The author was in attendance and witnessed the demonstration. The 2x4 easily penetrated the vinyl-clad wood frame and even a brick veneer wall, but was stopped by the precast concrete wall. A subdivision of concrete homes using this type of construction was built in Naperville, Illinois.

Blocks noise – sound transmission: The STC rating of two 2" thick concrete walls together is 49, which is very good (Precast/Prestressed Concrete Institute. 2010, 11-25). STC stands for Sound Transmission Class, and higher numbers block more sound. The rating is based on the decibel scale, which is logarithmic to base 10. This means that an STC difference of 10 equates to either ½ or twice the sound energy level, depending on the reference. By comparison, a standard 2x4 wood stud wall with batt insulation has an STC rating of 34 to 39 (STCRatings.com). As this world becomes more crowded, and traffic and car alarms more prevalent, the ability to block exterior noise is certainly desirable.

Can be assembled without the use of heavy equipment or formwork: Wright believed that precast concrete—that is, concrete "units"—would supplant cast-in-place concrete, as was previously used to great effect for his design for the Unity Temple in Oak Park, IL (1904):

> *"But at the present time there comes a less cumbersome and a cheaper because less wasteful method than the molds on a large scale that built Unity Temple. It was necessary then to build a rough building complete in wood as a "mold" into which the temple would be cast. Now, in this easier more plastic method, standardization enters as the 'unit-system'."* (Wright 1992a, 242)

He goes on to describe the unit as based on the "mass of concrete" that a man can lift. It sounds like, if he had it to do over again, the Unity Temple would have been constructed out of precast concrete units. He has a point. Large, single-use formwork is wasteful. Better to use a few small molds and use them over and over again.

In modern times, precast concrete has made inroads against cast-in-place and standard masonry construction for many building types. Modules are factory-cast to a size as large as will fit on a truck for delivery to the job site. There, they are erected with the use of a crane.

Precast masonry-like units, as used by Wright, has similar advantages, only it doesn't require the rental of an expensive crane. Construction can proceed at its own pace, allowing other trades access as required, without worrying about multiple move-ins with the crane. This is most beneficial on residential projects where the budget is limited.

No maintenance required: If cast and assembled properly, exposed precast concrete walls require no maintenance. The normal variation in tone and coloration between units adds character and authenticity, as one would experience viewing a European cathedral or Mayan ruin.

Fig. 6 Arizona Biltmore cottage, built 1929

No VOC's: Concrete is inert, and doesn't off-gas like some other building materials that contain formaldehyde or other volatile organic compounds.

Patterns: Cast patterns were integral to the original textile block system. In Wright's words:

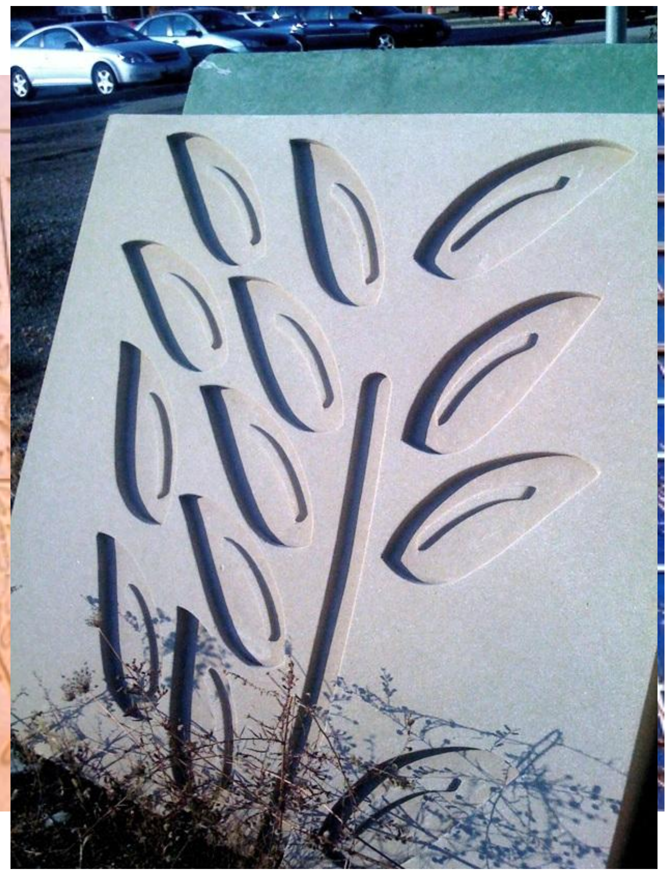
> *"The material* en masse *may be printed, "goffered," while fresh and wet, as the printer's die embosses his paper—and such effects had as may be seen in stone where fossil remains of foliage or other organic forms, either cameo or intaglio, are found in it. And this treatment would be nearer to its nature, aesthetically, than is any casting whatsoever."*(Wright 1992a, 304)

Here, Wright decries the casting of concrete to imitate other materials and offers "printed" patterns as a preferable alternative, "nearer to [concrete's] nature". In the early days of the concrete block industry, patterns were common. Starting around 1930, automated, smooth-face cinder blocks started to supplant stamped blocks for typical masonry construction.

In addition, the rise of the International Style, as promoted by an exhibit organized by Phillip Johnson in 1932 at the Museum of Modern Art, signaled the decline of patterned "decoration" on buildings. Wright's 1929 house for Richard Jones reflects this influence. There are very few visibly patterned blocks on this building.

In the 1950s, Wright abandoned the use of patterned blocks in the hope that a manufacturer would license and produce his Usonian Automatic block system. In an era where there was only one flavor of Coca Cola, patterned blocks would be too much for a potential manufacturing partner to handle. Standardization was believed to be the key to an economical, factory-produced system. Unfortunately, no manufacturer emerged, and the few Usonian Automatics that were built used the same labor-intensive methods utilized 30 years previously on the Los Angeles houses. These were experimental concept homes, funded by their original owners, perhaps unwittingly.

What can be said of patterned concrete today? With the demise of Modernism, ornamentation has come back. Vernacular forms are back, and concrete has again been "cast" into the role that Wright despised -- imitating other forms. There is some hope. Precast patterned concrete can be found here and there. The Los Angeles houses and the Arizona Biltmore cottages are treasured and revered more than ever. Wright enthusiasts routinely come up to the houses to stencil the block pattern. Some have recast the patterns for use as decorative walls.



Figs 7-8 Leaf pattern on the Corner Children's Hospital, University of Chicago, said to be inspired by the ivy-covered U of C campus. (PCI-IW.org)

Applications for the developing world: Masonry has traditionally been a favored material for the developing world. The raw materials are inexpensive and locally available. Heavy machinery and expensive fossil fuel is not required to install it and it does not take much energy to produce. With the introduction of magnesium-oxide based cements, concrete units can have a carbon-neutral or even carbon-negative effect on global warming. The ability to reuse the units creates a market for second-hand construction products, further enhancing the economy. It can be used in areas where the forests have been clear-cut and the only available construction materials are sand and gravel. Thermal mass benefit provides temperature control without the use of mechanical heating or cooling systems. The capability of the textile block to use custom patterns, pierced and glazed block enhances and beautifies an otherwise utilitarian product.

Assuming the aesthetics, philosophy and vision of Wright's original textile block system are sound, what recent advancements in building technology can improve the performance of the system?

Moisture resistance: One common complaint is that water penetrates the walls, entering the finished space. "Standing puddles" have been commonly observed in the living room of the Freeman house (Beltran 2006, 11-12). The roof on the Freeman house was replaced in 2002, but the water penetration continued. Alice Beltran, while an MBS student at USC, studied the problem and found that the dry-cast blocks were extremely porous, soaking up water "like a sponge" (Beltran 2006, 71). Despite this, the air cavity between the block wythes should have stopped any water that penetrated the outer wythe from entering the finished space. Beltran identified two likely mechanisms for infiltration. One route would be through beam penetrations. The beams bore on the outer wythe, so water could travel along the beams to the inner wythe. Secondly, areas were identified that had solid grouting between the wythes. Water could travel through cracks in the grout via capillary action to the inside. Chusid notes that the Freeman house is the only textile block building with mitered corners. The miters have been identified as a route for water infiltration, causing rusting and expansion of the steel. (Chusid 1989, 222) The other built examples used U and/or L-shaped corners.

The author has identified several other likely routes of water entry into the Freeman house. According to Neutra's detailed sketch of the textile block system, metal ties were used to tie the wythes together every 16" on center (or 32", according to Eric Lloyd Wright). Water could travel along the ties or condensation could form on the metal. Furthermore, if the foundation wall was built at or above floor level, which it likely would have been at the north wall, then water could travel down the inside of the wall cavity to the top of the foundation wall and weep to the inside instead of the outside. Furthermore, Wright did not put a cap flashing on the roof parapets, since that would disturb the look of the façade. Without a flashing, water could enter the wall at the top and travel along the inside wythe.

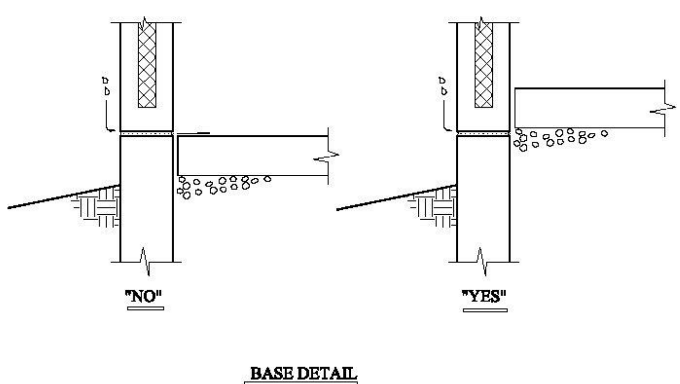
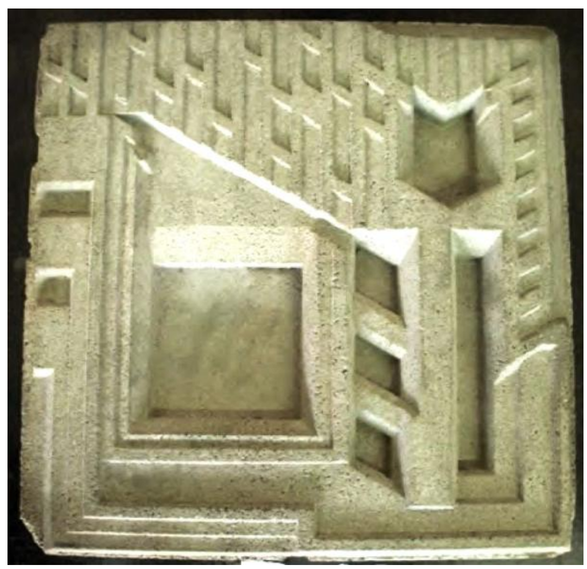


Fig. 9 Base Detail

What can be done to make the textile block system water resistant? As discussed above, proper detailing to minimize water infiltration is one thing, but that should be standard practice. One issue is the porosity of the block.

The concrete mix: Concrete masonry is typically dry-cast. This means that a very stiff mix is used, with as little added water as possible. This is done so the block can be formed and the form removed within minutes, while the block holds its shape. That way, the same form can be used over and over to make up to 100 blocks a day. The economy of concrete block construction is dependent on this method. A drawback with dry-cast blocks is that they can be porous if not produced properly. There may not be enough water available to send the cement paste into every nook and cranny.

One possible solution is to leave the blocks in the form overnight. The problem is that now up to 100 times as many forms are required. This was done for the Ennis house restoration. Thirty urethane rubber and fiberglass forms for each block type were used (author conversation with Paul Dreibelbis and Jeff Keenan of Moonlight Molds, 8/24/2010). The mix used was still a dry mix, since the blocks needed to match the existing blocks as much as possible. By contrast, a wet-cast block has a much smoother surface, and is not as appealing to look at. Wet cast surfaces are typically treated after casting by water wash (with retarder), sandblast, acid-etch or stain to provide a more pleasing appearance.



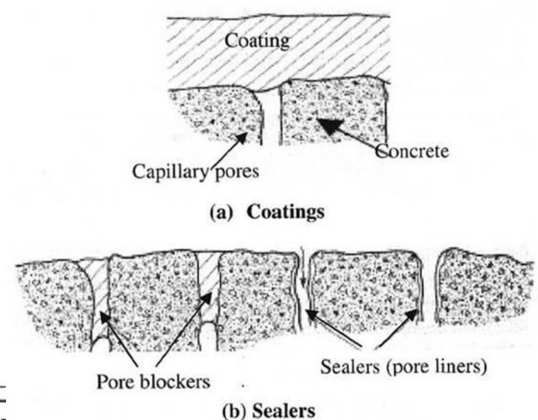
Figs. 10-11 Original dry-cast Freeman block, 1924 *A wet-cast Freeman block*
(McAlister 2009, 123)

Admixtures: In addition to leaving the Ennis replacement blocks overnight in the form, an acrylic thermoplastic co-polymer emulsion admixture was used. According to the manufacturer, this admixture speeds up curing (cover overnight instead of 7 days) and improves workability at low water cement ratios, providing a denser product that is more resistant to moisture absorption and vapor permeability. A Type III, or high-early strength cement can also be used to speed up form removal.

Sealers: An applied sealer can provide another, supplemental means of protection against water penetration. Silane/siloxane-based sealers have been used successfully. The benefit of this type of sealer is that it penetrates and does not affect the color or surface texture of the concrete. It doesn't form a film and leaves the surface breathable, so vapor can escape. This could be at least a partial solution to the water penetration problems on the historic Los Angeles textile-block houses as well.

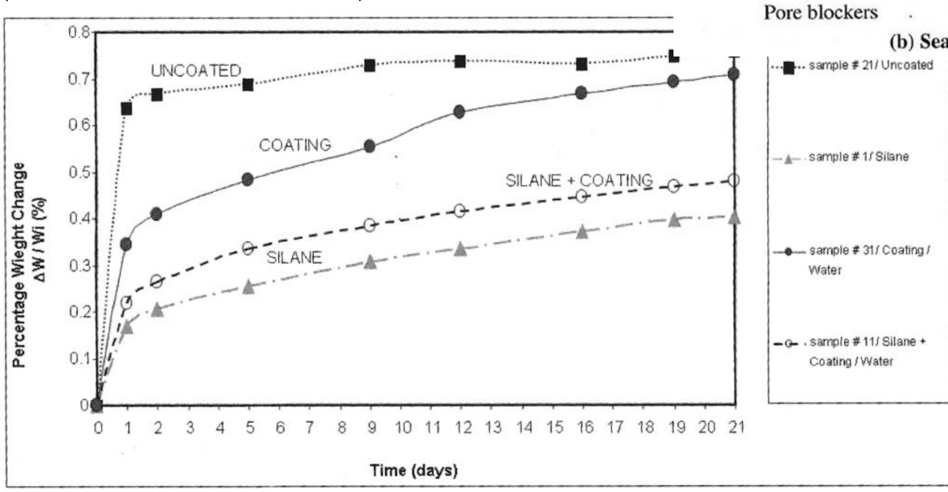
Unfortunately, many of these products don't comply with the South Coast Air Quality Management District Rule #1113 for volatile organic compounds in sealants, and so would be illegal in California, and not eligible for LEED points in other states. There are some recent formulations, however, which are below the California requirement and eligible for LEED points.

Figs. 12-13 Sealers versus coatings:



Below is a graph of water uptake by concrete coated with a silane sealer, and/or a coating. The silane sealer alone provided best performance with the added benefits of not altering the appearance of the concrete surface or trapping water vapor like a coating would.

(Shi and Mo 2008, 335, 347)



Insulation: The textile block houses were not insulated, except by an air gap between wythes of from 1" to 2 ½" wide. The R value can be calculated as follows:

Outside surface:	0.25
2" concrete	0.20
3" average air gap	1.00
2" concrete	0.20
Inside surface	0.68

Total R:	2.33

Not very high! It's about the same as a double pane window. Adding insulation would be highly recommended. One possibility is a soy-based insulation product. Despite its biological source, it does not support mold growth and will not provide food for insects or other organisms.

The weight of a typical product is 1.7 psf with an R value of 5.9 per inch for the closed cell product. (Closed cell is recommended when water penetration is an issue or to provide a vapor barrier.) A 3" layer can provide R-19 for the wall assembly, well above the California Title 24 wall requirement of R-13:

Outside surface:	0.25
2" concrete	0.20
3" soy insulation	17.70
2" concrete	0.20
Inside surface	0.68

Total R:	19.03

The insulation could be foamed in place after assembly of the wall (through ports or temporarily omitted blocks). Alternatively, it could be incorporated into a dual-wythe block using non-conductive fasteners to connect the wythes together, forming a sandwich. This would have many other advantages. It the connectors were rigid, the block would behave compositely. Instead of two 3" thick block wythes, one would have one 8" thick block. It would be much more stable. The need for temporary wall bracing would be reduced.

Based on engineering mechanics, a composite wall is eight times stiffer, can take three times the flexural stress without cracking, and has twice the ultimate strength of an equivalent non-composite wall of similar thickness. To accomplish this, the wythe connectors need to be stiff enough to transfer shear between the wythes. Non-conductive connectors are preferred to minimize thermal bridging.

One drawback of a dual wythe block is that it will weigh twice as much as a single wythe block. This can be mitigated somewhat by using lightweight concrete and thinner wythes. Assuming a concrete weight of 110 pcf and 2" wythes, a 16" square composite textile block would weigh 65 lbs.

Another possibility would be to use an insulating concrete rather than organic insulation. The University of Aachen, Germany has sandwiched a layer of lightweight self-consolidating foam concrete (SCLFC) between two thin layers of fabric-reinforced concrete to create a lightweight insulated concrete wall. (Mott, Steinhoff, and Brameshuber 2010) The concept could just as well apply to a concrete block. Wright would likely have been interested in this concept because it is a "mono-material". Even the insulation would be made of concrete. The insulating concrete has a density of 450 kg/m^3 (28 pcf). Despite its light weight, it has load-bearing capacity. A foaming agent and lightweight aggregate were used. It is not suitable for use as a surface exposed to weather, however, so 3/8" thick layers of high-strength concrete reinforced with a fiberglass fabric are used for the outer wythes. The resultant R value is relatively low, however: 1.38 per inch. It would require a 13" thick wall to achieve an R-19 wall assembly rating. That may be too much of a penalty to pay for a true mono-material.

Connections: The textile block system gets its name from the crisscrossing network of ¼" steel reinforcing bars that hold it together. Wright was very fond of this system and used it on all the textile-block buildings, from the first Los Angeles house in 1923 to the last Usonian Automatic in 1955. The intent was to eliminate the mason, the skilled union labor that he believed helped drive up the cost of construction for the homeowner. By using a form dimension equal to the module, be it 16" square or 12" by 24" (Usonian Automatic), there was no need to level each course, because if the blocks fit tight together, the module dimensions would be maintained "automatically". In reality, even under the best of conditions, there would be at least a 1/16" dimensional variation from block to block.

As noted previously, it was difficult to ensure that the grout completely filled the channels and encased the reinforcing. Often it did not (Fidler 2007, 25). Water penetration and corrosion of the reinforcing is a serious problem on the Ennis house (Fidler 2007, 37). Both the Ennis and Freeman houses were significantly damaged in the 1994 Northridge earthquake, primarily due to inadequate reinforcing, in the author's opinion.

Post-tensioning: One way to protect the reinforcing would be to move it further inside, between the wythes. Using a composite block, as discussed above, would allow for vertical and horizontal post-tensioned reinforcing in the insulated cavity. Unbonded post-tensioned mortarless masonry has been determined to perform very well seismically. Shake table tests were conducted at the University of Auckland, New Zealand. The post-tensioned walls exhibited ductile behavior and actually self-righted after a simulated seismic event. (Wight 2006).

Cement and the environment: Portland cement has been around, essentially unchanged since its invention in 1824. There are many varieties of cement with quite a selection of admixtures, but the basic process for making it is the same as it has always been. Like the internal combustion engine, the basic principle is unchanged,: Powdered limestone and clay is heated to a temperature of 1500 deg. C (2700 deg F) in a process called "calcination". There it combines into marble-sized pellets of a substance called "clinker". The clinker is combined with gypsum (to control set time) and ground to a fine powder.

Cement production is responsible for 5% of man-made carbon dioxide (CO2) emissions globally. Atmospheric CO2 is believed to be a primary contributor to global warming. 50% of the CO2 is released in the chemical process of cement production, and 40% is from the use of fossil fuel to heat the kilns. The remainder is due to transport emissions. (World Business Council for sustainable Development 2002, 21) It is estimated that 800 tons of CO2 are released for every 1000 tons of cement produced.

Magnesium-oxide based cements: Several companies have developed cements that use magnesium silicates instead of calcium carbonate (limestone). (This is equivalent to replacing the internal combustion engine with a hydrogen fuel cell and electric motor.) The advantage is that more CO_2 is absorbed during the process than is emitted. It can produce concrete that is net “carbon-negative”. For one thing, the production of magnesium-oxide cement requires lower temperatures than used for portland cement: 600 deg. C (1112 dg. F) vs. 1500 deg C. This means that renewable fuel sources are sufficient to provide the required energy. The resultant chemical reaction absorbs, rather than emits CO_2.

The targeted initial applications are masonry block and pavers. The porous surfaces will continue to absorb carbon dioxide from the air over the years. A pilot plant is being built in London for producing the magnesium-oxide based cement. Magnesium silicates are abundant—at least 10,000 billion tons—though mining infrastructure will be needed to extract them.

Other companies have developed magnesium-based additives to portland cement which cause the resultant product to absorb carbon as it hydrates.

A concrete block cast using magnesium-oxide based cement would act like a tree, absorbing carbon dioxide from the air. That’s an organic concept Wright would have approved of.

Local Manufacturing: Wright searched in vain for a manufacturer to produce his Usonian Automatic system. By the 1950s, the time had passed when casting blocks on-site was economical. The industry was now geared toward producing a cheap, utilitarian product. A precast concrete architectural block, as Wright championed, was a costly niche item, if available at all. The emerging architectural precast concrete industry was not organized until 1966, with the formation of the Architectural Precast Association. Wright passed away in 1959, and the last Usonian Automatic house was built in 1964. According to Wright’s grandson, Eric Lloyd Wright:

> *“Although steel forms were used to create the blocks for the Automatics, the blocks still could not be made with the precision necessary to lay them without shimming. It was my grandfather’s desire that, ultimately, these blocks could be picked up in any building supply yard and stacked up by individuals wanting to build their own houses…He realized that only if the blocks were machine made would it be possible to lay them out without shimming, but he was never able to interest anyone in taking on the manufacture of the blocks.”* (Hess 2005, 459)

The textile-block system fits between concrete masonry and architectural precast. The blocks are larger than typical masonry and smaller than typical precast concrete. An architectural precaster has the ability to create a textile block, but a concrete masonry manufacturer does not.

Architectural precast plants are already located nationwide -- there are usually several within a few hundred miles of each of the major metropolitan areas of the U.S. To produce blocks of the high quality used as replacements on the Ennis house, the units should ideally set overnight in the forms. With 100 forms, 11,000 blocks would require almost four and a half months to produce. By contrast, with dry-casting, re-using the form every 2.5 minutes would allow 3 crews with three forms to complete the job in less than a month. The economics of dry-casting are compelling, but the long-term durability and water resistance of dry-cast blocks can be a concern. Something in-between, say 30 forms turned 4 times a day might be a good compromise, allowing sufficient time for the blocks to hold their shape prior to form removal, with a large enough pour to fill the hopper.

Conclusions: When all the variables are taken into account, a case can be made that Frank Lloyd Wright's textile block has the potential to be a successful sustainable building product. Taking advantage of modern materials and methods as used by the architectural precast industry, the system has the potential to reduce carbon emissions and the use of fossil fuels during manufacture, transportation, construction and over the life-cycle of the product. It may now be possible to realize Wright's vision of an aesthetically pleasing, locally produced, economical, easily assembled, thermally efficient, durable, fire-resistant, sustainable and reusable precast concrete building system—A truly Modular, Machine-age, Mono-material.

Fig. 14 Eric V. Brown House, Kalamazoo, MI, built 1949

Appendix: An Annotated Bibliography

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