# Anastylosis with Glass Fill

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**Abstract**
Since the beginning, man has attempted to make restoration invisible, and then more subtly, less distracting from the artifacts as reassembled. Glass used as fill, both structurally and as interpretive surface, allows us to come tantalizingly close to the theoretical goal. As a membrane defining historic enclosure (where missing) it can protect as a vitrine while providing the armature to suspend the artifacts in their earlier positions. If carefully managed it can mediate the environment within to provide passive conservation. Glass can be stronger than wood and many masonry materials and thus can become a prothesis to complete a structural member within its original dimensions allowing it to be placed back into service using carbon fiber where tension connections are necessary. Laminated glass not only provides redundancy for structural considerations but multiplies the myriad of coating options as well as the ability to imbed OLED arrays allowing computer imaging support of interactive interpretation. When faced with necessity and no other good solution, the authors undertook the appropriate design, structural analysis and physical failure testing to verify the prior statements for an actual project, gaining the support of Rob Cassetti at Corning Museum of Glass. Full scale installations in Plexiglas and plywood to protect some weather sensitive areas were installed demonstrating constructability and visual effect. We feel that this research should not die with our project.

**Keywords:** structural glass, carbon fibre, historic ruin, Menokin.

## 1. Introduction

Fig. 1,2: Menokin during mid-20$^{th}$ century at left; and in 2010 at right.

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Fig 3: Menokin reassembled with glass providing the structure and fill (Computer rendering by Declan Nevin)

The recipe in hindsight is quite simple. Take one Apple Cube and cut it to the ragged profile of the ruin. Adjust the fins to the thickness of the ruin walls and to positions on either side of openings. Hang structural glass shelves between the fins to support belt courses, floors, doors, and windows. By the way, do not make any places that cannot be reached for cleaning.

Getting there was a bit more difficult. John Lee and Charles Phillips have collaborated for decades. While working to stabilize the ruin at Menokin it became apparent that even though a superstructure had been built, it was so high that it was not protecting the remains, including wooden floors and timbers from rain – then the sun would come out and it was a terrific parasol. Obviously the ruin needed to be enclosed to

Fig. 4,5: Looking up through the Apple Cube Store, 5th Ave. NY, USA; Menokin 3D CAD build out.

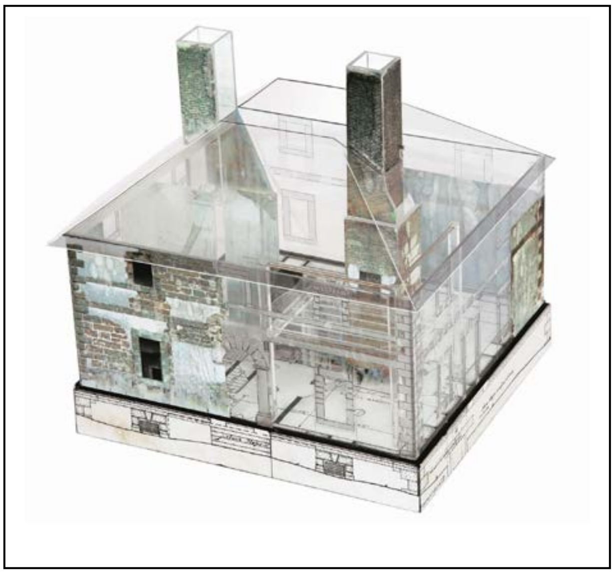


Fig. 6,7: The Harry Ransom Center, The University of Texas, USA; Original model of Menokin shown to Tim Macfarlane.

preserve a number of the materials. The superstructure was so minimally structured that it would not allow enclosure. In addition it was considered a visual blight that distracted from interpretation of the site. After lengthy consideration as to where to place the walls of the enclosure [if the walls are too close to the structure then it cannot be reasonably observed from inside the structure – if the walls are reasonably far from the original walls then the enclosure on the site overwhelms the site interpretation.] we realized that from an interpretative point of view matching the original walls was the only place where the enclosure would not be a detriment. Matching the original walls could add to the interpretation by connecting elements and visually providing the building mass.

Phillips as an architect, conservator and perpetual student of museology was often intrigued by the interpretive power of The Harry Ransom Center at the University of Texas which utilizes architectural glass to describe the sort of archival material that is contained in their collection. The Byzantine Chapel in Houston Texas, by François Minel incorporating frosted glass panels to provide the original spatial organization for rescued frescos also provided inspiration into the capabilities of glass. Ads were starting to come out for LCD glass in monochromatic colour; but it was the Apple Cube that connected mental image with reality. Tim Macfarlane was the lead engineer for the Apple Cube glass. Phillips, Lee, and conservator Ellen Hagsten arranged to meet Macfarlane for Breakfast at the 45th Annual (2006) Seminar on Glass at Corning, New York where he was a primary speaker. Breakfast turned into four hours; Tim joined the team and carried the model on stage when he spoke.

This paper is limited to our work directly associated with development of the glass house and associated glass prosthesis concepts. The direction of years of archaeology and documentation of the unpacking process, determination of the original framing plan and matching all of the timber artefacts to the plan, sorting the artefacts removed before the collapse which had been at moved at least twice before being piled

Fig. 8,9: 2005 Photo and 3D position documentation of artefact removal during unpacking the ruin; 2007 Sorting the interior trim removed before 1968 collapse (one room shown minus base and cornice).

into the artefact store room on site [along the way interiors of two other houses joined the disorganized stacks] cannot be dealt with here. We also will largely ignore the stabilization and conservation of the masonry and plaster remains. However it does need to be mentioned by way of context that Menokin was the home Francis Lightfoot Lee, who was one of the 56 signers of the our Declaration of Independence. As such this ruin of a well designed Georgian Cottage is of national significance.

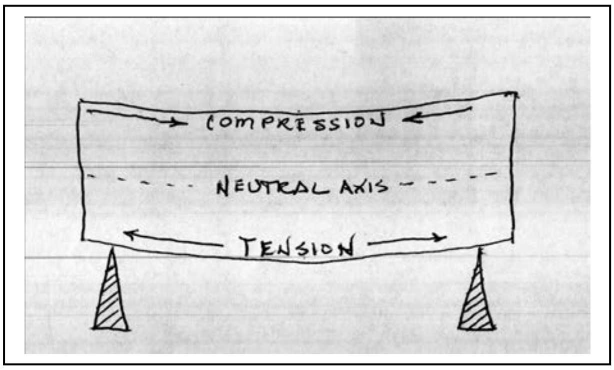
## 2.0 Glass Fill

Philosophies of work on cultural properties have long advocated that one not attempt to falsify the record by confusing the old and the new work. At the same time infill must reconcile the losses and allow the artefact to be perceived as it was created allowing for reasonable aging. This often moves toward reducing the visual contribution of the fill. This can some times be accomplished by allowing the substrate to show in the missing areas if it is not too visually strong that it competes with the intact portions. Glass as a fill can even provide the structure when that is missing. It becomes not just feasible but compelling to accept a philosophy of allowing the artefact to be visible in the entirity of its remains while subtly implying the missing components. There is never any question of what is real artefact and what is not. The savings of interpretive time and space explaining what is and what is not, is emence. The visible building is a compelling concept. It allows us create an exhibit of this building as an artefact. It allows us to stabilize and store all of the miscellaneous parts and pieces that have been salvaged in their appropriate three-dimensional locations so that strange markings—evidence—on one piece can be related to apparent damage on other pieces, or a symmetrical location can be found on another piece. At the individual object level, these things are close to impossible to deal with—one cannot find the forest for the trees.

The arrival of Macfarlane really opened the team's eyes to the potential of glass. At that first breakfast he suggested that the glass skin be carried on structural glass fins rather than a metal armature and immediately saw the potential to use glass as a prosthesis for damaged structural artefacts, allowing them to be placed back into service. Under the worst case, the artefact could be suspended between two beams of glass, but as we talked it became apparent that in most cases the glass could be connected to the artefact and carry the original dimensions of the member across to its intended bearing point or other connection. We had been thinking of large sheets of glass as floor where the original boards were long since rotted. Macfarlane pointed out that since the glass was stronger than the original wood and since most of the floors were splined, we could use three layers of laminated glass where the central layer was not as wide as the top and bottom creating the groove for the spline. By using a tinted acrylic spline it would be visible within the floor and interpret the original construction. Since in most cases we could determine the varying widths of the random width floor boards they could just as easily be made the correct widths as they would be cut out by computer.

Several rules of thumb:

1. If glass is laminated with three or more layers, all of the layers can be fractured and the assembly will still carry the design load.
2. Standard glass sheets are about 5 times stronger that wood. This means that a glass beam 1/5 as wide as a wooden element will carry about the same load. 1/4 provides an additional factor of safety and if two laminated beams are spaced so that their outside faces are aligned with the outside faces of the wooden element, the composite provides the visual dimensions of the original with slightly more than two times the strength of the original. [dimensional compatibility and redundancy – a great combination]



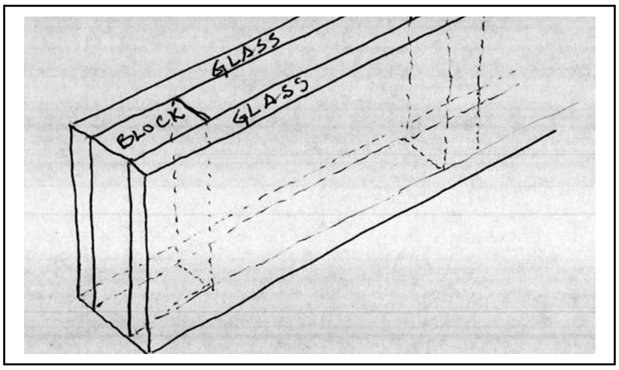
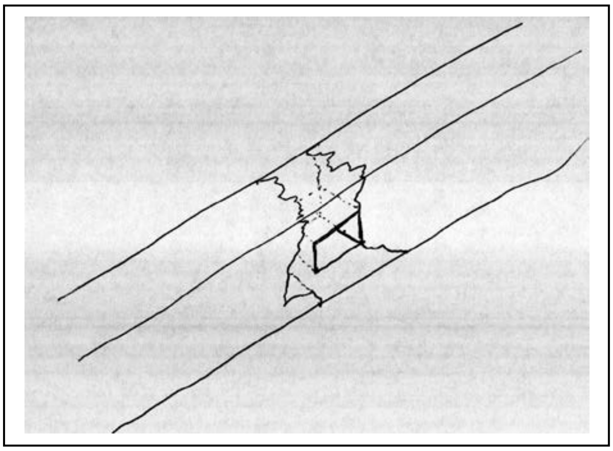




Fig.10,11: Basic forces in a simple beam; Glass beam of two laminated faces with blocks between.



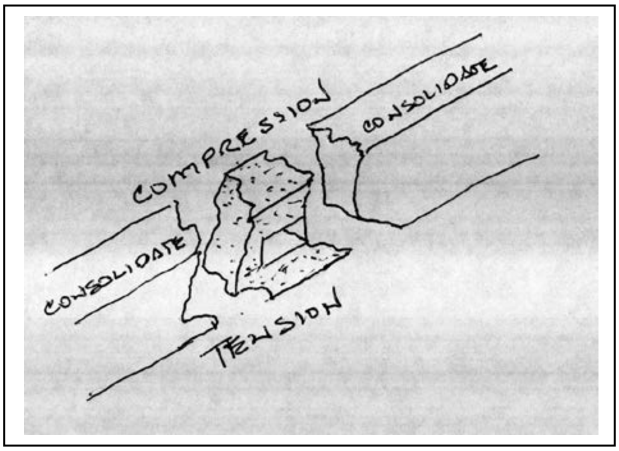



Fig. 12,13: Beam with completely deteriorated area at a mortise; Exploded view with a loose casting to fill the missing portion – if tightly assembled, in theory it only needs a tension connection at the bottom to function. See Fig. 14-17.

3. Standard construction epoxy adhering carbon fibre tape to the face of wooden elements fails within the wood itself; typically at the point where the epoxy ceases to penetrate. This means that high-tech adhesive systems are not necessary to exceed the strength of the original wooden system.

4. No book or computer simulation can tell how a specific deteriorated then conserved artefact fitted with a prosthesis will actually perform. Therefore All members returned to service must be tested individually, and as assemblies where appropriate, to a factor of safety beyond expected loading, in a rig that mimics the attachment that it will have in service. This is not testing to failure, but rather verification that anticipated capacities have been achieved.

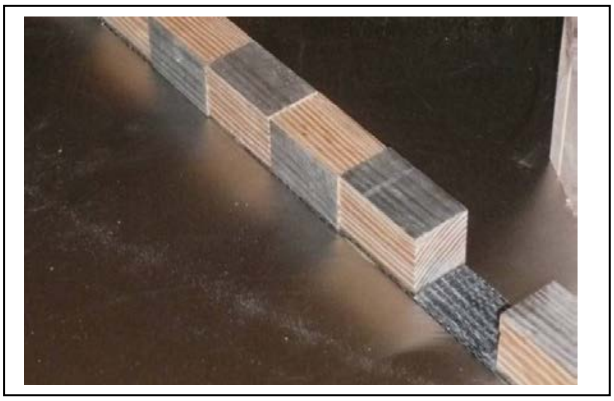


Fig. 14,15,16,17: Loose blocks epoxied to a 1.5in. carbon fibre tape in various arrangements from bent causing the blocks to spread and become quite flexible, to very rigid as the blocks come into contact and meet compressive forces. The stick spanning the chair and table will easily support a 200lb. person – the table is likely the weakest element. The three sticks at the right are: at the top a series of blocks with a tape below; the center stick has a 1.5in tape inserted into a saw cut; the bottom stick has the tape fully covering the face. With the tape on the side opposite the force, each will resist more strongly that a plain stick without the tape. Note: the loose blocks do not even need to be attached to the tape toward the center of the span – The tape requires a sound connection to the end blocks only. Attachment to several at the ends helps distribute the adhesive bond strength. A mechanical attachment to the end blocks would relieve the need for any adhesive.

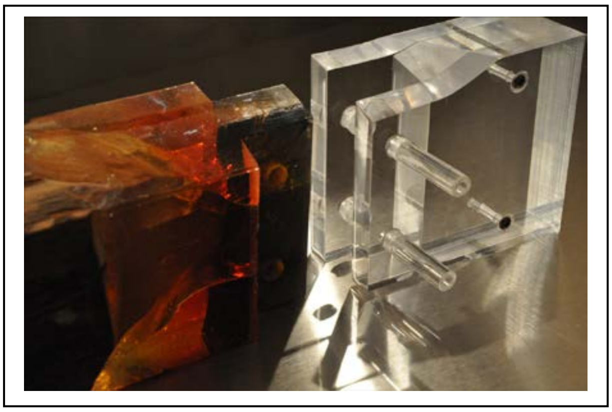


Fig. 18,19: Two views of the initial concept model for the glass prosthesis. The fragment of old wood is not from Menokin and salvaged from an urban trash container. It happened to have an angled top face and thus the top of the prosthesis was beveled at the point of contact. This would not likely occur in actual usage but obviously can be accommodated. The Prosthesis in the model is acrylic.

We went back to the basics; asking what do we really need for this element of the structure to do? Where are the forces and what are their magnitudes? We know that the original configuration was working quite well until the roof was allowed to leak. Therefore if we can work back toward the original configuration that should be adequate. Trust but verify. Most engineering texts and computer simulations are a poor approximation of real life. We are designing for real life not for some mythical computer simulation. Since we cannot look up the critical values for a deteriorated element we are forced into a testing program that will determine element by element what its actual resistance to force is.

Many of the beams and joists have had one or both ends rotted to non-existence. Some have pockets of rot that likewise, no longer exist even as the equivalent of frass. Some are little more than a veneer surface. The realization that a series of loose parts connected by a tension component such as a carbon fibre tape can carry more load than a single element of the same material and overall dimensions without the tape, was very liberating.

The primary point is that one can treat a deteriorated beam that developed serious rot at several major mortise locations 4 to 5 feet apart and is now in 4 major pieces and missing the mortises and put it back into service. There need not be any major armature outside of the piece or major loss of fabric from cutting away material for splices. The new and the old are always apparent, but now one can see where the structure goes and what it was intended to attach to and how the assembly worked. First the individual pieces that made up the element must be consolidated so as to be handled without loss and to be able to resist compression. Then loose castings must be made of the missing mortise portions [no loss of fabric] and if one end is missing several feet then an end transition for a prosthesis must also be cast. The prosthesis


Fig. 20, 21: The initial jigs were quick, crude, but effective. The force gage was old and out of calibration but provided a good comparative analysis.

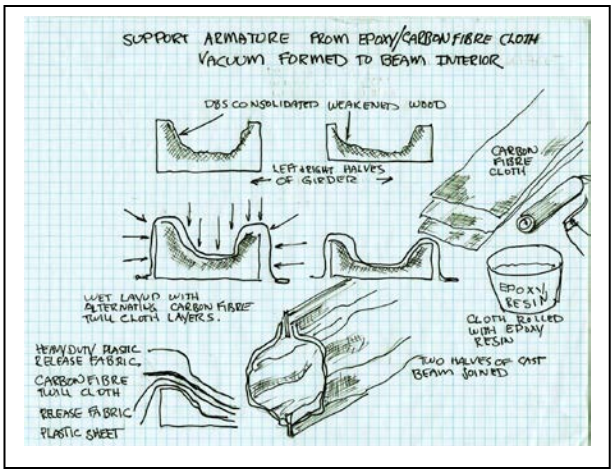



Fig. 22, 23: As the project progressed we got a little more sophisticated. This rig on the left is testing shear in torsion between the wood arm and the carbon fibre faced block seen just below the brim of the hat. The drawings on the right show the steps to making a carbon fibre core for a timber with a rotted center. Note the core will be filled with foam to reduce buckling.

fabricated to dimension and finally two or more carbon fibre tension members must be attached between the end of the prosthesis and the other original end. Test the beam for the necessary loads and put it back in place having lost very little of the information contained in its skin. Joists are just narrow beams with few mortises.

It would be nice to have an easy method to drill longitudinal holes that would essentially allow post-tensioning of the assembly with no visible skin loss. That is something for future research. We also looked at the possibility of creating a woven tube of very open design similar to a Chinese finger locking device like the ones we had when we were children, where one sticks a finger in each end of the woven tube and then the tube shrinks and tightens as one tries to remove the fingers. This wrapped around the assembled original parts and missing pieces would make it whole again while being completely reversible.

Fig. 24, 25, 26, 27: Show the steps described in figure 23.

Fig. 28, 29: Macfarlane and Phillips conferring about details for the East wall enclosure. As with most projects that involve unique detailing, it is best to do much of it on site. The right view shows the Plexiglas enclosure in place before the shading film detailing was applied. Although the glare provides a presence for the glass skin it does not visually over power the original structure. It does temporarily mask the interior which aids in understanding the form of the building.

Fig. 30, 31: When not standing where the glare is brightest, one can see the plywood fins. At the right the cast concrete bases for the fins are easily visible – a more elegant solution can be found. There is a sheet of plastic between the concrete and the historic masonry as a bond breaker. Interpretively this relationship with the glare also allows one to see the interior makeup of the building and how it goes together (form/detail).

We were faced with a problem of temporarily protecting the wooden floors and plaster in the North East Quadrant. Rain was blowing in and we could not wait until the whole glass house was funded. After rejecting the initial suggestions of a tarp, which would be difficult to control in a wind and probably dangerous; not to mention ugly. Then rejecting a plywood wall which would be comparatively expensive and just as ugly as the tarp; we proposed an equally expensive option using this as an opportunity to mockup the glass house concept and get some constructability knowledge about actually getting things into place. It is one thing to draw the fins in place, but how do you get them into place? How do you control a large fin without knocking down the ruin in the process? How close do you cut the contour (We chose 1/2in. – it worked) of the only fin that must embrace a portion of the wall where the outside half thickness collapsed leaving the interior half still holding up the second floor? Needless to say we learned a quite a bit.

We chose to use MDO plywood over a 1.5 in thick wood frame for the fins. This was 2.25 inches thick while the glass was intended to be only 2in. but the wood was readily cut and manipulated on site. For similar reasons of on site adjustment we chose Plexiglas over true glass. Actually from a structural standpoint the real glass would have been a better choice and its rigidity would have made some of the end connections less of a problem. This being a temporary construction the cost difference was also in the favor of using the alternate materials.

The costs were minute however when compared to the current interpretive value and the ability of this mockup to sell the final product. Again it is one thing to talk about the visual impact and a computer rendering looks awfully good but a full scale portion in place is stunning and hard to argue with.

The interpretive value of the glass is immediately apparent. The ghosted in window stones and sashes could even be less pronounced but even as it is, the understanding of the building that it conveys is tremendous. Without the frosting how many visitors realized that the straight sections of the broken edge of the wall were actually the edge of the window stones? It takes much less imagination now to start to connect the elements to the missing corners and imagine the house complete; either as original or as envisioned in glass. What opportunities would be available, what exhibits could one develop with the ability to change the image on the glass? Make it display whatever can be created on a computer screen and then animated? This is a house of Georgian design and it was based on Classical proportions. What if, as one described the descriptive geometry of the façade, the construction lines appeared there in the glass? Menokin is located in the small rural community of Warsaw, one hour from Richmond the Capital of Virginia and about two hours from Washington, DC. Why not invite the town and surrounding neighbors to a picnic on the grounds and when

Fig. 32, 33: These views show the appearance of the shading film detail from the exterior and the interior.

the sun sets, show a movie like "Star Wars" on a portion of the front façade? In terms of sparking the imagination The Corning Glass Company has published a video on YouTube that may surprise you. Actually they have recently released an update: "A Day Made of Glass 2." They are both worth watching. How would you use glass as infill? We hope this paper opens the door to more inventive uses of glass in heritage conservation and thank Hugh Miller, Richard Wolbers, Rob Cassetti and Peter Drobny for their kind support.

More information on our work at Menokin is available at
http://www.johngreenwaltlee.com/menokin/Home.html


Fig. 34: This is a composite of three views from http://www.youtube.com/watch?v=jZkHpNnXLB0