Trajectories of the hollow stone: representational strategies for visualizing the integrated structural space frame

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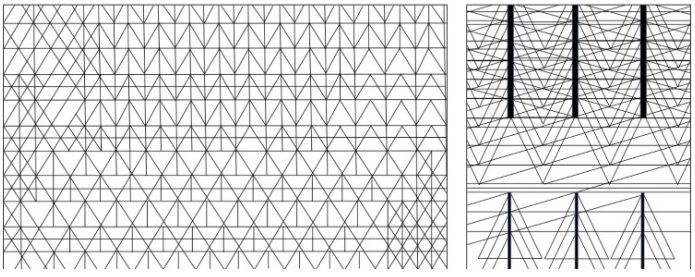
Abstract In 1953, the acclaimed architect Louis I. Kahn expressed some of his early and formative thinking on the potential of the space frame, writing: *"In Gothic times, architects built in solid stones. Now we can build with hollow stones. The spaces defined by the members of a structure are as important as the members….The desire to express voids positively in the design of structure is evidenced by the growing interest and work in the development of the space frame."* (Kahn, 1953, p. 23) For Kahn, the hollow stone became a metaphor for the integration of the latest scientific thinking in the building arts. He saw architecture as a researching of the history of materials and structure enhanced by a practical application of contemporary scientific thinking.

As a lightweight complex structural system, the space frame typology manifests significant representational challenges, whether with regard to illustrating the spatial implications of its many members and their varying trajectories or in terms of the joint/joinery of the system itself, where many structural forces intersect within a small node of critical connection. This paper examines representational strategies for manifesting the invisible spatiality of a structural system that is itself based on voids, and it also briefly examines the joints within this 'hollow stone' system. The vehicle for this discussion will be an outgrowth of two academic graduate level courses recently delivered; Architecture 811/812/Thesis: Transplaced by Pororsity: Geometry, Structure and Materials at Three Scales, and Architecture 409/Fabrication Studio: Steel Space Frame Pavilion, two recent competition entries that range in scale from that of a house to that of a bridge, and the scholarly research of a recent study of the space frame canopy over the Monlinete Roman Ruins in Cartegena Spain by the architects Amann-Canovas-Mauri. Representational images from these venues will advance a discourse on the merits of Planimetric, Isometric, Perspective, and Composite Drawing, with regard to the spatiality of various space frame derivatives.

Fig. 1 Space Frame Abstractions – Line Drawings Recreated after Kahn (left) and Wachsmann (right) – Bruce Johnson



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Introduction

In 1899 Alexander Graham Bell, the father of the telephone also became the father of the modern space frame[1] when he began experimenting with a repeating structure of tetrahedral shells/frames as a means for considering flight. These ultra-light structural cells were developed for kites, flying discs and even a viewing tower that was assembled in less than a day out of prefabricated components made possible by a joint system that could quickly attach numerous diagonal members. By the 1950s Buckminster Fuller, Konrad Wachsmann and even Mies van der Rohe were experimenting with the spatial and structural implications of the space frame derivative. In 1953, Louis Kahn, expressed some of his early and formative thinking on the potential of the space frame with regard to his un-built City Hall project that was done in collaboration with Anne Tyng, writing: "*In Gothic times, architects built in solid stones. Now we can build with hollow stones. The spaces defined by the members of a structure are as important as the members. These spaces range in scale from the voids of an insulation panel, voids for air, lighting and heat to circulate, to spaces big enough to walk through or live in. The desire to express voids positively in the design of structure is evidenced by the growing interest and work in the development of the space frame."* (Kahn, 1953, p. 23)

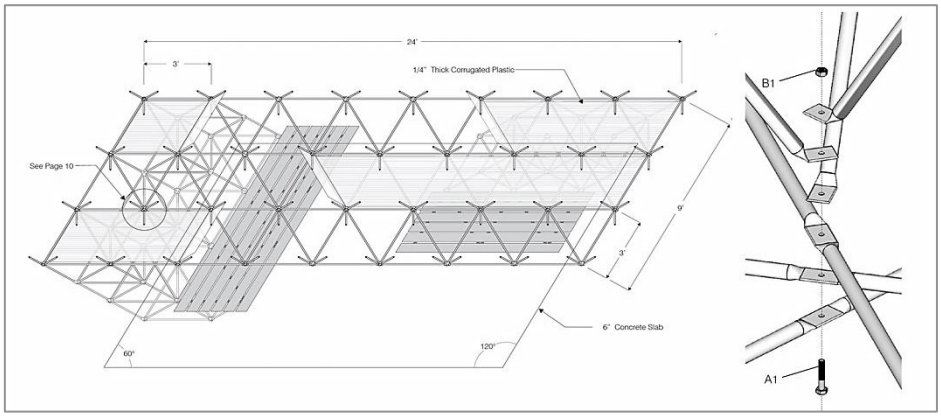

Fig. 2 Steel Space Frame Pavilion – Isometric (left) and Joint Detail (right) - Architecture 409/Fabrication Studio: Seth Dugger, Kim McKeever, Alex Wolfram, Yi Dong and Savannah Gregory

When Kahn spoke of the hollow stone, he was speaking to the integration of emergent materials and environmental systems within the lightweight structure of the engineered space frame whether manifest in steel, concrete, etc. In a space frame system, each of the structural members forms a three dimensional loading system that together provides a greater structural potentiality than when used independent of one another, as is typically the case with a traditional column and beam system. Space frames can be distorted or pure geometries (Fig. 2 illustrates the reductive simplicity of a nearly pure geometry) or both and can be designed as either multilayered latticed/space grids (with or without diagonals and with or without moment connections) or as a space truss. In the 1960s-70s, space frames were widely popular with the Japanese Metabolists, such as Kenzo Tange, Kisho Kurakawa and Arata Isozaki, and with the emerging English Avant-Garde like Archigram and Cedric Price, who were likewise creating projects that took their cues from the repeating DNA-like adaptive cellular nature of the lightweight space frame. Recently there has been a revival in the interest of the space frame, perhaps driven by its formal

[1] Note: the space frame typology has been traced historically to the wood latticed Mongolian 'Yurt' – Bell is privileged here in terms of materials, geometry and industrial processes with regard to the joint and mass production

adaptability and in terms of its prevalent voids, which are readily available for use with integrated mechanical, data or 'green' systems.

Some current works of architecture that incorporate hollow structure are Norman Foster's roofs/additions for the British Museum and the Smithsonian Institute, where the existing buildings are laced into a kind of warped space construct, and OMA's Seattle Public Library along with Toyo Ito's Sendai Mediatheque, both of which manifest an all encompassing system of structure and systems as a spatial field. A space frame is difficult to represent in terms of its largely homogenous and non-relenting repetitious nature. How does one draw a system that is made from hundreds of thin line-like members from lines themselves, which are the very essence of drawing? Consider how both Kahn and Wachsmann utilized abstract line drawings to communicate the internal directional bias of both scale change and individual member trajectory as recreated in (Fig. 1, left – Kahn: City Hall 1953, right – Wachsmann: Airplane Hanger 1950-55). Where does the system begin and end? How does one represent hierarchy or directionality from such a totalizing and repeating network? For Wachsmann, the Crystal Palace of 1851 was a model of this in terms of its ability to represent its totality from a drawing of a single module, Wachsmann writes: "*What is fascinating is that the whole structure is made up entirely of small, simple parts; there is no suggestion of a large powerful, overwhelming mass. There is nothing which in not immediately intelligible, down to the finest detail*." (Wachsmann, 1961, p. 14) Writing on the Crystal Palace Kenneth Frampton says: "*…the tectonic potential of the whole would seem to derive from the eurhythmy of its parts and the articulation of its joints."* (Frampton, 1995, p. 20) As a lightweight complex structural system, the space frame manifests significant representational challenges, whether with regard to illustrating its many members and their varying trajectories or with regard to the joint/joinery of the system itself, where many structural forces intersect within a small node of critical connection (Fig. 2 illustrates the potential of the isometric to clarify repetition, geometry and connection nexus). For Kahn the expression of the joint is fundamental when he writes: "*The feeling that our present-day architecture needs embellishment stems in part from our tendency to fair joints out of sight, to conceal how parts are put together*." (as cited in McCarter, 2005, p. 82) With a structural typology based on hundreds/thousands of members, how is the spatial experience conveyed in drawing form? On the work of Fuller, K. Michael Hays writes; *"…the nature of materials and the organizing structures of perception itself (diagonals, layers, rotation) are folded back on themselves to become the object of aesthetic expression and experience…*" (Hays, 2008, pp. 5-6) Fuller himself says: *" I am convinced of the utter integrity of the total experience...*" (as cited in Hays, 2008, p. 17) Given the importance of the role of the joint, how is best it communicated in a drawing? Because a space frame (whether concrete, steel, aluminum, carbon fiber, plastic/PVC, bamboo, or composite) is predominately void, how does one draw/represent the 'empty' quality of the space frame? What are advantages of various forms of representation (plan/section, isometric, perspective, detail, composite, etc.) and how can they be exploited?

James Corner, whose work to record the American landscape as the intersection of industrial tooled earthworks and natural beauty, might yield insight into some possible means and methods of representation when he explains that: "*Composite montage is essentially an affiliative and productive technique, aimed not toward limitation and control but toward emancipation, heterogeneity, and open relations among its parts…. Moreover, composite techniques focus on the instrumental function of drawing with regard to production…utilizing a variety of analytic and analogous imaging techniques, otherwise disparate parts can be brought into a productive relationship…*". (Corner, 1999, p. 166) Composite drawings can take advantage of traditional orthographic projections like plan and section, but they can also incorporate cultural residue in the form of iconography or photography from an actual event that all work together. These abstractions are in essence representative of what Marco Frascari calls "technographies" which are images that are: *"…between a real architectural artifact and a reflected or projected image of it…. that rests in the collective memory of a culture."* (as cited in Corner, 1999, p. 163) These

methods of drawing might themselves be thought of as weaving between the physical attributes of a thing/structure and the essence it re-presents to not only the designer but to the spectator.

The Limits of Plan

A recent competition entry for a low-budget Cambodian house (Fig. 3) illustrates the limits of traditional orthographic projection when using space frames. Tethered on a heavy stereotomic concrete block infrastructural services supply wall, the house utilized a repeating series of bamboo space frames that were considered a series of inhabitable hollow bundles. The project created two basic elements: a heavy stereotomic (masonry wall) anchor and a "tethered" lightweight tectonic living space, where the space frame bundle became wall, roof and service interface as an expandable house. Basic plan and sections were used to convey the reductive/economic simplicity of the bundle module and yet neither the plan nor the section could communicate the intended spatial sensuality or the flow of the overall design. This miss-fit is nothing new in terms of a designers struggle for an appropriate form of architectural representation – imagine Mies van der Rohe's Barcelona Pavilion floor plan or section as read by the average person. The space would remain flat, without program, and would resist its authentic carefully bounded internal and external flows. This maybe why the buildings plan and section

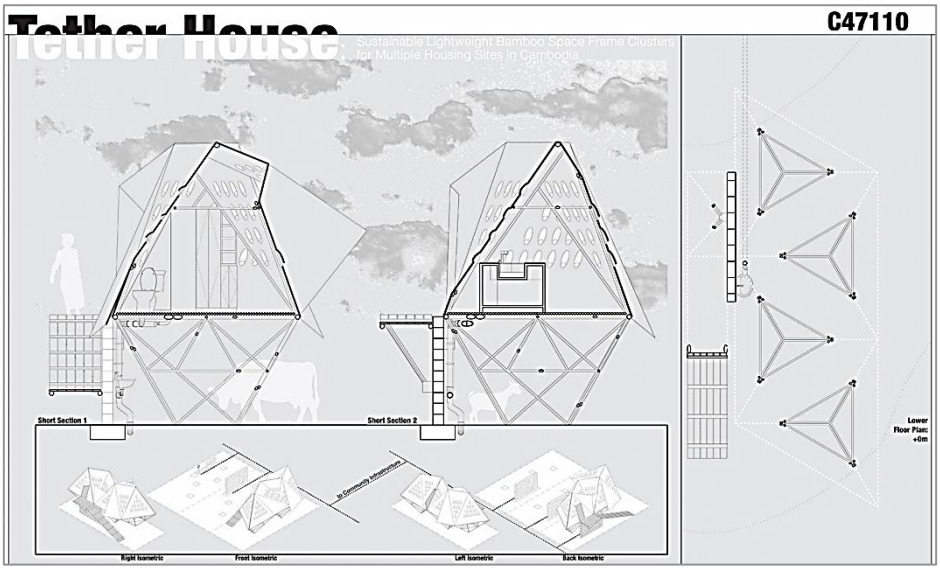

Fig. 3 Low Budget Cambodian Housing Proposal with Bamboo Space Frame – Section(s) and Structural Plan
Bruce Johnson and Genevieve Baudoin

were paired with photography from its inception in order to generate scale and vibrancy. This drawing strategies resultant spatiality was deemed so important that the building was literally resurrected and rebuilt due the success of this simple yet affiliative representational strategy. Mies would capitalize yet again on the viewer's cognitive ability to affiliate images in his infamous interior collage for his un-built 1954 Convention Center project, which grafted a photo of a crowd under a seemingly endless space frame/space truss roof structure. Mies understood both the power and danger of the endless repetition of the space frame typology in terms of its ability to signify infinity and the need to create moments within and under its blanket of diagonals through the use of program/activity as represented via composite images.

Perspective and Composite Drawing

In the "Brug Polder" pedestrian bridge competition entry for Amsterdam (Fig. 4), a series of space frames were developed to create a legible extension of the Dutch synthetic landscape as an inversion of the typical Dutch Polder land reclamation system. In this case the ground as space frame (rather than the ground as made solid/dry by the construction of a levee) is meant to be experienced as a porous surface, upon which layers of landscape and paving become an exposed 'true' synthetic and which supports one as they cross the Amstel River. The hollow space frame structure facilitates multiple system interfaces that support water collection, the ground cover and the needs of its users (i.e. kitchen, toilet, café infrastructure, etc.). Wachsmann believed that perspective drawing was useful in exploring the interwoven nature of space frame derivatives. In regard to a 1953 structural/spatial study of his own Wachsmann writes: "*The initial result…exists only in the form of a schematic perspective and a few diagrammatic sketches…. There emerged a new principle of distributing forces that released a new dynamism through the entire structure*." (Wachsmann, 1961, p. 194) Brug Polder uses the sectional perspective to facilitate the dynamism and continuous structural distribution that Wachsmann refers to with the added intention of creating a sense of an incomprehensible and synthetic 'new' triangulated steel ground. The composite drawing of the competition entry lends legibility to the structure and the scheme within the context of the city, but more importantly it supports the perception of floating on a synthetic landscape (i.e. drawings floating/sliding over other drawings) - a goal supported by the choice of the space frame structure itself that forms the core of the artificial landform. Composite drawing can communicate not only infinity and stability but also the programmatic juxtaposition. The Brug Polder competition drawings operate in an intentionally collage-like manner in order to provide both an instant but also largely episodic scale. In Corner's words they operate as means where: "*…otherwise disparate parts can be brought into a productive relationship*." (Corner, 1999, p. 166)

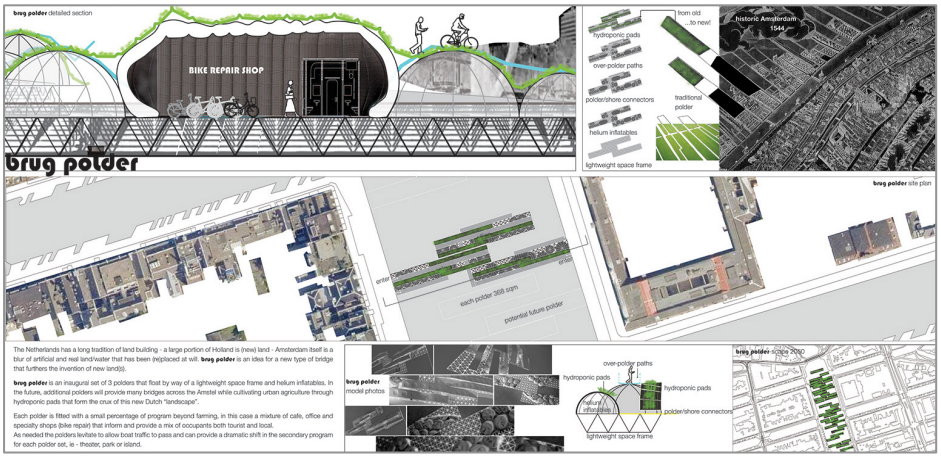

Fig. 4 Composite Drawing with Sectional Perspective – 2011 ACCA Competition 'Brug Polder' Space Frame Bridge Proposal for Amsterdam –- Bruce Johnson and Genevieve Baudoin

Analytique and the Joint

The joint within the space frame system itself is another scale, (Fig. 5, right) as illustrated in a recent student independent study project that can be reduced to a series of interlocking slots - in this case for both structural purposes and for programmatic nesting. The stressed skin space frame illustrated here and developed by Kadim Al Asady produces a singular member design that contains slots in multiple directions – those not used for structural connection become available

for use with systems interface and with program attachment. The composite drawings (Fig. 5 – center and right) manifest perspectival views that while prescriptive, are largely only suggestive of an overall configuration of program and space. Far more telling is the plan/section, (Fig. 5, left) which reads largely as ornament and relies on its neighboring composite images for any hope of legibility. The additional icons, images and photographs in the composite drawing draw the structure beyond a geometrical/ornamental reading.

M. Saleh Uddin says: "*The fusion of two or more drawings results in experimental hybrid graphics with variations in scale, type of drawing, reprographic technique and the use of repetition and overlapping elements.* " (Uddin, 1997, p. 3) In *The Portfolio and the Diagram*, Hyungmin Pai points out that the Beaux-Arts analytique manifests: *"…an understanding that elements exist as part of a whole, and the whole could be an element…. The analytique was then not only a piece of the whole but also its miniature*." (Pai, 2002, p. 46) Contemporary composite

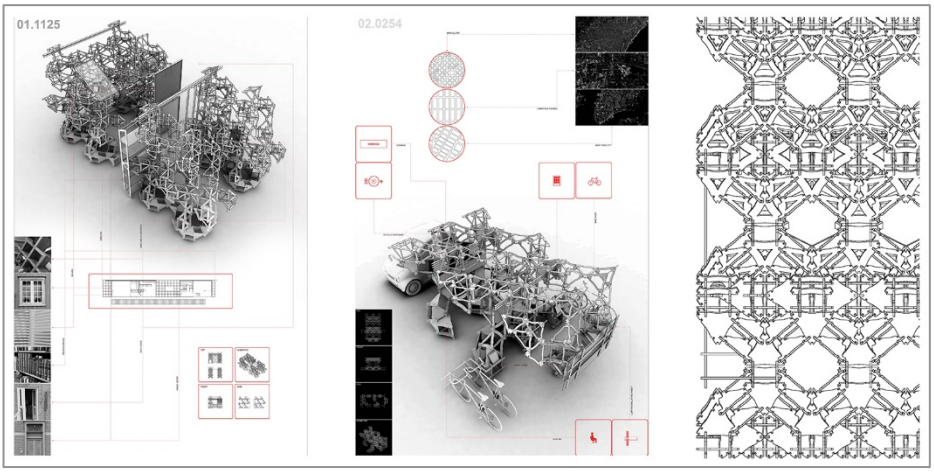

Fig. 5 Stressed Skin Space Frame Thesis - Composite Drawings (center and left) – Plan/Section (right)
Kadim Al Asady

drawing when done well is in essence Beaux-Arts analytique, but when prepared with the addition of multimedia possibilities that have grown out of collage and photography; both bring the trace residue of reality with them as a means for activating affiliation at a psychological level. Kadim Al Asady's composite drawings attempt to focus on the programmability of the joint, but he fails to achieve the timeless part-to-whole Beaux-Arts sensibility that Pai eludes to, as his drawings remain a series of objects as opposed to nested inversions between scales of operation and they miss the mark of psychological affiliation in terms of an evocative spirit or in Corner's terms they fail to: "*...open relations among its parts*." (Corner, 1999, p. 166) In the end, these slight but significant representational shortcomings manifest a project reading that is about the of totality of a system that Kenneth Frampton argues is often a negative one in terms of syntax: "*This expressive inadequacy is…evident…in the technocratic proposals of Fuller and Wachsmann, in which productive and geometric means rather than institutional ends will be the prime movers of form.*" (Frampton, 1995, p. 354)

Collage and Program

A recent roof canopy over an exquisite set of Roman ruins in Cartagena Spain, designed by the Madrid firm of Amann-Canovas-Maruri, takes its cue from typical scaffold-like industrial roofs that protect archeological digs during excavation (Fig. 6, left), but moves the canopy toward an intensity of dynamically faceted folded planes. Situated in the midst of a functioning city but

below a larger ruined Roman fortification, this lacey steel canopy activates a tourist site while protecting the visitor from the harsh Spanish sun with its translucent and elegant cladding. The composite drawing prepared and illustrated here (Fig. 6, left) attempts to situate the cultural meaning of viewing multiple Roman artifacts, walls and mosaics under a single canopy. The structure used in the drawing/composition is clearly not the one developed for the project, but it was chosen intentionally to conjure the essence of a more generic system, and which takes Mies' 1954 Convention Center structure and composite/collage as a point of departure. This was done as form of analysis so as to make a stronger reference to the canopy's generic conceptual origin (scaffold) and to provide a provocative stance on the contents of the ruins as viewable subject matter and as things/artifacts that require protection (program). Because this drawing was prepared as analysis, it was allowed an exaggerated freedom that would be less appropriate as a design drawing. In the end, the attempt was made to manifest the larger scale impact of a 'sheltering sky' roof system that operates in reality not so much to explain its constructional logic but to manifest Frampton's institutional emphasis and to thereby become less a hollow stone/space frame/space truss that literally encompasses services, but rather as a hollow stone that supports a cultural/civic function.

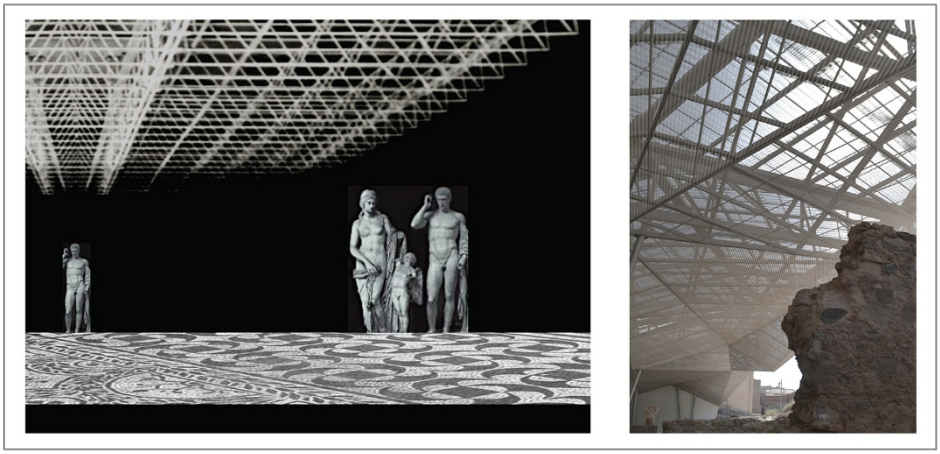

Fig. 6 Composite Drawing after Mies: Monlinete Ruins – Bruce Johnson (left) – Monlinete Space Frame and Ruins (right) - Bruce Johnson

In the end the ruins/relics below the space frame become culturally significant, but only by the manifestation that is afforded by the canopy design itself in terms of our collective desire to preserve them for society. Robin Evans has written that: "*Architectural drawing affects what might be called the architect's field of visibility. It makes it possible to see some things more clearly by suppressing other things: something gained, something lost. Its power to represent is always partial, always more or less abstract… It is not a neutral vehicle transporting conceptions into objects, but a medium that carries and distributes information in a particular mode. It does not necessarily dominate but always interacts with what it represents*." (Evans, 1997, p. 199) In the case of the hollow stone canopy in Cartagena, the architecture operates like an architectural drawing: it brings the ruins into focus and makes itself obscure. The choice of a repetitive and technically complex steel structure composed of seemingly endless diagonal members goes far to facilitate this endeavor; providing both the needed protection and visibility for the ruins, and remaining difficult to conceive structurally and thus suppressed while in plain site in order to fulfill Frampton's larger tectonic expression of an institute. Here, composite drawing conjoined with actual photography can express intention but not technical precision that is best represented in plan, section or detail.

Conclusion – Hollow Stone Trajectories

Since Bell, the modern space frame/space truss typology has proven representationally elusive when viewed from the singular vantage point of the plan or section. Even the isometric and perspective can be limiting in terms of a larger spatial/structural communication, and yet contemporary architects are exploring the hollow stone as a means of more thoroughly integrating systems and even whole buildings as in the case of Foster at the British Museum or at the Smithsonian. The difficulties with a drawing typology that is largely congruent with the line-like quality of the space frame itself, in combination with the density of members, has played a role is this dilemma. The reductive space frame drawings of Kahn and Wachsmann as reconstructed in (Fig. 1), were originally drawn as a means for studying the pattern shifts and scale changes and were completed through the medium of the line itself, but without joints or program in an attempt to represent the larger spatial energy of their work/projects, because both Kahn and Wachsmann were grappling with the representational problems of the space frame. With the arrival of the mixed media composite drawing as the re-emergence of the Beaux-Arts analytique, there is now a means for more adequately representing the part-to-whole nature of the space frame itself, but only when seen as one means of representation amongst a combination of the others.

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