OFFSITE FABRICATORS AND CUSTOMIZATION IN HISTORY AND PRACTICE

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The robust dialogue between design and fabrication intensifies with significant advances in technology. During the Industrial Revolution and in today's digital age, the balance between mass production and customization has played a central role in this dialogue. Examination of the contemporary metal fabricator Zahner, with supporting historic research on James Bogardus and Francois Hennebique, reveals prefabrication methods that exhibit systemic approaches to customization, detailing and maintenance of quality. Investigation of proprietary control and labor practices presents how these fabricators protected and promoted their technological advances in the face of competition.

In each case, these off-site fabricators delivered total customization in conjunction with precision of detailing, allowing architects to subvert the appearance of repetition within prefabricated systems.

In the 19th century, James Bogardus produced innovative prefabricated cast iron façades. Originally a watchmaker, Bogardus invented the eccentric universal mill. In 1847, while designing a factory to produce his mills, Bogardus's interests expanded to the fabrication of cast iron façades. Building upon his experience with watches, he carefully considered the interaction of each piece and how connections could be hidden from view.

A façade by Bogardus exhibits simple and systematized organization. A continuous horizontal lintel defines each floor. Beneath the lintel, columns frame large glass windows to delineate repetitive bays. At the roof line, a cornice replaces the lintels. (Figure 1)

However, individual façade elements are not as clearly defined as they seem. For example, castings for columns are hollow and include only the front half of the shaft. The columns are cast with flanges along their length which provide both rigidity to the structural frame and the opportunity to easily bolt to lintels. These flanges are hidden behind "L" shaped covers to create the appearance of a partially engaged column. Integral horizontal flanges in the engaged column provide purchase for bolting to lintels above and below the element. (Figure 2)

The continuity of the lintel is also deceptive. Individual lintel pieces run from center line to center line of the columns. This segmentation provides ease of fabrication and mounting. At the end of the lintel a flange is formed perpendicular to the web. Bolts through the flange allow connection to form a single continuous member.

Figure1. 75 Murray Street exhibits James Bogardus's typical façade organization.

Assembly began by connecting major elements together with concealed fasteners along the back side of the façade. Ornamental elements then affixed to the front of the façade, hiding seams, preventing penetration of moisture, and allowing customization of the basic framework.

Using cast iron's strength, Bogardus connected to the building structure at finite points through standardized locations of concealed fasteners. Designed as self-supporting, Bogardus's cast iron façades were a precursor to curtain wall construction.

Turning to reinforced concrete, François Hennebique's patented reinforcing steel system provided a refined and versatile method for developing reinforced concrete structures at the end of the 19th century. While Hennebique's method does not strictly constitute prefabrication, his structural system was broadly adopted for industrial applications across the built environment.

Figure 2. 85 Leonard Street detail. Note partially engaged columns.

When Hennebique entered the market, the standard location of reinforcing rods occurred at the top and bottom of beams. Hennebique's reinforcing system tied these disparate elements into a cohesive system, by introducing patented stirrups that attached in a perpendicular orientation along the length of the beam's reinforcing rods.

Bending the ends of the stirrups at the top allowed them to key into the floor slab reinforcing, fixing the beam to the slab.

Using his reinforcing system, Hennebique developed a simple structural frame which he could tailor to the individual needs of his clients. Limiting superfluous materials, Hennebique often stripped his projects down to two components, the concrete frame and glass infill. Unlike Le Corbusier's Domino House, some twenty years later, these buildings did not suppress the beam structure in an undifferentiated slab. The detailing of the beams added specificity to the construction, and emphasized the system. Exposing the reinforced concrete frame on the façade served to advertise the structural benefits of this new material to future clients.

Peter Collins, in his book *Concrete: The Vision of a New Architecture*, cites Hennebique's mill designs as significant to the development of modern architecture. He comments, "Hennibique perceived that his columns, beams and floors were sufficient in themselves, so that traditional wall surfaces could be abandoned altogether in favor of an infilling that was entirely transparent. Thus was created the idea of a visible reinforced concrete frame… creating an exciting new scale of proportions both as regards to the unaccustomed slenderness of the supports themselves, and the shape of the voids created by the wider spans. It was some time before architects became familiar with these new forms, and when they did, the more enthusiastic of them saw in this use of glass a novel and exciting mode of expression, to be applied not only to factories, but to buildings of many other types and requirements."[1]

Today, Zahner designs and fabricates metal skin systems which allow the building envelope to be customized in x y and z planes. In addition, Zahner offers systemic connection to structure that provides precision in installation, and integration of performative capabilities such as concealed drainage.

In 1989, L. William (Bill) Zahner became chief executive officer of Zahner. Just as with James Bogardus and Francois Hennebique, Bill Zahner is an inventor and entrepreneur. He is also a civil engineer. Under Bill Zahner's leadership, Zahner transitioned from a regional sheet metal producer to an internationally recognized architectural metal fabricator.

Architectural metal installations typically attach along their surface to substrate supported by the building's structure. To produce irregular geometries, and in particular geometries curving in multiple directions, Zahner reconsiders the support of architectural metal installations, creating a point loaded system analogous to curtain wall construction. Panels with concealed fasteners or shingles on substrate attach to proprietary curved flange I-beams, producing structural fins that can be individually customized to precisely follow digitally defined curvatures. As a result, Zahner's support system is free to warp and bend to follow an architect's geometries, while still logically connecting to the main building structure. (Figure 3)

In order to determine locations of the structural fins, Zahner directly utilizes the architect's digital model of the project. From the architect's original design, an algorithm creates a new model, transforming the geometry into a parametric surface. Additional proprietary algorithms then provide framing and fastener layouts, specify seam locations, and position flashing.

Figure 3. Zahner's headquarters, structural fins without metal panels. Also shown is the curved profile of the flange, forming a D shape. This shape allows panels to attach at any angle along the circumference.

By creating a point loaded wall, Zahner's installations maintain independence from the rest of the building. Prefabrication provides complete control of tolerances at the production plant. However precise installation is contingent upon control of variation in field conditions. By incorporating the structural support into the installation, Zahner restricts connection to a limited number of controllable points on the main structure. Advances in technology allow Zahner to access real time geo-referencing of these points in order to address variations in their location at the jobsite. During the prefabrication process, the parametrics of the design model respond to these locations, allowing the fabrication of the façade system to slightly shift and change in response to the field conditions.

Architectural metal fabrication has historically accommodated both planar and curved geometry. Seams connecting panels along roof or façade geometry run in the general direction of gravity to shed water. These seams are often raised, the result of folding edges of panels together to create a seal. Zahner's seams utilize an inverted channel, oriented with flanges facing out from the building surface, to which panels attach. This channel establishes the location of the panel seams. It also provides an internalized gutter system which moves water away from the building. Proprietary concealed clips to the channel provide panel movement in response to thermal conditions, and the ability to customize the width of the reveal between panels. Three of Zahner's five patents encompass these gutter and clipping systems.

An inverted seam benefit is the channel and associated panels do not need to align directly along the building geometry. As a result the architect can customize the angle at which the seam and panel pattern overlays the geometry of the building. Because the seams are linked to the parametric model defining the building geometry, they maintain continuity even as the geometry warps and folds.

Traditional seamed or shingled installations over regular geometries allow the architectural metal worker to prefabricate numerous panels or shingles of the same size across the field condition. In contrast, digital fabrication accommodates variation in panels that arise through parametrically defined geometry. These variations occur across the general field condition responding to slight changes in geometry and size. As a result, prefabrication can occur while maintaining individual design for each panel or shingle. In traditional architectural metal work, designing the field pattern is relatively simple in comparison with the difficulty of solving edge conditions. Zahner's parametric modeling system does not differentiate. The algorithm projects patterning across building corners and other edge conditions to create customized panels and with no additional labor.

With regard to individual panels, digital fabrication precisely forms edges so that panels provide "clean sharp lines and smooth coplanar visual nature."[2] In the case of lapped shingles, digital fabrication offers a method for creating a completely flat installation. With traditional lapped shingles, a fold is used to create connection between shingles. Digital control of profile and the use of concealed fasteners remove the need for folding. As a result, Zahner's lapped shingles provide a proprietary flat installation that emphasizes the overall shingle pattern.

Figure 4. The façade of 41 Cooper Square, by Thom Mayne reveals hazy rectangles through the use of Zahner's perforation system.

Zahner reconsiders traditional embossing, stamping and perforating of metal panels through the use of a proprietary imaging algorithm. Zahner uses a digital control language which translates the images into a customized pattern of bumps, dimples, perforations, or a hybrid of these elements. Employing parametric modeling, patterns are applied continuously from panel to panel, while automatically taking into consideration the edges which attach to concealed fasteners. (Figure 4)

While cast iron and concrete were available in small quantities historically, their presence on a mass scale provided Bogardus and Hennebique with the opportunity to repeat customized elements to create a system of prefabrication. In contrast, architectural metal has been available at the scale of large installation for centuries. Because architectural metal fabrication is based on prefabrication of units, innovation rests in customization. Digital modeling and digital fabrication provide the economic efficiency to make such customization achievable. In addition, Zahner's experience in traditional metal fabrication informs and challenges digital modeling and fabrication, advancing digital sheet metal fabrication technology.

Proprietary Control and Patents

While Bogardus arguably developed the first self-supporting cast iron façade, competition quickly advanced. In 1850, Bogardus received the rights for Patent 7,337 (1850), encompassing the innovation of iron floors and iron roofs. In the same patent, Bogardus applied to protect his design for the cast iron structural frame used in his façades.[3] However, his claim was denied, being cited as bearing too similar a resemblance to public knowledge within the quickly developing foundry industry. Bogardus's aide, John Thompson complained "As a substitute for his safe and simple joint, wedges, mortises, chairs and other complicated devices have actually been patented."[4] In 1856, Bogardus published the brochure *Cast Iron Buildings: Their Construction and Advantages*, emphasizing the particular design characteristics of his prefabricated system within the broader industry. By 1862, twelve years after he began fabricating cast iron facades, and faced with mounting competition, Bogardus retired.

Hennebique worked secretively for twelve years to develop his reinforcing system for concrete. In 1892, the year he opened his reinforced concrete consulting company, he was awarded two patents for his structural reinforcing system. Patent 611,907 (Europe 1892, US 1898) introduced stirrup shaped reinforcing rods connected to a beam's reinforcing rods. Patent 611,908 (Europe 1892, US 1898) bent the ends of the stirrups to become horizontal.[5] By 1910, Hennebique's system was challenged in the United States courts. Eventually the patents were declared invalid, as they became considered public knowledge within reinforced concrete industry.

Knowing his patents would be challenged, Hennebique developed a pervasive advertising scheme to build market share. He used every opportunity to make the case for reinforced concrete. He developed the slogan "Plus d'Incendies Désastreux" (No More Disastrous Fires), which he affixed to all drawings and advertisements. He established a yearly convention bringing contractors and engineers together to discuss the field. He published the monthly journal *Le Béton Armé*. Throughout his marketing materials, Hennebique adopted the new technology of photography to disseminate images of his projects. In addition to views depicting complex geometry and scale, he employed "scientific" photographs showing sacks of concrete loaded on floor plates to pictorially reveal the strength of this still innovative material to prospective clients.[6]

Today, Zahner holds patents and trademarks on a range of services and products: a structural support method, seaming systems, a patterning program, and many proprietary coatings. Zahner often develops new lines of products and processes to accommodate the desires of architects for particular design characteristics. Zahner then trademarks the product or process, and makes it available as a commercial line. Just as with James Bogardus and Francois Hennebique, the commercial line retains remarkable freedom for customization – allowing future users to adapt the product or process significantly.

Zahner holds five patents. Patent 7,434,366 B2 (2005) establishes the design and application of I-Beams with curved flanges. These I-Beams provide the structural support for the sinuous geometries of the Zepps™ system. Patent 5,272,849 (1993) describes the roof covering system that led to the trademarked Bold Batten™ standing seam. This system delivers concealed fasteners that can expand and contract in varied weather conditions and a concealed gutter system. Patent 5,394,666 (1995) describes the inverted seam roof covering system. This system provides control over precision and placement of seams. It also offers an internal guttering system that routes water away from the interior of the building. The Inverted Seam™ system draws upon this patent. Patent 7,210,273

B2 (2007) establishes a concealed attachment which allows for additional precision in seam location. This includes seam width control, providing flush installation or specific reveals. The Inverted Seam™ system also draws upon this patent. Patent 7,212,688 B2 (2007) describes a computer program and method for converting a digital image into control data which drives fabrication machinery. The Zira™ imaging program and the machine language that controls the bumps, dimples and perforations of the Metasystems™ originate with this patent.[7]

Having authored comprehensive publications on the architectural metal industry and establishing the innovative technology making digital fabrication of architectural metal possible, Zahner is recognized as a global leader in their field. Currently, Zahner's greatest growth is in its design assist service, which provides an avenue for individualized design solutions as competition within the market grows.

Business Model and Control of Labor

Prefabricated units often allow the use of less skilled labor during installation. If a prefabricated system is highly customized then it becomes necessary for the fabricator to maintain control of labor.

Bogardus's first commissions for façades occurred prior to the completion of his own factory. As a result, he divided casting work between three independent foundries. After the completion of his factory, Bogardus continued to outsource production of his cast iron components to independent foundries. He established quality control through in-house filing and fitting of individual components. Eliminating casting operations but maintaining quality control allowed Bogardus to realize significant cost savings.

In addition, the self-supporting façade provided quick installation. Bogardus's workers installed façades in a few days rather than over the span of months. This significant savings in time afforded weather protection, permitting earlier commencement of interior work and direct cost savings to the owner.

Hennebique ensured quality control through an innovative business model of franchised offices and licensed contractors that, while typical in today's market, was unique among his contemporaries. Hennebique assumed the role of a design consultant, providing design documentation and structural calculations to his clients. He trained and vetted contractors in his construction methods and provided binding labor agreements. The contractors worked for Hennebique primarily, but also took on independent projects outside of reinforced concrete construction during slow times. Licensing contractors allowed Hennebique to control a large number of workers, and to manage fluctuations in project load. Through site visits and photography he controlled the quality of work, releasing underperforming contractors from licenses. This business model allowed Hennebique to quickly expand globally, while still maintaining customization in design and overall quality.

Today, Zahner provides services in design assistance, material fabrication, and installation. As a fabrication specialist, Zahner often acts as a consultant from the beginning stages of design through construction. This role provides the opportunity to negotiate contracts for design, fabrication, and installation services in lieu of bidding. Cost efficiencies in pricing stem from technology upgrades to façade design, offsite fabrication, and installation process.

Zahner is a union shop with 140 employees located in Kansas City, Missouri. During the construction phase, Zahner acts as a subcontractor to the general contractor. In order to work across state lines, Zahner negotiates agreements with local sheet metal unions. Depending upon the particular state, Zahner can utilize two to five of its own workers on projects outside of Missouri. Union sheet metal workers local to the place of construction comprise the remainder of the installation team. Sending workers from Zahner, who not only coordinate but also participate directly in installation, maintains control, quality, and communication with central operations.

In many cases Zahner produces the structural support for the sheet metal panels. The iron workers union holds the contract to install structural members, and Zahner belongs to the sheet metal union. In order for Zahner's workers to participate in installation across the United States, Zahner must negotiate individual agreements with the local iron workers union for each project. In many states, these agreements represent unprecedented collaboration across trade union lines.

Conclusion

Bogardus, Hennebique and Zahner are each distinguished by their profound understanding of marketing to an audience of designers and clients seeking infinite customization while also requiring warrantee for quality performance of their products.

The entrepreneurial spirit and inventiveness of these three fabricators has allowed innovative installations in varied sectors of the building industry. Participating in all phases of design, fabrication and installation, each fabricator's operations provide a model of successful balance between tailored design, quality, and efficiency. As a result, James Bogardus, Francois Hennebique, and Zahner distinguish themselves as instrumental in evolving the built environment.

ENDNOTES

1 Collins, Peter. *Concrete: The Vision of a New Architecture* 2nd edition McGill-Queens University Press:2004. Montreal Canada, 2004. p 68.

2 Zahner Building Envelope Systems, http://www.azahner.com/sys_building_envelope.cfm Site last visited 07.10.12

3 Gayle, Margot and Gayle, Carol. *Cast-Iron Architecture in America, The Significance of James Bogardus* Norton & Co.: New York. 1998. p 87.

4 Ibid. p 88.

5 Saurbrey, Alexis and Ransomme, Ernest Leslie. *Reinforced Concrete Buildings; a Treatise of the Patents, Design and Erection*

of the Principal Parts entering into a Modern Reinforced Concrete Building Nabu Public Domain, Original Copyright McGraw-Hill Book Company: New York, NY. 1923. p 42.

6 Delhumeau, Gwenaël and Jacques Gubler, Réjean Legault, Cyrille Simonnet *Le Béton en Représentation* Hazan Institute Francais d'Architecture: Paris. 1993.

7 Resources for patent information on Zahner

http://www.patentmine.com/grant/05272849_summary.html Site last visited 07.10.12

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