The Evolution of Skins:
A Case Study Comparison of Three Gehry Projects

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...while growth is a somewhat vague word for a very complex matter, which may depend on various things, from simple imbibition of water to the complicated results of the chemistry of nutrition, it deserves to be studied in relationship to form: whether it proceed by simple increase of size without obvious alternation of form, or whether it so proceed as to bring about a gradual change of form and the slow development of a more or less complicated structure.
—D'arcy Thompson, On Growth and Form

Given an original problem to resolve, one's first solution will invariably be one of unusual complexity. But the more it is worked over, and thought over, the simpler the solution becomes, until in the end it results in something almost elementary; one is only puzzled why in the world one did not think of the simplest way first.
—George Woodbury, "John Goff's Mill", NY: Norton, 1948, p.220

INTRODUCTION

One can read an exciting story of evolution in the work of Frank Gehry by comparing three recent projects: the Guggenheim Bilbao, 1997, in the Basque capital of Spain, Experience Music Project (EMP), 1999 in Seattle and the Disney Concert Hall currently under construction in Los Angeles. At a casual glance, the three buildings appear very similar. Each bears Gehry's signature exhuberant curves and thin metal skin, and each was developed using the computer program CATIA to make these forms buildable. Upon examination of the working drawing and construction photographs and after interviewing the manufacturers and project architects, the three buildings emerge as distinctly different stages in an evolution of structure and skin. The changes in approach are not merely due to the differences in material from titanium to stainless steel or aluminum, but rest instead on important technological developments in the manner of construction and connection.

While it is tempting to create a rational scenario describing a systematic and intentional path drawn chronologically from Bilbao to EMP to Disney, in fact the evolution - while generally moving in a progressive manner- is essentially chaotic and hard to understand. A close comparison of the panel details, structural strategy and construction methods can help us see the pragmatic differences in how the buildings were made. Attributing these changes to a development of tectonic philosophy is dangerous. The demands of a high design practice such as Frank O. Gehry and Associates (FOGA) do not provide the ideal ground for contemplation of the tectonic. As an academic, I can suggest a framework to view the progress and begin to see a pattern that will remain to be confirmed in Gehry's future projects.

The relationship between structure and skin in most of Gehry's projects has been one of complete autonomy. The sometimes awkward relationship between the two was the result of a highly designed exterior and interior sandwiching the necessary structure and enclosure systems. Though the skins that Gehry uses are examples of the most advanced technology, the building envelope contains enormous amounts of poché space between primary structure and skin. In this paper, I will argue that the recent work of Gehry is marked by preliminary exploration in the search for the optimal way to achieve his trademark forms. In five or ten years, we will regard this trio of buildings as a seminal group that opened possibilities for the creation of a truly fluid metal skin.

FOGA

Early examples of Gehry's work show an interest in exterior and interior forms and a disregard for how messy the underlying wall construction might need to be to achieve them. Gehry's work shows a willingness to let the relationship between structure and skin be resolved by happenstance, allowing incidental relationships occur as they might. In the Gemini G.E.I office building, the standard 16" o.c. wood stud frame is clearly visible behind the strip windows. Openings were determined by the interior light and the exterior façade proportion, not by alignment with the stud spacing.

In his essay, "The World Turned Upside Down: The Tortoise Flys and the Hare Threatens the Lion", Francesco Dal Co discusses the autonomy of structure and skin in Gehry's work.

> *The shopping center in Santa Monica, in fact, is a sort of theoretical presentation of how to represent the independence of the structure from the skin and a demonstration (in two versions) of the potential of this division. Gehry designs the entrance in correspondence to the main axis of the building (shifted from the 'natural' axis of the lot), excavating it, making it emerge 'in negative' from the volume. The resulting façade is composed of a fragmented collage, using bits and pieces left over from the underlying spatial grid, which is thus subjected to an arbitrary metamorphosis that changes its meaning, while openly declaring the freedom of the design choices thus displayed* [1]

Gehry's sculptural forms, such as fish made out of chain-link or glass had a clearly visible substructure that only roughly massed out the final form and a more refined support system that held up the exterior skin. Never occupied, the mass of structural elements inside the skin was never subjected to editing for spatial clarity.

Gehry's recent work, while far more sophisticated in many ways, continues to show autonomy between structure and skin.Throughout his work, the space between the two systems is rarely used and almost never occupied.

STRUCTURE

Looking at the structural solutions for each of the three buildings, one can see a radical shift in strategy between Bilbao and EMP with Disney as a kind of hybrid intermediary.The essential difference lies in the controlling geometries of the structure and skin. In Bilbao, the structure is composed of straight elements in a lattice grid. EMP uses curved structural elements, with no repetition. Disney has both the lattice grid and the curved structure – a hybrid approach.

The Guggenheim Bilbao, while undeniably one of Gehry's most successful buildings in terms of design, was not technically innovative. Relatively "conventional" for FOGA in its use of CATIA and the structural strategies employed, the thinness of the skin and the large scale of the building set it apart from previous Gehry projects.The structural engineers' description of the building's structure is a remarkable account of how they reduced Gehry's complex curves to a uniform lattice grid made of straight elements :

> *A structural concept in steel based on a relatively dense, discretized, modular grid interconnected by diagonals using standard rolled steel shapes was devised. A grid spacing of 3 m between horizontals and verticals was found to be flexible enough to generally conform to the architectural surfaces, with linear members between the grid intersections. This lattice grid framework wraps around the interior of the metal shapes of the galleries and the atrium.*
>
> *The steel grid frame solution allows prefabrication in a shop environment using computer-controlled techniques to achieve a high degree of accuracy for assembly in the field. The inclined "vertical" member shapes are rolled I-sections, while diagonal and horizontal members are pipes and tubes. The joints are made by a horizontal bearing plate at each node, which accommodates both vertical and horizontal changes between members. Typically, most joints are bolted.... This system for the faceted lattice grid facilitated the direct attachment of the metal cladding to the primary structure, while minimizing structural thickness. ... The fabrication/erection concept for the complex three-dimensional frames was formulated based on 3m tall 'bands' of framework, shop –connected in horizontal lengths that could be shipped to the site and then 'stacked' vertically and spliced horizontally to create the complete assembly.* [2]

The challenge to the designers lay in trying to work within the lattice system while creating completely fluid and non-repetitive forms. Lead designer Edwin Chan says that Bilbao is a curved building made of straight elements. "Our problem was how to make the curves while keeping within the straight element system."[3]

EMP, by contrast, had no repeated structural forms and a highly irregular grid.The building's extremely high budget allowed for much more innovative structural system. A firm in Oregon, Columbia Wire and Iron Works, pioneered a manufacturing technique which made it possible to fabricate curved wide-flange elements . The web pieces were cut with a CAD-CAM driven plasma cutter to the precise curve of the beam. Flange elements were rolled using computer driven sets of rollers that could shift to create convex or concave curves of varying degrees continuously along one piece of steel.The flange and web elements were joined with a specially designed robotic welder that rode along the flange.

The beam elements were curved, but their curves only roughly approximated the final overall form of the skin. The finished curved profile was made by a secondary structure of steel pipe which supports the metal panel skin. (see Figure 1)

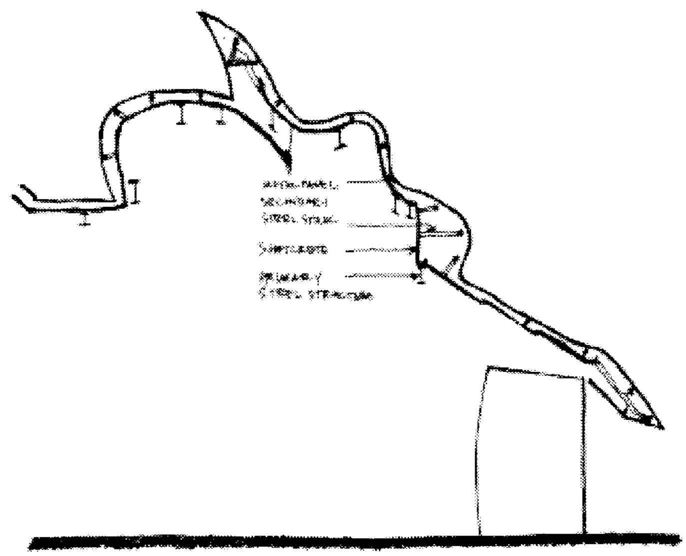

Figure 1. Section Diagram of EMP's structural and cladding system

Connection between structure and skin varied between an ideal of 22" to the decidedly non-ideal distance of 11'. Such a wide variation was accepted because it was unknown what curvature the beams could tolerate accurately. In hindsight, Paul Zumwalt, the client representative, wished that more of the curves had been made by altering the geometry of the primary steel [4] instead of using the secondary pipe structure to compensate for the most eccentric curves [5].

The last of the trio of buildings discussed is Disney Concert Hall. Throughout its long and controversial history, the project design changed several times.The protracted design phase– drawn out by rancorous legal battles– had one advantage: the added time allowed the building to take advantage of the technical innovation developed in EMP.The last incarnation of the Disney building incorporates the EMP-type beams for some of the more sculpturally expressive areas including the highly visible Founders' Room. The main concert hall, whose form has a prescribed regularity determined by acoustical requirements, bears a strong resemblance to the structure of Bilbao. Disney is a hybrid structure further complicated by the need for acoustical buffering zones. (see Figures 2 and 3)

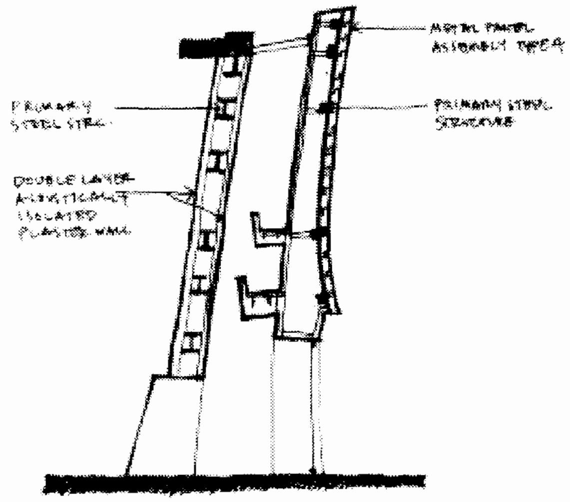

Figure 2. Section diagram through Disney Concert Hall Lobby

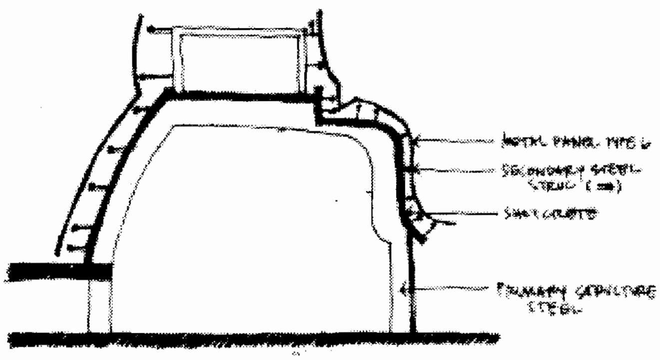

Figure 3. Section diagram through Disney Concert Hall Founders' Room

None of these examples begin to explore a potential that Greg Lynn and others call the search for the "divine" material- one that is strong, light, thin and could serve as both structure and skin [6]. "Blob" architects would prefer if the interior and exterior forms were directly related with only the thinnest of membranes separating inside from out. Gehry does not seem to care if the inside geometries and the outside geometries are related at all. Many examples in his work show a highly sculpted interior set of forms constructed out of sheetrock and a different but equally highly sculpted exterior set of forms constructed out of metal or stone.

However, if the "divine" material is found, I have no doubt that Gehry take advantage of simplifying his forms to a single structure/skin. For Gehry and others who may use this ideal material there remains the perennial issue of housing services and insulation within a thin and monolithic shell.

SKIN

The celebrated skin of Bilbao is made of titanium. Much has been made in the popular press about this glamorous material that was chosen for its sensual qualities and purchased during a rare dip in market prices. The material was chosen for the mercurial liveliness of the finish, which would alternately take on the color of the river or the sky. Its extreme strength allowed the panels to be just 0.38 mm thick, thin enough for a slight pillowing effect to soften the appearance of the building. Several pieces of metal together formed a panel attached to a sub-frame that could be directly connected to the building. Since the structure was assembled in horizontal bands, the skin could likewise be stacked. Adjustability was relatively straightforward because of the horizontal regulating lines.

EMP had no regular geometry that could govern its skin. In fact it could be said that it was the curvature of the skin that governed the geometry of the structure. Highly eccentric double curves and an irregular curving structure made the assembly of the skin extremely challenging. The metal pieces (either stainless-steel or aluminum) were formed into panels similar to Bilbao. But instead of attaching to regular horizontal primary members, the panels attached to an irregular secondary system of steel pipe. The connection from panel to pipe to primary structure allowed for adjustments in all directions. (See Figure 4)

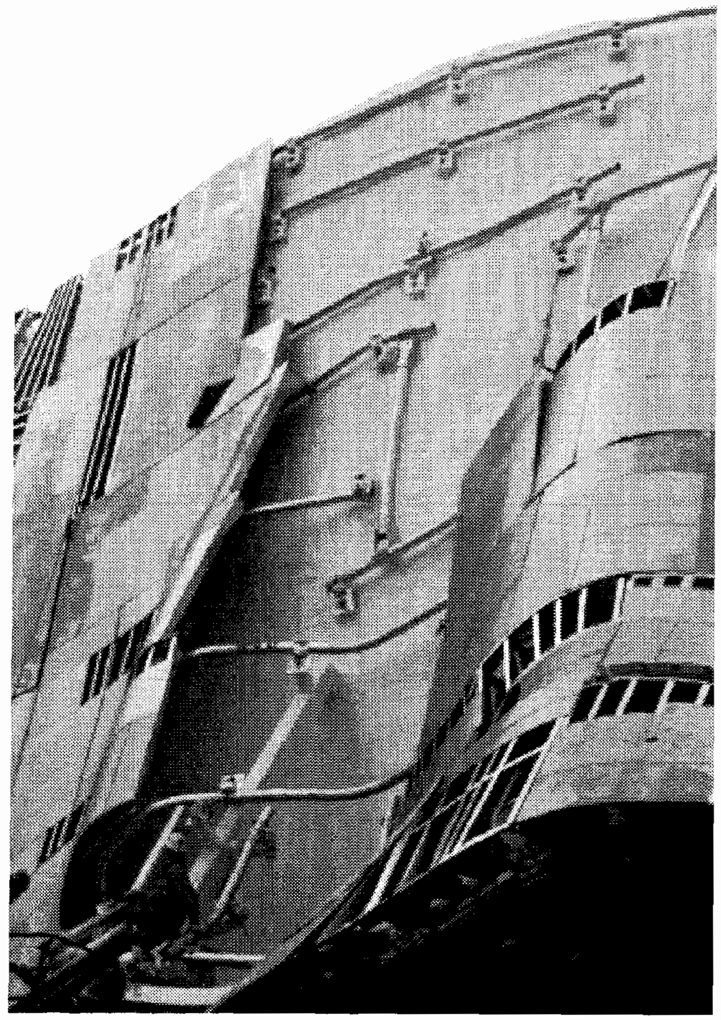

Figure 4. EMP cladding under construction – steel pipe support structure over shot-crete (photo by Eric Olson)

The use of CATIA models in design of EMP's skin was essential. The models were loaded with dozens of parameters – some aesthetic some pragmatic. For instance the model would not allow four corners of metal to join at a single point (an aesthetic choice). It would not allow curvatures of more than a certain degree (a manufacturing limitation based on how far the metal could be bent without resorting to casting techniques). The computer model was used to test forms that were developed in physical cardboard or foam models. Physical modeling drove the design, computer models were typically one step behind the physical development.

Though the physical models had primacy, there were two main areas in which the computer model could cause modifications in the design: structure and panels. Of those two areas, the panels were more likely to cause design changes than the structure. The forms had to be "rule-developable" - ensuring that panels could be created from flat sheets of metal. Once the decision was made to create curved wide flange members, the structural geometry rarely became a limiting factor. The tolerance of the curvature was conservatively estimated, sometimes requiring the use of secondary structure to support a highly curved area of the building.

The space between the primary structure and skin is occasionally occupied with mechanical systems, but for the most part, it is unused. During construction, the skin had a transparent quality where the grain of the sub-frame and the depth of the void contributed to very sophisticated and ambiguous cladding. As the skin was closed and the building forms took on their finished object-like appearance, all of these qualities were lost. Many of the openings are detailed as punched openings, a strategy that treats the wall system as if it were monolithic. There is one area near the monorail through passage where the skin is peeled back to create openings, a treatment that is much more tectonically consistent with the actual layered construction.

Disney Concert Hall has the distinction of specifying not one or two panel types, but six distinct panels each with their own types of connection to structure. The two driving forces for this wide variety of panel types are the hybrid structure and different degrees of acoustic isolation needed. Additionally there are places where access into the interstitial space requires a removable panel, the first in FOGA's extensive panel vocabulary.

The removable panel is a key development that may allow the interstitial space to be efficiently used for services or light filtering. The creation of this third zone, neither structure nor enclosure, offers new spatial possibilities yet untapped by Gehry. There exist several examples of rainscreen systems using the skin as a light filtering device, most memorably in the Swiss examples of the SBB signal box building by Herzog and de Meuron and the Forestry stations by Burkhalter and Sumi. However, in these examples, the skins are relatively orthogonal and the space between the structure and screen is held to a consistent dimension. Should Gehry decide to exploit this space, he would have to find a way to resolve openings in the enclosure and support of the skin without conflicting with these openings.

CONCLUSION

In his 1958 textbook written at the dawn of contemporary American curtain wall design, William Hunt lists the obstacles for the adoption of cutting edge curtain wall technology. This same list could describe Gehry's troubles in the twenty-first century.

> *Only within the last several years has the designer had at his disposal a protective covering for the major structure of the building that exploits our present-day manufacturing, prefabrication and erection methods. Many problems remain to be solved before this new construction completely fulfills our requirements, but the way is now open for their solution. Enormous obstacles to the new construction-an indifferent and sometimes hostile public; a labor force reluctant to accept new materials and techniques and plagued by jurisdictional disputes; antiquated building code restrictions; the lack of research and development within the industry-have been or are being overcome.*[7]

It remains to be seen whether Gehry's strategies will evolve towards an activated "poche" space or a skin which can serve as both structure and enclosure. At this point in time, he is poised uncomfortably between these two approaches. Choosing between the two will probably occur when one strategy becomes economically more efficient to construct or manufacture. Gehry's concentration on form leads me to believe that the spatial efficiency of one choice over the other will probably not be a deciding factor.

Given Gehry's demonstrated willingness to use hybrid systems, a combination of these two opposing strategies might also occur. Gehry's tectonic strategy is driven primarily by the geometries of his forms. Having a consistent theoretical relationship between structure and skin has not been a priority.

The extremely complex structure and skin solutions apparent in this trio of Gehry projects are beginning of a long evolution towards a simpler way to create fluid form. Whether this be through the use of transparent or occupied poché or through simplifying the structure and skin system into one, Gehry's office is engaged in a constantly evolving search for ways to achieve his fluid forms. To look at the current set of strategies illustrated in these three examples is to view a snap-shot of a tectonic philosophy that is in flux, as fluid and changeable as the building forms themselves.

ENDNOTES

[1] Dal Co, Francesco, "The World Turned Upside Down: The Tortoise Flies and the Hare Threatens the Lion" in *Frank Gehry: the Complete Works*, Rizzoli. p. 45

[2] Engineering International, 4/96, p. 227

[3] Interview with author, May 2000

[4] Interview with author, May 2000

[5] geometries that the project architect George Metzger calls the "whoop-de-do's"

[6] For more on this topic see the Architecture Magazine issue on Blobs *"Honey, I'm Home"*

[7] Hunt, W. *The Contemporary Curtain Wall: Its Design Fabrication and Erection*, FW Dodge: New York, 1958, p. 4