COORDINATING A UNIFIED AESTHETIC VISION BETWEEN ARCHITECT AND STRUCTURAL ENGINEER

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Abstract - Constructing a cohesive Japanese design aesthetic in America presented a host of engineering and design challenges related to the creation of a massive multi-level reinforced concrete cantilevered staircase. The focal-point, standing within a three-story open atrium, required a wide variety of daring engineering solutions and construction coordination in order to achieve a result possessing great fidelity to the architect's original design vision. This paper explores the methods by which the owner's representative enabled the design vision to be unified and ultimately successfully constructed by a highly skilled concrete subcontractor's team. The design for the staircase, located within a private museum, originated from Osaka, Japan based architect Tadao Ando in collaboration with a Chicago, Illinois based structural engineering team Thornton Tomasetti professional engineers.

Index Terms - Cantilevered Stairs, Reinforced Concrete, Structural Engineering, Tadao Ando.

I. INTRODUCTION

It must be understood that the basic operating principle upon which structural engineers work under is to search for the most structurally efficient solution that lies within a pre-defined realm of safety. With regards to engineering the structural system that outfits an entirely new museum building within an existing shell in the Lincoln Park neighborhood of Chicago, Illinois, the client selected Thornton Tomasetti structural engineers[1] to work along side with Tadao Ando Architect and Associates. Together, the two firms worked to create one of the city's most stunning structures and one which could bear an incredible amount of physical weight within (300 pounds/foot^2 or 14.36 kN/m^2 live loads). The struggle which shall be explored in depth in this paper is the understanding of how to finesse out the best performing structural solution to a given design problem, when also considering æsthetic appearance. In many contemporary solutions, the structure and how it performs is often times hidden behind walls, buried under layers of cladding—so that the elegance of an engineer's touch is not fully expressed. With regards to Tadao Ando's design work, building in the strict idiom of reinforced concrete which is typically left fully exposed, does not leave much latitude for camouflaging how a building stands up. In the case of this project, Wrightwood 659, in many areas the reinforced concrete walls are acting chiefly as a fireproofing element instead of a bearing component. While reinforced concrete structural walls do exist primarily on the fourth floor, the vast majority of the concrete used in this project on floors one through three are strictly in place as an æsthetic expression and are not bearing walls. The one area, completely visible in the three story atrium, where reinforced concrete is used not as fire-cladding, but both as a structural wall and as an æsthetic expression is the monumental staircase. This staircase provides this case study with a myriad of design challenges whose expressed structural solutions shall be fully explored.



Fig. 1: Wrightwood 659 originally as an apartment building.

II. BASIC CONSTRUCTION

A. Working with a masonry shell

The original structure, a four story, 39-unit apartment building, was built between 1929 and 1930, with starting occupation occurring sometime between December 1930 and January 1931. This building was constructed with an exterior shell completely made of three wythes of Chicago common brick. The interior, however, was composed of a variety of materials which changed depending on location and fire-resistance. First, the common corridor which stretched nearly the entire length of the building was likewise composed of three wythes of Chicago common brick. Three layers was the bare code

minimum qualification for a basic firewall although it far exceeded in some instances its structural requirement. Secondly, the composition of the ceiling of the first floor and floor of the second was built out of a layering of hollow flat clay tile, lightweight ash concrete, topped with a thin layer of concrete embedded with furring strips providing a nailing surface for the finish wood floor (see section in Figure 2).



Fig. 2: Section cut through first floor ceiling. 30 October 2014.

Above the second level, the remainder of the building was composed of conventional wood floor joists. The reason why the more sturdy and 'weighty' clay tile and concrete was the presence of the building's boiler room on the first floor, half sunken into the earth, below grade. The risk of fire spreading upwards code-required that the boiler room be contained within a masonry-clad enclosure, which was properly accomplished. There are no records indicating that the building ever suffered from any significant conflagration during its life as an apartment building for 82 years, 1931~2013.

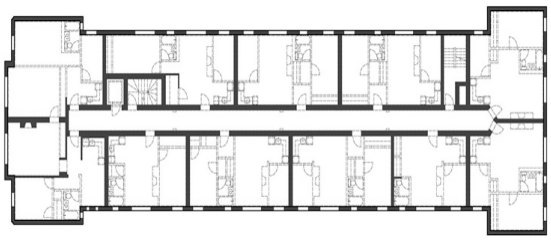


Fig. 3: Plan showing original brick load-bearing and fire walls, shown in black poché. Drawn by author.

B. A Tabula Rasa for the Engineers?

One of the most common questions asked by visitors to the gallery today is: "Is this brick original?"[2] Indeed, they ask this question of gallery guides upon their first glance at the soaring three story atrium, clad on three main surfaces completely in recycled Chicago common brick. The answer of course is a more complex one. First, the brick is correctly called recycled, but more specifically, it must also be termed 'relaid brick,' for it came from the demolished and deconstructed firewalls of the original center corridor which once served all the apartments. It was salvaged, sorted, cleaned and re-stacked on palettes before being returned to the building site to be re-purposed as complete interior wall cladding within the 42'-1" (12.82 m) tall three story atrium. The fact that the brick has been re-stacked is essential to be communicated for it covers up the original interior Chicago common brick which one used to be able to see within the space, and it also provided an æsthetic respite from the unsightly but highly functional layer of closed-cell spray-applied foam insulation/vapor barrier which was sandwiched in between the original brick wall (plus air space) and the newly installed, recycled brick interior wall.



Fig. 4: The monumental staircase fin-wall, prior to addition of reinforced concrete cantilevered steps. 8 September 2017.

C. A purely æesthetic staircase

Chicago, having suffered from a historically devastating fire in 1871, has some of the nation's most strict fire codes and egress life-safety codes in the United States, created in the aftermath of this event. This is due partially to a bit of paranoia about the great conflagration, which consumed 4 square miles of economically prosperous densely built urban land (10.36 km^2), covering almost the entire downtown area of the city and branching out into northerly residential neighborhoods [3]. The museum building which Tadao Ando designed was created in Japan where fire codes and exiting requirements are vastly different than that of the United States. Due to these differences, access doors leading to the two new fire escape stairs, embedded in the east mechanical zone of the building, needed adjustment. Gensler's Chicago office and Vinci|Hamp architects were the subsequent architects of record on the project, and they adapted the schematic design completed in Osaka for American, and in particular, Chicago building code requirements.

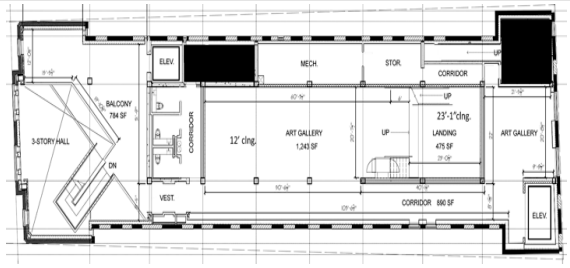


Fig. 5: Plan showing egress stairs (black) and angled monumental stair in three story atrium.[4]

When these tasks completed, irony lay within the fact that the monumental stair, serving levels one through three in the three story atrium actually falls into the category of an 'ornamental staircase' which serves no egress function nor is an approved route of escape in a fire, due to its location in a tall space where smoke theoretically can gather and asphyxiate the occupants of the atrium. In other words, a very sturdy and monumental stair, built entirely out of reinforced concrete, with a minimal amount of aluminum anchoring tempered laminated glass railings with stainless steel handrails, possesses almost no flammable material, yet still does not qualify as a stair that enables a safe path of egress during a fire. This is the strange condition which plagues building fire codes which do not possess allowances for special accommodations for unique conditions which abound within this museum building.



Fig. 6: Architectural Record 1999 article photo showing staircase of Chicago house.[5]

III. STUDYING A CONVENIENT ARCHITECTURAL PRECEDENT

Prior to engaging Tadao Ando in the summer of 2013 to take on the commission of this private museum project, it must be noted that the architect was intimately familiar with his client. This is due to the fact that between 1992 and 1997, the architect worked with the client to build a large residential home, as his first project outside of Japan intended for private residential use. The resultant home was so remarkable that it was recognized in 1999 in Architectural Record, as a "Home of the Year."[6].

This degree of familiarity that Ando san and his number one architect in the office, Mr. Masataka Yano, had of the owner and his expectation of spatial use of the building, provided the team with an innate sense of direction for the gallery project. Furthermore, the fact that there was a finished home, built to Ando san's specifications, right next door to the museum project, made it a fine exemplar from which the team could learn from—as a complete life-size maquette or finished, occupied 'case study.' The construction team composed of the general contactor, Norcon Construction, along with the concrete subcontractor, Elliot Construction, made frequent 'site visits' to the finished Ando house in order to study its form, construction, and better their own methodology in the early stages of the project.



Fig. 7: Staircase detail in owner's original house.

IV. Conveying an Architectural Æsthetic

A. Efficiency versus Intentionality

Thornton Tomasetti's Chicago headquarter office supplied a team, headed by executive Bill Bast and director Michael Murphy, who steadily lead the gallery structural design project to completion. However, as aforementioned, there were hurdles to clear where a specific design intentionality had to be communicated, at times it turned out overriding ultimate structural efficiency. The main component which received the greatest degree of debate between a triumvirate which included Ando's Osaka office, Thornton Tomasetti's Chicago office and the author

employed as Owner's Representative, was the thickness of the cantilevered stair and landing mid-way between floors two and three, and how this landing itself was to be supported.

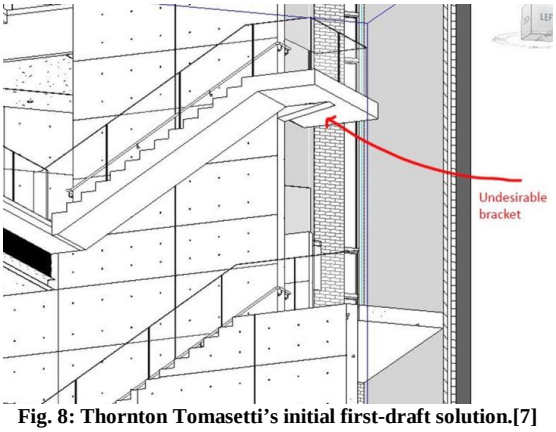


Fig. 8: Thornton Tomasetti's initial first-draft solution.[7]

B. **Adequately Communicating the Goal**

As Fig. 8 shows, the initial design solution suggested by the structural engineer was a utilitarian but highly efficient angled bracket or corbel. This is a common and structurally expedient method by which loads are collected and transferred from a horizontal plane to a vertical bearing area. Corbeled drop-capitals, also known as mushroom-topped columns, are ubiquitous in nineteenth-century warehouse structures as well as squared off forms in car parking garage structures built today. The corbel or bracket is an engineer's economical solution to transferring loads safely and effectively with efficient use of internal ribbed, graded and gauged reinforcement steel rods, known as 'rebar.'

C. Counter-Solution placed on the table.

Due to the strict geometric nature of Tadao Ando's work, it was known well ahead of time that the architect's office would not accept a simple bracket as the means by which their carefully designed landing should be supported. Without having to place a complex correspondence of debate upon the structural engineering firm, a simple photograph with annotation served as a direct method communicate to the engineers that an alternative design solution was requested. Hence, the Owner's Representative proceeded to photograph the underside of the staircase landing in the original Ando-designed home (see Figures 6, 7 and 9), circling the desired 'flat' connection between the landing and the supporting 'fin wall' and ask that the structural engineer reconfigure the geometric layout and/or increase the quality and gauge of rebar within the wall and landing connection to altogether eliminate the presence of the proposed corbel (Fig. 8). Note "Undesirable bracket" note in red was added by the owner's representative (author) to communicate the non-desired condition back to the structural engineer.



Fig. 9: Desired underside landing-wall connection.

V. A SOLUTION ENSUES

A. Calculating the Optimal Solution

Obviously, the engineering team at Thornton Tomasetti did not position the reinforced concrete bracket in place beneath the stair landing for no reason at all. It was what their experience, knowledge and computer modeling suggested as the most efficient solution. Instead, a new solution was found, where the bracket could be eliminated, but at a cost of adding a greater amount of rebar within the slab of the landing, and slightly increasing the overall thickness of the landing. This was difficult, because as common wisdom suggests (and physics demonstrates is true), the thicker a slab grows to accommodate more rebar, the more it weighs, and the larger amount of rebar it requires to carry its own increased weight. This highly sounds like a Sisyphean task has been assigned to the engineers—that being, an impossible problem to solve. They worked on the suggested change, and prevailed, without a remarkably severe increase in slab thickness!

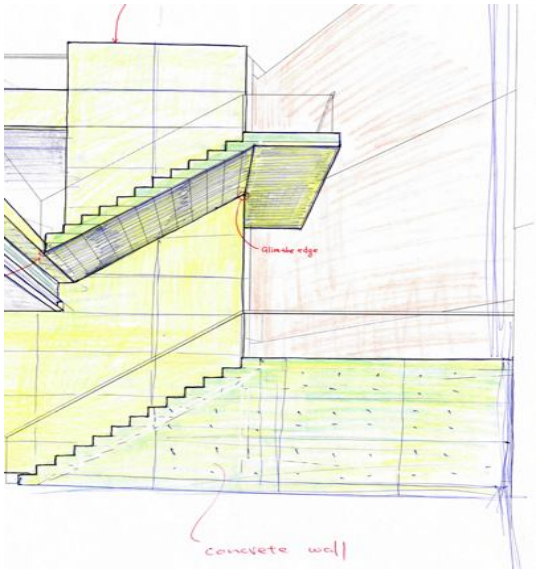


Fig. 10: The desired outcome, as graphically illustrated by Tadao Ando's office.[8]

B. Response and Confirmation from Osaka

In Figure 10, the small hand-written note, scribed in English in red ink, by junior associate at Tadao Ando's office, in charge of this project, Miyamoura Kazutoshi, states: "Ali[g]n the Edge"[9]. Here, in this note, Miyamoura san clearly indicates the firm's desire for the geometry of the underside of the stairs to end at the edge of vertical plane of the wall. Earlier versions did not always accomplish this precise alignment. The staircase landing at the house also did not (Fig. 9). Subsequent plan and elevation proposals following this edict did conform.

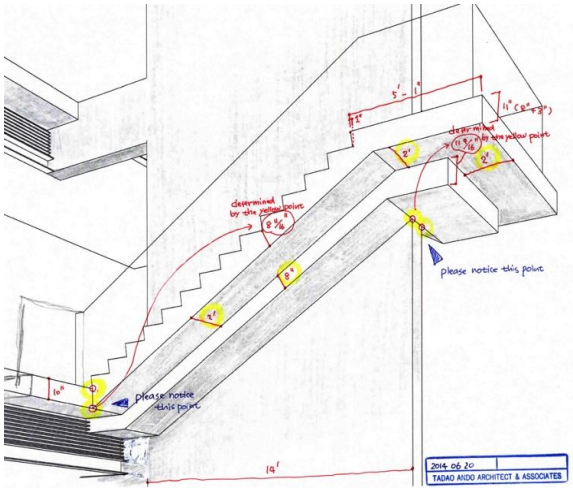


Fig. 11: Draft solution; ultimately found lacking. [10]

C. Searching for the Best Solution

Initial responses by both the architect of record in Chicago and structural engineer, consisted of making the underside of the stair thicker by adding a continual thick secondary support 'underside stringer', running along the underside of the stair in the form of either a continuous, linear, rectilinear drop-down support or a radiused corner condition. Figure 11 illustrates the stair support edge differences between the first proposed (Fig. 10) 'thin' cantilevered stair vision by Ando and the second (Fig. 11) 'thick' cantilevered stair solution by Thornton Tomasetti.

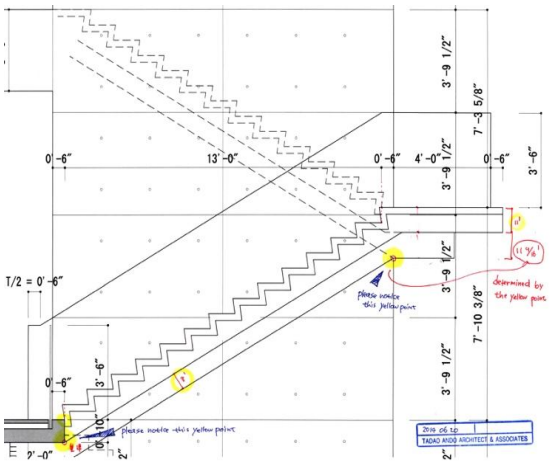


Fig. 12: Proposed draft solution elevation. [11]

VI. SUCCESS!

A. Narrowing down the desired design solution

Upon consultation with Tadao Ando's office, and review of the given set of options, a new edict was ordered whereupon an overall thinner edge profile was requested, sans stepped or cove support detail. This suggestion was returned to both the architect and structural engineer, and further calculations ensued to determine the best solution to proceed with, in order to satisfy the design architect's request.

B. Graphic illustrations of the Architect's vision

After initial meetings with Ando san in Osaka which occurred in the late summer of 2013, a series of computer renderings were issued from the firm near the end of 2013 and in the first quarter of 2014, to assist the client and owner's representative in visualizing the rather complex and cavernous three story atrium space. These renderings illustrated to some extent, an improbably bright amount of sunlight issuing forth through narrow slit windows oriented towards the south. True, these windows would eventually catch and transit a narrow ray of sunlight during the brightest of summer months, but due to an early 1880s brick rowhouse being situated on the eastern side between 9 1/2" and 4'-2 1/2" (24.13 cm and 128.27 cm) away from the museum building, a scant amount of real sunlight would ever penetrate. Hence, in order to appease the designer and his vision, and maintain a high degree of fidelity to the rendering, artificial lights, in the form of weatherproof outdoor-rated LED flood lights were mounted at various heights on the exterior of the building, fitted with lenses to focus their projected artificial sunlight through the intended narrow window openings. These tall, full-height windows range in width from 8" (20.31 cm) wide by 13'-4 1/2" (377.19 cm) tall at the first floor to 15" wide (38.1 cm) by 12'-3" (373.38 cm) tall at the second and 15" x 11'-0" (335.28 cm) tall at the third floor. Figure 13 shows the architect's computer rendering. Note the image shows the edge face of the cantilevered stair landing between floors 2 and 3.

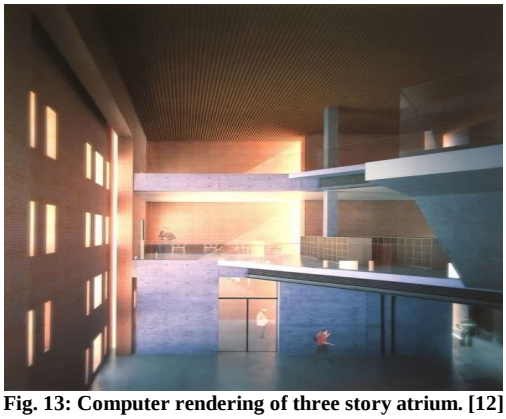


Fig. 13: Computer rendering of three story atrium. [12]

In addition to the set of photo-realistic computer renderings (which eventually totaled ten in all), a set of wire-frame computer-generated drawings, complete with hand-illustrated colored pencil renderings and hand-written notes, were provided not only for the client's edification but instead to enhance the local architect's understanding of material changes and corresponding geometric alignments.

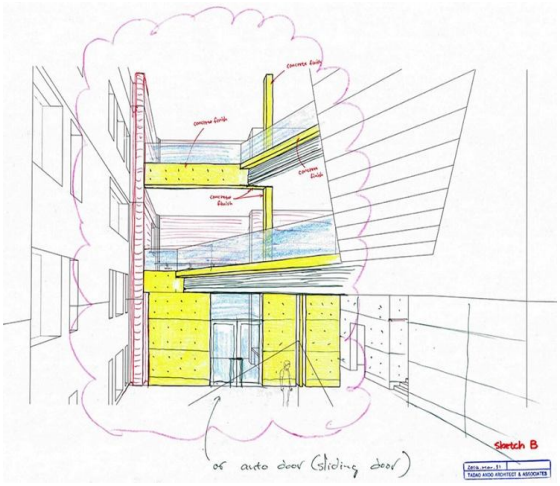


Fig. 14: Wire-frame model clarifying alignments and Ando's design vision. 31 March 2014.[13]

Figure 14 shows two major surfaces delineated, that being Chicago common brick shown in red pen (largely as horizontal lines) and architectural concrete (shown with formwork tie holes in an aligned grid pattern and in some areas, highlighted yellow). Figure 14 shows a particular perspectival vantage point positioning the viewer standing upon the large landing between the first and second floors, looking eastward. The computer program strangely illustrated the underside of the cantilevered staircase with lines, which, in reality, are not at all visible nor present in the final smooth-finish, sloped concrete underside of the staircase.



Fig. 15: Computer rendering looking northwest. [14]

C. Continual Refinement of the Architect's vision

Always improving the design, a sharp eye will recognize one major difference between two computer rendered images illustrated in Figures 13 and 15. The chief difference being the presence of a flat brick header making a 'proscenium (flat) arch'-like opening (see Fig. 13) framing an array of four-stories of windows which are all original fenestration belonging to the apartment building. This break-front monumental 'bay' contains the building's original triangular limestone pediment on the exterior. Ando purposefully chose to retain all windows with no edict from the municipality mandating such preservation. The flat proscenium arch or brick header shown in Fig. 13 is actually a later design iteration, issued later in April/May 2014, and was not part of the original design proposal, for it is absent in the 31 March 2014 drawing.

Figures 14 and 15 were issued in pre-April 2014, and both of these illustrations show the complete absence of a flat brick header at the intersection of the ceiling of the three story atrium and the monumental break-front bay. Later, as ceiling heights were gradually adjusted and the design was refined, the flat brick header was inserted to better 'frame' the array of windows contained within the giant 'four'-story 'bay' of Palladian-esque tripartite windows.

VIII. FINAL CONSTRUCTION

The ultimate realization of the project fully came together upon the construction of what had been drawn by hand and on the computer, in this case, greater than two years prior to final pouring of the concrete. Much rejoicing and excitement took place as the monumental staircase fully took form—when the cantilevered staircase, so carefully planned, was finally cast in its formwork and revealed in full grandeur upon removal of the formwork, seeming to float effortlessly in mid-air.

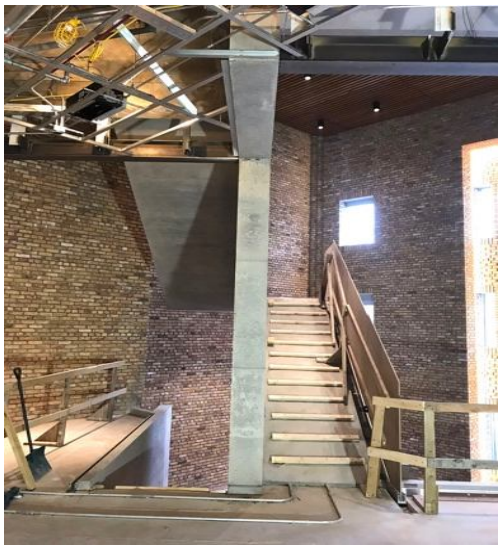


Fig. 16: Bearing concrete 'fin' wall, prior to stone step and glass railing installation. 10 December 2017.



Fig. 17: Completed staircase interior, August, 2018.

Fine finishing details, often times relegated to an interior design team or placed under the full jurisdiction of the local architect of record are never forgotten by Ando's office. Two elements which proved quite tricky entailed the finished brushed stainless steel handrail and the method by which it is mounted from the architectural concrete wall onto a bracket supporting the bottom side of the handrail. First, clear instructions requesting a non-directional stainless steel finish was made regarding all handrails contained within the building. Unfortunately, set bids had already been contracted by the general contractor for the procurement of handrails finished with a singular-direction brushed satin finish. Re-bidding and re-issuing the contract was a possibility, but a severe additional time premium would be instituted, which would have voided the promised soft opening date, where the gallery was to host Ai Weiwei's Trace exhibit on its first loan from the Smithsonian Hirshhorn Museum in Washington, DC. Such a change in time schedule was entirely untenable. Hence, single-direction brushed satin finish handrails were kept, installed and remain today.

Secondly, the brackets that support the handrails, while entirely designed and approved by Ando's team, were not manufactured and subsequently not attached in the pre-ordained fashion. The flat, finished 'bar stock' handrail was to contain a recessed or sunken 'shoe' in which a thin, flat anchor plate could then be entirely hidden into, and not visible from below. Instead, the creation of the shoe was never instituted, and the flat attachment plate is not only both visible, but also has a tactile presence for when one rises or descends the staircase. When an occupant places their hand onto the rail, and glides their hand up or down the rail, one can easily bump the pads of their fingers and fingertips against the rough edge of the small non-recessed plate. This is currently the condition which exists to this day, and no remediation has been scheduled for complete removal and re-manufacturing of all handrails would be required to insert or carve-out a shallow receptacle under all handrails to receive the thin flat plate. Such minute details as this the general public may bypass without care or notice, but nonetheless this is an un-fulfilled Ando detail, whose remedy unfortunately is not easy, inexpensive, nor of short time duration.



Fig. 18: Completed singular-direction brushed satin- finish stainless steel handrails, as installed.

CONCLUSION

In conclusion the structural, architectural engineering, and design teams in America had a particularly engaging task to satisfy the rigorous and exacting design vision propelled forward by Tadao Ando architect in Osaka. Ando's desire for a degree of precision in architectural concrete is unrivaled. Understandably, in order to achieve such a degree of precision, much pre-planning on iterative design stages occurred.

Patience, cooperation and a great amount of engineering talent and experience enabled the groups of professionals based in Chicago to accomplish what others may have regretfully declined: that is, the pushing of engineering and building materials to accomplish a design æsthetic which is rarely witnessed today, even in fine architectural commissions. Professionals and students alike can learn from this study about the methods that were employed to push engineering assumptions and efficient solutions to new, higher levels of æsthetic performance, yielding a cleaner and more finely derived design than many may have initially thought was possible.

Kudos are given to all levels of workers involved in the fine crafting of Ando's new private museum in Lincoln Park, Chicago, Illinois, USA.

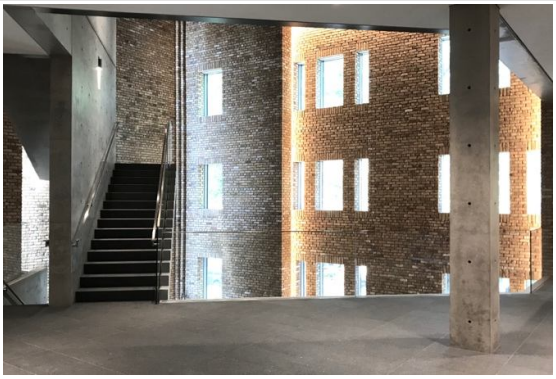


Fig. 19: Completed staircase interior, view north toward inside face of monumental façade, August, 2018.

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