Toyo Ito's Second Age of Aluminum: Toyo Ito + Masato Araya's Experiments in the Structural Use of Aluminum

As common as a cola can, aluminum is widely available, strong for its weight, corrosion-resistant and very versatile. For more than half a century, aluminum supply and demand have only moved upward—and at an amazing pace. Nonetheless, while between 1/4 and 1/3 of all aluminum consumed globally is used in building construction, only 13.2% of Japan's aluminum ends up in buildings..

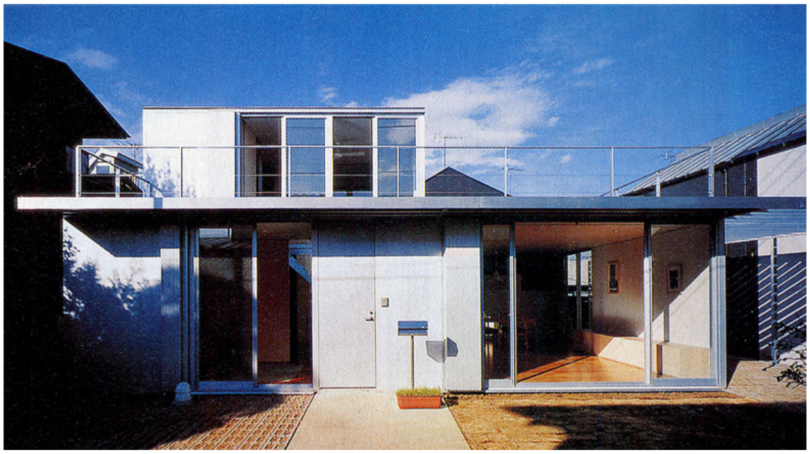
DANA BUNTROCK
University of California, Berkeley

MASATO ARAYA
Waseda University

INTRODUCTION

At the beginning of 1998, a number of well-regarded architectural professionals were approached by the Japan Aluminum Association to discuss untapped markets for aluminum in buildings. Toyo Ito chaired the group, the "Home and Aluminum Study Group", which would come to advocate the structural use of aluminum. The Home and Aluminum Study Group successfully made a proposal to Japan's NEDO (New Energy and Industrial Technology Development Organization) for financial support for a demonstration house under the title "Eco Building Material House Technology Development". (*Shitsunai*, 149) The reference to ecology may seem odd to Westerners aware of the embodied energy in aluminum production (although, secondary production requires far less electricity than processing from bauxite), but the idea that building materials could be readily recycled was particularly appealing in light of the two- to three-decade lifespan of most Japanese houses.

With the NEDO support, two prototype structures were built out of aluminum in the late 1990s, for research purposes only. These were then quickly followed by the first fully aluminum structure built for residential use—with exterior finishes, floor and roof slabs, shear walls, columns and beams all aluminum—designed in the late 1990s by Toyo Ito and structural engineer Masato Araya, consulting closely with the Building Center of Japan, a quasi-governmental organization. The house was completed in January, 2000.



1

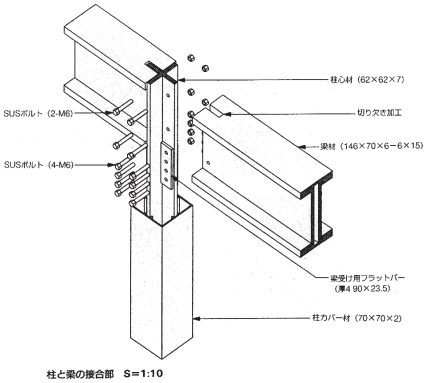
ALUMINUM HOUSE A.K.A HOUSE IN SAKURAJŌSUI

This trailblazing all-aluminum house was located next door to an earlier one Toyo Ito designed in 1975, also referred to in English by the same name, "House in Sakurajōsui". (Figure 1) Sakurajōsui is a neighborhood in Tokyo's Setagaya Ward. (Both homes were designed for the same client.) Design took two years, from 1997 to 1999, but construction was considerably speeded up, requiring only three winter months to build. It was a simple building, but the greater reason for quick construction was that there were few components: the structure, for example, also acted as exterior finish and waterproofing. The process of assembly was vastly simplified by the use of aluminum, parts quickly clipped together with stainless steel bolts or slipped into sleeves and tracks. Araya broke the schedule down as thirty days for the concrete foundation, twenty days to erect and weld the aluminum structure, and forty days for interior work. (AIJ 2000, p. 116) It is worth noting that there were many novel aspects to the erection and no established trades to rely on for the work, thus making the three-month period even more remarkable.

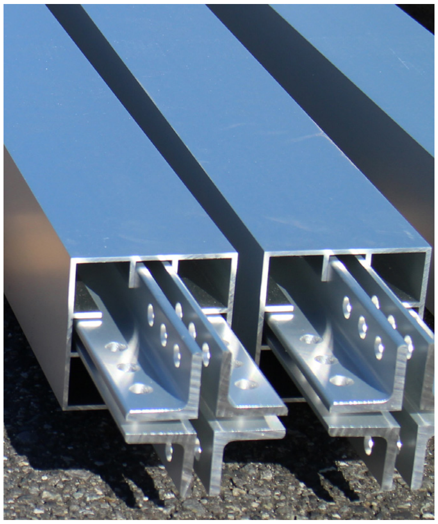
The unusual double-webbed wide-flange beams used here illustrate Araya and Ito's overall approach. (Figure 2) The beams were more stiff than a single flange beam, important because of the ductility of aluminum. Furthermore, assembly was speeded up: a gusset plate slipped into an internal slot of the web and was easily bolted to a cruciform column. But while assembly was fast, greater planning—and greater cost—were required to develop the novel shape and work out fabrication. It's a watchmaker's detail, fully expressing Araya's tinkerer tendencies.

Columns in this building were made up of two pieces: the central cruciform-shaped core was slipped into a square sleeve, which reduced the potential for buckling by locating more material at the periphery. This configuration has become better known over the last decade in places where earthquakes occur, a key feature in the design of "unbonded" or "bucking-resistant" braces. (Figure 3) Many of Japan's leading structural engineers were already aware of the development of these systems in the late 1990s.

The columns and wall panels were neatly integrated with windows, thanks to the interlocking nature of aluminum components. This reduced the need for trim, but expanded the number of shapes produced for the column sleeve to three and also added expense to the project. Although an elegant solution, the extra difficulty these careful details created during fabrication and construction discouraged the designers from pursuing such a tightly purpose-driven approach



2



3

Figure 1: Sakurajōsui House. *Tomio OHASHI.*

Figure 2: Double-web beam and cruciform column connection. *Toyo ITO & Associates.*

Figure 3: Similar column detail used in a 2013 exhibition structure also designed by Masato Araya. *Dana Buntrock.*

4

to component design on later projects. Araya described the Sakurajōsui House, unlike other aluminum buildings that followed, as reflecting the fundamental character of aluminum—but at a cost, in both time and money.

At the time this house was built, aluminum was not officially accepted as a structural material under Japanese building codes. It was not until 2002 when the Ministry of Land, Infrastructure, Transport and Tourism released a bulletin explicitly permitting all-aluminum structural systems. (MLIT) Gypsum wallboard was used as an interior finish to comply with prescriptive building codes—effectively skirting the issue of aluminum's poor performance in fires.

Japanese architects tend to celebrate delicacy in design. The walls here were less than 85 mm (3-3/8") thick; floors only 156 mm (less than 6-3/8") deep. Structural panels were exterior finish; external wall structure and window frames were integrated. (Figure 4) The house has an unusually neat and simple character which was very well received both in Japan and abroad.

The slim components were also the result of norms for Tokyo homes, which are generally quite small. Ito used a central two-story sunroom (enclosed in single-pane glass, conventional then as now) to break the house into short spans over individual rooms; the longest span in the little 86-square-meter (925-square-foot) house is only 4.2 meters (13 feet 9 inches), which significantly reduced the depth of the roof slab. (Figure 6) However, even with insulation—unusual for a Tokyo home in the late 1990s—the designers reported that thermal bridging and

Figure. 4: Aluminum components were lightweight and easy to handle on site. *Toyo ITO & Associates.*

condensation caused considerable discomfort in winter. The limited cavity depth for insulation in walls and floors and the effective thermal conductivity of aluminum were the source of this discomfort.

However, this had little impact on the building's successful reception. Historically, homes in Japan were uncomfortable; Japanese architects tend to place higher value on careful detailing and thoughtful structural solutions, both evident here; and many aware of this building knew it only through photographs, which tell more about aesthetics and structural performance than comfort.

One important regional influence was the fact that buildings in Japan must be designed not only for gravity loading, but also horizontal forces caused by earthquakes. In earlier research prototypes built in aluminum, these forces were addressed with diagonal bracing. However, Araya instead complemented the framework of columns and beams with aluminum shear walls built up of 30 cm wide (1 foot), channel-shaped panels welded together. (Figure 5) Initial proposals considered making these panels wider (45 cm / 18 inches), which would have reduced the number of joints to be welded on site; however, the larger plank size would have added considerable production expense.

5

6

Araya came to realize over time that when aluminum is welded, its strength is compromised; later projects would rely more on bolted connections. But in this first permanent application of an all-aluminum structural system, channel ribs at wall and roof were welded together on site. Since the aluminum was also the exterior finish, the architect and engineer solved both engineering and architectural concerns with a single material, the welds also used to resist water intrusion.

Figure 5: Welding the channel-shaped components into structural diaphragms on site. *Toyo ITO & Associates.*

Figure 6: This construction site photo shows the short spans and thin components. *Masato ARAYA, Oak Structural Design Office.*

The house demonstrated not only a rich collaboration, but also the necessary support offered by the government and Japan's fabricators in order to determine, for example, how the size of aluminum channels could have a significant impact on costs. Although there was no direct application of NEDO funding on the Sakurajōsui House, project architect Akihisa HIRATA and Araya, in separate papers, note the importance of technical advice and materials testing by industry partners associated with the study group and with academe. (AL Ken, p. 3; AIJ, 2000, p. 116) Araya recently estimated the cost of the house at roughly half of what it might have been without this financial and technical support.

BRUGGE PAVILION

The second aluminum structure Ito and Araya designed together was a small, temporary structure in Brugge, Belgium. (Figure 7) A cathedral once sat where Burg Square is today, the site of Ito and Araya's 2002 *Brugge* Pavilion. French Republicans destroyed the church in 1799; important archaeological remains exist only a meter below grade, inspiring the designers to again propose aluminum, due to its light weight. (SK, 129) The ethereal structure still totaled 8 metric tons (17,637 pounds)—but the load at the wall was a relatively acceptable 250 kilos per linear meter (400 pounds per linear foot).

7

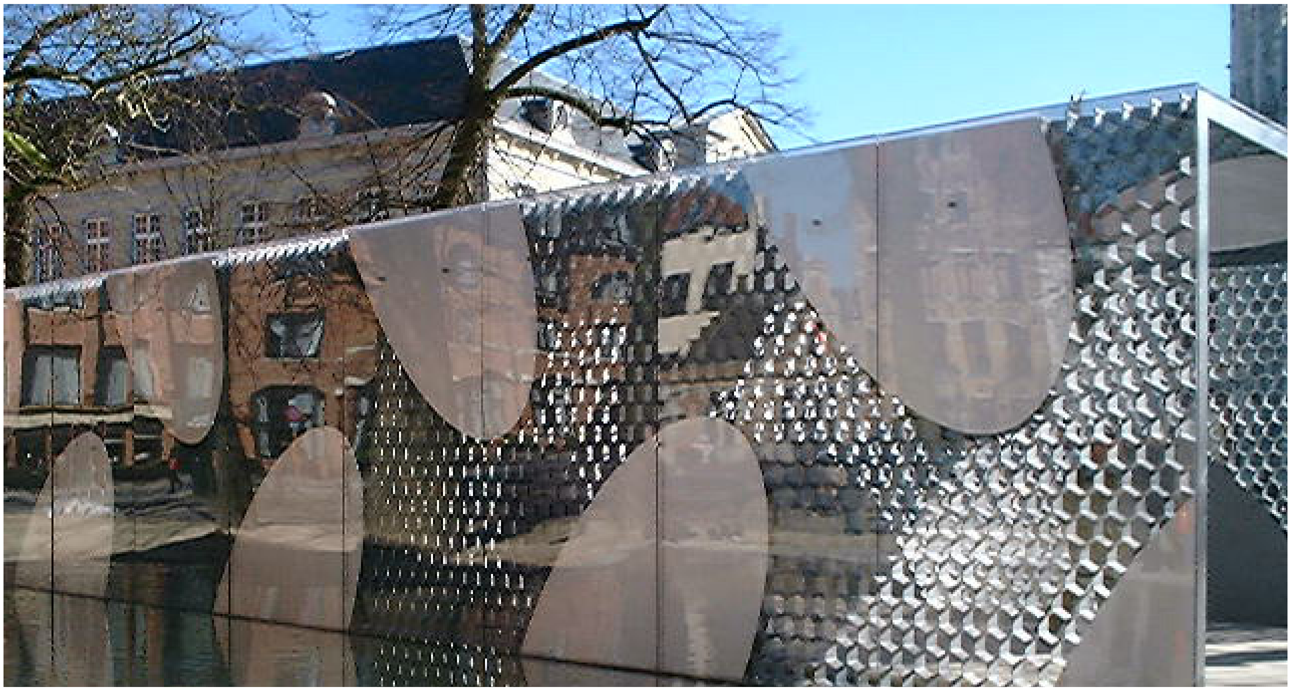
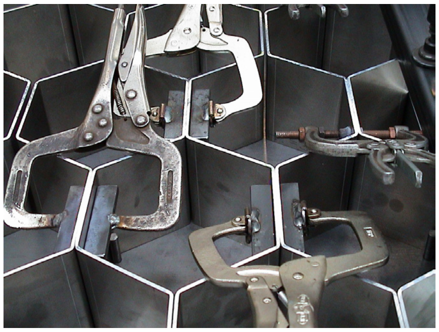


Figure 7: Brugge Pavilion. *Toyo ITO & Associates.*

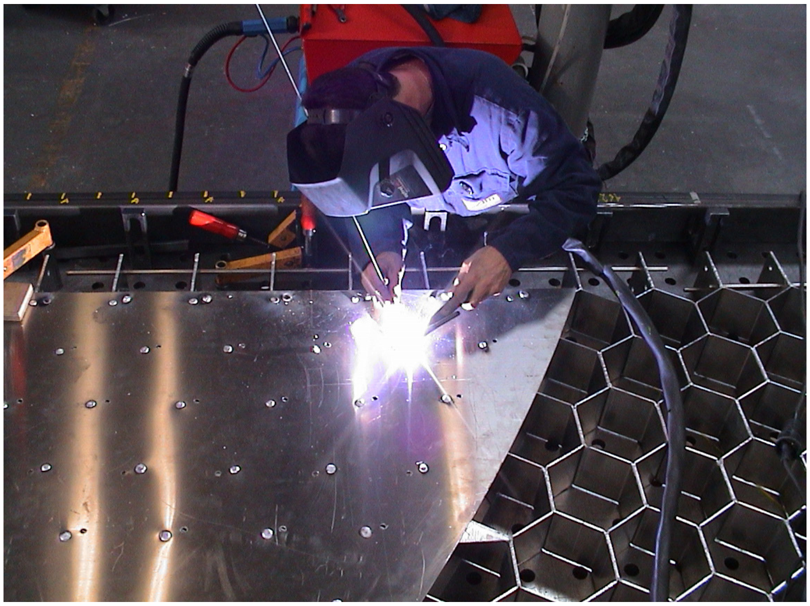
Araya has pointed out that aluminum is actually heavier than concrete when compared volumetrically; our perception of its light weight comes from the thin sections possible because of its strength. (SK, 129) But at Bruges, the honeycomb walls and roof resulted in more aluminum being used, increasing the weight compared to a post and beam structure.

The pavilion took a considerably different approach from the one developed at Sakurajōsui. It had no columns or beams; long walls and a roof slab were made out of a 125 mm- (5-inch-) thick honeycomb produced from 3-mm (1/8-inch) aluminum strips, folded into shape and welded. The original proposal was for a tunnel-like structure 8 meters (26 feet) wide and 28 meters (nearly 92 feet) long, but due to cautious structural testing, the size was reduced to about 85% of the original, a tube 6.75 meters (roughly 22 feet) wide and 16 meters (just over 52-1/2 feet) long. It was 3.75 meters (just over 12 feet) tall.

All of the aluminum structures Araya and Ito designed together were, with the sole exception of Brugge Pavilion, based on the use of extruded metal shapes, many of them unique forms custom-made for projects. The parts for every one of their jointly designed aluminum structures were also fabricated in Japan—with the notable exception of the Brugge Pavilion. The strategy used here directly reflected what the designers saw as fabrication opportunities in Europe unavailable to them at home. The honeycomb panels were handcrafted; Araya has written that this level of aluminum handwork would not have been possible in Japan. (SK 2002, 65) Each of the 33,400 folds making up the half-hexagons were individually shaped in a single jig; each of the 7500 welds done by the same person, whether in the shop or on the site. (Figures 8 and 9) The fabricator Aelbrecht Maes even produced the jig used to shape the honeycomb's half-hexagons, to the surprise of the Japanese team. (SK 2002, 65)



8



9

Formally, Araya treated the pavilion like a continuous portal frame. (Figure 10) The roof and walls were stiffened with an external skin of 12 mm- (1/2 inch-) thick polycarbonate sheets and the strategic addition of large, 3 mm- (1/8 inch-) thick aluminum oval "sandwiches" evenly spaced along the full length of the walls and roof. Each of the full-sized ovals was 150 cm (5 feet) long and 75 cm (2-1/2 feet) wide; those at the base were cut in half at a diagonal. Along the walls, these sandwiches were strategically located to respond to the higher moment stresses arising at the roof and at the base. The wall had minimal moment stress at its mid-point, which reduced the need for added rigidity there and allowed the designers to increase the transparent character of the structure at roughly the same height as an average person's eyes. Three more large oval sandwiches were located along the midpoint of the roof slab for added stiffness. All of the oval sandwiches were tied together with thru bolts.

Araya once described this structure as "architecturally rational, but mechanically irrational." (Aluminum Space p 47.) There is little in the way of established

Figure 8: Assembling the honeycomb from aluminum strips. *Toyo ITO & Associates.*

Figure 9: A single person welded all the panels at 7500 locations, both in the shop and on site. *Toyo ITO & Associates.*

10

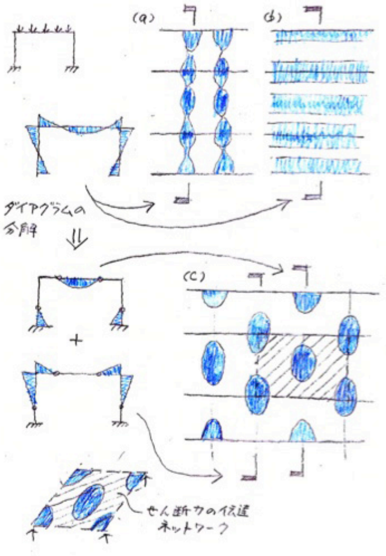


Figure 10: An early sketch shows how the “ornamental” ovals were deployed at locations where moment was highest. *Masato ARAYA, Oak Structural Design Office.*

engineering practice for the design of honeycombs; because of the way distortion propagates through them, finite analysis was of no use. Early in the design phase (which began in April, 2000, shortly after Sakurajōsui House was completed), Araya realized computer simulations inaccurately predicted little distortion in models made of stiff paper. The team, as a result, relied heavily on testing physical models and mock-ups to predict structural performance. (Figure 11) In a draft version of Araya’s essay about this experience for the Japanese magazine *Shinkenchiku*, the engineer repeated two adages the team took to heart: “Actions speak louder than words” and “Seeing something is better than hearing it 100 times.”

11

Figure 11: Deflection of honeycomb was tested in full-scale mock-ups. *Masato ARAYA, Oak Structural Design Office.*

But the fabricator, involved in later stages of these physical tests, at least partially blamed them for budget overruns; the final cost of 30-million Belgian francs (approximately $650,000 at the time) reported in a 2002 newspaper article was a not-insignificant five million over budget. The design team may have been permitted to use a novel material structurally without the same level of regulatory oversight required for a permanent building, but the fabricator reported some delays were also due to concerns caused by the structural use of polycarbonate.

Like the Aluminum House at Sakurajōsui, extensive prefabrication in the shop considerably sped up work on site, a particular benefit considering the cultural significance of Burg Square. The fabricators divided the structure into nine panels

12

(three for each side wall and three across the roof). Work on the pavilion lasted 1-1/2 months; aluminum erection, which included some minor welding on site, took only one month, and the polycarbonate envelope took about ten days. (AIJ 2004, 140) Additional landscape construction took as long as the structure itself, doubling construction time.

The *Brugge* Pavilion was originally designed to last only a year. There was very little attention to weather-resistance in the design: welds connecting the honeycombs were discontinuous and allowed water between the two strips of metal; there was no gasketting where the roof met the polycarbonate cladding. At the end of 2002, however, the Bruges mayor approved the popular pavilion for ongoing use; it remained in place until the end of 2013, eleven years longer than was originally anticipated. During this time, though, the pavilion fell into a period of neglect, precipitated by forklift damage to the internal plastic honeycomb bridge in 2006. The aluminum remained in good shape; it was cut into smaller sections with a torch (not following original panel lines) and stored with a stated intention to reconstruct it again one day, elsewhere—ironically following the same path as Mies van der Rohe's Barcelona Pavilion, one of Ito's key inspirations.

SUS COMPANY HOUSING

The largest of the aluminum structures Araya and Ito designed together, a 490-square-meter (5275-square-foot) dormitory, was completed five years after the Aluminum House in Sakurajōsui. (Figure 12) Their earlier buildings used aluminum in a linear arrangement of right angles; here the designers created gently curving walls of extruded planks (250 mm / 9-7/8" wide) only 70 mm (2") thick. With only two die shapes—using radii at 5.4 meters (17 feet, 9-1/2 inches) and 13.5 meters (44 feet, 3-1/2 inches)—the walls were laid out in loosely undulating lines. (Figure 13) A closed-box plank rather than a channel-shape, the components carried both gravity load and lateral stresses caused by earthquakes. This was far from simple—shear walls transfer lateral stresses best if there is a direct

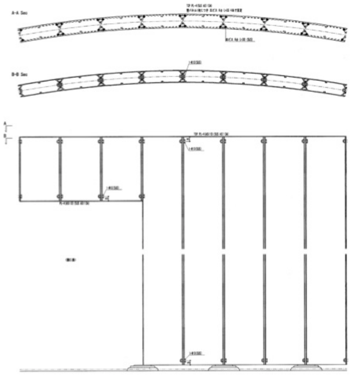
Figure 12: SUS Company Housing was the largest and most ambitious of the aluminum projects ITO and ARAYA produced together. *Toda Kensetsu.*

horizontal line for stresses to follow; a curve has a tendency to bulge out of shape instead of resisting lateral load.

Due at least in part to its larger size, there was greater attention paid here to cost control: all connections on site were done with bolts or screws. Lessons learned at the Sakurajōsui House clearly impacted planning. The tendency for aluminum to conduct sound efficiently—not desirable in places where people sleep—resulted in a plan with few common walls. (Figure 14) This more open plan was also an advantage in terms of fire safety, establishing a very short path of travel from any interior space to the outdoors. And while architects in Japan did not yet not customarily insulate buildings, care was taken to thermally enclose the interior; rooms were lined with 40 mm (1-3/4 inches) of insulating foam (although window frames did not incorporate thermal breaks). The ceiling construction included 15-20 mm (11/16 inch to 7/8 inch) of sprayed urethane foam.

SMALL WORKS

In addition to these three larger buildings, two others—a cottage and a "container" for outside exhibitions—were developed by Ito and Araya as prototypes. Mass production, rather than custom design, was the most logical approach to using aluminum since the cost of dies used to make unique shapes could be spread



13

Figure 13: Panels with two radii were used to produce the gentle curves. *Toyo ITO & Associates.*

Figure 14: Plan shows how the room layout takes into account sound transmission and fire safety through an open, cellular structure. *Toyo ITO & Associates.*

14

across greater use. Ito and Araya developed the aluminum cottage from June 2002 to August 2004 with the only Japanese aluminum producer dating to before the 1940s, the Nippon Light Metal Company, and the aluminum "container" for outside exhibitions with the SUS Corporation in 2005. The container was subsequently exhibited at an annual event that year, "Tokyo Designers Week". As I will discuss below, other architects were also involved in exploring the use of aluminum in novel ways, but only Ito and Araya, clear leaders, were able to collaborate with more than one aluminum industrial leader simultaneously.

The cottage was described as a "common-sense" solution to problems that naturally emerge when remote wood structures are unused for much of the year in a very hot, humid climate—aluminum, after all, resists decay and mold. The structure was built out channel-shaped panels and cruciform columns, complemented by aluminum cross braces and an internal layer of structural plywood that enhanced rigidity and, it was hoped, acted as a thermal break. Throughout, there was a stated effort to use simple connections of purpose-made extrusions. The building sat on a number of short supports spaced about 3-1/2-meters (less than 10-foot) apart, so did not require much foundation work. (Figure 15)

Like the other aluminum structures discussed here, erection was rapid, taking less than two months. However, overall the project seemed geared more to testing theoretic possibilities than developing a pragmatic prototype. Not only did it rely on five unique extrusions, but instead of using the extruded profile to transfer stress between panels (which would be inefficient because the profiles are not a tight fitting), the cottage incorporated a special paint on the abutting faces of channels to increase friction. (*Kenchiku Gijutsu* 2004.12 p. 116)

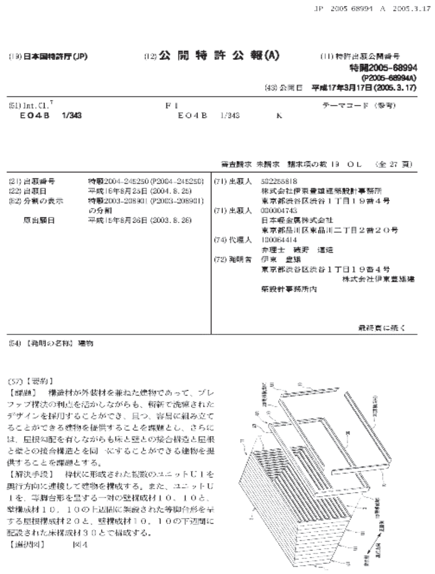
In the Fall of 2004, Nippon Light Metal announced they would bring the cottage to market in April 2005. The 75-square-meter (800-square-foot) prototype had a stated cost about thirty million yen ($330,000). This came to a fairly pricey $4400 per square meter ($408 per square foot) without land costs and other soft costs like utilities hook-ups. Material costs were estimated to make up about three- to five-million of the total—and an additional five-million yen was attributed to "manufacturing/machining costs". Roughly a third of the cost of the cottage could be attributed to the materials used. (LMD, no. 1705) The announcement stated a target of at least 10 units ordered before putting the project into construction.

The cottage was patented in early 2005. It did not make it to market. (Figure 16) The prototype was still in its original setting in 2008 and was in use promotionally. (Yokoyama)

The prototype for the "container" followed a gently curving geometry resulting from three subtly different extruded plank shapes that could be combined in various configurations, exploiting attributes harder to accomplish in wood, steel or glass. (Figure 17) This prototype was an outgrowth of the development of the curving sidewalls seen at the SUS Company Housing discussed above, under construction at the time the container was developed. This at least in part accounts for the unusually short design period, only seven months, in spite of the complex shape of the individual parts. By contrast, the Aluminum Cottage took twenty-one months to develop.

The column-free space within the container was 2.78 meters (9 feet 1-1/2 inches) tall and 3.7 meters (12 feet 1-1/2 inches) wide; it was 6 meters (19 feet 6-1/4 inches) long. (LMD no 1763). Its name, "*sudare*", referred to traditional Japanese blinds;

15



JP 2005 68994 A 2005.3.17

(19) 日本国特許庁(JP)　(12) 公 開 特 許 公 報(A)　(11) 特許出願公開番号
特開2005-68994
(P2005-68994A)
(43) 公開日　平成17年3月17日(2005.3.17)

(51) Int.Cl.⁷	F I	テーマコード（参考）
E04B 1/343	E04B 1/343 K	

審査請求 未請求 請求項の数 19 OL (全 27 頁)

(21) 出願番号　特願2004-245250 (P2004-245250)
(22) 出願日　平成16年8月25日 (2004.8.25)
(62) 分割の表示　特願2003-208901 (P2003-208901) の分割
原出願日　平成15年8月26日 (2003.8.26)

(71) 出願人　502255818
株式会社伊東豊雄建築設計事務所
東京都渋谷区渋谷１丁目１９番４号
(71) 出願人　000004743
日本軽金属株式会社
東京都品川区東品川二丁目２番２０号
(74) 代理人　100064414
弁理士　磯野　道造
(72) 発明者　伊東　豊雄
東京都渋谷区渋谷１丁目１９番４号　株式会社伊東豊雄建築設計事務所内

最終頁に続く

(54) 【発明の名称】 建物

(57) 【要約】
【課題】 構造材が外装材を兼ねた建物であって、プレファブ構法の利点を活かしながらも、斬新で洗練されたデザインを採用することができ、且つ、容易に組み立てることができる建物を提供することを課題とし、さらには、屋根勾配を有しながらも床と壁との接合構造と屋根と壁との接合構造とを同一にすることができる建物を提供することを課題とする。
【解決手段】 枠状に形成された複数のユニットU１を奥行方向に連接して建物を構成する。また、ユニットU１を、等脚台形を呈する一対の壁構成材１０、１０と、壁構成材１０、１０の上辺間に架設された等脚台形を呈する屋根構成材２０と、壁構成材１０、１０の下辺間に配設された床構成材３０とで構成する。
【選択図】 図４

16

Figure 15: The Aluminum Cottage was intended for mass production. *Tsuneho ASADA*.

Figure 16: Patents were taken out on both sluminum prototypes intended for mass production, the Aluminum Cottage and the Aluminum Container. *Japan Patent Office.*


17


18


19

Figure 17: Falsework was used to set up the long, bprad-like components of the Aluminum Container. *Masato ARAYA, Oak Structural Design Office.*

Figure 18: Cables threaded through the aluminum were used to compress the board-like pieces together. *Masato ARAYA, Oak Structural Design Office.*

Figure 19: The Aluminum Brick screen, the last of ITO and ARAYA's aluminum structures. *Copyright, Wim te Brake.*

ninety-two extruded plank-like components were assembled into a flexible sheet at the plant, strung like beads along cables spaced half a meter (20 inches) apart. (Figure 18) On site, they were pulled into the resultant curve over template-like falsework. Each of the planks—70 mm (2-3/4 inches) thick and 85 mm (3-3/8 inches) wide—weighed between 13.4 and 13.6 kilograms (roughly 30 pounds each). Thus, even though employing aluminum, the container weighed 2 tons, roughly the same as a similarly-sized steel shipping container; this is likely due to the additional material making up the cellular structure of each extrusion. (LMD no 1763) The result, while eye-catching, did not yield any clear competitive advantages over the common steel shipping containers usually employed for this purpose.

The container, too, did not go into production.

Finally, Ito and Araya's "Aluminum Brick" screen, a façade that tied together a new structure and a historic building, was in development for three years; it was not completed until 2005, the last of their aluminum structures. (Figure 19) Designed for the University of Groningen, its small brick-like pieces snapped together. They were produced with a great deal of technical assistance from the Nippon Light Metal Company and *Shinnikkei* and shipped to Holland for assembly. As built it appears quite modest. However, there were no beams or columns; the design team took advantage of the relatively low structural demands of this wall to explore the way the small units connected. The aluminum components were literally stacked like bricks, transferring the load through each extruded connection, which, because of play in the joints, transferred loads with less efficiency. This solution would have been impossible to attempt in a country with major earthquakes like Japan.

AKIHISA HIRATA ATTEMPTS AN ALUMINUM STRUCTURE

The project architect on Ito and Araya's very first aluminum building was a young man in his late twenties, Akihisa HIRATA. (Figure 20, next page) His contributions to that project are underscored by the fact that he coauthored an academic paper on the lessons learned during the development of that project and was invited to write an article on the building for an aluminum trade magazine. Hirata was also charged with the task of developing the *Brugge* Pavilion for the firm. In 2005, he opened his own small practice. Not surprisingly, Araya and Hirata began to work together—in fact, they developed the most formally challenging of Araya's aluminum works, an inhabitable sculpture, in 2008. (Figure 21)

It was never built. Notably, when Hirata and Araya again worked together in 2011 on a pavilion for Tokyo's Museum of Contemporary Art, it was built not of aluminum, but of sheet steel.

Araya's work in steel, in fact, benefited from these experiments in aluminum; his design for the 2011 Makabe Densho Building, employing strategies learned with the aluminum projects, received numerous major awards. The relationship between Araya's experiments in aluminum and the award-winning steel structures he later developed will be explored in a subsequent paper.

THE END OF ANOTHER ALUMINUM AGE

Together, Ito and Araya designed six aluminum structures: a house, a dormitory, two small prototypical structures that never went into production, a pavilion intended for short-term use, and a façade. In addition, Ito designed a group of small public toilets in Fukuoka, a city in southern Japan, working with the engineer Mutsurō SASAKI; Araya designed a large sculptural work with one of Toyo Ito's former employees, although it was never built. Most of these structures were produced outside of the normal regulatory oversight within which architects and engineers generally work. Some were inhabitable, but not strictly considered buildings. Some—the *Brugge* Pavilion, *sudare*, Project K—benefited from the greater freedom allowed temporary works.

The House at Sakurajōsui complied with earlier prescriptive building codes that had not anticipated the lower melting point of aluminum, essentially conforming to the letter of the law, but skirting its intentions. But later regulatory changes did permit the use of aluminum; the dormitory was built with conventional oversight and the aluminum cottage was planned within regulations, though not required to have building approvals.

Japanese professionals, especially those of stature like Toyo Ito and Masato Araya, have opportunities to work in liminal territory that many architects and engineers elsewhere tend to consider outside their scope of practice. The aluminum industry and these building design professionals were able to develop an experimental body of work that fell between their conventional territories and thus test whether aluminum could be economically adapted to new structural uses. While the use of aluminum they explored did not yield new markets, they were able to make discoveries about its potential.

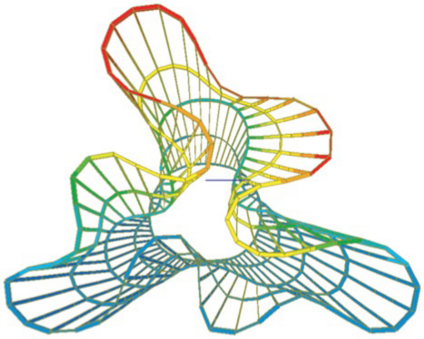
And the engineer and architects benefited professionally by doing so.

In addition to the designers discussed here, who played a particularly large role in exploring new uses of aluminum, suppliers worked with other respected architects during this period, including Riken YAMAMOTO, Kazuhiro NANBA, Mikan Gumi, and Coelacanth K&H (the latter working with Araya on an aluminum model house built with off-the-shelf parts). One other engineering office, the considerably larger IIjima Structural Design Office (with 35 employees in three locations), was active on many projects—and in fact played a key supporting role when Toyo Ito turned to Mutsurō SASAKI to design the small public toilets erected in southern Japan. But Araya's work with Ito was significant even in this illustrious group, evidenced by the two awards he was given by the Japan Structural Consultants Association. The first, in 2001, was an Award of Excellence for the House at Sakurajōsui; the second, given two years later, was for his collective contributions to the advancement of the structural use of aluminum, recognizing the first house again, the two overseas projects, and an aluminum mudsill in another project I have not included here.

During this time, there were a number of other promotional efforts by suppliers. *ecoms*, a subsidiary of SUS, began publishing a quarterly magazine under that name in January 2003, featuring a variety of works using aluminum at a scale between furniture and small buildings. Design competitions, friendly to student participation, were held annually starting in 2003, with well-known architects and engineers—not limited to those experienced with aluminum—serving as jurors. First prize was a million yen (roughly $8,500 initially). The first year, with Ito chairing the jury, there were over 450 entries. (LMD no. 1648) Design professionals who had employed aluminum in novel ways were not only jurors, but also compensated speakers at various professional events.

Market response to these aggressive efforts to promote new uses of aluminum in architecture was modest. The competitions stopped in 2010; *ecoms* ceased

20



21

Figures 20 and 21: The Unbuilt Project K, designed by ARAYA and Akihisa HIRATA, a former ITO office staffer. *Masato ARAYA, Oak Structural Engineering.*

ENDNOTES

This paper uses the Western order for Japanese names, with family name capitalized on first use to avoid confusion. Toyō Itō's given name is written in the more conventional Western spelling, without macrons.

publication in July, 2012. In 2006 *Shinkenchiku* published a book of collected works in aluminum, starting with Ito and Araya's Sakurajōsui house. Although there were still proposals like Hirata and Araya's Project K in development, not one of the important built structures from this innovative era is missing from this monograph. The New Age of Aluminum was coming to an end.

The final curtain was drawn on this experimentation on March 11, 2011. Ito and Araya's SUS dormitory is located in Fukushima Prefecture, not far from the nuclear plants that melted down following a severe earthquake. Aluminum production, even when involving recycled aluminum, requires cheap electricity to accomplish—in the mid-20th century, Reynolds Metals proudly referred to the material as "solid electricity." (Peter, p. 9) Production usually occurs in the shadow of nuclear power or hydroelectric plants. But the 2011 disaster closed nuclear plants across Japan and cut off roughly one-third of the nation's electrical power supply. With skyrocketing costs for electricity, these experiments, earlier considered ecological because of aluminum's light weight, durability and recyclability, became far less practical.

BIBLIOGRAPHY

AIJ 2000. Araya Masato, et al. "Structural Design of a House with Aluminum Panel Resistant to Earthquake: New spacial (sic) expression realized by the abstracted Aluminum structure" *AIJ Journal of Technology and Design* no. 11 (2000.12) p. 111-6. In Japanese.

AIJ 2004. Araya Masato, et al. "Design of Honeycomb and Sandwitched (sic) Panel Structure With the Use of Aluminum Alloy: A new special (sic) expression realized by abstracting the structure" *AIJ Journal of Technology and Design* no. 19 (2004.6) p. 135-40. In Japanese.

Alum. "*Aruminiumu Kenchiku no Setsugōbu* [Connections in Aluminum Architecture]" *Kenchiku Gijutsu* (2004.12) p. 114-7.

Hirata. Hirata Akihisa. "*Aruminiumu Kenchiku Kōzō no Jisseki Shōkai* [Presenting the Realization of an Aluminum Structure]" *AL Ken*, p. 3-7. In Japanese.

Ishida. ISHIDA Yasuo, IIjima Toshihiko, and KURIYANAGI Akio, eds. Aluminum Space (Tokyo, *Shinkenchikusha*: 2006). In Japanese.

NEDO. "Development of Ecology Housing Technology" # 98Z33-018. In Japanese.

LMD no 1648. *Light Metal Digest no. 1648* (2003.8.11) *http://www.kallos.co.jp/member/today1648.html*. Accessed 2013.1.6. In Japanese.

LMD no 1705. *Light Metal Digest* no.1705 (2004.9.27) *http://www.kallos.co.jp/member/today1705.html*. Accessed 2013.1.6.

LMD no.1763 *Light Metal Digest no. 1763* (2005.11.21) *http://www.kallos.co.jp/member/today1763.html*. Accessed 2013.1.6. In Japanese.

MLIT. "Necessary Technical Criteria Concerning Structural Engineering Practices using Aluminum Alloys". Ministry of Land, Infrastructure, Transport, and Tourism Bulletin no. 410 (2002).

Peter. Peter, John and Paul Weidlinger. *Aluminum in Modern Architecture*, vol. 1 & 2 (Louisville: Reynolds Metals Company 1956).

Shitsunai. "*Aruminiumu no Ie ga Dekiru Made* [Aluminum House to Completion]" *Shitsunai* (1999.11) p. 149-51.

SK 2002. Araya, Masato "Making Architecture: Making Architecture in Brugge" *Shinkenchiku* 77.5 (2002.5) [52]-67, 218. In Japanese.

SK 2004. "*Aruminiumu Sōzai ha Kenchiku ni nani wo Motarasu no ka? Taidan: Itō Toyō x Araya Masato* [What kind of architecture does aluminum bring about? A Dialog between Toyo ITO and Masato ARAYA]" *Shinkenchiku* (2004.12) p. 129-131. In Japanese.

USGS. Menzie, W.D, et al. "The Global Flow of Aluminum from 2006 through 2025: US Geological Survey Open-File Report 2010-1256. Available from *http://pubs.usgs.gov/of/2010/1256/.*

Yokoyama. YOKOYAMA, Hiroaki. "Aluminum Gate House," Morld Journal (blog) August 25, 2008. *http://journal.morld.jp/2008/08/_aluminum_gate_house.html.*

Dana Buntrock also conducted interviews in Tokyo with Toyo ITO and Masato ARAYA during December 2013 and January 2014.