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Abstract. The Glass Station, designed by Shoei Yoh in 1993 in Oguni, Japan, is an early example of the integration of computational design methods in Japanese architecture. This paper investigates and details the Glass Station's design and construction processes to expand insights about the nature of the "digital turn" in architecture in the early 1990s. Utilizing archival sources and interviews with key stakeholders, the case study explores the interplay between traditional and computational methods, including how the complex double-curved glazed roof was developed through physical soap bubble models and finite element analysis software, alongside the use of commercial CAD software that came into practical use in the late 1980s. It reveals that the project relied on both digital and analog techniques, with physical models acting as conceptual bridges in validating computational designs. The case study further demonstrates how collaboration between architects, engineers, and builders created a social environment that fostered experimentation and innovation. Ultimately, the research contributes a deeper understanding of the incremental adoption of computational methods in architecture, challenging prevailing narratives of technological determinism in the context of Japan's architectural informatics evolution.

Keywords. computational design, digital design history, minimal surface models, cable-net structure, parametric design, Glass Station, Shoei Yoh

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1. Introduction

The Glass Station designed by architect Shoei Yoh and built in Oguni, Kumamoto, on the Western island of Kyushu, Japan in 1993 is an important, yet less examined example of the early use of computational design methods in Japanese architecture (Figure 1). Although Yoh (1940-) is appreciated in Japan as an innovator of large span timber structures (Koshihara, 2019), and globally recognized as a digital pioneer in architecture (Lynn, 1996, Lynn, 2013), contemporary re-evaluations of his legacy are now bringing to light more grounded and nuanced accounts of the "digital turn" in architecture (Carpo, 2013, Carpo, 2017), as well as the history of architectural informatics in Japan. For example, Aaron Tobey (2022) has drawn on the concept of the "database imagination" to question the technological determinism of prominent global digital turn narratives that have been read into Yoh's work. Extending this thinking, this research paper presents an in-depth case study of Yoh's Glass Station project that draws out its contextual specificities and reflects on its relationship to architectural informatics.

The Glass Station serves as an early example of the integration of computer software into both design and construction processes. The project employed three significant early software tools including MiniCAD and Form-Z for documentation and 3D modelling, and ADINA for structural simulation and finite element analysis (FEA). MiniCAD was released by Graphsoft, a company founded in 1985. ADINA was established in 1986, and Form-Z was introduced in the US in 1989. The use of these commercial software packages in the early 1990s positioned the Glass Station at the forefront of adopting computational design techniques.

The Glass Station case study draws on primary data from three archival sources including physical and digital drawings, project meeting notes, and physical models deposited at the Shoei Yoh Archive at Kyushu University in 2019, project assets held at the Canadian Centre for Architecture (CCA) archive in Montreal, and project documentation held by the construction contractor, Takao Yonemitsu of Ando Construction. Additionally, the case study draws on qualitative data from a series of in-depth interviews conducted with key project stakeholders, including Yasuhiro Shinano from the Yoh Design Office, computer data analyst Kenshi Oda (Taiyo Kogyo), the head of construction Takao Yonemitsu, and Hiroaki Kodama, the current manager of the client's company, Harada Kosan.

Figure 1. Glass Station, 1993. Images from Shoei Yoh Archive

2. Design Process of the Glass Station

2.1. SOAP BUBBLE MEMBRANE MODEL

The design of the Glass Station project commenced in 1990 (Iannacci, 1997) in Oguni town, Kumamoto, Japan. Oguni Town is where Yoh created his innovative timber buildings in the late 1980s. The client for the project was a concrete company called Harada Kosan who approached Yoh with the brief to create a petrol or "gas station" that didn't resemble a standard gas station and could become an iconic landmark for the town. In response, Yoh proposed a design comprised of four concrete arches touching down at the edges of an irregular site to support a double-curved undulating glazed infill. Borrowing from Frei Otto's form-finding methods, Yoh's initial design studies used a soap bubble membrane model (Figure 2) to generate the glazed roof's complex form and to tailor the form to the " … irregular site shape " (Yoh, 1994).

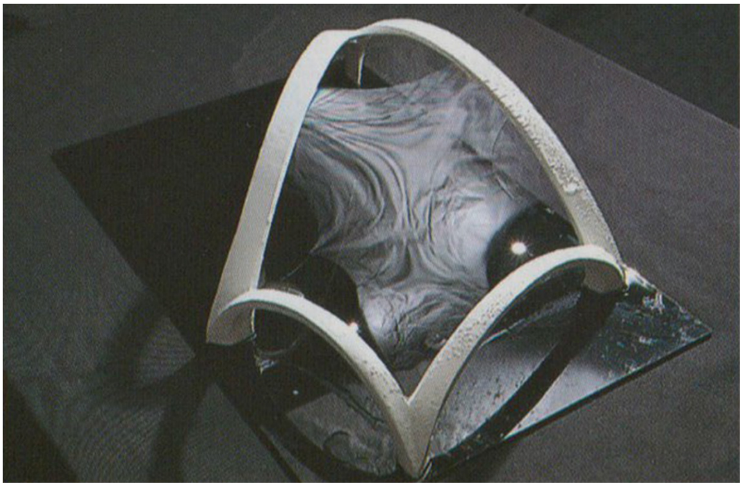

Figure 2. Soap bubble membrane model. Image from *Shinkenchiku* (January 1994)

2.2. COMPUTATIONAL STRUCTURAL ANALYSIS

Given the Glass Station project's proposed complex, non-standard form, Yoh established a collaborative partnership with Taiyo Kogyo, a construction firm renowned for its expertise in membrane structures and three-dimensional trusses. This partnership was not unprecedented, as Yoh had previously collaborated with Taiyo Kogyo on similarly geometrically complex projects during the mid-1980s. Among these, Galaxy Toyama (1991) is a notable project, which was showcased in the "Archaeology of the Digital" exhibition (2013) as a seminal example of parametric design.

Yoh Design Office and Taiyo Kogyo initially explored the feasibility of constructing an arch utilizing steel frames or implementing a membrane structure with fabric material. However, these proposals were ultimately rejected due to the difficulty of construction and fire protection requirements. Subsequently, an alternate design was conceived, involving spanning a cable net between the concrete arches to support a glass roof. Designing a glass roof over a gas station however also created a fire risk. As a result, Yoh Design Office worked closely with the glass company AGC to develop composite glass and perforated metal sheet roof panels to meet the fire resistance requirements.

A subsequent challenge in the Glass Station design process concerned the method and implementation of structural analysis. While the soap bubble model was an effective conceptual-physical model at that time, conventional structural analysis software could not compute its minimal surface form. Consequently, Yoh's Engineer Kenshi Oda from Taiyo Kogyo used a finite element analysis (FEA) program designed for civil engineers called ADINA (Shan et al, 1993).

To realize the minimal surface with cable nets and glass panels, it was necessary to divide the curved surface into a quadrilateral grid. It was decided that the unit of this grid would be about 1m square based on the manufacturable dimensions of the composite glass panels. Mr. Kenshi Oda of Taiyo Kogyo, who oversaw the structural analysis, recalls that the most difficult part of the analysis was considering the division of the cable net. At the time, there were no algorithms to optimize such structures and geometries. Finally, Oda collaborated with a mathematical engineer from Taiyo Kogyo, Mr. Chiaki Yamamoto, to devise a method for converting coordinates from a square configuration to the irregular quadrilateral. This transformation was necessary to accommodate the irregular shape derived from the site borders. Figure 3 shows a diagram of the coordinate transformation.

The initial input shape was a square ABC_0D_0 with the longest boundary arch AB as one side; point C_0 was moved piecemeal to C and point D_0 to D toward the final desired shape. At each stage, coordinates that satisfy the equation of equilibrium for that boundary condition were obtained. In performing this analysis, the engineers noticed that the length of sides AB and AC was approximately twice the length of sides BD and CD, therefore they inputted the number of cables connecting AB and AC_0 as twice the number of cables connecting BD_0 and C_0D_0. This was a little but important mathematical trick to make the analysis easier.

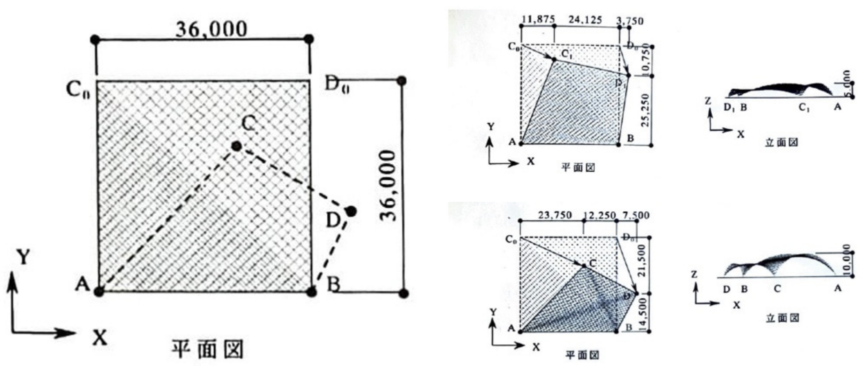

Figure 3. Boundary beam and cable layout at the initial input *(left)*, The shape at the intermediate stage *(right top)*, the shape at the final stage *(right bottom)*. Images from Oda et al, 1994

In the analytical process, computational limitations precluded the simultaneous transformation of all coordinates. Consequently, a stepwise approach was adopted, wherein the coordinates were incrementally adjusted through 5 to 6 stages to derive the final configuration and the precise coordinates of each intersection point. It is only more recently, with the wider application and use of structural optimization methods using genetic algorithms that engineers at Taiyo Kogyo have come to reconceptualize the analysis conducted for the Glass Station project as an example of a "genetic algorithm with manual intervention".

3. Construction Process of Glass Station

3.1. COMMENCEMENT

For the construction of the Glass Station, Yoh Design Office selected Mr. Takao Yonemitsu from Ando Construction as the site supervisor, leveraging their established professional relationship from previous collaborations on residential and clinical projects. Yonemitsu, one of Yoh's most trusted site supervisors, proposed an unconventional contract based on actual cost settlement due to the unpredictable nature of the construction method at the time of order acceptance. This rare contractual arrangement, which entailed the client reimbursing the contractor for monthly incurred construction costs, was only feasible due to the strong mutual trust among the client, builder, and designer. The client's ready acceptance of this proposal facilitated the project's progression. The construction of the Glass Station commenced in September 1992, with earthwork and foundation work initiating in November of the same year.

3.2. CONCRETE ARCH

The construction of the Glass Station's complex curved concrete arch presented a significant challenge. Yoh Design Office and Ando Construction worked together to determine the arch's overall shape. It was decided that the intrados of the four arches would form parts of a perfect circle. To create the formwork, Yoneimitsu requested that Yoh Design Office produce cross-sectional drawings of the arch and determine the precise dimensions for each section at 906mm intervals. This 906mm spacing was determined to match the intervals of the formwork supports.

Upon this request, Mr. Yasuhiro Shinano of Yoh Design Office utilized MiniCAD3 to prepare the drawings (Figure 4). At the time, Yoh Design Office had recently adopted computer technology. At the end of 1990, Yoh decided to introduce computers and instructed Shinano, who had just joined the company, to prepare the digital environment. Shinano chose Macintosh IIci and introduced MiniCAD3 and Form-Z as the main software. MiniCAD3 allowed for the numerical input of 3D data, which Shinano used to accurately draw the complex shape of the arches (Figure 4). At the same time, renderings were created in Form-Z to create the presentation images (Figure 5).

Using Shinano's CAD drawings as a reference, Yonemitsu manually redrew the shop drawings. To ensure accuracy, he even created a scaled-down mock-up of the entire arch structure (Figure 6). This meticulous approach, combining digital precision with traditional craftsmanship, ultimately led to the successful realization of the Glass Station's intricate arch design.

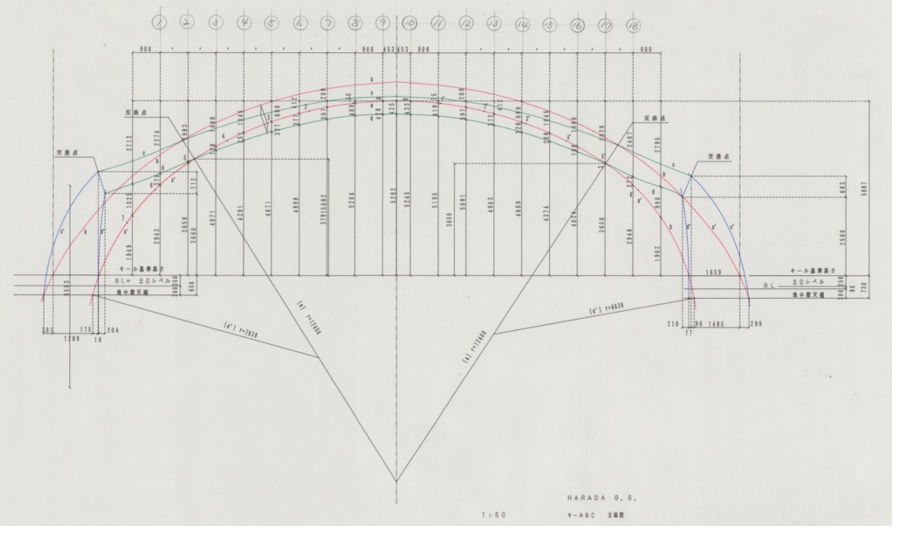

Figure 4. CAD drawing of concrete arch, 1992. Image from the personal collection of T. Yonemitsu

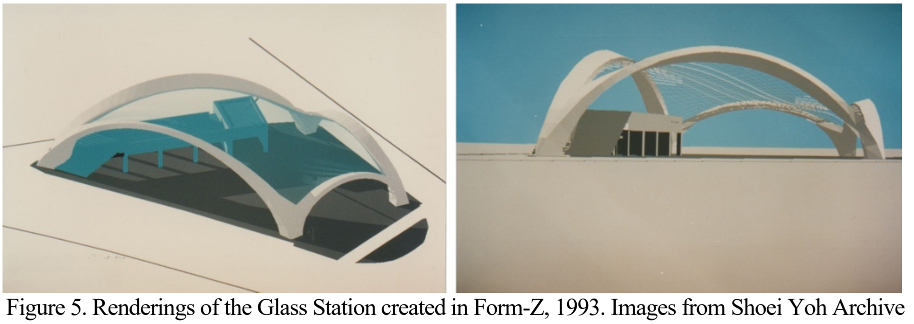

Figure 5. Renderings of the Glass Station created in Form-Z, 1993. Images from Shoei Yoh Archive

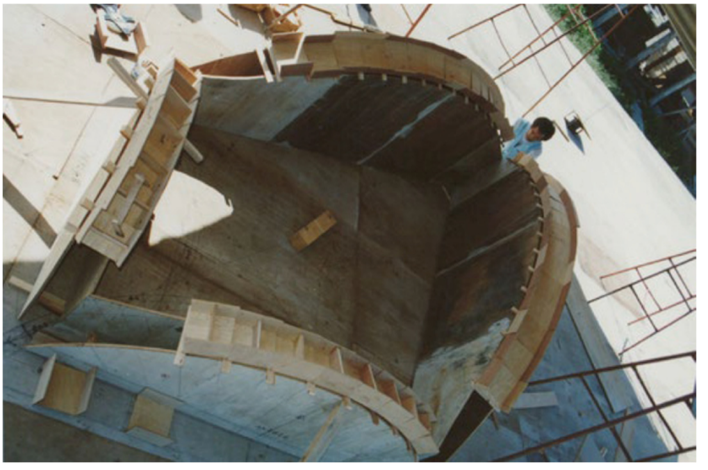

Figure 6. Mock-up of the arches, 1992. Image from the personal collection of T. Yonemitsu

3.3. THE INFLECTION POINTS

Yonemitsu also created an extremely unique physical model, using "yakitori skewers" as its materials, to accurately grasp the position of the inflection points on the curved roof (Figure 7). At the time of the construction contract signing, while the coordinates of the cable intersections for the curved roof were provided, the inflection points remained undefined. Accurately identifying these inflection points was crucial for the proper installation of the steel rods supporting the glass panels. To address this challenge, Yonemitsu created a physical model using yakitori skewers to represent the coordinates specified by Taiyo Kogyo. By visually examining this model, he was able to pinpoint the exact locations of the inflection points.

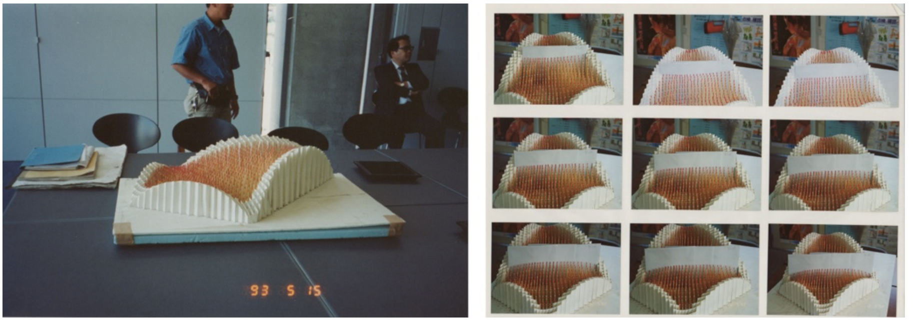

Figure 7. "Yakitori skewers" model to identify the inflection points, 1993 *(left)*, Photographs of the model. A white paper is inserted between the yakitori skewers, allowing the curved surface to be understood *(right)*. Images from the personal collection of Takao Yonemitsu

After Yonemitsu created this model, Shinano later used CAD to confirm the inflection points. Again, Taiyo Kogyo provided him with coordinate points used in structural analysis. Given the absence of email at the time, this information was likely transmitted via 3.5-inch floppy disk sent by mail. Shinano then manually input the 3D coordinate data into MiniCAD3, utilizing the resulting model to verify the accuracy of inflection points identified by Yonemitsu (Figure 8). This workflow, where physical models preceded computer-aided design, exemplifies a typical approach characteristic of digital design's nascent period.

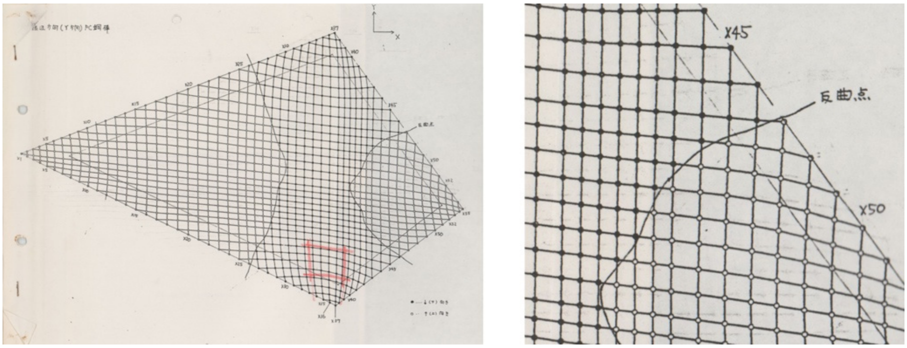

Figure 8. The drawing showing the location of the inflection points, 1993 *(left)*, Enlarged view of the drawing. The vertical relationship of cable intersections is indicated by black and white circles. Images from the personal collection of Takao Yonemitsu

After identifying the inflection point, Yonemitsu created a full-scale partial mock-up of the glass roof to verify the installation process for the pre-stressed steel rods and glass panels. The steel rods were put in place during April and May of 1993, followed by the installation of the glass panels and the construction of the structure beneath the roof. The construction of Glass Station was completed in July 1993, with a total construction cost of 250 million yen, exceeding the initial budget by 20 million yen.

4. Discussion

The case study of the Glass Station project, reveals significant historical and sociotechnical insights about how and why computational design methods were integrated within its design and construction processes. Firstly, this includes how Taiyo Kogyo engineers anticipated structural optimization using genetic algorithms through mathematical ideas and manual iterations. These computational methods built on approaches that Yoh and Taiyo Kogyo began exploring collaboratively in the early 1990s in projects such as Galaxy Toyama. In Galaxy Toyama, Yoh and Oda had developed a form-finding method using structural analysis software for 3D trusses. It was this established collaborative relationship and project experience that enabled Taiyo Kogyo engineers to perform highly creative computational analysis for the Glass Station.

Secondly, digital tools proved instrumental in overcoming the challenges associated with constructing complex three-dimensional curved surfaces. In particular, MiniCAD3 was employed for drawing tasks that demanded precision, such as delineating the complex concrete arch and pinpointing the inflection point of the minimal surface. Shinano, who led the CAD drawing process, recalled that computer-aided design offered a level of accuracy unattainable through manual drafting, and that Yoh was also aware of this advantage despite his lack of personal computer experience. Yoh Design Office leveraged coordinate data from Taiyo Kogyo's structural analysis to reconstruct a three-dimensional model using Form-Z, which was subsequently used to generate renderings. However, it's important to note that critical design decisions, including geometric shape determination, were primarily made through the creation of physical models and MiniCAD drawings. Form-Z's role was predominantly confined to presentation purposes, serving as a tool to showcase the final design concept.

Thirdly, the physical model served as a crucial conceptual and communicative bridge between the architects, structural engineers, and builders. During the design phase, the soap bubble model and mesh fabric models acted as a conceptual tool to foster a shared understanding between the architect and engineer. In the construction phase, the yakitori skewer model crafted by the builder became instrumental in identifying the inflection points, a key aspect of the construction process. It's noteworthy that the physical model created by the builder, who relied solely on hand-drawn drawings, preceded the inflection point determination made by the engineer and architect using 3D CAD software. This sequence, where the physical model took precedence and computer technology followed as a supplementary validation tool, was unique in the early days of digital design. It stands in contrast to the typical design processes of the present. Faced with the challenges of complex building construction, and by first engaging with manual techniques, the design team came to appreciate the power of digital technology.

The Glass Station case study demonstrates an iterative interplay between traditional, tangible design mediums such as physical models and analog computation, and emerging digital tools in architectural design, engineering, and construction. The hybridisation of analog and digital design mediums and processes, similarly described in accounts of projects by Gehry Partners in the early 1990s (Glymph 2003), had numerous benefits. By using their hands, the engineer was able to compensate for the lack of computer performance, and the builder was able to solve problems that the architect and engineer had not anticipated. And by re-verifying the results of these manual processes using digital tools, the architect and builder gained confidence and trust in both the manual work and the calculations. In this way, the Glass Station project is further evidence of the role that hybrid design practices play in technology adoption and their role in preceding and ushering in technology acceptance. As such, this case study also offers valuable insights for understanding and navigating the dynamics of architecture's current and rapid phase of digital transformation.

5. Conclusion

The comprehensive case study of the Glass Station project presented in this paper has revealed new historical insights about how computational design methods were integrated within design and construction processes in Japan at the outset of architecture's "digital turn" in the early 1990s. It has detailed a characteristically hybrid design process that toggled between analog and digital mediums and discussed the significance of this in relation to wider processes of technology adoption and acceptance. Moreover, it provides an important sociotechnical account of intangible dimensions such as the relationships and interactions between the project's architects, engineers, and builders that were also central to the project's technological experimentation and innovation. Significantly, the case study's sociotechnical insights offer valuable perspectives to expand thinking on approaches to architecture's current and rapid digital transformation.

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Perplexity AI (Perplexity AI, 2024) was used to correct errors in spelling and grammar.

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