Efficiency and Elegance: The Effects of Structural Form on Experience

Can thinking of structure and form as one be a tool to generate new spatial and aesthetic organizations that are the most efficient at meeting their functions socially, economically, and aesthetically while elevating the human experience?

In "The Function of Form" Farshid Moussavi states "A new binary process has emerged: architects endow a built form with unique sensorial qualities while engineers and technicians address its technical requirements. This disconnect between needs and desires results in over-specified and over-complicated built forms, and does not allow the design process to respond effectively to urgent problems which are the outcome of a variety of causes, or to potentials that may reside in multiple spheres, weather climate change, urban sprawl, the decompression of the urban industrial city, housing diversity, or digital tools and technologies".[1] The buildings I analyzed are examples of instances where their designers address both needs and desires simultaneously to address the problems of their time.

I studied the works of four designers this summer on a mission to find out the stories behind buildings where the structure is integral to the design as a whole and the designers who made them possible. What drove them to this combination of form and functionality? Some of these designers, engineers, and builders are well known and loved such as Antoni Gaudi and modern architect Shigeru Ban, some no less great

but less well known in the United States such as Felix Candela and Eladio Dieste. I traveled from Mexico, to Uruguay, to Spain, and France, studying everything from grain silos, to warehouses, factories, markets, museums, homes, and churches, constructed from an array of materials ranging from concrete to brick, to stone, and wood. Each building with a unique structure that was a product of the area and function.

The investigation began with a question. Should structure follow form or should form follow structure? Should they be one in the same? Is there a particular formula for the best designs? As pointed out by Andrew Charleson in "Structure as Architecture", architecture and engineering have often had a "Me vs. Them" mindset and attitude.[2] However, what could we do if we thought of these two aspects—form and structure—as two sides of the same coin, where they are in constant interplay with each other, and each dictates the other not in a back-and-forth game of tug of war but as a unit recognizing that one will yield and influence the other. As Heino Engel puts it "The differentiation of architectural design and structural design has to be dissolved."[3] What if when we imagined the form, we simultaneously imagined the structure. As Engel again puts it "Structure personifies the creative intent of the designer to unify form, material, and forces. Structure thus presents an aesthetic, inventive medium for both shaping and experiencing buildings".[4] The realm of design, however, goes far beyond the physical, beyond just form or structure it deals with the social, psychological, and political components, I

will attempt to explore each of these through the buildings and designers I studied.

In each case the designer had an immensely strong understanding of geometry and the way in which forces act upon an object. Using construction and geometry to simultaneously create beauty and stability. Each with their own way of expressing it, these architects took the structure and geometry of their buildings beyond just providing stability, they made the beauty and structure intermingle and become one while simultaneously paving the way for new inventions in design by pushing the boarders of what had been previously done.

Each of them drew inspiration from their region and past as well as the newest technological solutions and social ideas. They took great inspiration from certain architectural styles but thought that style should not solely dictate the design and should not be a hard set of rules but instead should be the catalyst for unique designs that are careful to respect the context.

While Gaudi's architecture shaped a new movement in the late 19th century and early 20th century, Eladio Dieste and Felix Candela were at the forefront of modernism in the Americas during the 20th century, and Shigeru Ban is currently paving the way for a new movement in architecture that responds to changing environmental and social issues.

It is pointed out in seven structural engineers: the Felix Candela lectures in a quote by Billington that some believe efficiency is in contradiction to beauty,—if it is efficient and economical, can

it really be art?[5] While others believe that if you create something efficient and functional it will inevitably be beautiful.[6] This, however, depends on one's idea of efficiency. For these architects the idea of efficiency and function where about more than making a building stand and work. There are many examples of warehouses that are efficient in terms of economy and in their ability to be structurally stable and serve their intended purpose but are by all accounts unpleasant and far from beautiful, while there are also beautiful works art that are widely inefficient in a economic or functional sense. The following architects, through acting as interdisciplinary designers, were able to create efficiency on the technical and psychological level elevating the nature of design to enhance the human experience.

While each building was unique, I found a commonality between them all. Each of the designers and buildings were striving to be

both efficient and functional, form and structure were the tool which they used to achieve this; however, the form and the structure were influenced by and/or influenced several additional aspects, the sociopolitical environment, economy, construction, material, light, art, and location, and each one of these aspects influenced and effected the other becoming an interconnected web all influencing one another.

This paper will be an investigation into how structure and form as one affects these aspects and how the designers' own ideologies, time period, and location effected the way they think about form and

structure. Exploring what drove these architects to push the boundaries of what had been done, what was their inspiration and motivation behind these designs and how the social and political environment affected this.

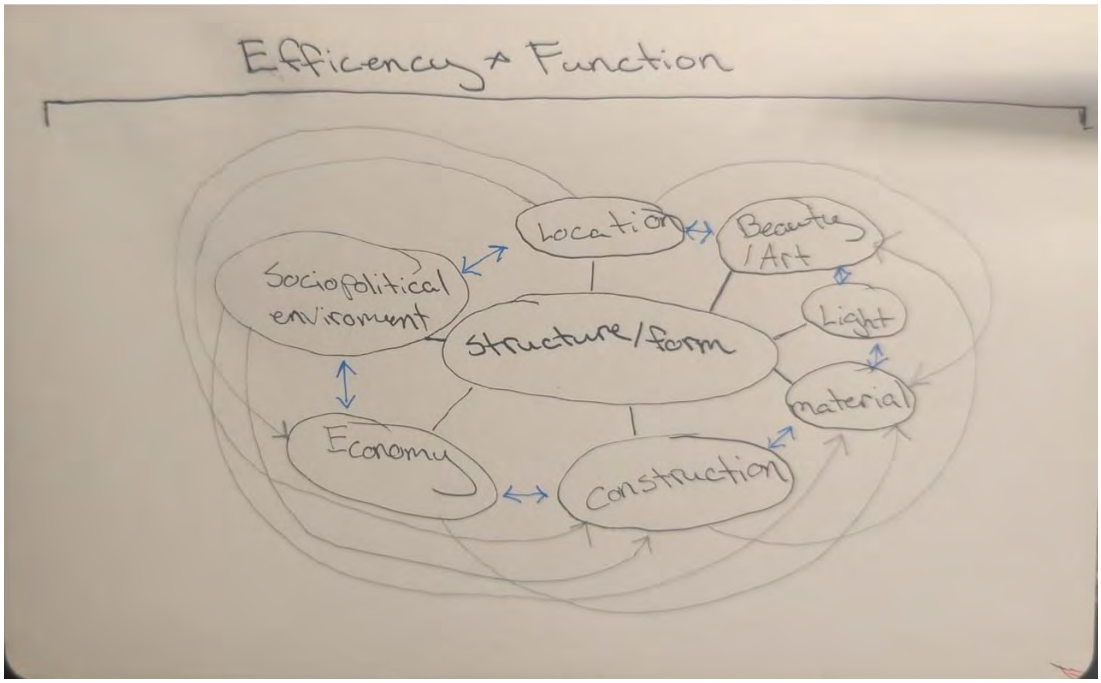


Fig.1. Design Process Diagram

Fig. 2 World Map of visited locations

Iglesia de la Virgen Milagrosa (Lady of the Miraculous Medal Church, and Candela in Mexico:

Fig. 1. Felix Candela, Interior view of main entrance to main nave and alter, La Medalla Milagrosa, Mexico City, Mexico, 1953-1957.

The first building on my journey was Medalla de la Virgen Milagrosa, a church in Mexico City in the municipality of Coyoacán designed by Felix Candela in 1953 and completed in 1957.[7] He considered this one of his greatest masterpieces and felt it was the only project where he had total freedom over design.[8] It only took Candela one week

to design the church and ten months to construct it.[9] Within the church he employed several of his initial structural innovations in a new way. In plan the building resembles a traditional gothic church based on a rectangular plan. The form of the church is where its unique structure reveals itself. The church is said to resemble Gaudi's naturalistic play of shapes and the cubist experiments of Picasso.[10]

La Medalla Milagrosa consists of the bell tower, the porch, and the church, including a main chapel with a nave and side aisles as well as a reception space with confessionals and a smaller side chapel.

Fig.2. Felix Candela, Image on the right: Bell tower, Image on the right: Reception area, La Medalla Milagrosa, Mexico City, Mexico, 1953-1957.

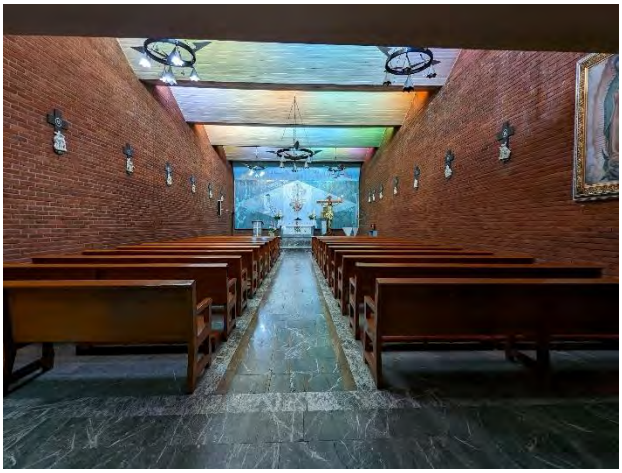


Fig.3. Felix Candela, View into smaller side chapel, La Medalla Milagrosa, Mexico City, Mexico, 1953-1957.

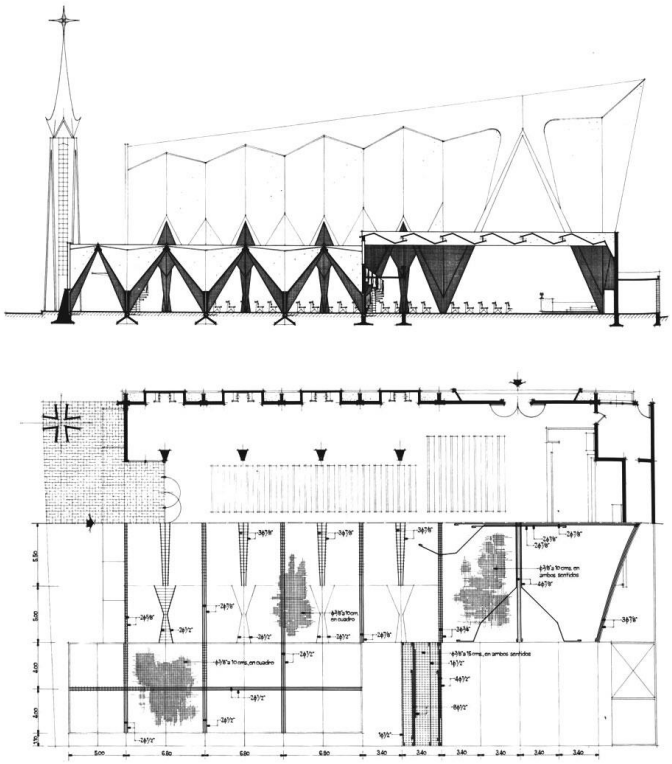


Fig.4. Felix Candela, Floor Plan and Section, La Medalla Milagrosa, Mexico City, Mexico, 1953-1957.[11]

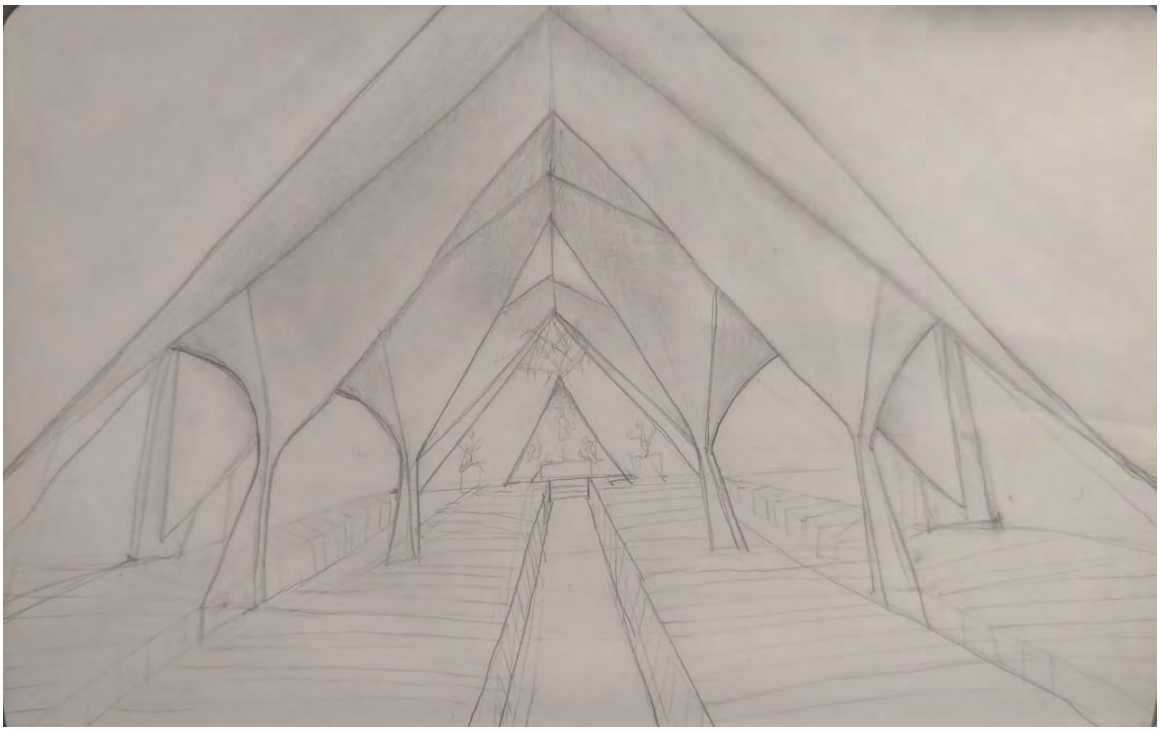


Fig. 4. Felix Candela, Interior view of main entrance to main nave and alter sketch, La Medalla Milagrosa, Mexico City, Mexico, 1953-1957.

To understand the church, its inspiration, and its impact we must first know more about Felix Candela himself. Through an interview with Juan Gerardo Oliva Salinas, a Professor at Universidad Nacional Autonoma de Mexico (The National Autonomous University of Mexico, or UNAM) and an expert on light weight structures and the work of Felix Candela, I learned that Candela was a Spanish born architect.[12] Candela was born in 1910 and died in 1997.[13] Candela graduated in 1935 from Madrid Superior Technical School of Architecture with a bachelor's in architecture.[14] In 1935 Candela also began a small studio with Eduardo Robles and Ramirez Dampierre.[15] When the Spanish civil war broke out,

he joined the Republican cause and was later exiled from Spain after the end of the war and moved to Mexico where he would do most of his works with some being in the USA and various other south and central American countries.[16] He was a ground breaker in terms of building technology and structures and his form work with long span light weight concrete shells paved the way for a new type of exciting and innovative design that pushed the limits of structural expression.

Candela was known as a man of many skills—architect, structural artist, engineer, professor, and builder. In the book "Candela /The Shell Builder," Ove Arup recalls his experiences with Candela saying, "What he has learned becomes a part of his own mental equipment—an equipment that includes a thorough understanding of geometry, which enables his fertile imagination to think out the spatial forms that will best suit his purpose." Candela was admired for his ability to be an engineer, architect, and constructor all in one taking on the role of a multi-disciplinary builder.[17] He was known as a man of many skills—architect, structural artist, engineer, professor, and builder. In the book "Candela /The Shell Builder," Ove Arup recalls his experiences with Candela saying, "What he has learned becomes a part of his own mental equipment—an equipment that includes a thorough understanding of geometry, which enables his fertile imagination to think out the spatial forms that will best suit his purpose." Candela was admired for his ability to be an engineer, architect, and constructor all in one taking on the role of a multi-disciplinary builder.[18] In the same interview with Professor Oliva Salinas, he recalls having Candela as a professor at the same university when he

was a student, "he was passionate about teaching the younger generations and he was not stingy with his knowledge".[19] Ove Arup also describes him as charming and a man of "intellectual honesty," straight forward but also kind.[20] It is important to understand that Candela was an ambitious man of many interests who was driven by innovations, exploration, and the acquisition of new knowledge. For without these qualities as a person he likely would never have made the advancements in design that allowed him to arrive at such a masterpiece as La Medalla Milagrosa.

La Medalla Milagrosa is a thin shell structure made from concrete and brick. This was a result of his geographic location, the time and the sociopolitical environment which he was operating in.

Sociopolitical Environment:

Candela began his practice in the post WWll era. It was a more economically prosperous time for the country with the circulation of goods and materials with an emphasis on industrialization and urbanization. While many of Candela's buildings like Eladio Dieste's were of more humble origins—factories, markets, bus stations, metro stations, as well as several churches—he was also at the forefront of the most important public works happening at the time. He was operating in and influenced by the modern movement in architecture. This idea of efficiency and lightness which was at the heart of modernist ideals is what led him to his use of thin shell structures, which not only appeared modern in their thinness and minimalism but were also economically feasible.[21] In Mexico there was a call for a

more rationalist and functional architecture that would take advantage of new materials and modern technologies.[22]

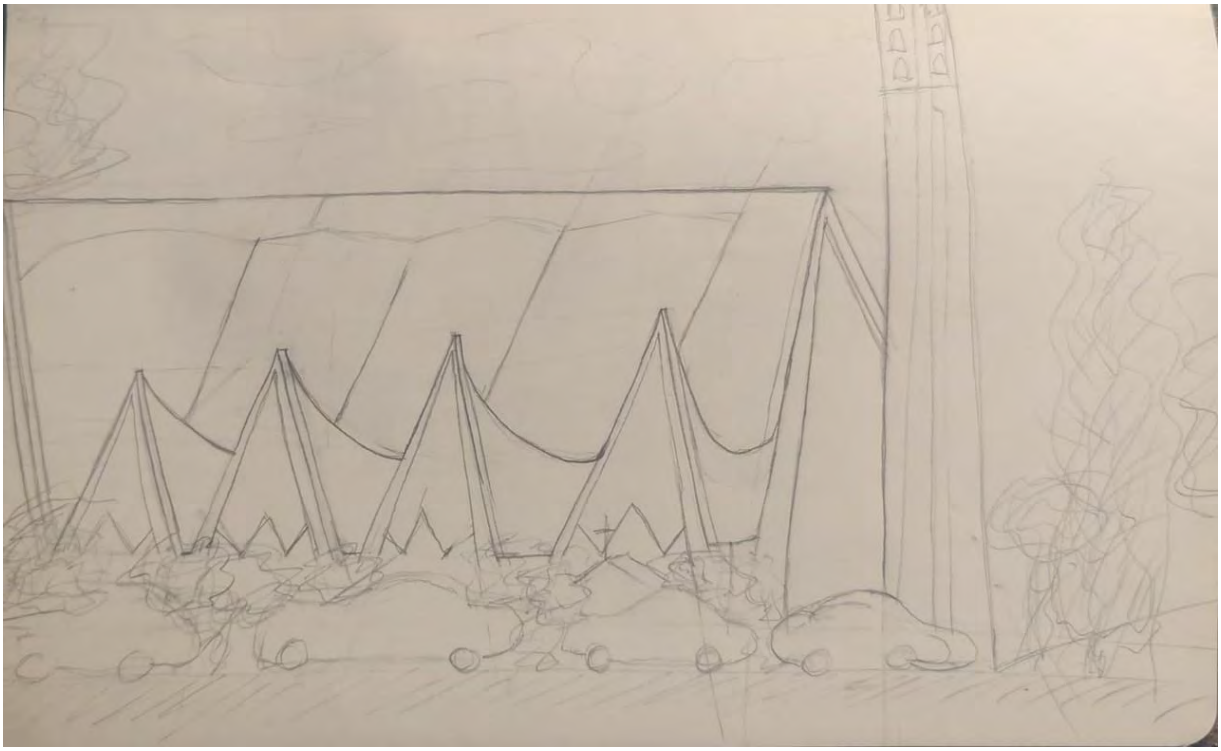


Fig. 5. Felix Candela, Interior view of main entrance to main nave and alter, La Medalla Milagrosa, Mexico City, Mexico, 1953-1957.

Structure:

With this context in mind, we can begin to investigate structural and material innovations in La Medalla Milagrosa and Candelas earlier works. Candela was known to conceive his designs based on their geometry, writing once after critics on these methods "The imposing stone vaults of Gothic cathedrals and the daring domes of the renaissance were built without help of differential calculus but instead with great sense of equilibrium and sound judgment of the play of forces: qualities more necessary indeed to a real builder than full

knowledge of mathematical intricacies".[23] One such form he began experimenting with and eventually used in Medalla Milagrosa was the hyperbolic paraboloid. A hyperbolic paraboloid, or hypar, is a double ruled surface that takes on the shape of a saddle or Pringle potato chip in its simplest form. His use of hypars allowed him to transmit almost exclusively compressive stresses, which allowed for thin shells of a consistent thickness. Much like many shells found in nature from turtle shells to seashells, the hypar relied on its curvature rather than its thickness for its strength. He would often combine multiple hypars in order to create the effect and structural rigidity he sought, slicing and rearranging them to shape space and create structural order.

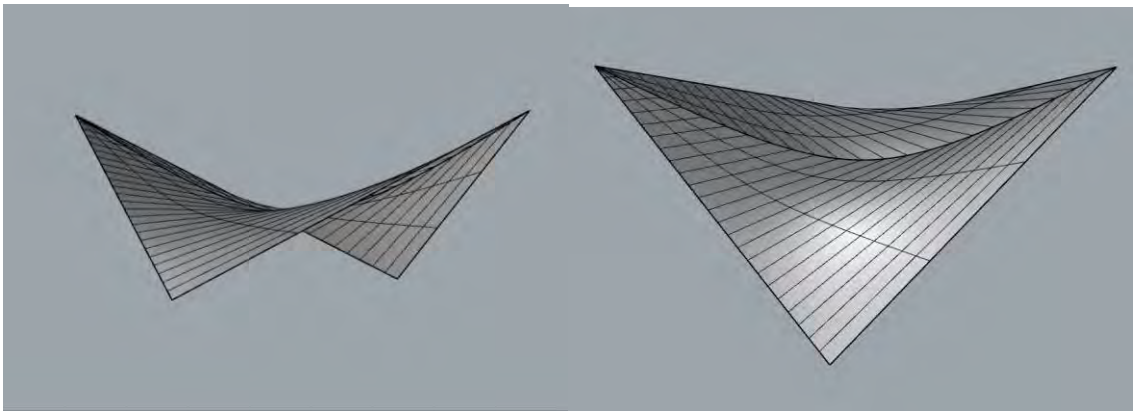


Fig. 6 Hyperbolic Paraboloid

He used this form when he built his first concrete shell, "The Cosmic Ray Pavilion," on the UNAM campus, a structure which is still in use by students and faculty today. He was able to achieve a roof structure that was 5/8 inch thick.[24] The form of a hyperbolic paraboloid was ideal because it allowed him to achieve maximum spans

with minimal thickness, in the spirit of the modern movement at the time which emphasized the importance of minimalism.

Fig. 7. Felix Candela, View of Exterior, Cosmic Ray Pavilion, Mexico City Mexico, 1951.

Candela later developed what would become known as his umbrella forms, where he combines 4 hypars to create a form that resembles an inverted umbrella.

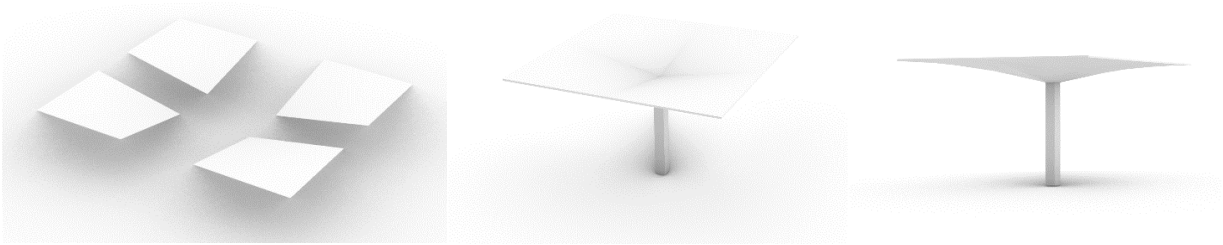


Fig.8. Umbrella Form

This umbrella form would become the key to the La Medalla Milagrosa, Candela used the umbrella in Mercado de Coyoacán, a market located near La Medalla Milagrosa, the umbrella became a very popular form for markets and metro stations.

Fig.9. Felix Candela, View of interior structure, Mercado de Coyoacán,1955.

In La Medalla Milagrosa, the church is made up entirely of warped surfaces. Candela uses the umbrella form, taking advantage of its self-supporting hypers to create the warped surfaces.

This church represents a unique adaptation to the umbrella form. Candela first turns the umbrella onto its side and then inverts the hypars creating a new umbrella form that acts like a funnel channeling its loads down to its supporting columns and from there down to its footing. He goes a step further by turning the hypar onto its side and stretching one side to create the bay units that would make up the main nave. Each inverted umbrella gently swooping down to a point joined by its neighboring hypar to create the plan of the church. The hypars to the left and right reach up touching each other gently and creating the main nave with lower aisles to the left and right formed by the short end of the inverted umbrella form.

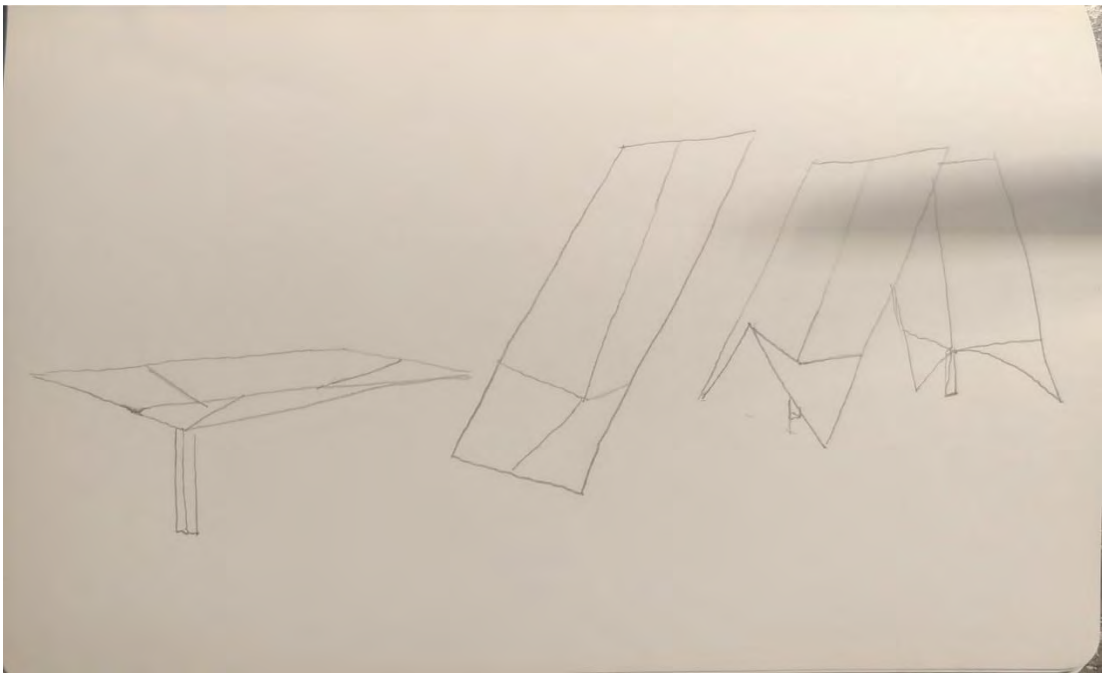


Fig.10 Diagram of La Medalla Milagrosa church bays.

It is very simple in plan and resembles a classic gothic style church, which is what the congregation had asked for. In fact, they had no

idea they would be getting anything other than that until the construction was already well underway.[25] However, Candela was excellent at combing modern techniques and design ideals with traditional styles. When visiting I noted that the amazing thing about the structure is that it respects the traditional aspects of a catholic church—nave, alter, and aisle—while it simultaneously creates a form that is truly unique and modern. The church felt familiar, comfortable, and navigable, but exalting at the same time. It was amazingly respectful, as though it knew it was honoring something greater than itself—community and tradition. When the priest spoke, his voice reverberated throughout the church bouncing smoothly from one hypar to the next until reaches you eventually floating up to meet the peak of the nave.

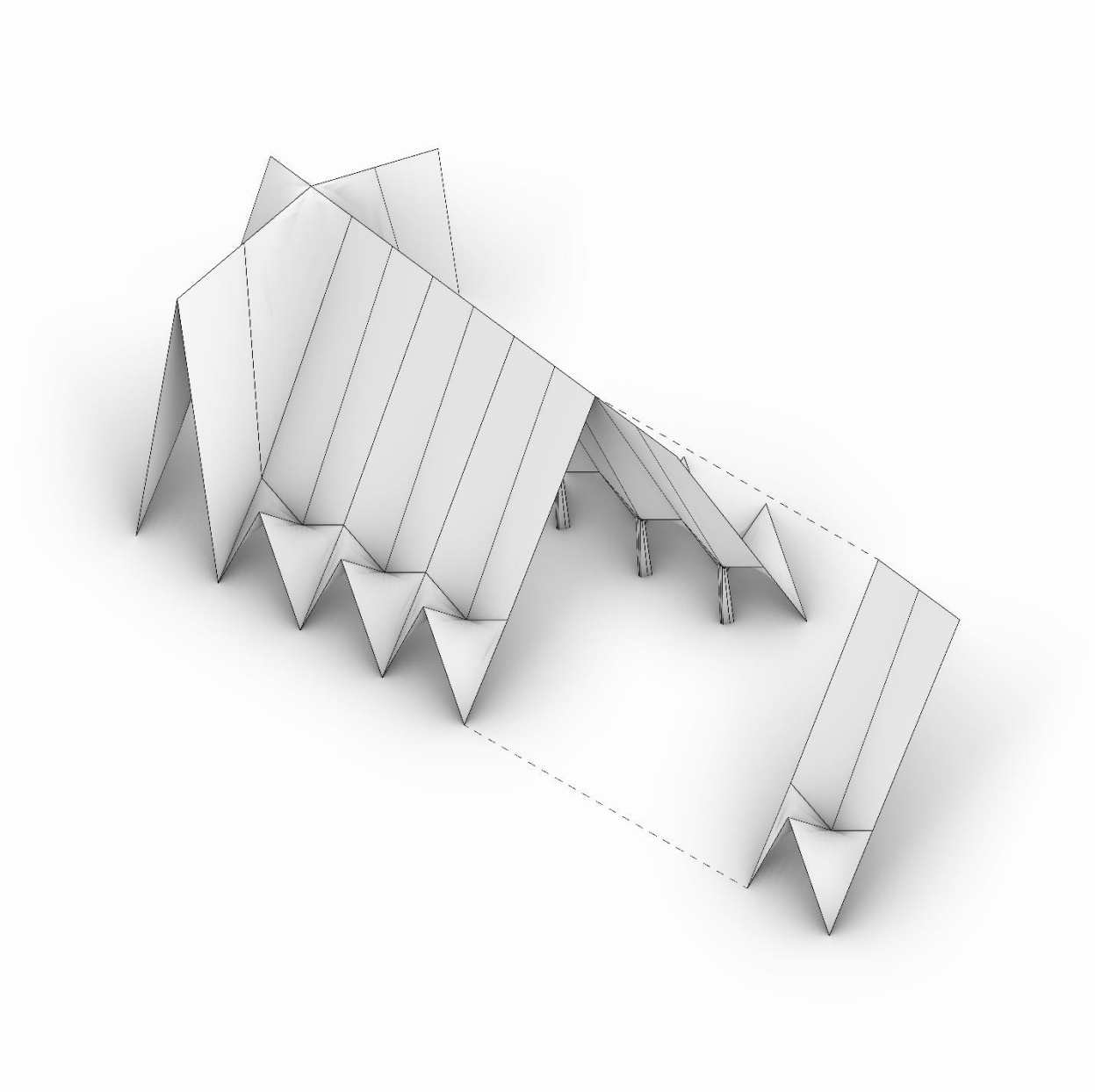


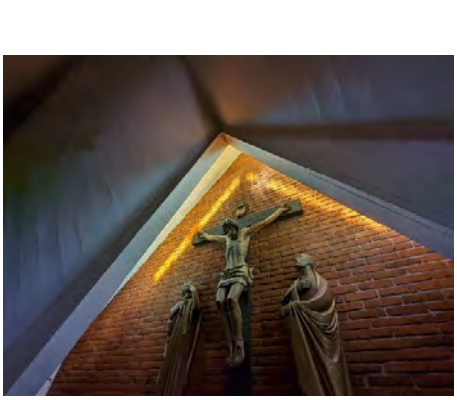
Fig.11 Church Bays Diagram

Material:

Concrete was the main material used in Medalla Milagrosa and in all of Candela's designs due to its prominence, cost efficiency and availability. This region of Mexico, both in the past and present, has been dominated by concrete and brick. This became quite evident to me

in Mexico City as I traveled the area and observed its built environment. Candela understood the compressive and tensile properties of concrete and focused his career on the development of its use and construction. While Felix Candela's work stands in sharp contrast to the rest around it, he did not seek to abandon the traditional methods of building but rather to revolutionize the way these methods could be carried out, drawing on what local builders and workers were already familiar with in a new way. In my interview with Professor Oliva Salinas, he pointed out to me that the construction of thin shell concrete structures did require a great deal of labor, with Medalla Milagrosa being no exception, making it less feasible to create some of the same works in the USA or Europe where labor is more expensive.[26] Considering that labor was more readily available, and workers were used to construction with concrete, it was the completely rational decision to work with concrete. The secondary material used in Medalla Milagrosa was brick, which was used to fill in between the concrete structure to create enclosure. The dark color of the bricks makes the light-colored concrete structure stand out even more and Candela uses the opportunity presented by the structure and materials to create a beautiful play between light, brick, and concrete. Because the brick walls are not structural, he is able to leave thin gaps for light to filter in through constantly creating mysterious light that does not reveal its source. One such light source is located under the porch of the church near the entrance. A closer image reveals the way the structure lets the light come in.

Fig.12 Thumbnail Sketches of La Medalla Milagrosa



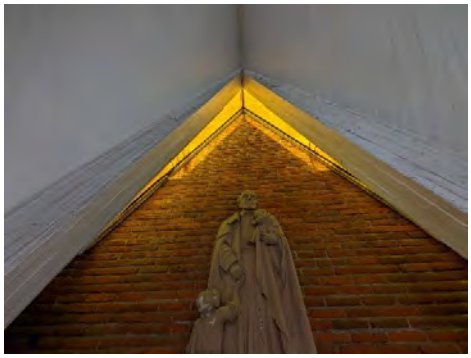


Fig.13 Felix Candela, Far right image: Interior view of reception area, Middle and far right: View of porch, La Medalla Milagrosa,1953-1955.

Construction:

Despite the complex look of the many forms created by Candela, they were not all as difficult to construct as they might seem because it was possible to use straight line geometry to create the double curvature that gives his structures their structural rigidity. Scaffolding can be erected using straight pieces of wood which become

the framework for the concrete to be poured onto. The geometric nature of a ruled surface makes this possible.

Once the scaffolding and thin form boards are in place, a thin layer in the form of a mesh screen lays over the top to provide a little bit of reinforcement. Buckets of concrete are poured evenly over the entire structure to create the shell.[27] However, Candela's process was not always perfect, and he occasionally ran into scenarios where the typical method did not work. Medalla Milagrosa was one such example of this. In Medalla Milagrosa the upper horizontal edges were only half as long as their oblique opposites, making the surface too steep he solved this by using parallel bars that were discontinuously placed and filled the empty space between them with large wedges, allowing the boards to twist without need to bend.[28]In this church like many of his other buildings he uses an inverted umbrella form as the footing which gives more support to a structure that may experience shifts in the ground, this is likely why so many of Candela's buildings like Los Manantiales have survived earthquakes in the past and continued to stand.

Fig.14 Felix Candela, Exterior view along canal, Los Manantiales, 1958.

An interesting and pleasant aspect that was a side effect of the construction process what the texture of Candelas structures. As Professor Oliva Salinas pointed out, after construction the thin form boards are left behind in the concrete and their direction and arrangement can still be seen.[29] This was unlike the other concrete structures in the area and a direct result of the way in which Candela constructed his buildings. Although unintentional, the effect is quite nice. When in Medalla Milagrosa and various other projects by Candela, I found that the texture gave a point of comparison to the scale of the building. It allowed me to more quickly get a sense of the scale in comparison to myself. In this way, the space could feel large and vast but also comfortable and embracing in a way that a completely

smooth surface would not. It is a small detail that you likely would not notice without visiting the works in person, but it greatly changes the way you perceive these buildings when you are interacting with them.

Fig.15 Felix Candela, Interior structure texture detail, La Medalla Milagrosa,1953-1955.

Light:

Candela viewed structure and sculpture as going hand in hand. In this building he strives for maximum efficiency through forms as art. You see this particularly in the way that light and color interact with

the structure and form. The curvature of the walls allows them to be reflected against them when they shine in through the beautiful stained-glass windows, which begin to make the structure glow with color at certain points, as seen in the photos above. In some cases, as you are approaching you cannot see the source of light, as the undulating ceiling form that makes up both the ceiling and form block it. A glowing green on the structure's surface creates a sense of mystery and beauty that compels you to explore the space closer.

Fig. Felix Candela, Light on structure over side aisle in main chapel, La Medalla Milagrosa,1953-1955.

Fig.16 Felix Candela, Stain glass over entry from main chapel to reception and confessionals area, La Medalla Milagrosa,1953-1955.

The altar sits behind a brick vail with a V shape punched out, and behind it light floods in to illuminate the virgin Mary and alter. Contrasting the dimmer space that houses the congregation, the light-colored concrete that makes up the structure floats with a cloud-like appearance and feel.

Fig.17 Felix Candela, View of alter, La Medalla Milagrosa,1953-1955.

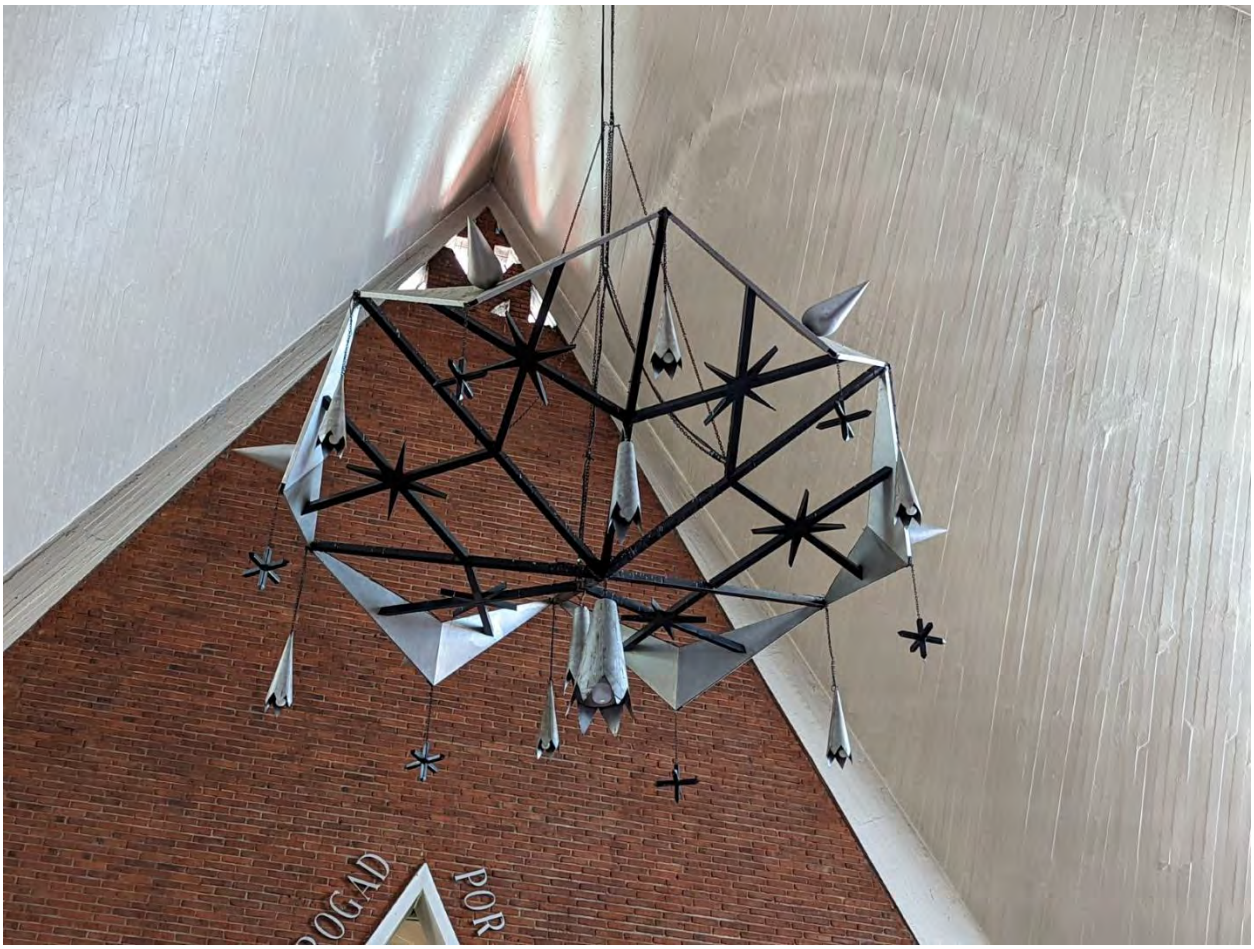


Fig.18 Felix Candela, Lighting fixture, La Medalla Milagrosa,1953-1955.

Fig.19 Felix Candela, Interior view of exterior wall, La Medalla Milagrosa,1953-1955.

I noticed too that while there were lighting fixtures that hung from the ceiling, they were never turned on during the daytime, with the natural light produced through the various openings in the structure was enough to illuminate the space. I also noticed the thermal comfort in the space and how amazingly cool it was inside

compared to the warm temperatures of summer in Mexico City when I was visiting. This is due in part to the height of the structure which allows the heat to rise further away from the occupant and also on the thermal qualities of brick and concrete. Both brick and concrete warm and cool very slowly and stay warm or cool for longer periods of time, leading to both less heat loss and gain allowing the church to rely on its materiality and form for thermal regulation of the space.[30]

Through light, structure, and material, Candela is able to achieve function, efficiency, and art in his space.

In the evenings around sunset, it gets relatively dark in the church, but the sun hits the church so that light floods in through the side-colored panes and fills the church with color and light. The form of the church cast dark shadows but contrast with the windows on the sides, creating a beautiful glow between the two that is quite elegant. Particularly in the evenings, the light floods in from the left side of the altar illuminating the angel. It is almost impossible to resist looking up, drawing your gaze to the heavens with or without your consent. At the bottom you feel humble, small and minute but as you gaze up your presence feels lifted like your soul is somehow raised closer to the top of the structure. The vibrations of the priest voice fill the space and you can feel them in your chest as your heart starts to beat faster and you feel excited yet calm at the same time—like your stomach is filled with butterflies that escape in the form of tears floating to the sky with the priest’s voice. You feel so small and unimportant yet seen and special at the same time.

Even when you close your eyes you can sense the form of the church guided by the vibrations. It is clear that Candela wanted the structures of his church to reflect the religious ideology. Having rational order, yet seeming to defy gravity and logic—yet you trust it, believe in it and know somehow that you are safe within it. It is the effects such as this that elevate the work of Candela as being more than structurally efficient works to being works of art that elevate the human experience and ignite one's senses. I believe his understanding and respect for local traditions and styles with a mind for a more innovative and efficient future is what led to the success of his structures. I was curious to know if the people of the area who use and experience his buildings felt the same. What I discovered was not a disappointment although few knew who the designer of the building was, I found that everyone I spoke to of Candela's designs held them with fondness, admiration, and pride. It shows, since most of his buildings having been kept well and utilized to this day.

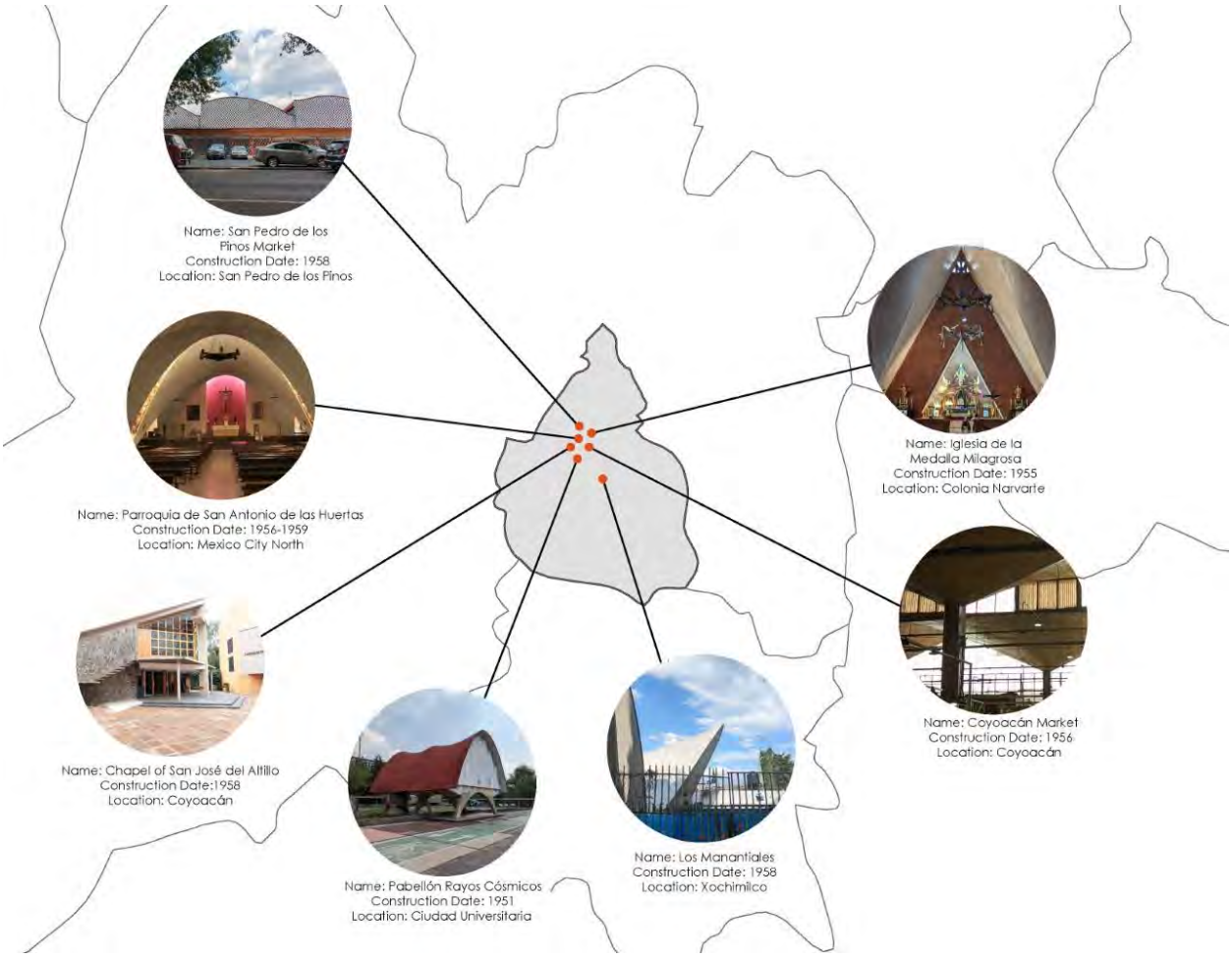


Fig.20 All projects visited in Mexico by Candela

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Cristo Obrero Church,and Eladio Dieste in Uruguay

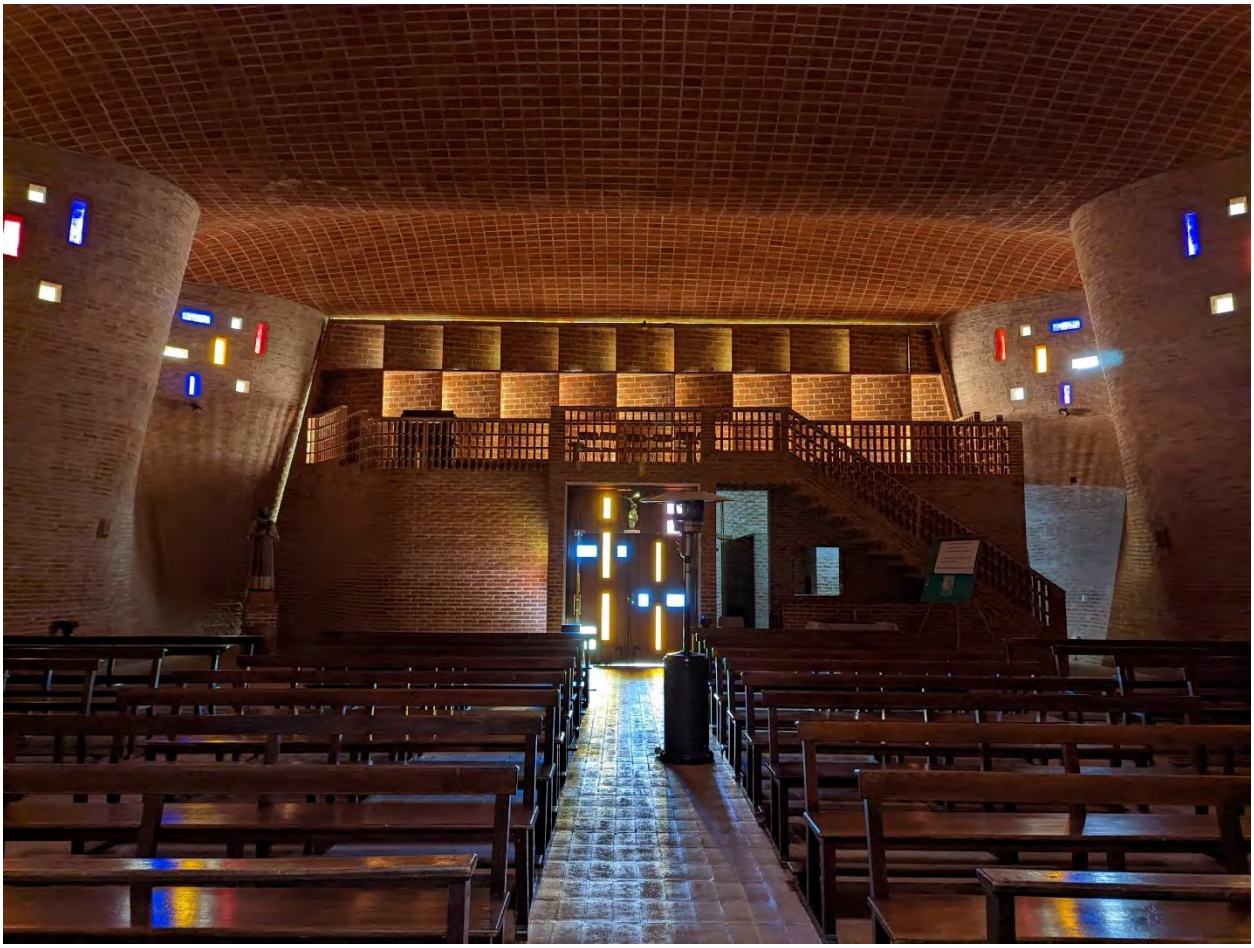

Fig. 1 Eladio Dieste, View of entry door from alter, Atlántida, Uruguay Cristo Obrero, Atlántida, Uruguay, 1953-60.

The next stop on my trip was Uruguay to visit the work of Eladio Dieste and his partners. Iglesia de Cristo Obrero was one of the first projects Dieste ever built constructed in 1958-60 and is known as one of its most prominent for its daring yet elegant structural achievements.[31] Much like Candela, Dieste considered this church to be

one of his greatest masterpieces. Located in Atlantida, Uruguay it serves a small population of 5,562 most of whom are farmers, it is a great example of Diestes "cosmic economy" which I believe results from thinking of his design process more interactively.[32] The site consists entirely of four parts the church the bell tower, the baptistery, and the parish house which was demolished in 1964 to make way for a schoolhouse.

Fig.2 Eladio Dieste, Bell Tower, Cristo Obrero, Atlántida, Uruguay, 1953-60.

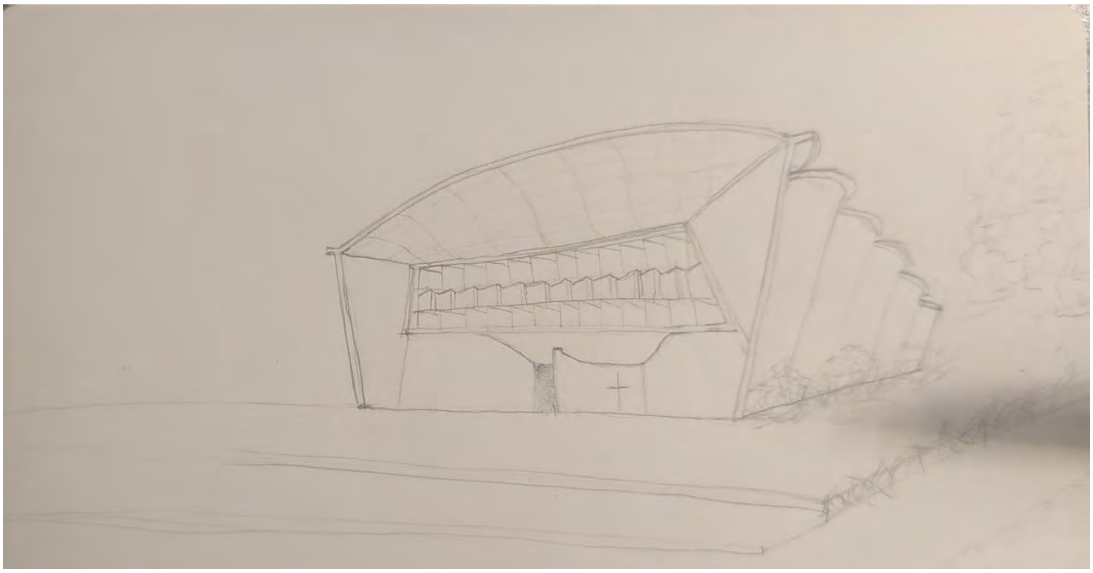

Fig.3 Eladio Dieste, Sketch of North Façade, Cristo Obrero, Atlántida, Uruguay, 1953-60.

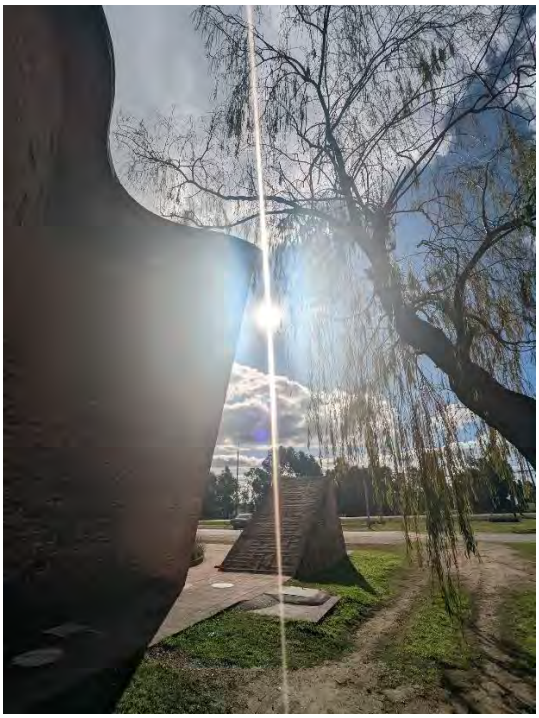

Fig.4. Eladio Dieste, View of baptistry from church yard,, Cristo Obrero, Atlántida, Uruguay, 1953-60.

It is a simple rectangle in plan taking on its complexity from its 3-dimensional aspects. Cristo Obrero church in Atlántida, Uruguay was the project of interest to me, but it would be hard to understand Cristo Obrero without understanding Diestes greater body of work and the context he was working

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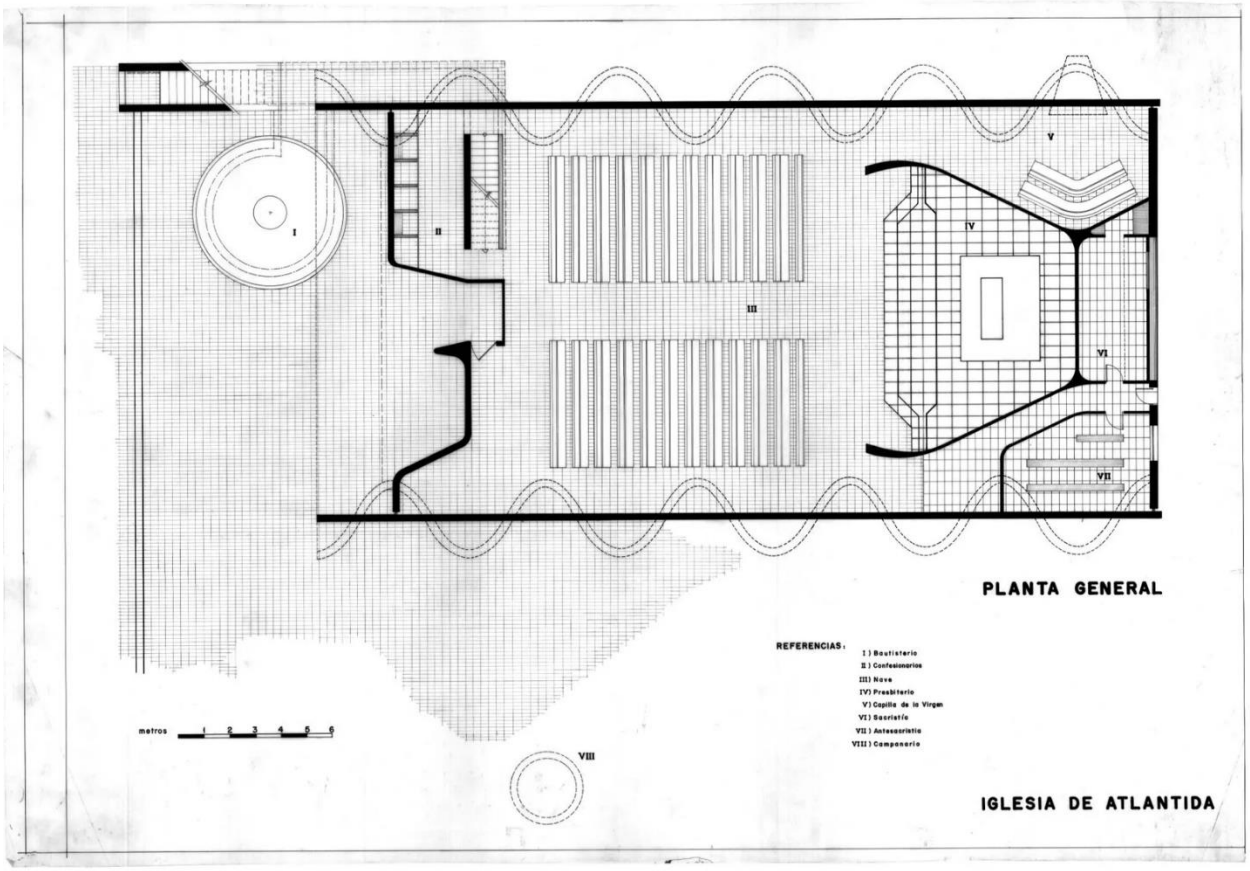


Fig. 5 Eladio Dieste, Floor Plan, Cristo Obrero, Atlántida, Uruguay, 1953-1960.[33]

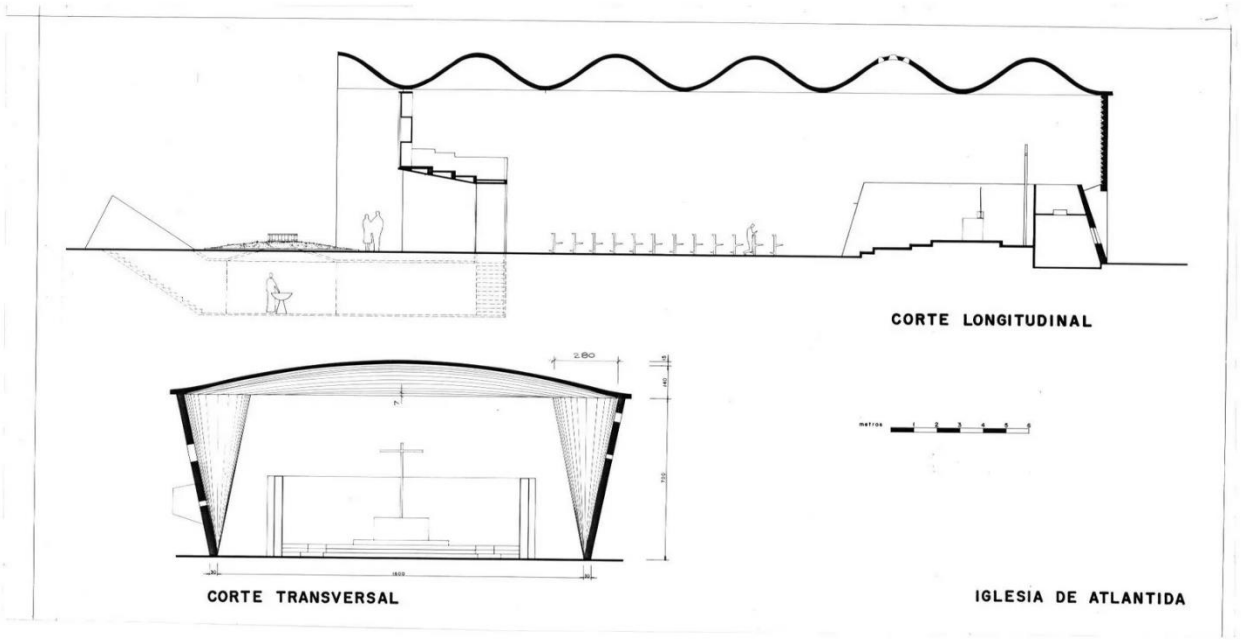


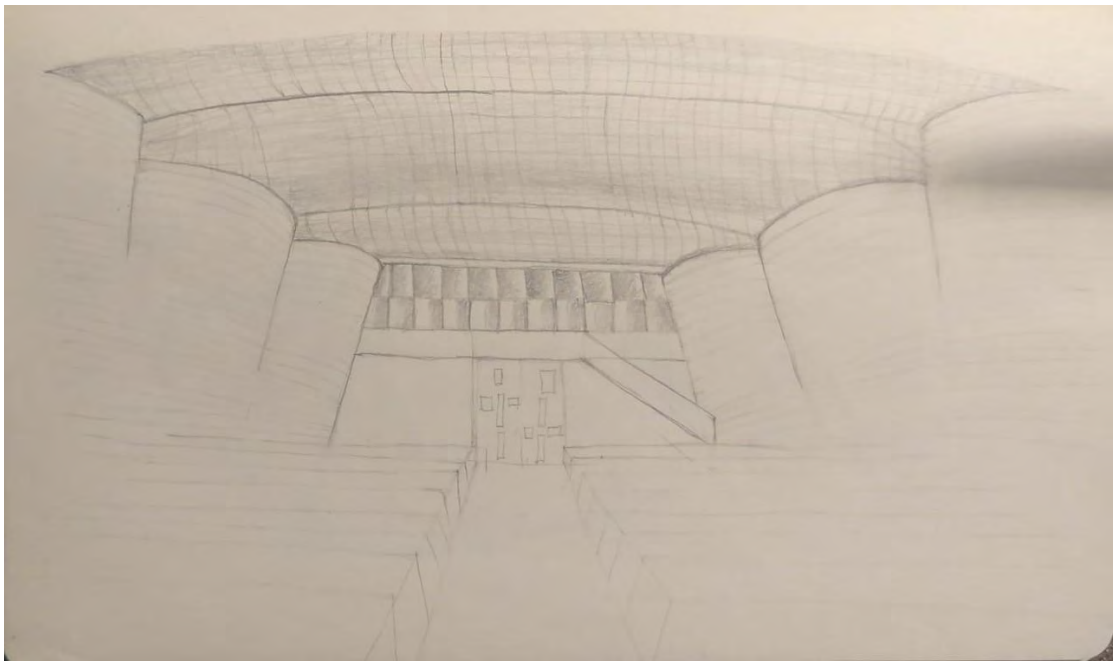
Fig.6 Eladio Dieste, Section, Cristo Obrero, Atlántida, Uruguay, 1953-1960.[34]

Dieste was a Uruguayan-born individual of immigrant parents born in 1917 and died in 2000. Dieste became educated as a civil engineer at the University of the Republic in the capital Montevideo but was no less of an architect, builder, and artist.[35] He graduated in 1943 and worked as an engineer for the Highway Ministry of the Uruguayan Ministry of Public Works for three years and was head of the architecture office from 1945-1948, from 1949-1958 he worked for the Vermont piling company, Dieste was also a professor for the faculty of engineering.[36] According to his son Esteban Dieste, who I had the great honor of meeting, he was very passionate about spreading his knowledge and educating the younger generations. Esteban Dieste described his father as a serious and solemn man who was contemplative and believed spaces that allowed one to meditate and reflect were of great importance and benefit to mankind.[37] Along with his son, I was able to

meet his granddaughter, Leticia Dieste who recalls her grandfather being a cheerful and happy man who loved his work.[38]

He became best known for his work with reinforced ceramic vaults, particularly in long span structures. Creating some of the most beautiful and elegant structures made from brick in his time and still to this day. The first project with reinforced brick was while collaborating with a Catalan architect, Antoni Bonet on a house. In 1954 he opened his own practice with Eugenio Montanez founding the firm Dieste y Montanez S.A.[39] The firm is still in operation today in Montevideo where I had the honor of touring it. Eladio Dieste believed in the idea of "cosmic economy" which he described as "to be in accord with the profound order of the world" buildings that were efficient in material usage, construction, cost, yet also beautiful.[40] Dieste was also a man greatly concerned with social justice and the inequities that face many Latin American countries, with a strong moral compass which influenced tremendously his designs. He was wary of the Industrial Revolution; he saw its potential to be a positive thing but also the way it was taking place with great injustice.[41] He was a man concerned with the wellbeing of the lower classes and as Esteban Dieste was quick to point out "Whether it be a grain silo, a warehouse, a factory, or a church, Eladio Dieste believed that all architecture deserved care and beauty and that everyone residing in whether to worship, work, or live, deserved a beautiful and quality

space”.[42]



He began his practice during post WWII and all through the cold war. There was the rise in global communication and numerous trade agreements which led to the mass circulations of goods, people, and ideas, made possible by the mass production of goods and new materials due to the Industrial Revolution. Eladio had a great deal of respect for workers and their rights after having spent time working in an industrial city in France, he came to distain the working and living conditions were forced to contempt with. Saying “I will ask the same question again and again. Is development desirable at the price of this sordidness and misery?”[43] I believe that this is why Eladio Dieste built even his most humble structures with the greatest care. You can see in several of his warehouses the amazing quality of natural light from above because he has said “Without glimpses that show us that the world has meaning, we would succumb to despair”. Eladio would often argue for slightly more expensive solutions then what could have been

done in several factories because as he said "The worker who lifts his head from what he is doing and sees the clouds pass by or the marvelous security and grace of a bird in the air will not be as tired and will acquire in this contemplation new energy. In the end, he will produce more. In a hierarchy with appropriate intentions, all of this should be a reality, not an intention.".[44] I immensely enjoyed visiting the many warehouses built by Dieste and speaking with the workers as I did not run into a single worker or user of his buildings who were not immensely proud and loving of their space. Reflected by the upkeep and expansion of many of his buildings. His warehouses flooded the workers with light from above illuminating the large space and intermingling with the warm red tones of the bricks. One such factory I visited was Lanas Trinidad (Trinidad Wools). This sheep wool factory was built in 1980 and has since had three additions carried out by Dieste and Montanez S.A. It is an excellent example of the self-supporting vaults that Dieste came to be known for.

Fig. 7 Eladio Dieste, Lanas Trinidad (Trinidad Wools), Interior wool storage area, Trinidad, Uruguay, 1965-1980.

I believe perhaps one of the most moving buildings I experienced by Eladio Dieste was a small 3 room schoolhouse in rural Uruguay. Charming and poetic, it created the perfect space for a learning environment its curved edges and warm colored bricks made you feel safe and comfortable, while the windows flooded you with light and scenes of nature resisting the feeling of being enclosed and tramped that often comes with educational buildings.

Fig.8 Eladio Dieste, View of classroom, Escuela rural tipo, Canelones, Uruguay, 1962-1975.

Fig.9 Eladio Dieste, View of classroom, Escuela rural tipo, Canelones, Uruguay, 1962-1975.

Equally impressive as the schoolhouse was the principal and head teacher. Whom, after reaching out endlessly to the community around her, over quadrupled the size of the school in less than two years and even prevented it from being shut down. What stood out to me was how moved she was by the space and architecture originally put into place by Eladio Dieste. Finding herself suddenly entirely short on space she reached to government who had additions added to the school in the form of terrible shipping container like spaces, but she realized the value that space brought to a learning environment and refused to

settle for anything less than the excellence that Eladio Dieste once gave to a school of overly deserving children and teachers. This teacher worked tirelessly to raise funds from businesses in the community for an expansion of the school but not just any expansions an expanse following the style and spirit originally brought by Eladio Dieste. Not only did she raise the money for expansion single-handed, but she also worked tirelessly to track down and contact the firm left behind by Eladio Dieste to request that they be the ones who expand the school. Whom after hearing the story and needs of the teacher as well as her love for the architecture of Eladio Dieste could not resist offering their service. So why do I tell you this long winded yet inspirational story? To emphasize the importance of pouring one's heart and soul into every design no matter what its function, I believe it should be every designer's goal to design a space so magnificent and perfect that years later someone in an entirely different profession would fight tooth and nail not only to preserve it but expand it. This is the beauty of Eladio Dieste, his designs went beyond style, art or fashion to the heart on need utility and use. He understood that use and function were the most imperative things, but that beauty had everything to do with the success of these ideas. In an essay Dieste says “When the final result of a project is earnest and humble, it will achieve art but without having sought after it. The building or buildings in which we achieve difficult goals will have exemplarily power over the city. In these buildings men will see the true expression of mankind. They will recognize one another, and their weariness will be overcome. Architecture that is

understood and felt in this way is poetry. We are not all able to create it but we all need it.” [45]I feel that for that teacher that school was her poetry. These examples show that Eladio Dieste was truly a designer for the people.

Structure:

In an interview with Federico Garcia Lammers he explained that Dieste was known for his use of ruled surface walls, self-supporting vaults, gaussian vaults, and folded plates.[46]

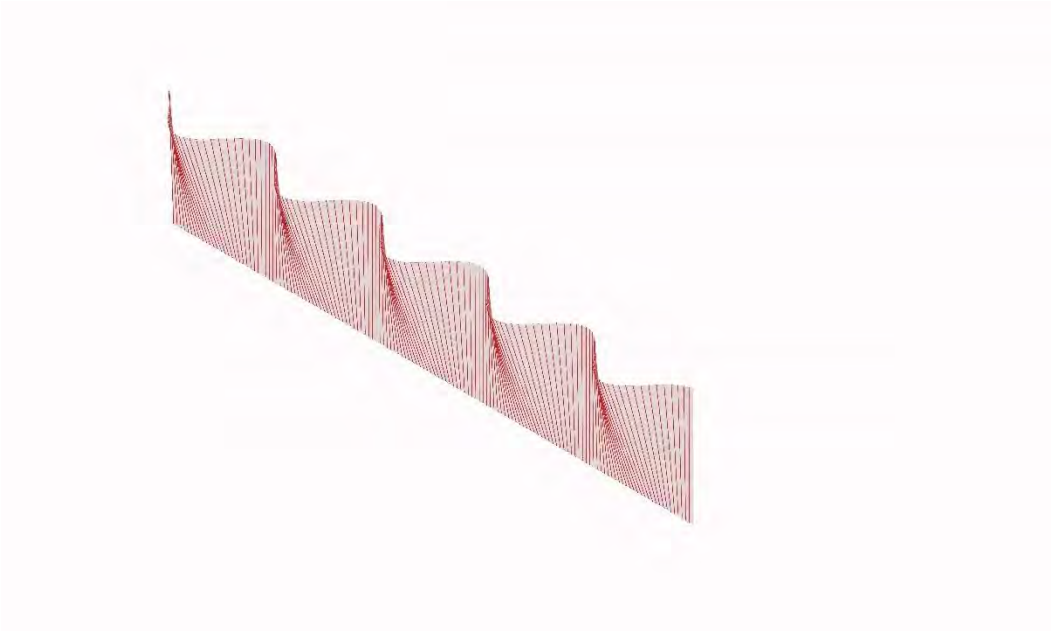


Fig. 10 Side Wall of Cristo Obrero

The construction of the church essentially consisted of 4 parts the roof composed of double curved gaussian vaults, the side walls made of load bearing conoids, and the front and back walls, it is 528 m2 (33 m long by 16m wide, by 8.24m high), it is also covered with 5 and a half internal vaults.[47] The side walls composed of conoids composed of ruled surfaces are completely self-supporting. If you were

to take away every other piece of the building each wall would stand sturdy. These walls are the load bearing support for the rest of the church acting in a way like a gothic buttress. In this case however, instead of a traditional buttress with additional supports along the wall to carry the load down the wall relies on its geometry rather than additional support to channel the loads to the foundation. In an interview with Professor Monica Silva-Contreras, from Universidad Iberoamericana in Mexico City and an expert on the construction and work of Dieste, she explained that the roof is a double curvature gaussian vault much like many of the ones used for his factories. However, in many of the warehouses and factories there is a tension rod that runs from one end of the roof to the other to resist any tensile forces. In the church Dieste did not want the steel rod to be visible so he engineered the gaussian vault to dip lower than usual and concealed the tension rod within the vault itself so it's not visible from the interior or exterior.[48] Thanks to the double curvature of the roof the walls and roofs meet on an even plane with one another.[49]

Material:

The primary material used by Dieste was brick largely because of its availability and use in Uruguay. As someone who valued economic responsibility it was imperative to use local material. He was innovative in his use of brick, creating geometry that was not typical of the material. He also engineered the construction process of his buildings to achieve the structure but made his best effort to keep on par with what the local builders were familiar with. As he put it

"Construction will always be indiscernible from architecture because it is like its flesh and bones."[50]

The entire church is made up of brick the same traditionally produced Uruguayan red brick. However, through rotating its orientation and configuration Dieste can produce a variation of textures that mesh to create a singular space but also discern themselves from one another to mark certain areas. Although the bricks need to be oriented in the directions that they are for the construction Dieste does so in such a way that they take on a greater meaning than just constructability. In very few select areas he cuts the bricks at an angle to achieve the form necessary but makes every attempt to avoid needing special cuts to not further prolong or complicate the construction. The traditional material meshes well with its surroundings and makes the church geographically and economically feasible for the small rural town.

Construction:

Fig. 12 Eladio Dieste, Photo of Construction, Cristo Obrero, Atlántida, Uruguay, 1953-60.[51]

Fig. 13 Eladio Dieste, Photo of Construction, Cristo Obrero, Atlántida, Uruguay, 1953-60.[52]

To build his unique structures, Eladio Dieste had to design the construction process with as much care as he designed the building. Workers in Uruguay were very familiar with brick as it was a very common Uruguayan material. Eladio Dieste designed temporary scaffolding which could be moved as each section of the church roof was constructed which allowed him to use less materials in the construction process as well.[53] The scaffolding constructed was the size of one vault and was moved back consecutively as the vaults were completed. To accommodate the curvature of the walls as you moved from one vault to the next Eladio Dieste gave the scaffolding arms which could fold up to be moved and back down again when it was time for construction.[54] The walls of the church were constructed using straight wires that followed the undulations of the wall at the top connecting

to a straight line on the ground, the guides for the wires were a wood frame.[55]

Light:

Fig. 14 Eladio Dieste, Interior wall view from alter, Cristo Obrero, Atlántida, Uruguay, 1953-60.

Because the front and back walls are not structural other than for the sake of enclosing the structure Dieste was able to play with the light in a very special way. In the front wall he leaves a very small gap between the wall and the rest of the structure, which allows light to surround the choir. He does the same thing on the back wall but in such a way that the gap is not visible. This allows the back wall to glow with a mysterious light that the source of is not imminently

evident, creating a feeling of a sacred space. Directly above the altar is illuminated with light from circular sky lights in the roof directly above. In the same interview with Professor Monica Silva-Contreras, she explained how the rings that make up the skylight are from old clay pots that had been cut into several rings.

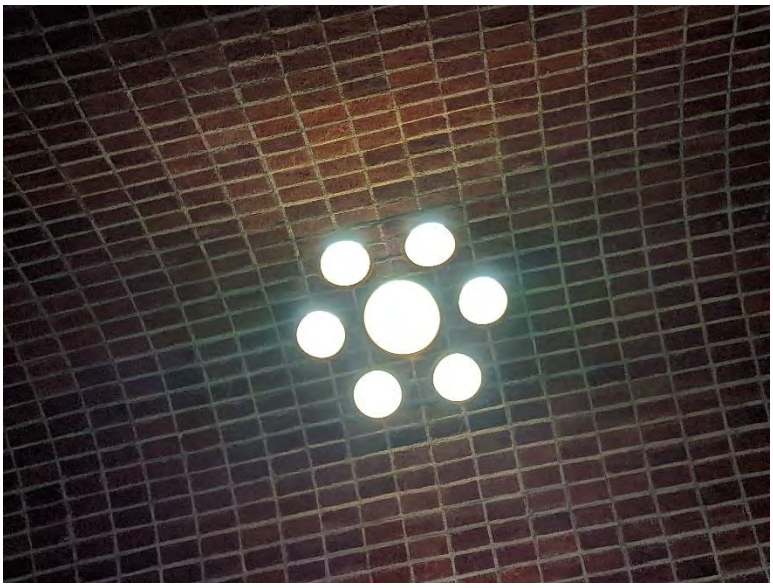


Fig. 15 Eladio Dieste, Skylight in Cristo Obrero, Cristo Obrero, Atlántida, Uruguay, 1953-60.

A reflection of Dieste's love for humble materials particularly when they are from a recycled source, a trait he shared in common with Antoni Gaudi, and Shigeru Ban. The way in which Dieste used light in relation to the structure allows you to experience the space differently depending on your orientation. Facing the entry and choir which sits above the entrance, you can see the aperture for every source of light, multicolored windows in various rectangular sizes puncture the upper sides of the conoid side walls, the curvature of the walls slowly revealing the lights as you walk from the alter to the entrance. On the other hand, when you are facing the alter you are

still experiencing all the light, but its source is never revealed. The curvature of the load bearing walls conceals the apertures by placing them only on the side of the conoid not visible when facing the altar. The waving motion of the double curvature ceiling makes the apertures above the altar invisible unless you stand directly underneath them. According to Esteban Dieste the reason his father wanted it this way was because when you were facing the alter, he wanted you to be completely focused on the ethereal, removed and undistracted by the outside world, a space where you meditate, reflect, and pray elevated by the lightness of the space but not distracted. I was shocked upon visiting how light and delicate the space felt on the inside. From the outside there are very few apertures visible and the dark red solid brick structures seem like it might feel heavy and dark on the inside. However, the way Dieste uses light creates the direct opposite. By using the form of the structure, he conceals and reveals lighting in a way that illuminates the entire space. I observed while there how the light enters in through the apertures in the side walls hitting the curve in front of it and reflecting and diffusing back into the space so as to never create a glare no matter what the time of day. The only spaces which the light is directly illuminating are moments of great importance the altar, the choir, and the baptistry.

Fig. 16 Eladio Dieste, Skylight in Cristo Obrero, Cristo Obrero, Atlántida, Uruguay, 1953-60.

Art:

Art was very important to Dieste he strongly believed that it was a fundamental part of humanity and that architecture itself was a form of art. He did not view the art aspect as being separate from the construction of structure of a building but as part of it saying "A building cannot be profound as a work of art unless it has an earnest and subtle fidelity to the laws of matter. Only the reverence that this fidelity requires can make our buildings serious, lasting, and worthy partners in our contemplative journey".[56] According to Dieste, art and beauty elevates human existence and improves our quality of

life. Every one of his works down to the water towers could be considered a work of art and structure and form were his tools for creating it.

Fig. 17 Eladio Dieste, View from road, Water tower, Canelones, Uruguay,1966.

Nature:

Dieste perhaps of all the designers took the least direct inspiration from nature but when asked about it Esteban Dieste responded that Eladio Dieste didn't necessarily take direct inspiration from nature but agreed that nature is an amazingly efficient engineer and felt that good architecture should strive to be like nature in terms of its efficiency and beauty.[57] A trip to the office of Dieste revealed that he was greatly influenced by the golden ratio which he found frequently in the natural world.

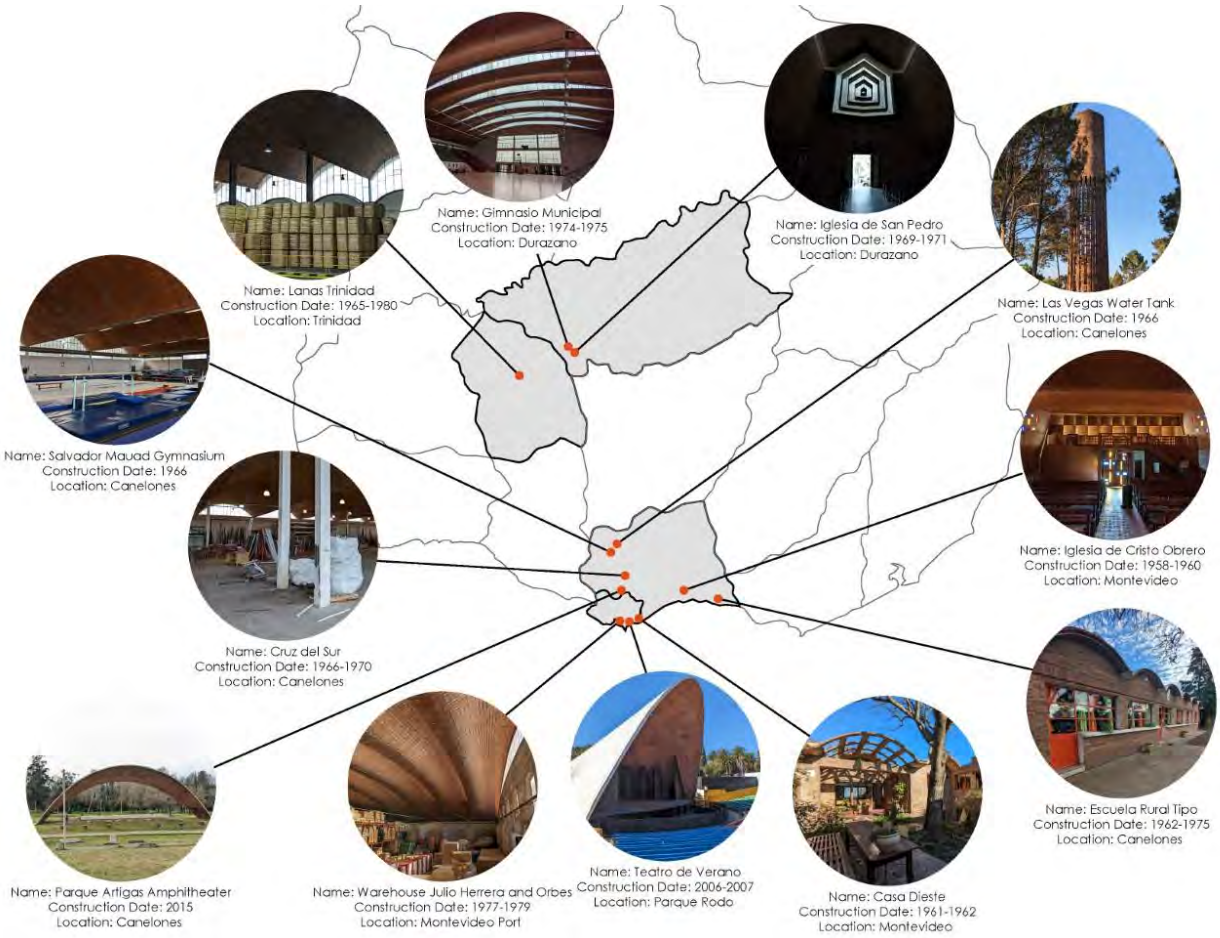


Fig. 18 All Projects by Eladio Dieste Visited

Colonia Guell and Gaudi in Spain:

Fig.1. Antoni Gaudi, Exterior view of portico, Colonia Guell, 1890-1914.

Spain was my third stop where I studied Colonia Guell by Antoni Gaudi. Much like Dieste this was Gaudi's first major commission which set the groundwork for his many commissions that followed. His most famous building is certainly La Sagrada Familia Church where he incorporated every structural technique he had used in his past projects. What is unique about Colonia Guell is that it allowed him to use and test out many techniques that would later be used in such projects as Sagrada Familia and others.[58] He was commissioned by Eusebi

Guell in 1898 to build a church for the workers in a factory town.[59] Located in an area with several trees, the church sits on a hillside that embraces the church and blends it with the surrounding forest. Other artists and architects who worked with Gaudi on Colonia Guell include Jose Canaleta, Francisco Berenguer, engineer Eduardo Goetz, and Juan Bertran sculptor.[60] The full church was never completed with only the crypt with its choir area and the portico to the crypt having been fully completed. Nevertheless, the space awe inspiring and audacious particularly for its time.

Fig.2 Antoni Gaudi, Choir area behind alter, Colonia Guell, 1890-1914.

Fig.3 Antoni Gaudi, Interior view towards door, Colonia Guell, 1890-1914.

Fig.4 Antoni Gaudi, View from portico seating area, Colonia Guell, 1890-1914.

Sociopolitical Environment:

Antoni Gaudi was a Catalan born in 1852. He was very influenced by the Catalan movement which sought to bring back traditional Catalan building methods and styles although he paired this with new innovations. He designed throughout the late 19th century and the early 20th century a time ignited by the industrial revolution. He was educated at Escola Superior d'Arquitectura in Barcelona where he

graduated in 1878 with an education in architecture.[61] He was a man greatly concerned with the social problems of his day and in 1878 at the Paris world fair his project for a housing development for workers was displayed.[62] Although the first project Gaudi ever received was for a lamp post in Barcelona. In 1882 Gaudi got his first large commission from Eusebi Guell a man he would go on to complete several more commissions from.[63] He was an extremely religious man and he never married and toward the end of Gaudi's life, he dedicated himself entirely to Sagrada Familia, which was being threatened with abandonment due to lack of adequate funding. The church which was known as "the church of the poor" was entirely funded by donations.[64] He continued to work on plans and models for the church while taking it into his own hands to raise funds from donations. He died on June 10, 1926, when he was struck by a trolley car crossing a street.[65] The Sagrada Familia continues to be one of his most famous works and is still under construction today thanks to the many documents and models left behind by Gaudi.

Fig.5. Antoni Gaudi, Exterior view of front, La Sagrada Familia, Barcelona, Spain, 1882.

Fig.6. Antoni Gaudi, Interior View of ceiling, La Sagrada Familia, Barcelona, Spain, 1882.

The church is in a town which was constructed to be a textile factory town, it was similar to many of its kind. It had all the amenities the workers of the factory may need including housing, shops, a school, and a church.

Materials:

Brick, limestone, vitrified slag (from the waste of smelting furnace), basalt stone, and Portland cement were the main materials used in the construction of Colonia Guell however, broken tiles and

chinaware entirely made up the ornament and mosaics and recycled sewing machine needles were used for the grills over the window.[66] This method of using broken tiles and chinaware was not only unique to Gaudi. On a tour through Barcelona with Camilo Cerro, professor at the American University of Sharjah and architect with residence in Barcelona, he brought to my attention a certain Lluis Domenech Montaner, another Catalan architect working around the same time as Gaudi who designed Palau de la Música Catalana, a music hall that stands for its extensive use of broken tiles on the exterior and interior for mosaics and decoration.[67] You can see the way Gaudi uses the broken tiles for the mosaic above the entrance door to Colonia Guell.

Fig.7. Antoni Gaudi, Mosaic over entry, Colonia Guell, Barcelona, Spain 1890-1914.

Gaudi wanted to show how typically humble materials could be used to create a space of dignity and beauty.[68] The materials also greatly contribute to the thermal comfort of space, as I visited in the month of August and found that once you passed under the portico of the church, it was quite cool despite the smoldering heat of the outdoors. Each of the eleven columns that support the portico have a slightly different texture to them allowing them to appear as though they are their own forest of diverse trees. On the inside the materials help to

delineate the space and elements within it. Columns on the inside vary in materiality continuing the trend established by the columns under the church porch creating continuity between the outside and inside through a continuous forest from the natural world to the man-made world.

Fig.8. Antoni Gaudi, Interior view towards door, Colonia Guell, 1890-1914.

The columns that define the main nave are made up of stone while the columns that define the side aisle are composed primarily of brick. This change in materiality had a greater effect than I had expected upon visiting. The many columns on the inside combined with their slanting angles can begin to make it hard to delineate one space from the other. However, once in the same the materials begin to guide your interpretation of the space. The ceiling of the space is made of brick

in which much like Eladio Dieste, he changes the orientation and direction of the brick to create patterns within the brick and distinguish the elements from one another.

Fig.9 Antoni Gaudi, Brick Detail, Colonia Guell, 1890-1914

The darker coloring of the brick on the ceiling makes its presence stand out distinctly however the way that the brick ribs seem to extrude themselves before branching down to rest on the columns and arches which connect one column to the next allowing the interior of the church to read as a singular entity despite the extensive variation in materiality. The space feels large and grand yet also warm and intimate, similar to how it might feel to walk beneath a lush

forest canopy. Gaudi liked to leave the materials raw and exposed to give them more expression, but plaster was used to smooth the lower half of the walls and columns so that visitors would not be scraped by the wall.[69]

Construction:

It is said that Gaudi would consider the practical methods of constructing his building when designing it. Warped surfaces were easy for local masons to build because both the hyperboloids, and hyperbolic paraboloids are ruled surfaces that allow for reinforcement by straight steel rods.[70] Gaudi made use of the Catalan vaulting method which proved very useful during construction, "making use of several layers of thin brick, the first of which is set in plaster and used as a form replacing the wood forms and simplifying the scaffolding, both of which were costly in Catalonia where wood is imported" .[71] Gaudi was constantly searching for a better way of constructing then that used in Gothic cathedrals, he was quite opposed to flying buttresses, which he was able to exclude by creating tilted columns that carry both load and thrust.[72]

Structure:

He is perhaps best known for his hanging chain model and use of hyperbolic paraboloids which gave him the ability to design in 3-D. The perceiving of the churches structure and form started with a model rather than the typical 2D drawing methods.

Fig.10 Gaudi Hanging chain model used for Colonia Guell

This would be the first time Gaudi tested out the hanging chain model he is so well known for now. The hanging chain Model for Colonia Guell consisted of cords that are hung to create catenary curves with small weights hanging from them to represent the loads. The cords represented the arches in the church, and the weights that represent the loads cause them adjust into the form needed to resist those loads through compression. This method allowed Gaudi to generate equilibrium in his structure through hyperbolic paraboloids as he was going, so as he adjusted the form the structure simultaneously adjusted as well.[73] The inclined columns that you see inside the church and the portico

are a result of the model and their sizes each vary as they were each adjusted to be the size necessary to carry the expected load. The ceiling of the main nave Gaudi uses a "double system of arches" a method very similar to the typical girder beam relationship but adapts to accommodate the arching and curvature.

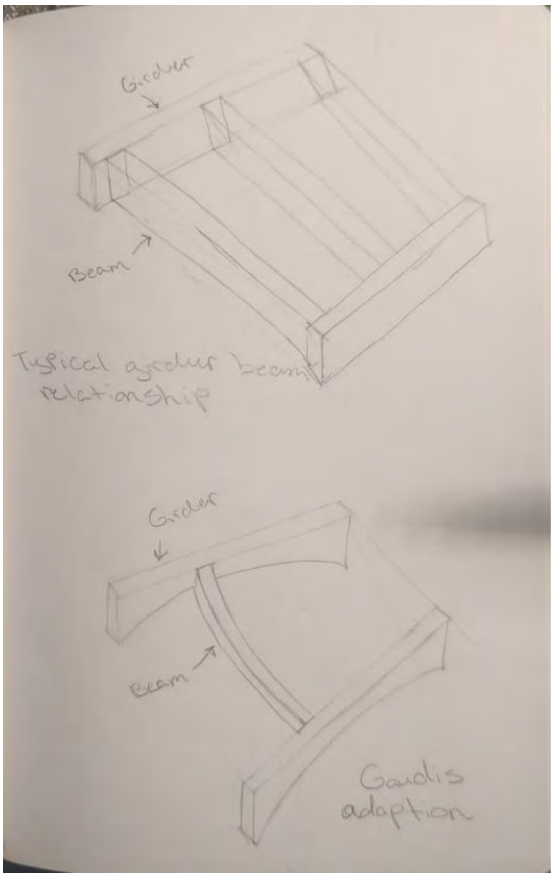


Fig.11 Drawing of ceiling structure in Colonia Guell

Low-rise arches branch from one column to the next; on this sits the system of brick girders and beams which hold up the roof.[74] Gaudi addressed the inefficiency of gothic buttressing through hyperbolic paraboloids and tilted columns. This allowed him to have one singular

structural element to absorb all the loads applied to it reducing the need for materials and reinforcing.[75]

Light:

The lighting effects in Colonia Guell are not as successful as some of his later projects such as Casa Mila, or Sagrada Familia. Nonetheless, there are many incredible aspects of the lighting that Gaudi produced. The lighting sources make themselves well known from any point in the main nave, which reduces the sense of mystery that is produced when one sees the light but not its source which I believe is often a more powerful form of light. However, we must remember that this was one of his first projects and largely experimental, in later projects like Sagrada Familia he uses light in a more mysterious manner integrating it into the structure more fluidly.

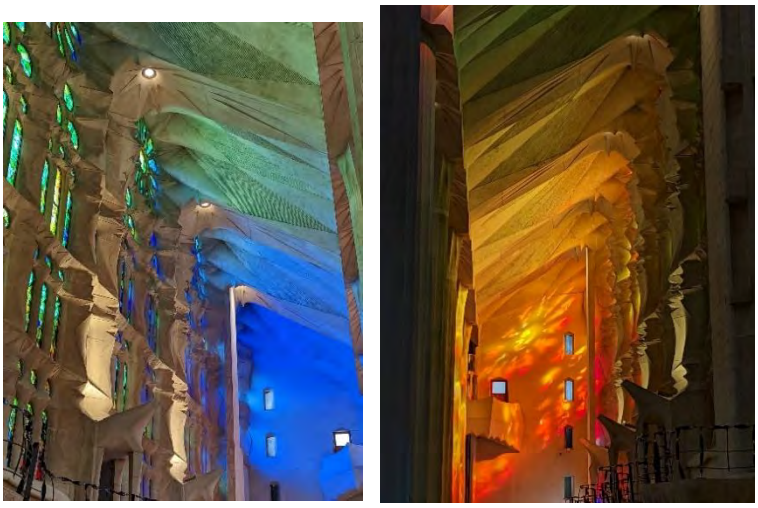


Fig. 12Antoni Gaudi, Interior view of lighting, La Sagrada Familia, Barcelona, Spain

In Colonia Guell, the space is well lit during the day but certainly on the dimmer side, allowing the stain glass windows to stand out beautifully in contrast to the rest of the space. From the

exterior the stain glass windows do not stand and are less noticeable as they begin to blend with the exterior wall. You do not expect them to glow with such vibrance which makes the experience as you enter much more powerful.

Fig.13 Antoni Gaudi, View of Stain Glass Windows, Colonia Guell, 1890-1914.

The windows shine with a vibrance of color that is not made obvious from the exterior due to the amount of natural lighting. It left me with the impression that if the interior space had been more highly lit that the effect of the stain glass windows would not have been so bold. The colors emitted their light onto the floor which illuminated it with a soft colorful glow. The colored light does not cast itself against the structure as it does in sagrada Familia. Some of the larger windows are operable allowing them to be opened to further allow natural ventilation through the space. The same

geometric form would also be used for Gaudi's windows in La Sagrada Familia.

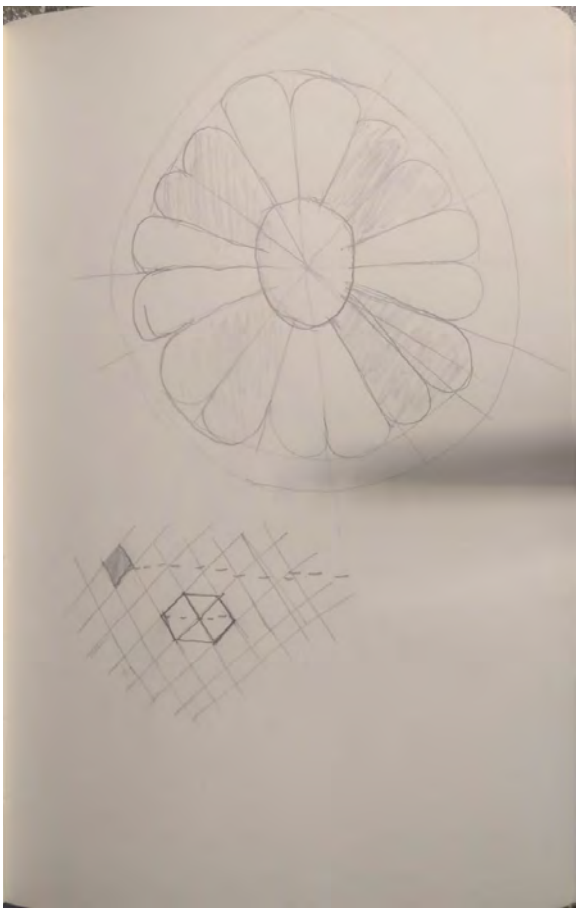


Fig.14 Drawing of window geometry

Nature:

Gaudi was most obviously inspired by nature. However, as I traveled and took the audio guides through the many buildings he designed and listened to countless people talk about and describe his work I could not help but feel that he might have been a little bit disappointed by it. There is not a person alive who has visited his works that could deny the immense inspiration that came from nature, but I was shocked by the sheer amount who did not understand why he took inspiration from nature. You see it wasn't just because he liked

nature or thought it was beautiful, indeed his understanding of nature when far beyond that he took inspiration from nature because of his love and passion for structure and structural ingenuity, as he said there is not greater a structural engineer than nature itself. And indeed, he did not copy nature, instead he merely interpreted the language of nature and its structural ingenuity into architecture. So, I think it is imperative to emphasize when talking about Gaudi that he did not merely replicate nature for indeed I think he would have found that quite lazy and negligent he merely recognized it for the structural and geometric, and poetic genius that it was and drew from it a wealth of knowledge and inspiration that lead to his unique designs and form. In a book by Juan Perucho, he states "I mean that it was not the ornamental or symbolic effect which was the principal impulse or concern of the artist...it was the structure, according to the way in which he saw it and understood its necessity, that determined, as a secondary consideration, his exceptional expressiveness".[76]

It is disappointing how many people are unaware of the structural, geometrical, and mathematical genius of Antoni Gaudi. His work is indeed organic and free but is in no way sporadic or unplanned, lacking reason, or logic, it is in fact the direct opposite of this with each piece having a place and distinct purpose, lacking the traditional symmetry of the time but being no less part of an interlocking whole and system. It was through nature that he discovered geometry did not have to be perfectly symmetrically, proportionate, and comprehensible to the human eye to be beautiful,

efficient. He looked at traditional architecture and considered how he might create a more efficient form of design. He wanted to generate equilibrium directly, he didn't want to rely on symmetry and years of written rules in classical order, he had a burning desire to let his architecture be free and indeed it was. He was able to achieve this through his hanging chain model which allowed him to generate equilibrium as he was designing the form and space.9

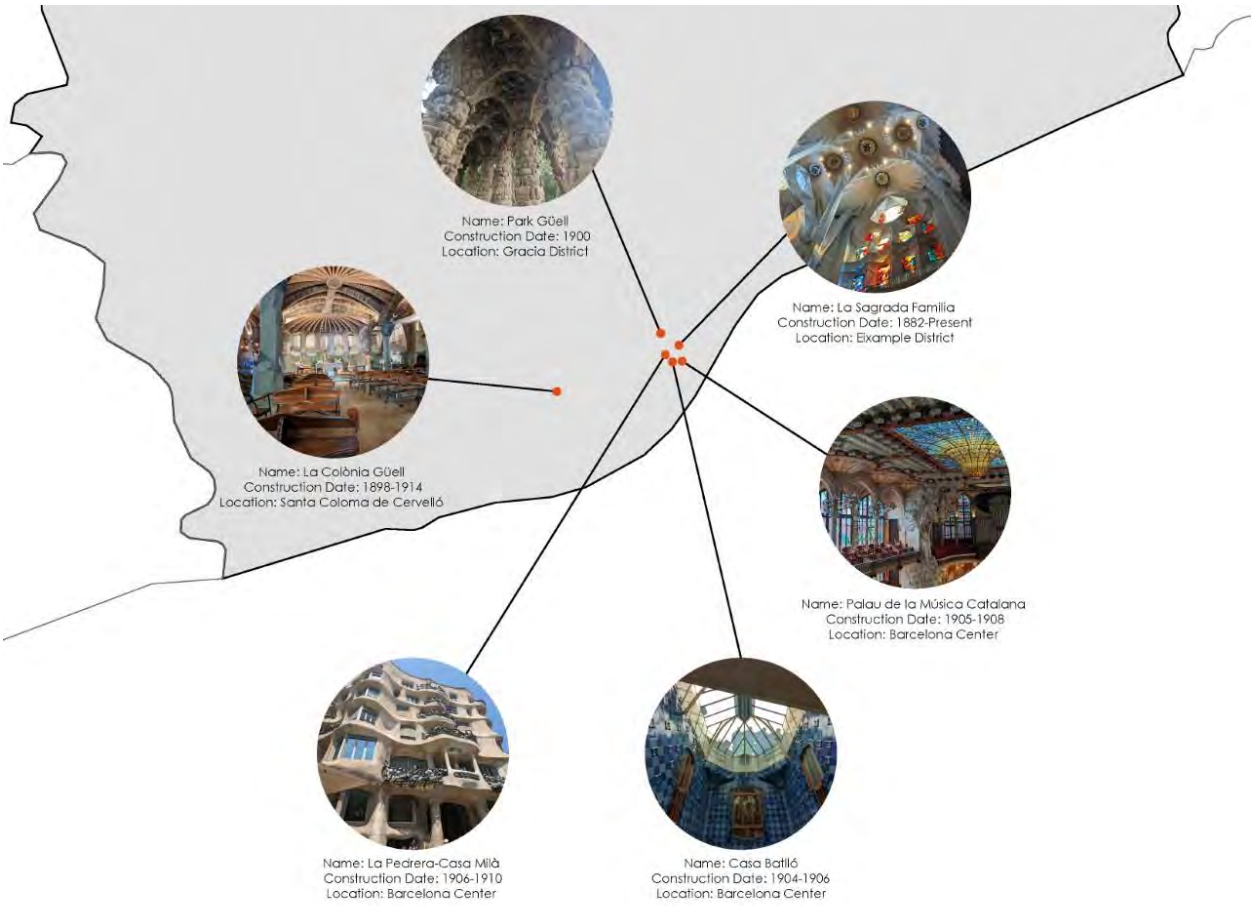


Fig.15 All Projects visited in Spain

Centre Pompidou Metz and Shigeru Ban:

Fig.1 Shigeru Ban, View of exterior approach to entry, Centre Pompidou-Metz, Metz, France, 2006-2010.

The last stop of my journey was in Metz France to visit Centre Pompidou by Shigeru Ban in collaboration with Jean De Gastines and Philip Dumuchdjian. This is one of his most recent works and it uses wood in a new and innovative way. It is a museum of modern and contemporary art located between the modern business district and the historical areas of Metz, France. Centre Pompidou Metz was designed as an annex for Centre Pompidou in Paris by Renzo Piano, as the Paris

location was not large enough for the collection, and lacked space for large scale exhibitions.[77]

Shigeru Ban born 1957 is a Japanese born architect although he has buildings across the world, his office is currently in Paris, France. He is known best for his innovative use of wood and paper. Shigeru Ban always had an interest in structure and construction even as early as high school as he says "Students were called to create a structural frame out of wood, paper, bamboo – each week. I would always produce two solutions for each assignment. An interest in materials, structure, and methods of construction was already evident in my work and approach at this early stage.[78] He began in 1977 at the Southern California Institute of Architecture and later went on to transfer to Cooper Union where he would graduate from in 1984.[79] In 1985 Ban began his own practice although he had no previous work experience.[80] In 2000 he collaborated with the German architect Frei Otto on a paper tube structure for the Hanover Expo's Japan Pavilion, this was one of his first projects to gain him serious global recognition for recyclable architecture.[81] In 2001 Ban became a professor at Keio University.[82] He has several types of structures from churches to airports, to homes but he is particularly involved in ways to quickly and efficiently construct housing for those affected by natural and political disasters. Much like the architects above, his innovative use of materials requires him to engineer new ways of building and constructing. He is also mindful of sustainability both economically and environmentally.

Fig.2 Shigeru Ban, View of exterior approach to entry, Centre Pompidou-Metz, Metz, France, 2006-2010.

Sociopolitical Environment:

In a time when climate change is on the rise and more natural disasters are occurring with initiatives to build sustainably and use sustainable materials gaining more importance and prominence in design. Increasing globalization and the quick flow of information due to the internet has also allowed the world and designers to become quickly informed about world events. With this in mind Shigeru Ban has focused much of his design efforts on the use of sustainable materials such as wood and paper and construction methods that avoid waste. He has also largely dedicated himself to designing temporary shelters that can be quickly and economically constructed for those who are refugees due to natural disasters or political conflicts. He stands out in his efforts to design quality spaces no matter the type of

structure, sharing much of the attitude of the following designers that every person has a right to quality of space. While Centre Pompidou is a museum rather than housing for refugees it embodies several of the ideals that Ban carries over into all his design.

Centre Pompidou as mentioned is in France while Ban is a Japanese born architect, although Shigeru Bans office is now located in Paris, so he is very familiar with French style. Ban is interesting in how he was able to incorporate French symbolism and style into the structure and function of the building making it more than ornamental symbolism. "The main structure and plan of the museum is based on a hexagon which holds great significance for the French people as the hexagon is considered a symbol of their country as the shape is similar to the geographic shape of France".[83]

While it differs greatly in style from the traditional historical architecture of the area it also does not adopt the steel and glass modern style of non-historical Metz. I was curious to know what the locals thought of the museum. After talking with various individuals at bars and cafes the overwhelming consensus was positive. Most acknowledged that it was an unusual building for the area but felt that it still meshed with the historical area or at least did not disrupt the style of the area, part of this might be due to its location. Overwhelmingly most individuals had great disdain for many of the modern buildings. One individual saying, "The steel and glass are too cold and stark in their appearance, I do not enjoy passing

them on the sidewalk and street in the way that I enjoy the old buildings". When asked if he felt the same about Centre Pompidou, he responded that it was different from the other modern buildings in that it did not impose itself on the area in an aggressive manner. I think this is in large part due to the form and material, the wood is lighter and warmer, and the form lends itself to a more organic form with soft edges and curves rather than sharp edges. One thing I found comforting about the historic buildings in Metz when passing by them is the ability to get a sense of scale in relation to the building which happens through its materiality its texture which gives you a scale to compare yourself to and makes it easier to judge its size, whereas the lack texture in glass and steel makes it very hard for an individual to get a sense of scale to the building which can make it seem large and towering and unsettling to walk past. Thus, I believe Centre Pompidou was successful in creating something new and modern without disregarding the historical style of the area but also without replicating it, introducing a newer material in the area but still maintaining the spirit of the area.

Economy

For Ban the ability to experience the museum is not something he wanted to be reserved for the upper classes only. He wanted anyone regardless of economic status to be able to use the space, whether they intended to venture into the exhibits or not. He achieved this by creating substantial outdoor space, which is covered by the building's roof form; glass walls divide the inside from the outside, but the overall unifying roof form makes it feel as though it is one singular

space, unifying the interior with the exterior space. The largest of the gallery spaces located at the entrance is free to everyone and the curtain walls make the art visible even if you do not entry the exhibits. There is also a café to one side of the museum, this café and outdoor space can be used by anyone in the community without having to pay entry to the museum. "Lauret Le Bon, director of the Pompidou Centre-Metz says, "The outside, moreover, is necessarily altered by this architectural presence, which is open to a visiting public that is itself in the process of construction and that, as one already knows, goes far beyond the limit of regular visitors to cultural institutions.".[84]

Fig.3 Shigeru Ban, View of Main Gallery, Centre Pompidou-Metz, Metz, France, 2006-2010.

Structure:

The museum consists of 3 rectangular volumes approximately (15m wide and 90m long) that make up the galleries each facing a different direction to frame a specific view (Railway station and cathedral), the three galleries are arranged around a hexagonal steel frame tower a large gallery on the first floor to permit the exhibition of large works (21 meters tall and 1,200 square meters of space), an auditorium, a studio, and a café with outdoor seating. All the spaces are housed under one roof which unifies the spaces and creates the form.[85] The central tower which the galleries are arranged around is 77 meters tall, in honor of when the first Centre Pompidou was opened in Paris in 1977.[86] Each of the gallery's volumes are completely free of internal structure making it completely flexible to accommodate any exhibition style.

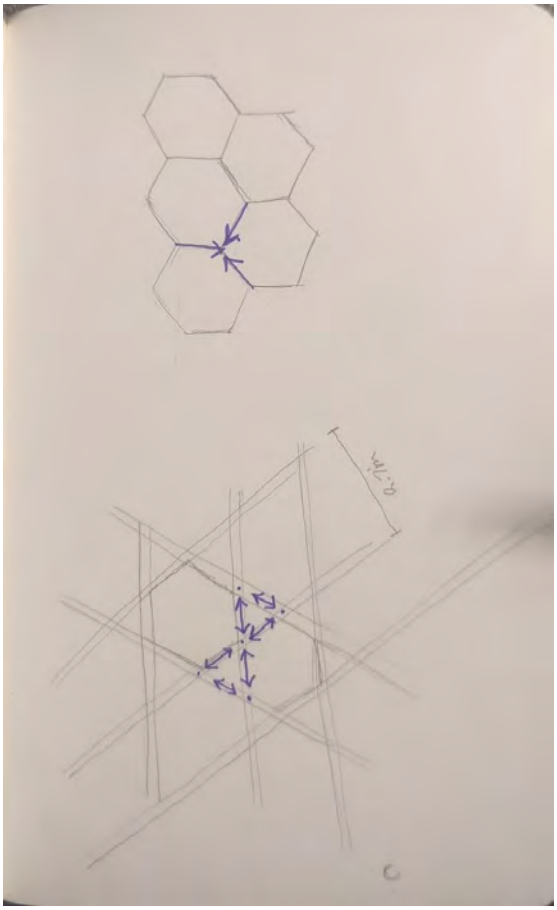


Fig.4 Sketch of forces acting on a joint

Aside from the hexagon having cultural significance it also creates structural rigidity through its geometry. Triangles have the greatest stiffness but as the architects put it "by dividing up the whole surface into triangles, six wood elements would converge at each intersection producing extremely complex joints by creating a pattern of hexagons and triangles only four wood elements ever intersect." thus making the construction process much easier while still getting the same structural rigidity.[87] A unique aspect of the construction is that it does not use mechanical metal joints at the intersections "because if they were used, the surface would become voluminous and the lengths of the elements would all become unique, increasing the

complexity and also the cost of the joints." This is where the construction method used for traditionally woven Chinese hats is quite useful as it allows each of the wood members to overlap mimicking bamboo wicker work.[88]

Ban's inspiration for the structure as he tells is it "This idea came from a traditional woven Chinese hat I found in an antiques shop in Paris in 1999 while designing the Japan Pavilion for the Hanover Expo." Ban took great inspiration from Frei Otto a notable German designer (He worked on the Hanover Expo with Otto) as he puts it "since first seeing his design of the Institute for Lightweight Structures and Conceptual Design at the University of Stuttgart, I was fascinated with the tensile wire-mesh structure" He was particularly drawn by the architectures ability to create an interesting interior space while using the least amount of material possible.[89] Ban combines Frei Ottos tensile wire –mesh with a compressive shell structure since wood has the ability to act in both compression and tension. Through maintaining minimum vertical structural elements Ban is able to create a continuation from the exterior to interior space.

The woven roof is a double curvature three-way timber grid shell. Each of the three galleries are made of concrete and stacked on top of each other, each rotated 45 degrees from the other. "Due to its geometry it is a hybrid system between a grid shell and a catenary action". "Spacing for the grid shell was determined by dividing the side length by 33 which was approximately 2.7m perpendicular spacing of members on plan" the roofs geometry allow the members to curve and twist to follow the form of the roof.[90]

The roof is made up and supported by a series of elements funnel columns, tube rings, support building, and hexagonal tower. There are four columns that branch down from the roof in a conical manner to meet the floor and provide support to the rest of the roof. This maintains unison between the vertical and horizontal elements of the form as they all become one intertwined surface through the roof. Near the center of the museum in a hexagonal steel core which houses the circulation for the building while also providing support for the roof. The structure is stabilized by the concrete core, the steel tower, and the conoid columns.

Fig.5 Shigeru Ban, View of exterior coulmn, Centre Pompidou-Metz, Metz, France, 2006-2010.

For the membrane on the roof, it is generally divided into rectangular panels that are roughly 5-6m wide.[91] These are attached to the top of the timber in order to help protect it from water damage due to condensation. The roof was based on the idea of "minimum surface" which is the same geometry as a soap foam bubble forming between a rigid boundary.[92] The material is standard softwood glulam which consists of two layers of planks. The timber planks would be prefabricated and cut with a special CNC machine to varying lengths and then taken to the site for construction.[93]

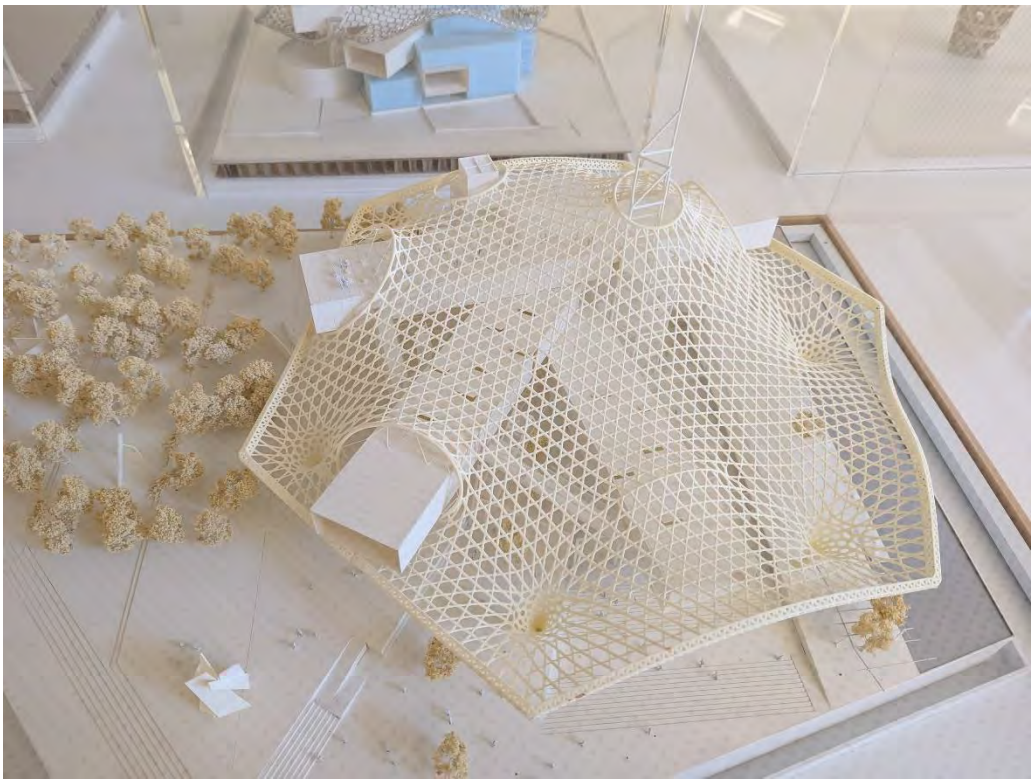


Fig.6 Shigeru Ban, Model on display in museum, Centre Pompidou-Metz, Metz, France, 2006-2010.

Fig.7 Shigeru Ban, Joint detail, Centre Pompidou-Metz, Metz, France, 2006-2010.

Material:

The main material is glue laminated timber and concrete, with steel as a secondary material used very selectively. The three galleries are made up of concrete while the roof structure is made of glue laminated timber and the central tower of steel. The façade is made up of glass shutters which can be easily removed, they do not provide any structural support and are merely there for enclosure to the space. The roof also helps conserve energy by keeping the sun off of the curtain walls. The wooden roof is covered by Teflon coated fiber glass membrane which helps protect the wood roof and also allows light to be emitted through so that the space is lit my natural lighting.[94] The way the lighting is diffused through the roof and from the sides creates a soft even light while preventing any areas inside

the museum from being in direct sunlight or over lit. The Structure is also highly emphasized as the light shining in through the Teflon highlights the hexagons of the structure.

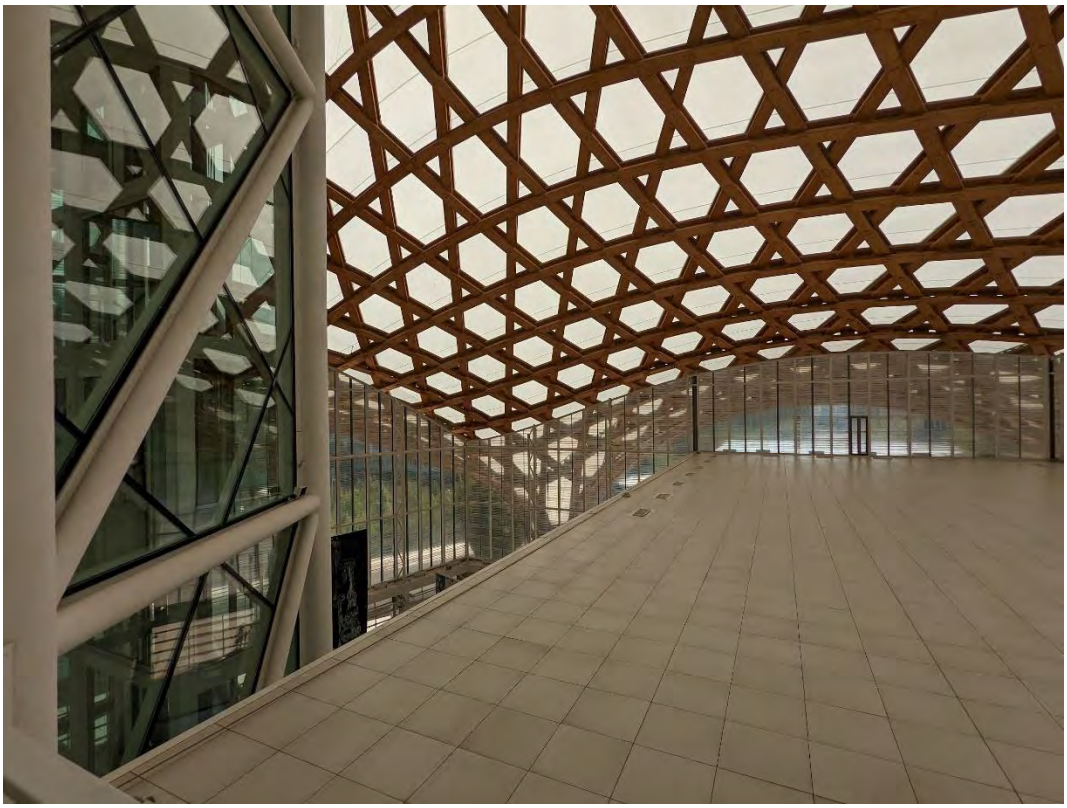


Fig. Shigeru Ban, View of roof structure from interior, Centre Pompidou-Metz, Metz, France, 2006-2010.

Conclusion:

The buildings selected truly mastered the art of thinking about structure, form, art, and material not in a linear pattern where one follows another, or one is secondary to the other, but rather as all one integral process. My studies revealed that it takes someone with the knowledge of an engineer thinking and seeing through the eye of a designer to yield exemplary one-of-a-kind buildings or in some instances discover a new method. Someone who thinks only spatially and someone who thinks only technically can never arrive at the architectural genius of someone who thinks of both. I feel that Each of the designers I studied regardless of what material, structural system, or location designed so that the structure and form were integral, and function and form dictated its aesthetics. Each designer wanted to create an elevated space no matter whom or what it was intended for, they did this through the lighting effects, materiality, and the detail. Through design and use of structure these multidisciplinary designers were able to address the social needs of their time and area and achieve "cosmic economy".

Each designer had an infinity for humble materials, stone, brick, concrete, broken tiles, and so forth. This was however a direct result of the context which they were designing in, the material or materials they choose were those most suited for economical, and sustainable reasons to the designer's region. They understood that any material could create a beautiful structure if the designer had the ability to

embrace its positive qualities. There is a certain power that a building has when it is an elegant piece of art yet made of a humble common material, that even buildings of the finest materials may not. They were each able to create these beautiful works of art and function through accepting the materials inherent properties to create a form and function that would make the most economical use of these materials without allowing the structure to lose its elegance. They combined this with an understanding of the local work force and a deep understanding of construction in order to achieve their works.

It was not despite but instead because of the limitations and challenges that the designers faced that they were able to arrive at the structural master pieces that paved the way for a new movement in design.

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