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The semantics of Félix Candela's thin shell structures: a case study of two churches

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Félix Candela's contribution to modern architecture is internationally acknowledged. Regarded rather as structural art than architecture, his notable thin shell structures combine structural rationality, extraordinary form efficiency, and high aesthetic value. But his radical designs have so far been mainly studied from a constructive point of view. Scholars have focused on the spatial and formal characteristics of the hyperbolic paraboloids, the geometric form Candela worked most intensely with. The aesthetic beauty of these forms has also been considered only in its relation to the function, efficiency, and economy of these structures. In this article, I focus on the semantics of Candela's structures and the meaning they convey. I use the methodology of semiotic analysis to study selected examples of churches designed by Candela in Mexico. I argue that understanding the inherent logic of the structure and reading the encoded symbolic meaning of the form leads to the intuitive perception of architectural space as a sacred place. The impact of these forms on the subconscious level is especially important in ecclesiastical architecture, which is both a community space for social gatherings and a very special personal space for contemplation and divine experience.

Introduction

Félix Candela's (1910–1997) contribution to modern architecture is internationally acknowledged. His name ranks among those of renowned architects and designers who 'were also known to challenge conventions of structural forms and redefined the relationship between the aesthetic beauty and the structural function'.[1] Originally trained as an architect, but being more interested in the technical aspect of architecture, Candela was not afraid to question the fundamental dogmas in structural analysis. As a result, he became one of the most prominent figures who pushed reinforced concrete to its architectural limits. Undoubtedly, by the time Candela started working with concrete, the most widespread material in the twentieth century was already considered as the epitome of the underlying principles of modernism. On both sides of the Atlantic, architects were experimenting with the potential use of concrete as a means of creative expression. They aimed to revolutionise architecture by building an unprecedented variety of dramatic new shapes that were unthinkable in other materials. Candela contributed to these endeavours through his interpretation of thin shells, one of the most optimal forms for this material. The inherent

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strength of reinforced concrete in both compression and tension renders it appropriate for the creation of this very specific category of spatial structures. The structural resistance of their double curvature allows for a minimal thickness with a span that can exceed it by five hundred times.

A prolific builder with more than 800 realised projects, Candela masterfully merged art and technology in the creation of these exceptionally rational forms that combined optimal structural strength, ease of construction, and low cost with innovative and striking sculptural beauty.[2] Inspired by the works of masters who blazed the trail in structural design, such as Antoni Gaudi (1852–1926), Robert Maillart (1872–1940), and Eduardo Torroja (1899–1961), Candela created a new style in architecture. The extremely thin and simple geometric shapes of his buildings were transformed into art forms.[3]

The local context of Mexico, where the Spanish-born Candela was self-exiled after the Spanish Civil War, turned out to be the most fertile ground for his experiments. Utilising the weak regulatory framework of building practices, the low labour cost, and appropriate climatic conditions to his advantage, he developed thin shell structures that were perfectly adapted to the specific local needs at the time. Even though his projects were at first rejected 'on the pretext that earthquakes and defective subsoils make them impracticable',[4] Candela was convinced that his approach was right, and persisted in following his dream until he got his first commissions. To do so, he became his own contractor bearing responsibility for every stage of the design and building process, and respectively 'the whole responsibility for the good performance of the structure'.[5] This enabled him to fully develop his skills as a structural artist who conceived the new form, visualised its final appearance, defined it by calculations, and developed the means to build it.[6]

However, his radical designs have so far been mainly studied from the point of view of their construction. Existing scholarship has focused on the spatial and formal characteristics of Candela's shells, and more specifically his hyperbolic paraboloids (hypars), the geometric form he worked most intensely with, and implemented into his most significant structures. Aesthetic beauty achieved as a consequence of the rational form has been considered only in its relation to the function, efficiency, and economy of the structure.[7] In this article, I focus on the semantics of Candela's structures and the meaning they convey. I use the methodology of semiotic analysis to study selected examples of churches designed by Candela in Mexico. Candela considered churches to be the most representative buildings of each epoch. For him, the commission to design a church was 'the greatest opportunity that can be granted to an architect to try, at least, to do something transcendent'.[8] Undoubtedly, religious buildings are some of the most exquisite architectural examples from antiquity to the present. Described as the 'House of God' or the 'gate of Heaven', church buildings have always played a central role in communal life. In building them, generation after generation have applied the most advanced construction technologies, using the most refined materials without sparing resources or labour. The most talented architects and artists have historically been engaged to create worship spaces that promote faith and articulate the commit-

ment of the community to God in the best possible way. Epitomising human aspirations to perfection, churches embody Vitruvius's triad of *utilitas*, *firmitas*, and *venustas* in the highest order.

Like a 'Gospel in stone brought to life',[9] in traditional church building each detail is conceived to inspire worship, and to represent heavenly realities for the faithful. The spatial organisation, scale, size, lighting, and ornamentation of a church are all intentionally conceptualised to manifest transcendence. Yi-Fu Tuan has argued that the revelation of the transcendent significance of a cathedral occurs at three levels, as the building directly appeals to the senses, evokes feelings, and subconsciously affects the visitor.[10] All these levels holistically serve to attach a special meaning to the place of worship, and to establish a unique relationship between man and space. In this article, I argue that understanding the inherent logic of the structure and reading the encoded symbolic meaning of the form enables the intuitive perception of architectural space as a sacred place. I do not focus on the distinctive external form, but rather on the connotations this carries, and the spiritual message it conveys to the laity. This subconscious impact is especially important in ecclesiastical architecture that aims to serve both as a community space for social gatherings and a very special personal space for contemplation and divine experience.

Modern versus traditional church architecture: the modern church questioned as a building for worship

The diversity in the stylistic characteristics of the church building is conditioned by factors such as the period when it was built, the variety of branches in religious traditions, the changing trends in theological traditions, and the architects' personal vision of what a sacred space should look like, as in the notorious chapel at Ronchamp by Le Corbusier.

Considering the church building as a representation that signifies the Church, the assembly of the People of God,[11] every epoch has tried to materialise the ideal, invisible community through the union of the utilitarian with the sacred. And this conception has evolved significantly with time and place. It reflects the people's understanding of heaven and reality, as this is also shaped by material and technological advancements.

The architectural language of contemporary church buildings ranges from traditional edifices rooted in local vernacular practices or representative ecclesiastical styles, such as the Classical and the Gothic, to exceptionally austere minimalist environments or purely utilitarian spaces that have been conceived as gathering places of the community. Twentieth-century churches certainly surpassed in number and style the sacred buildings of previous historical periods. The urbanisation process that drew more and more people to cities after the industrial revolution accelerated the development of new suburban areas. As such, demand for new places for worship also rose. Churches had to be erected quickly, often with limited budgets. This forced architects to turn to new materials and techniques in response. Supported by reforms in Christian tradition, and based on the modernist rejection of historical patterns and the

foregrounding of the simplicity of a form that should emerge directly from the function of the building, a new era in religious architecture was established.

However, the majority of the endeavours to provide a new interpretation of the sacred ecclesiastical space were criticised as 'backward-looking' attempts to present well-known formal concepts of the past in a new package.[12] To create a meaningful environment, architects of the modern church needed to consider the shifting understanding of 'the Church itself, its nature, its structure, the worship that is its distinctive activity, and its function in the modern world'.[13] Among the exceptions that represented a new archetype in terms of the architectural programme of religious space were the church buildings by Rudolf Schwarz (1897–1961). Schwarz's work proposed a new functionality that emphasised the active participation of the faithful in the liturgical act. The German architect disseminated his ideas about the art of building churches through his writings that questioned the church as a living form, consisting of both building and people, body and soul, humans and Christ.[14]

The rise of the liberal theological movement situated the church within contemporary culture, philosophy, and science. In this broader context, the church no longer clashed with the modern spirit of the age, but was aligned with it.[15] This not only liberated architects to experiment with the shape of the church, but it also served as an opportunity to interpret traditional religious symbols into innovative forms. These corresponded to the shifting conditions of modern society, while still satisfying people's emotional and spiritual needs.

Twentieth-century churches were 'stripped of statuary, paintings and traditional symbols'.[16] Functionality prevailed over the sacral, and churches were conceived as abstract and austere architectural forms that merged floor and ceiling, interior and exterior, with minimalist aesthetics, and totally devoid of icons.[17] This was an architectural challenge, as people still expected to see the sacred symbols adopted and imposed over the years as carriers of timeless spiritual values in these new buildings. But in modern architecture these were either very subtly visualised or profoundly modified. Debates about the future of church architecture were conducted in both architectural and theological circles. They resulted in numerous publications that in turn defended or stigmatised modern architecture. Nonetheless, modernist innovations were so powerful that they eventually expanded people's expectations of ecclesiastical architecture. They instigated a powerful break with the traditional understanding of a church. This was the case with one of Candela's masterpieces Iglesia de la Medalla Milagrosa (Our Lady of the Miraculous Medal Church) in Navarte, Mexico City (Fig. 1). Candela's interpretation of the Gothic style was so unexpected that the clergy who commissioned the project were shocked by the completed design.[18] Conversely, local communities embraced it, although this was the first time they encountered such a bold version of a Gothic-style church. They were aesthetically pleased and greatly satisfied with the sophisticated interior, because they were intuitively aware that it represented the splendour of heaven. The radical approach to church architecture in this case is not about its functional typology. Candela did not alter the traditional liturgical configuration, but proposed an innovative architectural envelope that offered

Figure 1.
Félix Candela, Our Lady of the Miraculous Medal, Mexico City, 1953, © Len R. Cruz

totally new sensations and experiences of the space. He used the remarkably thin structure as a means to make a statement and express the pure essence of the building. The shell that enclosed the inner space thus became an exact expression of its content. As Schwarz noted, '[i]f truthfulness consists in clear expression, then shell construction is the truest of all',[19] and this sincerity cannot but be perceived and experienced.

But despite such bold interpretations of existing ecclesiastical architecture, successful examples of modern church buildings share some archetypal characteristics that have been historically imposed as indicative of a sacred place. Intrigued by the 'outwardly character' of Notre Dame in Paris, Michael S. Rose

analysed the cathedral to specify the transcendent qualities that turn it into a 'crowning jewel', a 'church par excellence', the 'epicenter' and 'soul' of the city. He specified the three rules that establish a building as a sacred place: verticality, permanence, and iconography.[20] Rose argued that all churches that people identify as sacred spaces, regardless of their location, style and age, have achieved this status because they faithfully follow these rules. The verticality of a church is articulated by the soaring heights of the interior space and the dominance of the vertical elements over the horizontal ones. Verticality plays a dual role. On the one hand, it expresses people's aspiration to reach heaven. On the other, it transcendentally brings heavenly Jerusalem to earth through the church building. Permanence is another crucial characteristic of a solid and enduring temple of faith that aspires to transcend space and time, and manifest God's permanent presence among the people. Most obviously expressed in the choice of durable materials that can withstand the impact of time and natural forces, a church's permanence ensures that the sacred building can successfully serve many generations. Finally, iconography refers to the symbolic meaning of the church. Its structure and ornamentation reflect the distinct purpose of the church, as they provoke contemplation and lift the spirit up from its secular concerns into a harmonious unity with the heavens.[21]

Though clearly Gothic in their essence, these three principles also serve as hypothetical metaphors that express transcendence in Candela's church projects. Candela's thin shell structures offer a new reading of the verticality of celebrated church domes and vaulted ceilings. They resist gravity by elegantly supporting the roof shell on its corner points (as in Candela's Iglesia de San José Obrero in Monterrey and Capilla de San Vicente in Coyoacán) or on a central pillar (as in Candela's Iglesia de Santa Mónica in Mexico City). As such, they create a sensation of lightness and detachment from the earth. The use of concrete in both a literal and a figurative sense is testament to the permanence of the church. The Pantheon in Rome that stands intact for nearly two millennia, an engineering feat unsurpassed in its elegance, guarantees the solidity and endurance of the material. Concrete thus represents continuity in a long-standing building tradition. But it is also a symbol of human progress as it has been implemented in some of the greatest and structurally most complex architectural experiments of modern civilisation. Candela's structures of extraordinary simplicity and unprecedented slenderness are a result of reassessing the properties of concrete. As such, they reveal the full potential of this building material. Finally, iconography is not to be found in specific imagery or ornament. In Candela's work, the structure itself takes on symbolic significance. His new tectonic vocabulary is derived from the specifics of the structural system. The plasticity of the form may either be assigned religious connotations or render the church building itself into an abstract symbol that communicates divine truths (as in Candela's Capilla Lomas de Cuernavaca). Fusing the spiritual with the material, a unique meeting point of heaven and earth is confined within the tangible boundaries of the church building. Candela's innovative structures that create these 'walls around the Unlimited'[22] are so pure and so profoundly exposed that they inevitably become symbols. As such, they powerfully encode the message of the divine mystery.

Joseph Pichard has argued that a church building should meet functional, visual, and mystical criteria.[23] All three of them coexist as essential characteristics of Candela's churches. Hypar shells with their large spans and cantilevers that do not interrupt the interior with redundant support form a very functional open space for people to gather. In addition, the truthful use of concrete in the construction of these shells celebrates the inherent qualities of the material. Because shape and structure are identical, 'the most honest structures'[24] are created. As a result, the design is entirely consistent with the principles of functionalism. Finally, aesthetics and structure are organically interweaved. When experiencing the building, the purity of the form evokes feelings of awe and delight, provokes reflection, and inspires. The visual impact of the space is undisputable. The structure has a 'majestic and grandiose effect and [creates] an atmosphere of remembrance in accordance with the solemn ceremony of the cult'.[25] As a sort of 'image' architecture par excellence, churches are saturated with symbolic meaning. They serve as 'signs and symbols of heavenly realities'.[26] Candela's genius and his sense of the beauty hidden in the logic of the structure has resulted in forms and symbols that both visualise humanity's highest achievements in structural design and express religious mysticism.

The pursuit of the perfect form

Shell structures are abundant in nature. Their intrinsic beauty has attracted the attention of artists who were inspired by their aesthetic value. But scientists have also explored the logic of the shell form from the perspective of natural laws that govern its formation and functioning. Candela's way 'to break the mystery surrounding shell analysis'[27] was by understanding the actual properties of the material and its structural capacity.

Following in the footsteps of pioneers in the use of reinforced concrete such as Maillart, Candela questioned existing approaches to the design and calculation of concrete structures. He experimented with new ideas that focused on the structural capacity of the form. Thin shells draw their structural strength and spatial stability from their specific geometry. The double curvature of the surface that points in opposite directions distributes the external forces and transforms them into membrane stresses without bending or torsion. The form is an almost literal translation of the laws of nature that act on it as 'a manifest composition of the static forces inborn in the material'.[28] Candela intuitively discovered the state of equilibrium of these forces. Through his sophisticated knowledge of efficient material performance, he reduced the shape to its pure essence. Eliminating supporting edge ribs, which were until then deemed necessary to stabilise the shape and prevent cracking, was his major achievement. This in turn enabled him to direct the attention of the viewer to one of the main characteristics of the shell structure, its extreme thinness.

Despite its visually complex shape, a hypar surface can be generated with two sets of straight lines. A concrete shell is therefore easy to construct with a formwork of straight timber boards. Candela reduced the method to simplified

calculations that justified his design. Controlling the building process, he observed the performance of the material and made necessary adjustments to compensate for imperfections in construction. Since his first projects were small in scale, he used them as life-size prototypes to test his ideas and optimise the construction.[29] The experience he gained from these first projects enabled him to construct larger and more intricate surfaces. His later structures experiment with the endless configurations in which such shells delimit architectural space. His bold experiments with the geometry of the hyperbolic paraboloid earned him worldwide fame. It was not long before his company Cubiertas Ala collaborated with some of the most distinguished names in Mexican architecture, including Richard Neutra (1892–1970), Enrique de la Mora y Palomar (1907–1978), Mario Pani (1911–1993), Pedro Ramirez Vázquez (1919–2013), and Fernando López Carmona (1921–2018). In collaboration with Palomar and Carmona, Candela realised some of his most emblematic structures, such as the Bolsa de Valores and Capilla de Nuestra Señora de la Soledad 'el Altillo' in Mexico City, Iglesia de San José Obrero in Monterrey, and Capilla de San Vicente de Paul in Coyoacán. Candela described himself as a structural engineer rather than an architect,[30] and explicitly underlined the contribution of his collaborators in his projects. But it is owing to his profound knowledge of the structural behaviour of shells and reinforced concrete as a building material that the role of structure in architectural composition is raised to a new level.

For Candela, form was never an end in itself. It was rather consciously considered as a synthesis of structural, functional, and aesthetic features. In Candela's work, form fits the intended purpose in the best possible way, and satisfies human perception in search of a certain psycho-emotional impact. Candela's belief in the importance of this synthesis is evident in his description of one of his projects:

> It is not about ingeniously solving a 'working' plan and covering it with a conventional structure and facades that are in accordance with the taste of use, but to achieve an expressive interior space, an enveloping sculpture that can be admired from within. But this sculpture cannot be capricious and arbitrary, since it has to respond to the eternal laws of structural equilibrium.[31]

Candela should be praised not only for his structural achievement that united form with the objective physical laws that governed its construction, but also for establishing a certain poetic expression. His work is unsurpassed in the ways it epitomised the play of forces into aesthetically pleasing and meaningful structures. Candela masterfully transformed rational structure into a powerful means of communication. Articulating meanings and their implicit values is especially important in church architecture. As Robert Maguire has noted, '[i]f you are going to build a church you are going to create a thing which speaks. It will speak of meanings, and of values, and it will go on speaking'.[32] Thin shell structures fully reflected their specific immediate cultural and social context. Their reception by local communities was so celebrated that this structural type became the most widespread not only in Mexico, but more broadly in Latin America.

Representing the sacred: two case studies

The hypar surfaces Candela utilised can be manipulated and combined in various configurations to generate a wide range of spatial typologies. I have selected to analyse two of Candela's most representative projects in terms of their semantics: Our Lady of the Miraculous Medal Church in Mexico City (1953) and the small Chapel Lomas de Cuernavaca in Cuernavaca (1958). As each of them features a different type of hypar surface, it respectively offers a different representation of the sacred.

The structure of Our Lady of the Miraculous Medal is based on Candela's trademark form, an inverted umbrella shape. This is usually made out of four straight-edged hypar surfaces that are joined together and supported either on the four corners or by a central pillar. The form of each bay of the church

> was determined by tilting an asymmetric umbrella, and balancing it back-to-back with another umbrella. The final step to obtain the shape was to pull up the middle of the edge supported on the ground to form a triangle at the edge.[33]

Extending from the roof to the floor, this series of interconnected distorted umbrellas create sharply sloped surfaces. These in turn emphasise the height of the space. They direct the viewer's attention upwards. In so doing, they are also reminiscent of Gothic cathedrals, especially in terms of their elevation and the resulting feeling of weightlessness. Although the structure is central to the architectural composition, the architect intended to create a captivating interior space (Fig. 2). Candela's combination of the hypar surfaces results in a highly dynamic interplay of forms that contributes to the expressiveness of the interior space with the 'chiaroscuro generated from what appear to be flat surfaces'.[34] But exactly how does the structure affect the perception of the interior space? How was the specific form of the structure used to express the transcendental meanings of the church? How does the geometry of the hyperbolic paraboloid communicate religious values? How was the form used to represent an invisible God?

The tradition of sacred geometry posits that symbolic meaning is purposefully ascribed to architectural elements in religious buildings. This serves to sanctify them, but also to use this supposedly supernatural power to protect them from the destructive power of the earthly world and the Devil.[35] Following this symbolism, the ephemeral space of the church is perceived as a protective shelter. But at the same time, it is also a finite portion of the infinite, as it alludes to universal space. In these buildings, the geometry of their architectural design is integrated with the geometry of the universe.

Gaudí, the great master of the parabolic hyperboloid shape, described its mysticism as follows:

> The paraboloid is generated by a straight line that slides along two others. If we imagine the three straight lines to be infinite, the first can symbolize the Holy Ghost that is the union between the Father and the Son represented by the other two straight lines. The infinite three form a totality which is one, invisible and infinite — qualities which coincide with the essence of the Holy Trinity.[36]

Figure 2.
Félix Candela, Our Lady of the Miraculous Medal, Mexico City, 1953, © Len R. Cruz

Accordingly, the combination of hypar surfaces that structure Our Lady of the Miraculous Medal can also be considered as being essentially sacred.

The basic generative form of the interior space and the hidden lines in the structure can be understood in a similar way. But what remains visible to those who use the building is the multitude of triangular shapes whose apex points upwards (Fig. 3). The Augustinian belief that all mathematical forms are thoughts of God imbues all numbers and geometric forms with meaning.

Figure 3.
Félix Candela, Our Lady of the Miraculous Medal, Mexico City, 1953, © Len R. Cruz

The triangle is associated with fire, human ascension, and unity with God. It also 'symbolizes the communication between earth (the material world) and heaven (the spiritual world)'.[37] Thus, the triangular shapes subconsciously suggest that the space of the church is a space for communication with God. On the other hand, the intrinsic curvature of the hypars that are joined together forms vaults open to further semantic interpretation. The vault represents the union of the sky-god and the earth goddess. It can therefore be interpreted as a

spiritual synthesis between heaven and earth, God and Man. A secondary meaning is added by the umbrella shape whose phallic significance renders it a father-symbol that alludes to protection.[38] This emphasises the function of the church as a protective shelter. From another vantage, the parasol can also be interpreted as an object that structurally unifies the wheel and the dome.[39] In this interpretation, the dome becomes a symbol of heaven and the wheel is a symbol of the world. As a whole, the parasol in turn signifies the earthly presence of heavenly realities. Superimposing all these connotations into a unified whole, every line and surface formed by the geometry of the hypar shell confirms that the church is indeed the House of God on Earth.

These meanings are fully comprehended only when one actively interacts with these spaces. It is the lived experience of architectural space that prompts reflection, awakens memories, provokes associations, and forms images. To construct mental structures, one needs to engage with their physical counterpart that involves all five senses. In experiencing a space, human senses become 'a means of igniting the imagination and of articulating sensory thought'.[40] This complex dialogue between architectural space and human body reveals the true poetics of architectural form. In experiencing a building, people are forced to act and discover the organising order in the spatial composition. By disclosing it, they derive satisfaction and aesthetic pleasure. The design of Our Lady of the Miraculous Medal Church arrives at the unifying image of the whole through the rhythmic repetition of the hypar surfaces. These generate a harmonious pattern that leads the visitor's gaze and directs their movement towards the altar, emphasising its importance (Fig. 4). At the same time, and because they are constructed from the same material, all umbrella structures fuse into a monolithic whole that is in turn perceived as an organic entity. But while the logical consistency of this spatial order is obvious and easy to comprehend, the challenge for the viewer lies in finding the generative principle behind the repeated element itself. This desire to unravel the secret of the tectonic language of the structure is instigated naturally. The structure challenges the viewer to understand how the form has been manipulated to appear as if it was organically grown; how the natural forces are combined to reach a state of equilibrium in a seamless fusion of load bearing supporting and supported elements; and how the harmony of the structure is a consequence of the capacity of the material. Although the structure of the building is fully exposed, these questions cannot be answered by the common church-goer. But even so, the visitor is aware of the architectural intricacy of the building. They are intuitively engaged by its inherent logic. As Juhani Pallasmaa has explained,

> We feel pleasure and protection when the body discovers its resonance in space. When experiencing a structure, we unconsciously mimic its configuration with our bones and muscles […] the structures of the building are unconsciously imitated and comprehended through the skeletal system.[41]

When they are expressed tangibly through their forms, the constructive aspects of all architectural elements can be effortlessly perceived. The classical analogy identifies the column with the human body, because one is familiar with the act of carrying weights, and their pressure. The load bearing purpose of the column developed in conformity with the distribution of forces is directly embodied in its

Figure 4.
Félix Candela, Our Lady of the Miraculous Medal, Mexico City, 1953, © Len R. Cruz

vertical form. The tectonic function of the support is manifest, while the supporting and the supported parts are distinctly articulated. This in turn leads to specific perceived sensations:

> No one looking at something upright and vertical thinks of its weight or, if the proportion of height to base is correct, of its stability. Nor are we reminded of weight as an active force in something horizontal; rather, it should be for us an eloquent symbol of absolute rest.[42]

The slanted columns in Our Lady of the Miraculous Medal that gracefully transform into ceiling vaults resist gravity in a mysterious way. They physically support the structure without conforming to the typical verticality of the column. This visual tension that is experienced physically is translated into a state of mind. The viewer empathises with the delicate non-symmetrical columns that struggle to endure the weight of the roof as if one had to carry the heavy load themselves with their own body. This can also be associated with Christ carrying the cross and culminate into a feeling of personal catharsis, a journey into one's inner self, or a metaphor of the purification and liberation of one's spirit that reasserts the transforming power of the church.

Although the design of the church is based on a traditional cross-shaped plan, the unprecedented delimitation of the interior space not only provides satisfaction with its sculptural expression; in achieving a perfect balance between openness and enclosure, it also offers functional diversity. The sharply varying heights of the ceiling create different sensations. In the more intimate and tranquil space in the periphery, people can be absorbed in themselves and contemplate. In the more formal and awe-inspiring space in the central nave, their spirit is released and the grandeur of the church can be fully experienced. Stained glass windows further accentuate the intimacy of the space and call for meditation, as they 'were not designed for the view beyond: they do not inspire us to look out onto the world, but to look in on ourselves, and, like the walls, they surround us with God's message'.[43] The architectural space is devised to carry the visitor away from secular life while still keeping them down on earth. It embraces them in a peaceful serenity when they need to reflect in solitude, but also encourages them to join with the others when they are ready to do so.

The small Chapel Lomas de Cuernavaca is located on a plateau in Cuernavaca. For this project, Candela collaborated with architects Guillermo Rossell and Manuel Larrosa. As the talent of these two young architects was combined with Candela's experience and experimental spirit, the limits of free-edge shells were pushed further. Their impressive joint project features a single self-supporting hypar that reaches up to 21 m at the taller end (Fig. 5).[44]

Chapel Lomas de Cuernavaca explores a hypar shape with curved edges: a parabola in the main space and a hyperbola where the structure is embedded in the ground. The form resulted from intersecting the hypar surface with various planes that produced an expressive structure with two opposite parabolic openings. Featuring a constant thickness of 4 cm and in the absence of reinforcement on its perimeter, the abstract simplicity of the structure makes a bold statement (Fig. 6). It perfectly fits in the landscape as a connection between the earth below and the sky above it. By the time the building was erected, the landscape around it was undeveloped. From the height of the hill of the chapel, one could indulge in a magnificent view of the natural beauty of the valley. The white colour of the shell distinguishes the structure from the surrounding greenery and attracts the viewer's attention. At the same time, its specific geometry serves as a funnel that absorbs the visitor to be immersed in the experience. As the shell shades the seating area and allows nature to freely enter the covered space, the borders between inside

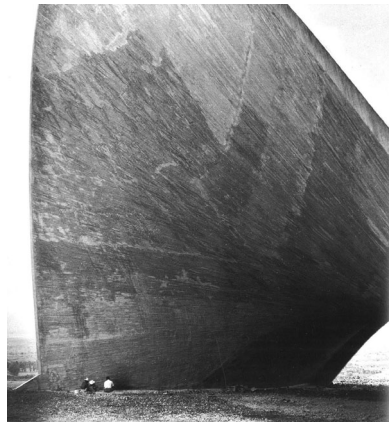

Figure 5.
Félix Candela, Chapel Lomas de Cuernavaca, Mexico, 1958, © Gallery 400

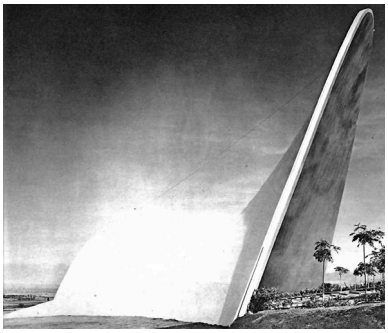

Figure 6.
Félix Candela, Chapel Lomas de Cuernavaca, Mexico, 1958, © Gallery 400

and outside, protected and open, are totally blurred. The perception of the space is described by Enrique de Anda as follows:

> The space is presented to the viewer with an unusual force of attraction; the traces of the wooden formwork rules contribute to transmitting a new dynamic sensation and underline the directionality towards the bottom. The limits of reality between above and below, the landscape and the interior of the building disappear.[45]

Sitting under this gigantic canopy, one feels embraced and protected by the raw simplicity of the space. A sensation of being in a natural cave is aroused. This semantic interpretation of the chapel as a cave alludes to the archetypal image of habitation that can be further understood as the space inhabited by God. As the cave connects with the heart, its symbolic role as a spiritual centre can represent one's inner centre of being or the centre of the world, depending on the microcosmic or macrocosmic interpretation of the symbolism.[46] This metaphor is also embodied in the shape of the plan, a truncated triangle that geometrically visualises the heart. However, this cave is not dark as in Plato's allegory. It does not represent the illusory world in which humans are deceived about the true nature of things. It is illuminated by the light that enters from the opposite end behind the altar. The cave as a conduit for the light of God is one of the main patterns of Mesoamerican symbolism. As God moves over the earth and passes through the cave, ill desires are removed. In Mesoamerican traditions, caves also serve as transformative spaces that provide both physical and spiritual access to the sacred realm.[47]

Finally, the very placement of the chapel on a hill is also semantically significant. The visitor has to walk the pilgrimage path to reach the culmination of their journey at the foot of a structure that impresses them with its striking height and fragile thinness. But it also evokes their reverence as it draws their eye upwards to God. The bilateral symmetry of the vaulted shell concentrates the spiritual forces and forms an 'earth-to-sky axial symbol'.[48] The structure gracefully levitates over the ground, as if it is ready to detach and fly off in the sky like a giant white wing. In Christian symbolism, wings signify the light of the sun of justice that illuminates the mind of the righteous.[49] 'That "wings" denote spiritual truths, is because "birds" in general signify intellectual things and thoughts; consequently "wings" denote spiritual truths, because all the intellectual is from these truths.'[50] Accordingly, the shape of the structure represents the wings of spiritual truth that lift one's spirit to the heavens and empower the truly faithful. Being 'under the wing' of the chapel might also serve as another metaphor for the protective function of the church.

Conclusion

The proposed interpretation of the symbolic meaning of Candela's geometric shapes in the selected ecclesiastical buildings demonstrates how the sacred essence of the church is manifested in its physical form, despite its seemingly modernist abstraction. This semantic interpretation of the hyperbolic paraboloid shells did not explore how their emblematic shape unfolds into expressive architectural space, neither did it focus on their aesthetic impact. It rather attempted

to foreground the mystic qualities that are encoded in the architectural composition, and the ways in which these can be decoded by a viewer who perceives and experiences these spaces. Although Candela has not explicitly mentioned that the connotations proposed here formed part of his intentions, both Our Lady of the Miraculous Medal and the Chapel Lomas de Cuernavaca are outstanding tectonic forms creating uplifting architectural spaces that encourage contemplation. Candela's innovative vision combined his profound understanding of reinforced concrete as a structural material, his intuitive understanding of the play of natural forces, and his strong sense of beauty. It produced architectural shapes whose contribution to modern architecture was unprecedented. Especially in his religious buildings, his thin shells transcend mere function. The psychophysiological impact of their pure structural form subconsciously renders them semantically significant to communicate the sacred character of the church. As the geometric shape of the hypar embodies a perfect balance of forces, it becomes a human-made structure that inherently alludes to the perfection of God. As such, this article has furthered our understanding of the significance of Candela's work, adding a new semiotic perspective to the already acclaimed functionality, efficiency, and economy of his structures. On the other hand, the article has also drawn attention to issues relevant to modern church architecture. Since the Second Vatican Council, which ratified the modern aesthetics of church design, recurring debates have questioned the appropriateness and compliance with the theological requirements of modern religious spaces whose design is 'strikingly different from that of traditional churches'.[51] Reading them as expressions of the concepts of modernism rather than those of the clerical dogmas, authors (such as Rose, Stroik, and Kieckhefer) have criticised modern churches for their controversial nature and absence of the 'sacred' in their minimalist architecture. This article attempted to challenge the notion that modernity is devoid of the properties that characterise a sacred space. With their seeming simplicity and structural honesty, Candela's two selected projects have been celebrated as a feat of engineering that has resulted in a unique sort of enclosure of architectural space. But when the hidden symbolic meaning of their structure is revealed, their immanent and transcendental character is also foregrounded. While the name of Félix Candela is not included in any major study of modern church architecture of the twentieth century, he was an architect who developed a new structural vocabulary of spiritual spaces defined within hyperbolic paraboloid thin shells.

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Notes and references

1. Among them the engineers Pier Luigi Nervi and Eduardo Torroja who have elevated structural design to the level of art. See Nan Hu, Peng Feng and Gong-Lian Dai, 'Structural Art:

Past, Present and Future', *Engineering Structures*, 79 (November 2014), 407–16 (p. 408) <https://doi.org/10.1016/j.engstruct.2014.08.040>; David P. Billington, *The Tower and the Bridge: The New Art of Structural Engineering* (Princeton, NJ: Princeton University Press, 1985).

2. Pepa Cassinello, 'Exhibition Centenary Félix Candela (1910–2010): The Achievement of Slenderness', in *Félix Candela Centenary*, ed. by Pepa Cassinello (Madrid: Universidad Politécnica de Madrid, 2010), pp. 25–57.
3. See Billington, *The Tower and the Bridge*. Billington was the first author to describe engineering works that epitomise efficiency, economy, and elegance as 'structural art'.
4. Clive Bamford Smith, *Builders in the Sun: Five Mexican Architects* (New York, NY: Architectural Book, 1967), p. 97.
5. Félix Candela, cited in Billington, *The Tower and the Bridge*, p. 217. Owing to his original training as an architect, Félix Candela stands out in Billington's list of engineers/structural artists. Candela's strong mathematical skills helped him calculate his designs. When he founded the company Cubiertas Ala (with his brother Antonio, and the architects Fernando and Raúl Fernández) in 1950, he was also able to realise his own engineering designs as a builder.
6. Maria E. Moreyra Garlock and David P. Billington, 'Félix Candela's Legacy', in *Félix Candela Centenary*, ed. by Cassinello, pp. 127–34.
7. Billington, *The Tower and the Bridge*.
8. Description of the church Iglesia de la Medalla Milagrosa (Our Lady of the Miraculous Medal Church) in Mexico City. This was the only church building that Candela designed alone as an architect and engineer. It was originally published in the Mexican journal *Las Españas* in June 1956, and in the Spanish journal *Informes de la Construcción* in December 1956. See Félix Candela, *En defensa del formalismo y otros escritos* (Bilbao: Xarait, 1985), p. 51.
9. Michael S. Rose, *Ugly as Sin: Why They Changed our Churches from Sacred Places to Meeting Spaces and How We Can Change Them Back Again* (Manchester: Sophia Institute Press, 2009), p. 8.
10. Yi-Fu Tuan, *Space and Place: The Perspective of Experience* (Minneapolis, MN: University of Minnesota Press, 1977).
11. Based on Thomas Aquinas's assertion that '[t]he house in which the sacrament is celebrated signifies the Church and is called "church"', Karsten Harries has argued that the church building has a very special cultural symbolism. It connotes the values and faith of the people who build it, signifying both the goal and the journey to achieve it. See Karsten Harries, *The Ethical Function of Architecture* (Cambridge, MA: MIT Press, 1998), pp. 99–110.
12. In 1957, the New Churches Research Group was founded to discuss the problems of modern church architecture. It organised numerous conferences and debates that raised fundamental questions on radical church design. See Peter Hammond, 'A Radical Approach to Church Architecture', in *Towards a Church Architecture*, ed. by Peter Hammond (London: Architectural Press, 1962), pp. 15–37.
13. Ibid., p. 17.
14. Rudolf Schwarz, *The Church Incarnate: The Sacred Function of Church Architecture* (Chicago, IL: Henry Regnery, 1958), p. 28.
15. Friedrich Schleiermacher, *The Christian Faith* (London: T&T Clark, 1999).
16. Duncan G. Stroik, *The Church Building as a Sacred Place: Beauty, Transcendence, and the Eternal* (Chicago, IL: Liturgy Training Publications, 2012), p. 68.
17. Ibid.
18. Garlock and Billington, 'Félix Candela's Legacy'.
19. Schwarz, *The Church Incarnate*, p. 28.

20. Rose, *Ugly as Sin*. Rose is an ardent critic of modern church design. He seeks a return to the expressionism of historical church archetypes. See also Michael S. Rose, *The Renovation Manipulation: The Church Counter-Renovation Handbook* (Cincinnati, OH: Aquinas Publishing, 2000).
21. Ibid.
22. Joseph Pichard, *Modern Church Architecture* (New York, NY: Orion Press, 1960).
23. Ibid.
24. Mike Schlaich, 'Thin Concrete Shells and Other Light-Weight Double-Curved Structures', in *Félix Candela Centenary,* ed. by Cassinello, pp. 111–23.
25. Candela, *En defensa del formalismo*, p. 51.
26. *General Instruction of the Roman Missal* <http://www.vatican.va/roman_curia/congregations/ccdds/documents/rc_con_ccdds_doc_20030317_ordinamento-messale_en.html#DECREE_OF_PUBLICATION> [accessed 28 May 2020].
27. Félix Candela, 'The New Architecture', in *Félix Candela: Engineer, Builder, Structural Artist*, ed. by Maria Garlock and David Billington (New Haven, CT: Yale University Press, 1985), pp.178–80 (p. 179).
28. Agostino Catalano, 'Félix Candela: Craftsman and Precursor of Contemporary Technologies of Thin Concrete', in *Félix Candela Centenary,* ed. by Cassinello, pp. 149–54 (p. 149).
29. Candela, 'The New Architecture', p. 179.
30. Ibid., p. 178.
31. Candela, *En defensa del formalismo*, p. 53.
32. Robert Maguire, 'Meaning and Understanding', in *Towards a Church Architecture*, ed. by Hammond, pp. 65–77 (p. 67).
33. Tim Michielis, Maria Garlock and Sigrid Adriaenssens, 'Seismic Assessment of Félix Candela's Concrete Shells and their Behavior During the 1985 Mexico City Earthquake: A Case Study of the Church of our Lady of the Miraculous Medal', in *Structural Analysis of Historical Constructions: Anamnesis, Diagnosis, Therapy, Controls*, ed. by Koen van Balen and Els Verstrynge (London: Taylor & Francis, 2016), pp. 2038–51 (p. 2043).
34. Enrique X. de Anda, *Félix Candela, 1910–1997: The Mastering of Boundaries* (Cologne: Taschen, 2008), p. 31.
35. Colin Joseph Dudley, *Canterbury Cathedral: Aspects of its Sacramental Geometry* (Bloomington, IN: Xlibris, 2010).
36. Antoni Gaudi, cited in Albert Smith, *Architectural Model as Machine* (Oxford: Architectural Press, 2007), p. 93.
37. Juan Eduardo Cirlot, *Dictionary of Symbols*, trans. by Jack Sage (London: Routledge, 2001), p. 16.
38. Ibid.
39. René Guénon, *Symbols of Sacred Science* (Hillsdale, NY: Sophia Perennis, 2004), pp. 253–58.
40. Juhani Pallasmaa, *The Eyes of the Skin: Architecture and the Senses* (Chichester: Willey, 2005), p. 45.
41. Ibid., p. 67.
42. Gottfried Semper, *Style in the Technical and Tectonic Arts; or, Practical Aesthetics* (Los Angeles, CA: Getty, 2004), p. 645.
43. Richard Stemp, *The Secret Language of Churches and Cathedrals* (London: Watkins Media, 2016), p. 35.
44. Initially, the planned height of the chapel was 24 m. It included rosette-shaped apertures (designed by Rossell) in the top part of the shell. But in the construction phase, the shell collapsed. Although there was no evidence of structural instability, the height was

reduced to 21 m, and the apertures were eliminated. See María González Pendás, 'Erores concretos, o la magia de los cascarones', *Bitacora Arquitectura*, 37 (2017), 32–43.

45. De Anda, *Félix Candela*, p. 67.
46. Guénon, *Symbols of Sacred Science*.
47. Andrea J. Stone, *Images from the Underworld: Naj Tunich and the Tradition of Maya Cave Painting* (Austin, TX: University of Texas Press, 2010), pp. 34–40.
48. According to Tresidder, sacred caves, allocated usually on hills, gather spiritual force. This was often represented by a domed vault, pillar, or lingam that served as earth-to-sky axial symbols. See Jack Tresidder, *The Watkins Dictionary of Symbols* (London: Watkins, 2011).
49. Cirlot, *Dictionary of Symbols*.
50. Emanuel Swedenborg, *Arcana Coelestia* (Loschberg: Jazzybee, 2009), X, p. 5783.
51. Richard Kieckhefer, *Theology in Stone: Church Architecture from Byzantium to Berkeley* (New York, NY: Oxford University Press, 2004), p. 249.