PLENITUDE OF MATHEMATICS IN ARCHITECTURE AND ITS INFINITE POSSIBILITIES: A REVIEW OF PARAMETRIC DESIGN

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ABSTRACT

During the earlier stage of architectural education, we are exposed to the concept of mathematics in architecture such as the Vitruvian man, the golden ratio, the Cartesian, Euclidean and Pythagoras Theorem. After a while this so-called basic architectural knowledge is no longer that matter that we are much consumed by the freedom of art and aesthetic that drove us to oversight that science and technology are also important parts of architecture that we should never overlook. Therefore, this paper explores the use of mathematics in architecture, and how it can contribute in revolutionizing the architecture to a different and logical spectrum. Case studies, site visits and observations are conducted on selected buildings that used applied mathematics in the design process such as British Museum, England (parametric design), Sydney Opera House, Australia (algo rithm design), and Segrada Familia , Spain (sequence number). The paper suggests that it is been retained in a new emerging style of parametricism as the only way for the ideology survive with a better understanding of mathematics as an underlying principle and reasoning.

Keywords: *Sustainable, Building, Parametric Design*

INTRODUCTION

Due to the segregation of mathematical reasoning and architecture, slow deterioration of the hidden value in architecture can be seen in 20th century. The modern and contemporary architecture neglect the use of numbers as part of aesthetic and solely find it restrictive. If we look at the historical building such as The Parthenon, we can easily discover the aesthetic through the diversity of proportional approach. That simplicity gained from applied mathematics and geometry, and how it retains its aesthetics even after years of completion is astonishing. During the 19th century a segregation of science and art took place and the title of master builder was divided into two, architects and engineers. After the incident, architects no longer focus on the important aspects of mathematics in designing spaces, façade, cities, and tend to seek for other expertise to solve the design problem. Historically, architecture was part of mathematics, and in many periods of the past, the two disciplines were indistinguishable[1]. In the ancient world, mathematicians were architects, who constructed the pyramids, ziggurats, temples, stadia, and irrigation projects that we marvel at today. In Classical Greece and ancient Rome, architects were required to also be mathematicians. When the Byzantine emperor Justinian wanted an architect to build the Hagia Sophia as a building that surpassed everything ever built before, he turned to two professors of mathematics (geometers), Isidoros and Anthemius, to do the job. This tradition continued into the Islamic civilization. Islamic architects created a wealth of two-dimensional tiling patterns centuries before western mathematicians gave a complete classification.

PURE & APPLIED MATHEMATICS

Pure Mathematics is a branch of mathematics that evolved with the development of the mathematical subject itself, it is based on the logic of its purpose. Solely dependent on the growth of the mathematical idea without any specific use. Pure Mathematics is the mathematics, which underlies all applications. A deep mathematical theory was primarily developed for their own sake, to find application much later on. An example of this is the theory of whole numbers, which until about 1960 was not thought to have serious applications in the 'real world'[2]. Pure mathematics is defined as a subject that focused entirely on abstract concepts. It was also known as speculative mathematics in the eighteenth century. Applied Mathematics in contrast to Pure mathematic is a branch of mathematic that uses mathematical reasoning to solve issues. Thus, using the development of pure mathematics as a guideline and to test how the theory behind the formula works, solve problem and become something beneficial [3]. Applied mathematics can be used in any field, typically, engineering, business, chemistry, computer science, architecture, etc. The line between applied mathematics and specific areas of application is often blurred. Many universities locate mathematical and statistical courses outside of the respective faculty, in departments and areas including business and economics, engineering, physics, chemistry, psychology, biology, computer science, and mathematical physics.

APPLIED MATHEMATICS IN ARCHITECTURE

Applied mathematics in architecture can be explained as the use of mathematical reasoning into architectural design in many ways. In ancient history, master builders used mathematic as part of aesthetic, they believed that mathematic causes a subject to look aesthetically pleasing, harmony and balance. They used to have an idea on how to build a building that will look pleasing by defining the space using mathematic, with a few buildings introducing the idea of Golden ratio to its floor plan as well as their façade. For example, Notre Dame Cathedral in Figure 1, this heritage building is claimed to look in harmony due to the mathematical reasoning behind its design. Each component is designed and measured using numerical sequence with the presence of Fibonacci pattern and the obvious establishment of dimension and proportion in accordance to golden ratio[4]. The role of mathematics in architecture evolved through time. The segregation of architecture and engineering caused the mathematical aspect to lose its touch on the aesthetic. A case study on Aviva stadium discovered how parametric design can solve the site issues. In this scenario, the footprint of Aviva stadium should not exceed the site boundaries due to scarcity of land, while maximizing the space provided. The report shows how the design of cladding with certain parameters is the answer to the problem of the site. Each of the curve, each plate, and each corner had been mathematically calculated and formulated. Every single cladding plays an important role to make the design work for the site, the algorithm should be precise and not mistaken, in order to gain optimum result to fulfil the need of the building and integration with the site constraints. The result of mathematical algorithm in the façade design allows maximum use of internal space without compromising the perimeter of site given[5].

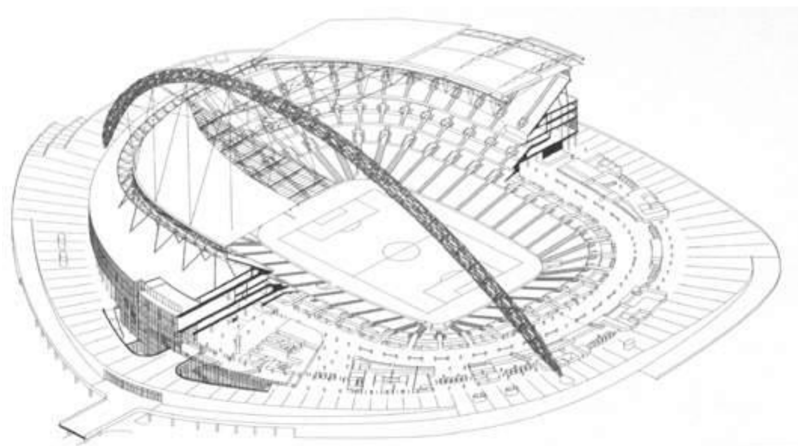


Figure 1: Aviva Stadium. Source: http://www.designboom.com/weblog/section.php

The interrelationship between mathematics and architecture is undeniable, the evolution might hit a hiccup but the revolution remains and is continuous. They have been closely related; both architecture is concerned with the creation of space; mathematics with its description and definition. In mathematics particularly, this has encompassed an increasingly diverse and abstract kind of space[6]. As the technology grew and the mathematics developed, we can see how it has an impact on the built environment as well. Mathematics is now widely used as part of parametric design. From this observation, this is not the case where they use mathematic for beauty, nor it is as problem solver. It covers broader aspect of design, it is for aesthetic, it solves issues, its eases the construction, and it makes the building simpler with far more complexity. The research will be further developed with a case study on how applied mathematics can contribute in improving an architectural design. A step-by-step reasoning will be unfolded to further explain the possibilities created by this branch of science, before using the idea of mathematic in architecture for personal design proposal.

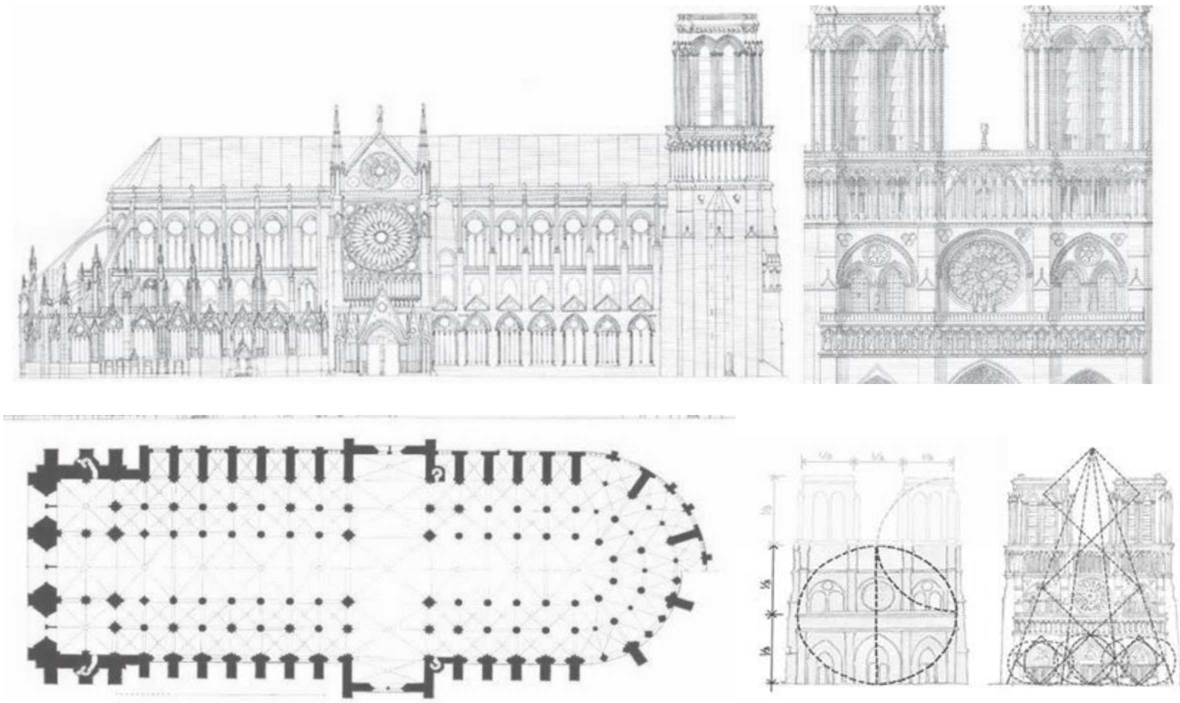


Figure 2: Plan and Sketches of Notre dame Cathedral

RESEARCH EXPLICATION

Figure 3: Sydney Opera House, Australia by Utzon. Roof was designed using the manipulation of sphere and geometry Source: http://www.panoramio.com/photo/81413549

a) ***Case Study 1: Sydney Opera House, Australia, by Utzon.*** Mathematics plays an important role in improving the understanding of architecture and structure. It is very crucial to consider mathematical parameters that can improve the aesthetic aspect of a design, especially in term of proportion and symmetry, as well as to the structural aspects such as load, thrust and reaction. Sydney Opera House, is a masterpiece of both architect and engineering through the inexplicable of basic mathematical parameters. The initial idea came from the peeling of an orange and it is further developed with an understanding of mathematics Jorn Utzon, and Arup finally find an answer after years of experiments, analysis, hard work and argument, to determine a feasible blend of geometry, materials, and methods of construction. Jorn Utzon fascinating sketch proved that the study of form for six years is not a waste of time but instead a milestone for a cutting edge design which challenges the world's foremost engineering firm to develop its structural proposal. The task was to find a repeatable form that allows Utzon's design to be executed in a cost-effective manner [7]. Mathematics and nature proved that its inspiring geometry and sequence could solve structural design problem.

The architecture and engineering team come out with numerous proposals using geometric shapes. Twelve iterations proposal was tested including parabolas and ellipsoids in their search for common mathematical denominator. This is before they finally find an answer from the geometric shape of segments of an orange, the segments of a perfect sphere [7]. While it is said to be easy in concept, the design still requires extremely complex mathematical computation. Each piece of the segment will be equally covered with specific design of mass-produced tiles thus requires it to be specifically measured with same radius and, identical in shape and with the same segment of all curve. The roof cannot be built without an explicit geometry clarification for the structural design of this shape and complexity, and it is crucial for it to be expressed mathematically. Without such a mathematical model, it is not possible to calculate the loads, stressed and rotational forces to which the vaults will be subjected and to estimate the impact of wind and temperature changes on their stability [7]. Utzon's first options for the profile and the vaults were parabolas and ellipses where both is not a buildable option. Ove Arup and the engineers of his London-based firm had been chosen to collaborate with Utzon in the execution of the structural proposal. Their initial idea is to build the vaults as thin, concrete, egg-like shells. Such roofs were coming into use at the time. In fact, Arup's firm had designed such roofs with concrete shells of only 3 inches thick. However, Utzon's pointed, abruptly rising vaults were not compatible with such design.

The design should be like a sail like roof structure with sequence of curving ribs, should start narrow at it bottom part and developed widely as they go higher, that is how Arup is convinced. Utzon is very confident with the idea of each roof vault to have a two curving fan-like structures, one is the reflection of another, soaring upward from the opposite sides to meet a circular ridge at the top. This only solved one problem, but the issue with the geometry remained. The question is there any geometry that would make a curving-sail like structure with standardized, mass produced components as efficient and buildable as possible? If the answer was no, then it would be impossible to execute Utzon's design and the project would collapse.

Figure 4: Sydney Opera House is define by the geometrical shape of the roof. The shells segment was taken from a single sphere. Each shell was made up of series of ribs formed by parallel lines Source: http://www.lilburnes. org/Students/Media2/Sydney

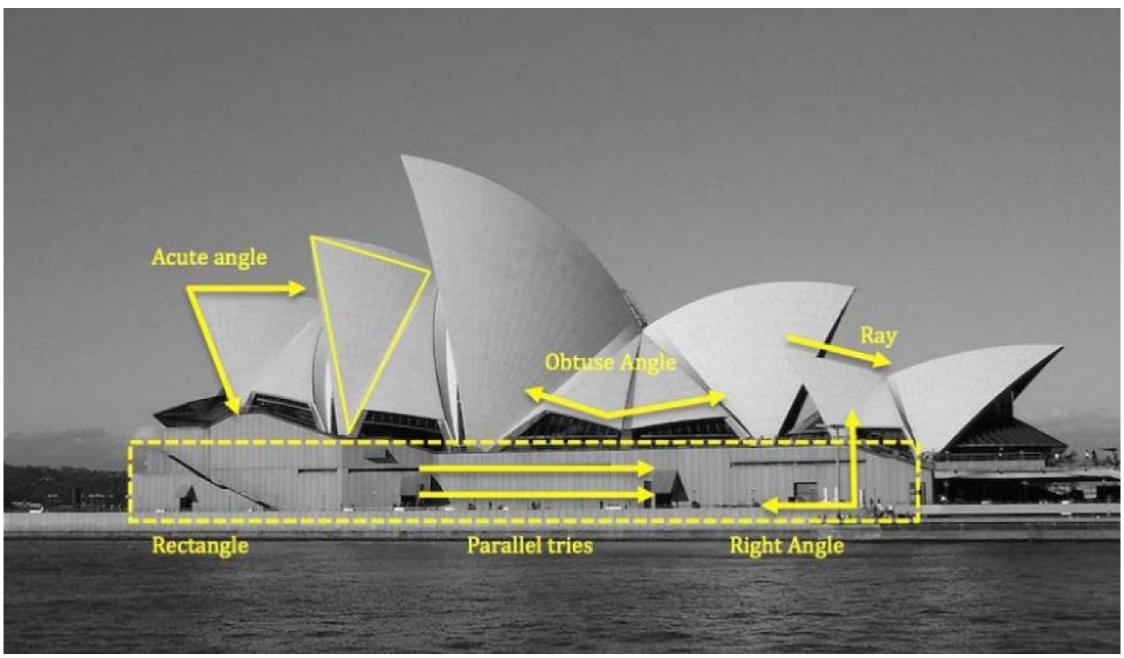


Figure 5: The shells was constructed with the idea of isosceles triangle with the present of acute and obtuse angle

A sphere of a given radius was Utzon's only option for the idea of surfaces that curve in the same way in all directions. Because a limitless variety of curving triangle can be drawn on a sphere, all the shells for his roofs could be designed as curving triangles on a sphere, the same sphere. This visualization of Utzon's saved the project. It started with an orange cut exactly to half. This curving triangular piece joined to its mirror image is a model of Utzon's vault geometry. Weighing matters of both aesthetics and structure, Utzon and Arup decided on 246feet as the radius of the sphere from which the design of all the matching pairs of spherical triangles would be taken. A total of 1498 standard rib segments of 12 different types and another 280 nonstandard segments were cast, each 15 feet long. With heavy construction cranes and an erection arch made of a curving steel truss, sequences of rib segments were placed into position and each triangular shell and its mirror image rose to completion simultaneously, segment by segment, one matching pair of ribs at a time [7]. The geometry of the shells really defines the Sydney Opera House. The ribs are made of series of parallel line. Within the shells you can see what appear to be acute angles and obtuse angles. This case study shows nature can produce simple, yet elegant forms with no apparent effort; man's attempts to copy her require highly developed math skills. Finding the mathematical common denominator made all the difference in constructability. Reducing the number of unique pieces and parts to a minimum made the project financially feasible.

Figure 6: Sagrada Familia, by Antonio Gaudi. The design complexity was achieved with the idea of parabolic and hyperboloid without the aid of any parametric software Source: https://www.flickr.com/photos/11266811

b) ***Case study 2: Sagrada Familia , Barcelona , Spain by Antoni Gaudi***.

The case study encapsulates mathematical sequence and pattern on façade design in where Antoni Gaudi already incorporates the idea of double curved and ruled surface in his design of the church of Sagrada Familia almost a hundred years ago. His signature concept of naturally developed form portrays both balance of organic and inorganic shape. To complete the construction both during his time and of future time, he has found a way to ensure fluidity of the construction, the more rationale and systematic approach via combination of intersecting ruled surfaces. His good relationship and communication with the stonemasons and model maker of his time and future time ensure the project and the church to continue its construction and to be completed. For Sagrada Familia, Gaudi achieves another level of spatial complexity without the aid of any digital computational or parametric software tools. His attempt to break from regularity can be seen through the design of a colonnade of inclined, bone like columns, transept, stepping pediment, intersection of geometries, sloping cornice, and giant causeway topped with parabolic pinnacle[8]. With the aid of today technology enhancement, the church ‘s naturalistic geometrical complexity can be easily unfolding and interpret.

Each of the elements is found to have similarity in terms of characteristic but still unique on its own. The patterns of the element dependent on a single parameter that ensure the element to develop and grow differently but accordingly. The elements can- not be transformed through scaling nor translation or reflection and rotation. What is the basis, to use anthropologist Gregory Bateson’s words, of this `pattern that connects’? The stepping cornice appears to even simpler conceptually: repetitive rectilinear shapes lie on a straight pitch line in elevation. Yet even variation in shapes through the curved plan, each appears to be uniquely sized, with some simple progression or growth algorithm controlling their size towards the apex[9]. The systematization of the geometry to replicate as closely as possible in the photograph, becomes an exercise in forensics, uncovering the mathematical sequencing and its underlying algorithms, while trying to sense the degree of anomaly needed to replicate the powerful organicism of the original design[6]. Further exploration and study to understand the relationship of geometry and pattern were later negotiated with the aid from parametric design software and digital computational tools. Models are produced from this help to understand the design pattern, the parameters and the variable relationships, transforming such information to geometrical schema. For example, the stepping cornice propagation relies on a quadratic function that influence different scale of growth in order to vary the rate that will result on the development of the steps growth between base and summit.

The last twelve years of Gaudi’s life, he has moved away from his idea of free form architecture, instead he later adopted a set of three (second order) surfaces, portrayed in two representations of virtual presence and real absence. During his final time, he was really devoted upon concluding Sagrada Familia church, with other project excluded, all using a combination of these surfaces of helicoid, the hyperbolic parabolic, and the hyperboloid of revolution of one sheet. When studying Gaudi work at this era, it can be seen that Gaudi used two obvious strategies, which are sewing and sculpting[10].

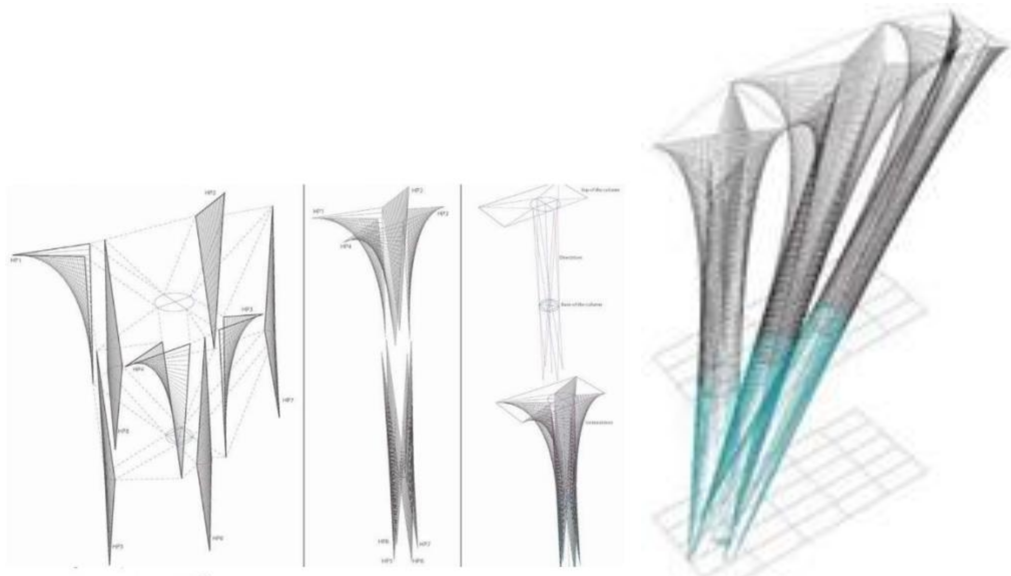


Figure 7: Sagrada Familia, study of parabolic and hyperboloid diagram. The diagram shows triforium module of an associative geometry and exploded of geomtry of the central column Source: https://wewanttolearn.wordpress.com

c) ***Case study 3: British Museum Great Court, London by Foster + Partner.*** The design of the glazed roof of the British Museum Great Court is highly influenced by the definition of surface and pattern. The geometry of the roof is defined by the shape of the surface and the steel structure that support the surface. Such design could be achieved by a technique named NURB surfaces. However due to the fact that the boundaries of the roof of both rectangular and circular shape of the Great Court, a simpler approach was used. This is due to the fact that the surface requires a grid member acting on existing boundary with singularity acting upon a curvature corner. Williams explain, "Is that the rectangular boundary was on sliding supports to avoid horizontal thrust on the existing building. The roof, therefore, could only be restrained horizontally at the corners where the resultant thrust is balanced by tensions in the rectangular edge beam [6]. Functions without a singularity in curvature must be horizontal at a horizontal corner, like a ski jump, where the thrust has to change direction rapidly as the corner is approached, thus causing structural problem. But cone lying on its side can have a slope even though it intersects two horizontal line crossing at right angles". A formula was created to achieve the desired shape of cone like atrium with its apex at the corner, ensuring continuity of curvature along the boundaries between new canopy roofs with existing building line.

The second part of the roof design is the face of the surface pattern. A triangular shape was chosen due to the fact that it gives best structural efficiency and because it does not require any additional flat quadrilateral panes or curved glass. The grid loosens up the structural tension on the surface by removing the discontinuities of the geodesic curvature using the series of nodes on surface; as a result, the weight is almost at average with its neighbors. The load is chosen to control the maximum size for each of the glass panel, for each piece is different. The number of variables and formula used not only enhance the design intention, but also allows geometrical optimization by manipulating the original control mesh and lead the design to a more efficient form and geometries especially in term of structural support and environmental performance criteria. The only shortcoming out of this design strategy is that, by ensuring smooth and continuous surface, they have to give up on the control over each of the point. In exact word, it is difficult to determine the exact boundaries of the roof. However, by using another method of constrained subdivision scheme, the vertex around the edges is snapped back to the boundary constrained by each subdivision step. As a result, to this shortcoming, they have to sacrifice the smoothness around the boundary edges. However, since the effect is localized around the edges and in comparison with the practicality of the design for the refinement of the optimal surface, the designer hence decided that it is a good conciliation [11].

Once the design limitation is solved, the surface and strategy can be further altered and explored. The structural grid becomes more flexible to changes and experiment. While the software tools have a subdivision limit surface by controlling the draping grids, or alternately optimizing the whole grid for structural improvement and simulated annealing, are being developed, the only other option is to subdivide itself using mesh tools. Thus, naturally resulted to smoother mesh with significant improvement on the smoothness of the surface and the numbers of repetition of member's lengths. Grid with similar parameter can regenerate in respond to the subdivision from initial state of the mesh [11]. By adopting this strategy of subdivision surface modeling approach for Great Court roof, the design is allowed to be altered with a few design options and proposal. It allows the designer to generate and test the idea before any decision-making. In addition, the ability to have more options allows the building to improve its performance in term of solar gain, acoustic, and structural efficiency [12].

Figure 8: Steel grid, Faceted Surface and evolution of structural grid Source: The new mathematic of architecture

DISCUSSION

1. ***Mathematics in Architecture before and now.*** Looking at the past history of mathematics in architecture, we can see how the basic idea of mathematic incorporated in the design is more transparent, visual, direct and visible. For example, Parthenon and The Great Pyramid of Giza, the underlying mathematical principle is viewable and readable from the drawing or by observation, thus helps us to understand the underlying principal of the design and how the designer used mathematics as part of the design strategies[13]. It can generally be studied from the way it looks like; the principle such as golden ration, phi, and sequence are understandable. In comparison, for 21st century, the mathematical principle used in certain design is far more complex, with the additional software tools such as Catia, rhinoceros and grasshopper, 3dsmax and Archicad. More developed formulations and scripting are required to achieve the desirable shape, structure and solution. Thus the more complex it gets, the more confusing the mathematical principle is. Due to the fact that it is far more complex the shape cannot be easily readable or understandable through visual analysis. It can be said that parametric design is the new avant garde and heir to the passing out of post-modernist style and deconstructivist style.

"The aesthetic properties of a work of art depend on the non-aesthetic properties of it. For example, a painting can have a sense of mystery and tension, which come from the dark colors and the configuration of shapes in it. He continues his argument that the non-aesthetic properties of a work of art, are divided in standard feature, variable feature, and contra standard feature. Which they decide to which category of art the work of art belongs (painting or sculpture, deconstrucivist architecture or modern architecture. The architecture style of both Patrick Schumacher and Peter Eisenman is obviously a non-traditional architecture[14]. They define architecture into two different categories, the architecture of construction of imagination and the construction of the real world. As a result to this perception, the architecture will produce two different thing, the design and the building. The whole idea of algorithmic architecture is to be perceived as a design strategy and a design process, the way we conceive it depends on the intention of the designer. Be it classic architecture or non-classic architecture. Which is more important the design or the building? Every work of art depends on the intention of the artist and the analogy of the work of the architect.

2. Defining Parameters. Parametric design can also be known as constraint design or control design. It differs from the traditional way of designing with sketch, pencil and eraser where you can simply draw and erase. Parametric is controlled with a certain parameter or formula that control the condition of the design[13]. Parametric design is a design that cannot be simply erased or cut, and cannot be pasted or add on. The act of designing with extension and expansion or reduction and subtraction cannot be applied directly to the design without going through a certain rule or parameter that controls the harmonic principle of the design strategies. The parametric equation is perhaps the most widely used form. This is because it works in both 2D and 3D and because it is constructive, that is, it can be used to generate points on the line. In contrast, the implicit line equation is good for testing whether a point lies on a line[15]. A line consists of series of points and vector. Given point K and a vector L, any point K (t) on the line has the functional equation:

$$K(t) = K + \mathrm{t}\, L$$

Where t is the real value that scales the vector L. Each value of t picks out a distinct point on the line.

Let Ko be the sum of Kl and L, then:

$K(t) = Ko + t\ (Kl - Ko)$

$\quad = (\ 1 - t\ )\ Ko + tKl$

Or in vector form:

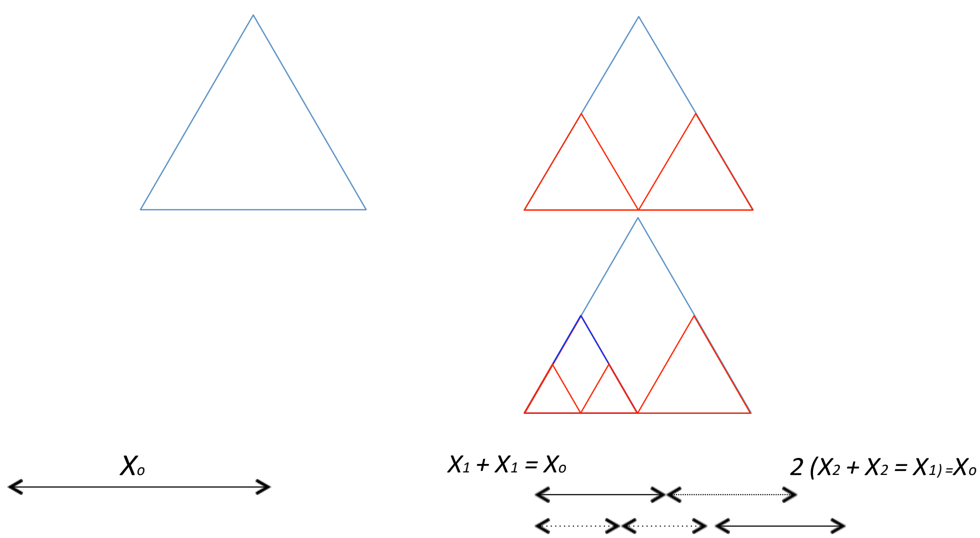
$K(t) = Ko + t\ (Ko\ Kl)$

Above example is called a $parametric\ line\ equation$ with parameter t. The equation can also be simplified as:

$K(t) = Ko + t\ (Kl - Ko)$

$\quad = (1 - t)\ Ko + tKl$

$\quad = toKo + tlKl\ , where\ (to + tl = 1\ )$



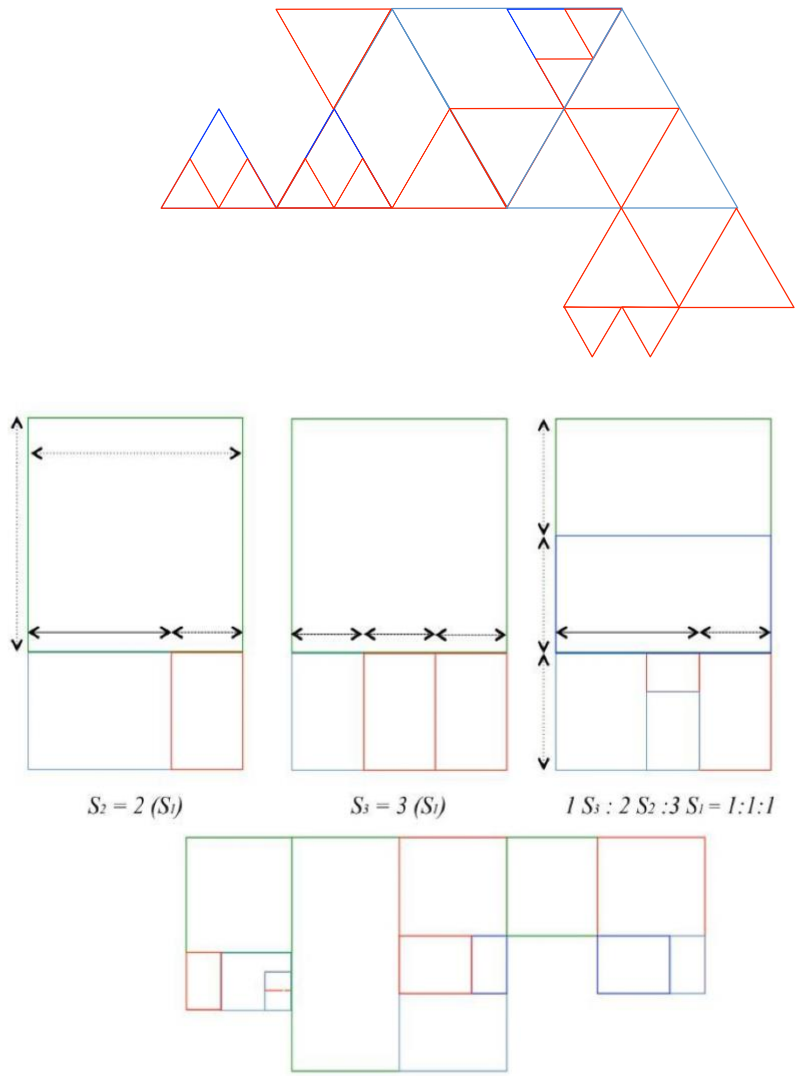


Figure 9: The parametric equation is always rely on a series of points but never on a coordinate systems, $K(t)$ solely depends on K_0 and K_1, the point remain independent at it location

3. Design Theory: What is Parametric. Parameters can be specified as the assumption of a value of a parameter for the purpose of analysis. As for parametric design there is no precise definition, it is more than designing buildings using certain tools such as software or equation. Parametric design is not a typical design that can be achieved through hand sketches; it basically relies on mathematical principle in order to modernize the design form and structure. It can produce a high quality model and also a bravura form. Moreover, the parametric system allows engineers and architects to design the structural components before the material is actually fabricated. Hence, parametric can solve certain issues in the built environment, as well as shorten the time taken for a building to be constructed and a stimulation scale model can be used in order to test the design structure. According to Schumacher, 2010 Parametricism aims to organize and articulate the increasing diversity and complexity of social institutions and life processes within the most advanced centre of post-Fordist network society[16]. It aims to establish a complex variegated spatial order, using scripting to differentiate and correlate all elements and subsystems of a design. The goal is to intensify the internal interdependencies within an architectural design, as well as the external affiliations and continuities within complex, urban contexts.

Parametric is synonym to computer generated design, computer aided and a digitally produced the idea; it involves both computer and algorithm that allows architects to create organic forms. This technique uses the parameters in mathematical order to generate interesting form, which sometimes can be very difficult to be achieved without the aid of software[11]. Parametric design is a way out for the architect to escape boredom due to cubism. Patrick Schumacher in his writing on Parametricism “Let the style wars begin”, 2010 highlighted the avoidance of parametricist taboos and adherence to the dogmas will help in presenting complex order. The taboos in parametric design include rigid form, simple repetition, and collage of isolated and unrelated image, rigid stereotype and segregation of functional zoning. While the dogmas that is fostered within the practice of parametricist are all forms must be soft, systems must be differentiated and interdependent, functions are parametric scenario and everything must communicate to one another.

Parametric design may someday be a benchmark for post-modern contemporary architecture style. It is a way for the architecture being a little bit out of the box, a typical horizontal and vertical member like the column and beam, added with infill. Parametric design allows the design to be more flexible. Being able to create variety and give more opportunity to the designer, the structural member itself creates a nice form or facade of the building. From this parametric intention, structural member may be diagonal or radial or perhaps both. Many architects are currently pursuing parametric design and Zaha Hadid is the most outstanding figure that is really into organic and parametric form. It can be said that parametric design might be the future of architecture [17]. Not only the form becomes more real, flexible, and systematic but the structure can also be designed easily, and time saving. In the midst of an increasingly uncertain global economy, architects are seeking new ideas and design processes to differentiate their designs and gain competitive advantages within the market. The latest advances in digital design technology are at the forefront of this conversation by fundamentally redefining how architecture can be designed, documented, and constructed. First, advanced tools offer a means to improve efficiency in the design, delivery process by allowing designer to easily manage complex project information. Secondly, new design technology offers opportunities for innovation by giving the designer the ability to expand the possibilities of buildable forms through new design and fabrication processes [13].

Parametric design is still in its early implementation, however the presence of generative tool makes it easier for the architects and designers to implement the technique into their project. It can be simple yet workable, this algorithm technique allows a variety of forms by designing the structure as a whole, hence shorten the time taken for architects, structural and civil engineer to rationalize the design into reality [11]. This proposal is to show how mathematical approach; parametric can be implemented using equations and software. The use is not to only design form, but to further explore human limitation with the aid of computer generated design tools. Again, it is not to use computers to generate form, but instead the software is usable to generate a proposal for solving a problem for certain condition. This approach is almost similar to the complexity of science. It is to understand the underlying principle, to alter and use chaos of theory and fractal to further test and contribute to design outcome. It is like designing without hand, the hand of the designer remains tied. The idea is pouring down to the basic principle which the design has to obey and develop based on the designer parameters. The designer will design the system, the growth and development of the design will occur naturally and intensively relying on one common source of the idea and that is how the parametric design produces its fluidity and rhythmic body to create harmony result. Parametric is part of mathematic in architecture, it is used for future possibilities and ultimately, discovers how advanced modelling tools and techniques can be widely used in various degrees to improve the momentum of architecture. The design studio should later discover that the mathematical techniques would become just as important as the architecture design project.

4. Designing Form. People often argue about the well know phrase of "form follows function", to some parametric is based only on aesthetic behind the mathematical principle. Frequent the technically minded people blamed the parametric enthusiast to just design form. But the argument does not stop here. Behind each parametric design there is certain aspect and reason for such process to take place. Often questioned, why? To go out of the box with parametric design is usually to explore what is the best form of a certain situation, most of the time the parametric modeling become the fundamental tool to explore the simplicity of structural mechanism. The idea is not to automate design. It is not about being able to complete a design with a click of the mouse. The purpose is to clarify aspects of the process that were vague up to now, so as to get a better idea of what we really want. It is about higher quality, not more efficiency. We want it better not faster. It is also not about having the computer to create a large number of proposals from which to choose. It is not about using computers to create unusual forms. When used like that, a computer would be nothing more than an extension of the pen in the hand. It is about using computers to think, as an extension of the brain [18].

5. The role of architect in Parametric Design. Parametric design is a very specific design strategy. It is fundamental for an architect to grasp the idea of algorithm before proceeding with the design parameters. The role of architect in parametric design is direct and simple. An architect should understand the use and the need of parametric. They should be able to understand the basic principle of the algorithm, the design approach and to be able to translate the idea into 3d modeling. It is not necessary for an architect to be an expert in parametricism but it is always better to know more as it is crucial for an architect to lead his team for his own design intention. When it comes to a control design environment a common question is "if the program can do it, why do you need the designer?" The first answer is the parameter; an architect is needed in term of idea and basis of imagination. The architect is there to guide the creation. Secondly, the architect role is to adopt a situation or environment into the design. Hence, the architect basically designs a control mechanism for the design strategy within a control setting condition. Thus, a parametric design is not a 100% computer generated design. Of course the software aid as a tool to design faster and better, but the design would not develop without any idea generated from human brain.

Figure 10: Muqarnas of Shah Mosque , Esfahan. Display raial symmetry based on N-gonal symmetry[19]

CONCLUSION

Mathematic was once a fundamental knowledge, acquired in order to be a good architect. No specific prove about when exactly is the date for the immersion of mathematics in architecture started, but during ancient Greece the idea of Golden Ratio is already being used in certain building design such as the Parthenon. It has also been suggested that the Parthenon was designed with proportion considerations which are based on the Golden Ratio [3]. Furthermore, the geometric pattern, tiling, repetition of muqarnas, and symmetry design of ancient Islāmic architecture also proved a trace of mathematical and numerical concern in the design [20]. The Renaissance architecture portrays the importance of symmetry and mathematical proportion. The concern was deliberately emphasized, and can be seen in the design of St Peter Basilica. The Pyramid of ancient Egypt is also known for its greatness and wonder, and such design is achieved by the miraculous mathematical proportion which made possible by the sequence number, phi, and the golden ratio, there is a lot more example of how mathematics was once an important subject in architecture [19]. The Hindu temples laid out using the mathematics of astrology, the fractal-like structure were the evidence of mathematical concern. Modern Architecture of the 20th century has also used mathematics as part of the design strategy. Most of the design used rectilinear Euclidean also known as Cartesian. The De Stijl movement uses the idea of horizontal and vertical as directional tendencies. The properties of dual direction can be seen in the roof design, wall planes and balcony.

The idea of mathematic in architecture is slowly deteriorating as the era of computations emerge. More software is being explored and used as part of the design strategy. The concern is how can the architect design using software without having a basic understanding in applied mathematics, algorithm, variables and parameters. Many expressed their concern on the ability of computers to replace designer. As the technology developed, the importance of mathematical understanding and reasoning seems to lose its grasp on architecture. Most of the design is formulated and generated by key in a certain parameter, thus the lack of understanding in mathematic become the limitation to the designer to design better [13]. It can be seen that the designer control the parameter, but the parameter controls the design. A new generation of architect can always learn and explore more software on their own, but exploring software does not make them a good architect, instead just a good software user. If the architect is to use mathematical principal as part of their design they should be an expert themselves in the first place. The segregation of architecture and mathematic create an obvious disability to the new emerging architect. As a result, most designs is not well explained, and no strong reasoning behind certain form and shape. To some who are against deconstructivist they find parametric as odd and bizarre, but with a strong mathematical understanding, the designer can produce better and wiser design which explain their design intention that able to control the tools, machines, and software, as they desired resulting much less criticism [11].

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