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How toExplore Golden Ratio in Architecture and Designing City

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ABSTRACT
In architecture, there are many different standards and rules to design buildings, urban and planning and principles and proportion are the clear limitations among the main standards. Golden ratio or golden section is considered as a clear proportion in the architecturaldesign. Severalacademic researches and studies can befound that talk about the golden ratio. This ratio also can be seen in natural division, arts, music and architecture. It is measured as a standard for the aesthetic and beauty of the architectural appearance. Thepresent paperdiscusses the golden ratio in general, its history that shows first use and understandingsand related to which ancient civilization. Furthermore, it explains the position of the golden ratio in architecture principles. Following that, this paper discoversa number of case studies that designed with this ratio existed around the world. Also, itdemonstratesthat,how it can be applicable in architecture field today? Then there isa summaryof the research inthe conclusion.

Keywords:Golden ratio, proportion, geometry, Phi, scales, and principles

I. INTRODUCTION

Through the ages,there are a sufficient number of factorsthat influenced on architecture such as mathematics, cultures and religions. Most of the influences can be found by looking at the architecture projects throughout the centuries. The Golden ratio is a one of the mathematical rules that has significant impacts on the design and final results. There are many examples that have the golden ratio in different area. Parthenon with its ratio of column's dimension and a one face of Notre Dame Cathedralare the famous and clear examples of the golden ratio (AL Sharif, R., 2014).

Beside the obvious present of the golden ratio in the history, it can be seen in modern architecture too (Kissinger, C. E., 2012). One of the significant principles in modernism was using mathematical sense and neglecting the traditional style, especially building elements (Salingaros, N. A., 2012).There is another system calculation that is near to the golden ratio which is the Fibonacci Series: 1, 1, 2, 3, 5, 8, 13(Ching, F.D. K., 2007).

II. SCALE AND PROPORTION

In general, scale and proportion came together in architecture studies and designs ofspaces and buildings. The meanings of both of them are quite similar. Scale means the size of the subject as an overall. It should compare with the main sources, and then it isindicated in its scale. Otherwise, proportion talks about the parts or elements of the subject. In another word, it considers the proportion between the parts(Ching, F.D. K., 2007). To illustrate; the two parts have the same dimension or the dimension of one part is abouttwice of the second part. Golden section is commeasurable as a clear point or parts in theories of proportion.

In architecture, the proportionis one of the main aspectsthat affecting material and structure design. In slabs, for example, there is a main span and the thickness of the slab. More clearances in one-way slab there is a ratio between the span and the thickness of the slab. The thickness of the slab with 2.5m spans is equal to about twice of this slab with 5.5m spans. It means that there is a proportion between the dimensions of the elements of a building (Figure 1).

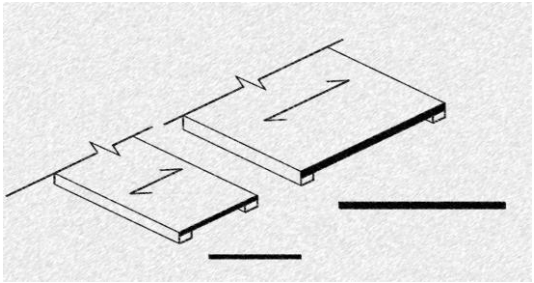


Figure 1: relation between the span and the thickness of the one-way slab
Source: (drawn by the authors)

There is a system for this proportion and it is not random. For creating the shape or design the spaces, many factors have an action on this system such as the environment, function and structure (Ching, F.D. K., 2007).From the viewpoint of Francis D.K. Ching, Golden section is one of the theories of proportion that describe from the theory of architecture (Figure 2). (Ching, F.D. K., 2007).

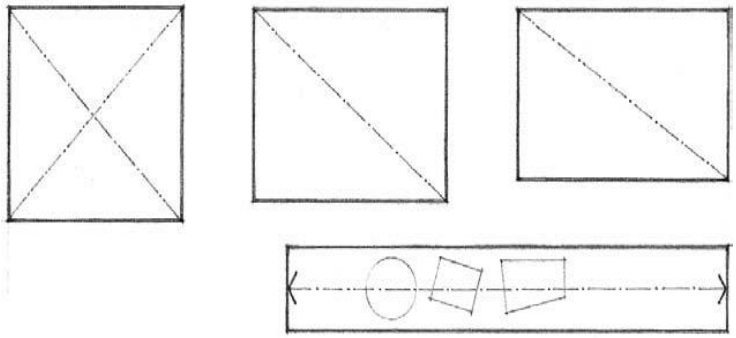
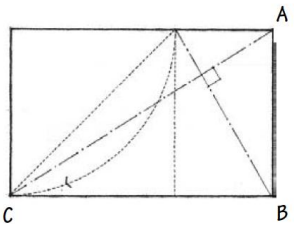


Figure 2: shapes with different ratio
Source: (Ching, F.D. K., 2007).

III. DEFINITION OF GOLDEN RATIO

There are varieties definitions of the golden ration. "Father of Geometry" is the nickname of Euclid who was the first one who discussed about the golden ratio definition and said that "A straight line to have been cut in extreme and mean ratio when, as the whole line is to the greater segment, so is the greater to the less" (Kissinger, C. E., 2012). Golden ratio is a ratio between sections or dimension of one element. In another word, for a line, the ration should be between two sections of it. For a plan or section, it should be between two spaces. The ratio can be shown by the equation (Figure 3) (Ching, F.D. K., 2007). Also called the golden mean (Ching, F.D. K., 1995). Golden section, divine proportion, golden proportion and golden mean are another terms for it. Some resources use Golden Number as another name (Kissinger, C. E., 2012). The ratio equal to Phi [Φ] = 1.618033988749895...The ratio represented by Phi (φ) in the ancient Greek (Md. Akhtaruzzaman et al, 2011).

$$\frac{a}{b} = \frac{b}{a+b}$$



AB = a
BC = b
Ø = Golden Section
$\text{Ø} = \frac{a}{b} = \frac{b}{a+b} = 0.618$

Figure 3: explain the equation of golden ratio with rectangular division (Ching, F.D. K., 2007).

From the viewpoint of Edmund Harriss (Harriss, 2015) if there is a pure rectangle with subdividing for as long as to the smaller rectangles into a square and even a smaller golden rectangle and if we draw a quarter circles in each square then we will get a spiral. (Figure (4)) shows the most famous images in mathematics, if not in all science. The curve is called the "golden ratio".

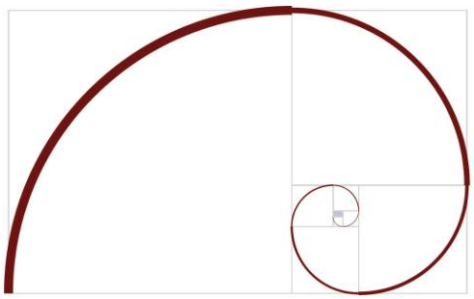


Figure (4): The golden spiral is a patchwork made up of quarter-circles. (Strictly speaking the golden spiral is a smoothed out version of this curve, Source: (the Guardian website, 2015)

The golden ratio dose didn't come suddenly. There are plentiful body of studies and experiments that demonstratedthe suitable ratio for aesthetically to the human eye.One of them is Gustav Fechner. He had done a psychological test to find aesthetical to the human eye. The test was carried out for 347 men and women. It was aboutchoosinga one rectangular between ten rectangular that were different in their ratio. The ratio was between 1:1 and 2:5. Among them, 35 percentages of them chose that rectangles that have the golden ratio 21:34 (Bozinoff, M., 2015). This test clarified that the golden ratio is a ratio that prefer among them to the human eye psychologically(Figure 5).

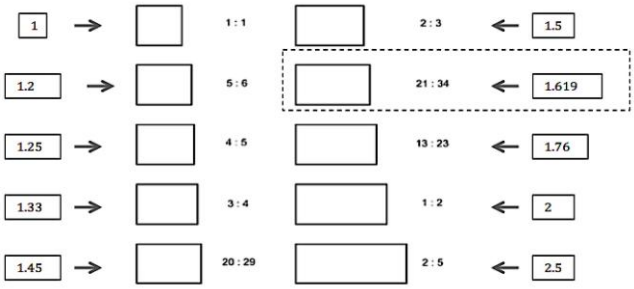
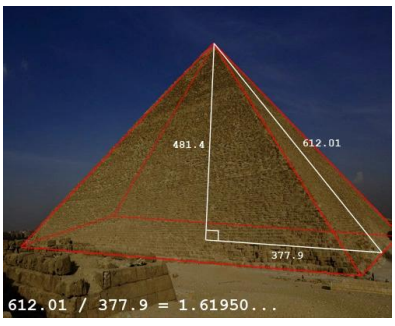


Figure 5: Ten-rectangular with different ratio
Source: (Bozinoff, M., 2015) sketched and calculated on it by the author.

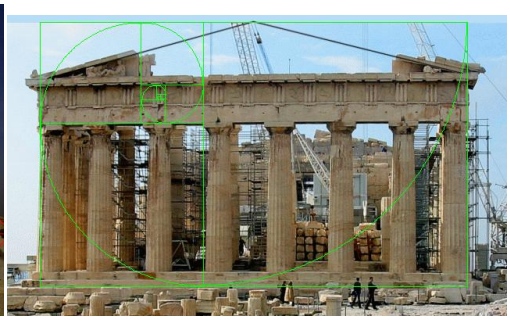
IV. HISTORY OF GOLDEN RATIO IN ARCHITECTURE

The relationship between mathematics and nature in architecture is the significant point of interest in ancient history. It is not easy to pinpoint, exactly, the first use of the golden ratio. There areseveralbeliefs about the first understanding and using of the golden ratio.A lot of believers think that ancient Egyptians were using the golden ratio firstly in their pyramids buildings. After that, Greeks designed their buildings and sculptures by this ratio (Kissinger, C. E., 2012). On the other hand, others have opposite believing and suppose that using this ratio at first goes backto the Egyptians, butwithout understood about this ratio. Otherwise, the Greeks had known about the division truly (Kissinger, C. E., 2012).The golden ratio was the strong standard in ancient Greece because of its importance in natural and beautiful (Bozinoff, M.,2015). They have expounded this relation between them by the ratio and mathematical representation and Phidias, Plato and Euclid are the words that used in this conversation (Bozinoff, M., 2015). Current evidences reveal that golden ratio was used about 2650 BC by ancient Egypt in their pyramids of Giza (AL Sharif, R., 2014).

During the middle ages, Renaissance,modernism, and many other architects used this ratio in their design. CN tower in Renaissance and UN building is the famous model of the golden section in their century (Figure 6).



Pyramids of ancient Greek
(Available at https://catphi.wordpress.com/2010/09/16/fibonacci-sequence/)



Parthenon
Source: (Bozinoff, M., 2015).

Renaissance - CN Tower in Toronto
(Md. Akhtaruzzaman et al, 2011).

Figure 6: examples in three different periods.

V. TERMS OF GOLDEN RATIO

As it has been mentioned above, there are a number of terms used for golden ratio in different cases. Each of them originates back to specific cases of using this ratio. To elucidate that, term of Golden Section can be used when it's used in cubic geometry. Golden Triangle also another term that seen. In isosceles, triangle when the ratio between the legs to the base have the golden ratio(Kissinger, C. E., 2012).Also, there is a term of Golden Spiral that to have the dimensions of parts the golden ratio (Kissinger, C. E., 2012).

The whole length divided by the longest part, then you will have the Golden Ratio (Figure 7) (Kissinger, C. E., 2012).

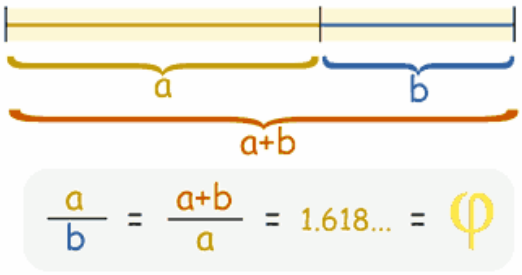


Figure 7: Dividing the line with golden ratio
Source: (Kissinger, C. E., 2012).

VI. CASE STUDY

Throughout the century design the buildings with golden ratio appear clearly and a number of them are becoming famous buildings. In this section some of them are explained. Parthenon: is a famous example in using the golden ratio. It was built around 440 BC by two persons (Salingaros, N. A., 2012).“As is well known, one of the marvels of the Parthenon is its carefully-computed curvature, or “entasis” It makes no sense to look for rectangles on a building that is essentially curved” (Figure 8)(Salingaros, N. A., 2012).

Focusing on its proportional part, it can be gotten that the ratio between the height and width of the building has the golden ratio. It does not mean that all dimensions and ratio of the building related to the ratio or have the ratio. To illustrate that, the ratio between length and width is 1:2.25. 1:3 (Figure 10) (AL Sharif, R., 2014).

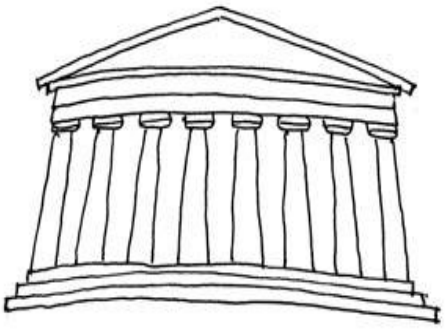


Figure 8: Parthenon frontal façade Source: (Salingaros, N. A., 2012).

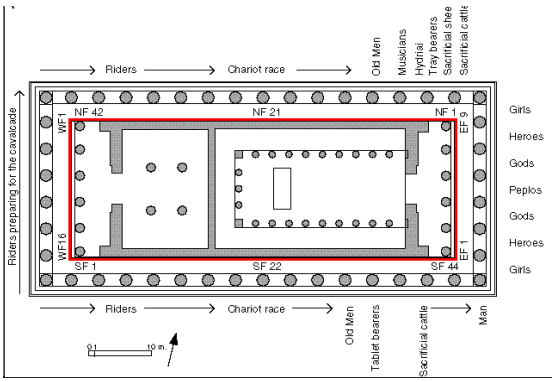


Figure 9: building plan of the Parthenon Source: Kissinger, C. E. (2012).

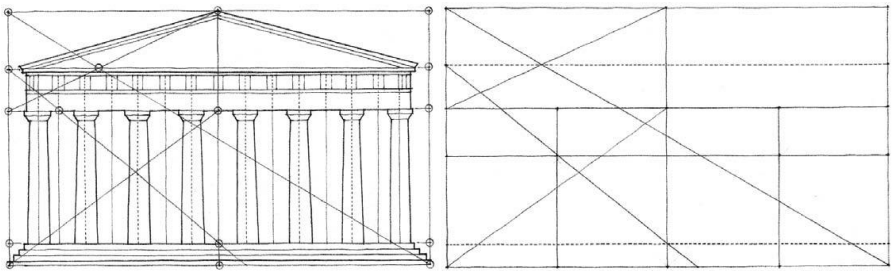
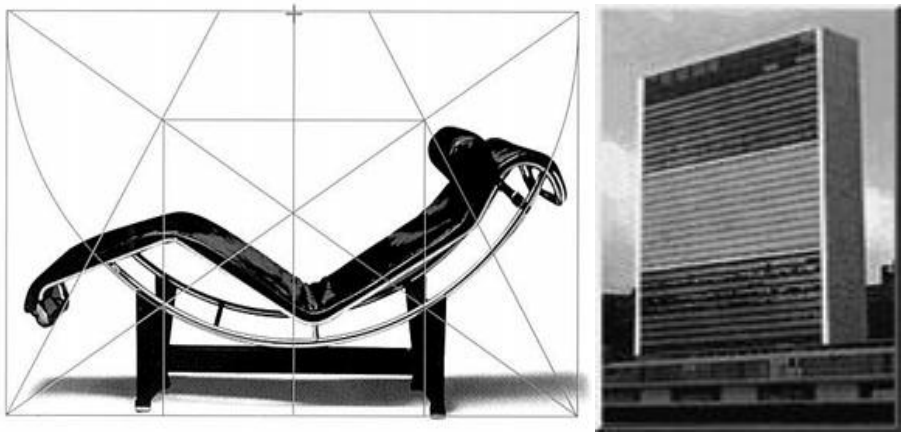


Figure 10: The Parthenon, Athens, 447–432 B.C., Ictinus and Callicrates
Source: (Ching, F.D. K., 2007)

Chaise: In modernism also as classic style, there is a golden ratio in their design. As known that Le Corbusier is one of the popular architects in modern time that design a golden Moduler mean (Md. Akhtaruzzaman et al, 2011). Also in his chaise design, Le Corbusier used the principle of golden rectangles. The width of the rectangle is equal to the radius of the frame curve of the chaise (Figure 11 (a)) (Md. Akhtaruzzaman et al, 2011).

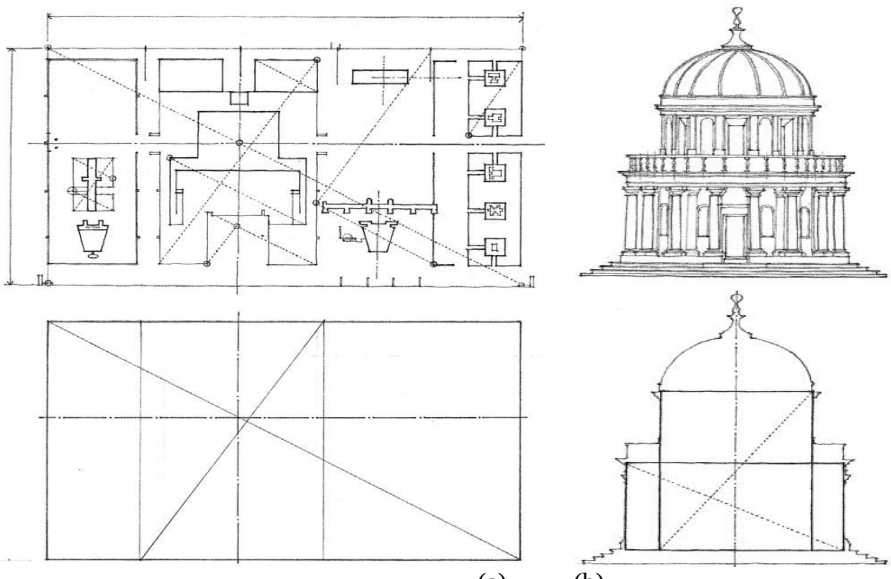


(a) (b)

Figure 11: (a) Chaise Lounge 1926. **(b)** United Nation building
Source: (Md. Akhtaruzzaman et al, 2011).

The United Nations Building: Talking about the tall building and how it looks like to viewdoes not seem to the low-rise buildings. It is clear that, a rectangular high-rise building cannot be seen like it's rectangular for those peoples that look at in near. Otherwise, it appears as a triangle with cutting off the top. The UN building is one of those tall buildings that does not appear as a triangular in near. This building has the rectangular empty shape. The golden ratio exists in its dimension as an overall and windows. Wallace Harrison and Max Abramovitz designed the tower in 1950 Salingaros, N. A., (2012). The UN high building is a highest tower that has the golden ratio (Figure 11 (b)) (Md. Akhtaruzzaman et al, 2011).

There are many other buildings around the world have the golden section. To illustrate that: the Great Wall of China also has a principle of golden ratio in its columns and length (AL Sharif, R., 2014). Also word museum in its plan, Tempietto of S. Pietro in Montorio (Figure 12) (Ching, F.D. K., 2007), The Bagdad City Gate, and number of house and villa have been designed bythe golden ratio.



(a) (b)

Figure 12: (a) World Museum, **(b)**Tempietto of S. Pietro in Montorio
Source: (Ching, F.D. K., 2007),

VII. USING GOLDEN SPIRAL IN CITY DESIGN

The two figures bellow (13) & (14) shows that how the concept of the city distribution get benefit from the nautilus shape. For instance, the penetration straight lines through the nautilus curves could be create different requirements for the city such as street networks, pedestrian, canals, urban boulevards as an access to the core city, parks, and…etc. as it is clear that in the linear and the circle city block sizes become smaller in the core city and the densities are more intensive, the same thing is true for the spiral city which is the density are increase and the block sizes become smaller in the city center. Moreover, the intersection among the straight lines and the curve lines allows the city to provide the residential areas, facilities, services, and parks, even more, the smaller curve lines let to the residents to provide their movement and transportation activities throughout the city even by walking bicycle or mobility. The larger mobility routes in the outer city will make huge green spaces.

Figure (13): shows the Spiral Header
Source: The Guardian website, 2015

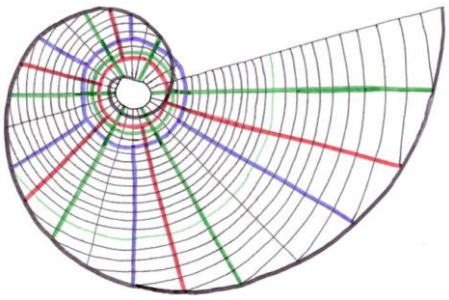


Figure (14): shows the golden spiral city plan
Source: The Guardian website, 2015

VIII. CONCLUSION AND RECOMMENDATION

From what have been explained above, rules and principles shouldbe considered for aesthetical purposes. Designis not just about sketch and finding the beautiful shape. There is no debate that many factors have effects on the designbuildings such as the shape of the land, location, environment and so on.Basically, there are several principles that the designers have to take into account while they do theirsketches and designs. This study reviewed one of the principal parts that is the golden ratio.

This study investigates that there areprinciples and basics in architecture design related to the mathematicsin general. It is obvious that mathematics has especial aesthetic if it used relatively more proper in designing buildings.This mathematic is not simply about the numbers only,it is also about the relation and the ratio between the numbers.The Golden ratio for the architects is a global term of use in different areas such as furniture, low-rise building and skyscrapers.

The case studies and proofs show that the golden ratio has its influenceson the architecture. In reality, the golden ratio is not just about equation and rules only, but it can be applied in very detail architecture in different scales. In many occasions, architectures consider the beauty and for argument on their design need proofs.Basically mathematic presents proofs and truth. In many cases, designers can use mathematics as golden ratio for proofing their works. It can be concluded that, understanding the almost principles are very important for architecture.

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