FINDING HARMONY IN CHAOS: THE ROLE OF THE GOLDEN RECTANGLE IN DECONSTRUCTIVE ARCHITECTURE
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deconstructivist architecture; golden ratio; golden rectangle; proportional systems; architectural design; geometry

Abstract

It is generally accepted that compositions in deconstructive architecture are irrational, fragmented, and do not follow proportional systems or principles of architecture, such as harmony, continuity, and unity. These compositions are understood as the result of compilations of random geometries that are often non-rectilinear, distorted, and displaced. In spite of this, deconstructive architecture is widely accepted and practiced in the last couple of decades. On the other hand, geometrical proportions have long been considered as a self-guided method of aesthetically proven designs. This paper examines the hypothesis that the golden rectangle as a proportional system is manifested, to a varying degree, in deconstructive architecture. Methodologically, the hypothesis was tested using two inter-related methods. First, Tension Points of three famous examples of deconstructivist architecture were identified using the Delphi method by a panel of experts. Second, a matrix of displaced golden rectangles was used to test the degree of correspondence between the tension points of the case studies and the golden rectangle. It was found that deconstructive architecture is not a type of “free-form” architecture; and that conventional proportional systems and aesthetics laws, such as the golden ratio, are partially manifested in its compositions and forms, thus confirming the hypothesis. This paper argues that since architects are trained to capture proportional systems and design according to certain organizational and proportional principles, this would inevitably be consciously or unconsciously reflected on their designs.

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INTRODUCTION

The effect of new ways of thinking and innovative philosophical ideas on architectural design is unavoidable and can be easily traced back through the history of architecture. This is particularly notable in the twentieth and twenty-first centuries. This influence is not restricted to the design process, but expands to impose a changing power on the final product itself as illustrated in the visual appearance of forms and compositions (Weston, 2011). One of the most notable and recent philosophical trends that have had a significant influence on contemporary architecture is the Deconstruction Theory (Wong, 2010).

This paper does not discuss the deconstructivist architecture’s focus on human experience of space, which has been a subject of a wider debate in the last decade. It attempts to draw attention to the outer form of deconstructive buildings and how these random-looking compositions are governed by concealed proportional systems. Such systems are causing them to inherit beauty that might justify the wide acceptance and spread of this movement. Forms in deconstructive architecture are known for being a compilation of random geometries that are often non-rectilinear, distorted, and displaced. It is generally accepted that the resultant compositions in this architectural style are usually irrational, fragmented, and more importantly, do not follow proportional systems nor principles of architecture, such as harmony, continuity, and unity (Jodidio, 2011). The movement itself rejects the purity of forms and attempts to create ‘new sensibility’ by creating buildings that disturb the common understanding of forms (Johnson & Wigley, 1988). Some authors described the movement as an “assault on such familiar norms as horizontal floor planes, vertical walls, and regular structural grid” (Weston, 2011, p. 199).

On the other hand, geometrical proportions have long been considered as a self-guided method of aesthetically proven designs (Dabbour, 2012; Nabavi & Ahmed, 2016). In particular, the golden ratio is arguably known as THE indicator of aesthetic quality of buildings, which respect laws of proportion of nature. Le Corbusier stated in reference to the golden ratio, “Behind the wall, the gods play; they play with numbers of which the universe is made up,” emphasizing the divine property of the golden ratio (Kappraff, 2004, p. 288). Architectural designs that rely on the golden ratio as an organizational and proportional framework are considered as the exemplars of architectural aesthetics and order throughout the history of art and architecture.

The assumption underpinning this study is that since proportional systems and aesthetics laws – e.g., the golden ratio- inherently exist in natural and artificial environments alike, and since architects are trained to capture these systems and designs according to certain organizational and proportional principles, then, these laws and proportional systems should be partially manifested in the deconstructive architecture, consciously or unconsciously. Hence, this study has attempted to provide evidence that forms and compositions in deconstructivist architecture are not as random, distorted, displaced, and fragmented as they are assumed to be. It argues that deconstructive architectural designs are governed, to a certain degree, by proportional systems and laws of aesthetics. Thus, this paper examines the following hypothesis:

1. The golden ratio as a proportional system is manifested, to a varying degree, in the two-dimensional generative elements of deconstructive compositions; and that a systematic representation of a matrix of golden rectangles is needed to unveil the proportional principles inherent in deconstructive projects.
To address these hypotheses, this paper employs two interrelated methods. Firstly, a matrix of golden rectangles, that are displaced and have variety of scales, was used to examine famous examples of deconstructive architecture in order to demonstrate the extent to which the generative elements of the forms manifested proportional systems. Generative elements in this context are understood as the two-dimensional elements from which the three-dimensional components of the elevations of the form were extruded. This method can also be used as a framework to guide new designs in a way that respects proportional laws and harmony. Secondly, the Delphi Method was used to identify the tension points of three famous examples of deconstructive architecture. Next, the proposed method was applied on these case studies to test the degree of correspondence between the compositions of each case study and the golden ratio. Tension points are related to the concept of visual tension in art and design, and are understood in this study as the points of the generative two-dimensional elements of the form at which the composition of a building starts to deform, distort, or fragment to create visual tension, interest, and imbalance.

**Deconstructivism**

During the 1960s, Jacques Derrida and Paul De Man set out the outlines of the deconstruction movement in critical studies of literature and grammatology. Their notion and forward thinking have inspired other fields, such as art, fashion, and architecture. In particular, Derrida’s philosophy and thinking became the foundations upon which revolutionary architects of the 18th century refuted the two main prevailing facets of architectural styles of their time, namely, Modernism and Post-modernism.

Consequently, the architectural style known as Deconstructivism was embraced by a group of architects known as the “deconstructivists”, who understood architecture as a kind of communication language. Based on this understanding, contradicting ideas and binary distinctions, such as presence and absence, solid and void, regularity and irregularity, harmony and chaos, are believed to occur in architecture just as they occur in linguistics philosophy. The traditional understanding believes that one concept in each binary distinction possesses a governing power, whereas the other is a subsequence of the first and is significantly less important. However, deconstructivism argues that the less advantaged concept, or the subjugated one, is just as important and necessary as the explicit meaning and expression of the first concept. It is argued that creativity and uniqueness lies in the way between the two concepts (Weston, 2011). In architecture, this way of thinking has created new opportunities to re-read the traditional architectural styles and opened possibilities to re-evaluate their values and concepts (Durmus & Gur, 2011). This, in turn, suggests that since buildings can be designed and constructed using the conventional laws of architecture, the non-conventional methods, such as deconstruction, could also be used to design functionally and structurally stable buildings.

When translating this philosophical understanding into architectural language and forms, architects tend to reject the conventional rectilinear geometries of the common architecture and transfer them into non-rectilinear shapes by manipulating the outer shell and external non-structural surfaces of the building. Unlike conventional architecture, the simple geometric forms are allowed to distort each other and the composition does not necessarily follow compositional rules that ensure stability and form purity (Johnson & Wigley, 1988). Hong and Hwang (2006) had summarized four general compositional methods in deconstructionism,
namely, decentering, disjunction, decomposition, and discontinuity, as well as the denial of history.

The resultant composition is often characterized by the absence of fundamental architectural principles, such as proportional systems, harmony, unity, continuity, and coherence. It also focuses on radical formalism with complete rejection of constraining notions, such as “purity of form” and “form follows function” of the modernism. This tendency among deconstructive architects to liberate form from the rigidity of historical, scientific, and technological rationalities has resulted in the use of opposing geometries and distorted grid (Wong, 2010). According to Jodido (2011), this random-looking and sometimes conflicting geometry is used by deconstructivist architects as a metaphor to reflect the competing forces in contemporary cities that would often lead to fragmented and unstable societies.

This movement was crystalized by the famous 1988 New York exhibition, “Deconstructivist Architecture”, organized by Philip Johnson and Mark Wigley. Frank Gehry, Daniel Libeskind, Rem Koolhaas, Peter Eisenman, Zaha Hadid, Coop Himmelblau, and Bernard Tschumi were the avant-garde architects featured in this exhibition. Perhaps, the simplest and clearest description of this movement can be found in the exhibition’s Fact Sheet, which stated: “Deconstructivist architecture focuses on seven international architects whose recent work marks the emergence of a new sensibility in architecture. The architects recognize the imperfectability of the modern world and seek to address, in Johnson’s words [Philip Johnson], the "pleasures of unease." Obsessed with diagonals, arcs, and warped planes, they intentionally violate the cubes and right angles of modernism. The traditional virtues of harmony, unity, and clarity are displaced by disharmony, fracturing, and mystery.” (MoMA, 1988, p. 1).

Arguably, deconstruction architecture pays a great deal of attention to people’s experience of space, which is quite similar to the Soviet Constructivists that formed the base for the deconstruction architecture in the west (Valon, 2009). However, in a recent study, Mohtashami (2016) argued that the deconstruction movement has influenced architectural designs in semantic, physical, and technical aspects. He analyzed 23 buildings and found that deconstruction criteria are mostly realized in the physical characteristics of buildings, rather than in the semantic or technical characteristics. In fact, forms and compositions of buildings seems to be the primary focus of the movement since its inception.

In this century, the rapid development of computer-aided designing and drafting systems, coupled with the technological advancement in construction systems and materials, have greatly facilitated deconstructivism to flourish in architecture. This growth is supported by the unprecedented desire among contemporary architects to produce buildings that are surprising, impressive, eye-catching, and aesthetically sound. Designers are now able to create unexpected and complex shapes and compositions that would have been impossible otherwise. In addition, CAD systems offer the facility to simulate the post-construction effect of buildings, in terms of their environmental impact, energy use, and structural stability, which in turn support and provide justification for the deconstructivism movement. These advancements have allowed architects to create forms that are able to “disturb our thinking about form” making them deconstructive (Johnson & Wigley, 1988, p. 10).

This movement has received strong criticisms from several architectural critiques and philosophers, such as being detached from the context, holds little social significance, and embraces capitalism (Frampton, 2007), and undermines the historical reading of the site.
(Weston, 2011). Nonetheless, this movement has managed to find its notable place within the world's architectural scene, declares itself as a leader and trend-maker in architecture, and incites more public interest and reception (Durmus & Gur, 2011).

Producing a generalized definition of deconstructive architecture has been difficult because heterogeneous and un-repetitive forms are among the principal characteristics of the movement (Valon, 2009). However, nowadays, the architectural community accepts that forms and compositions in deconstructivist architecture may appear distorted, dislocated, fragmented, and consisting of discordant pieces, with the final product being unpredictable, not following proportional systems, and showing controlled chaos. These characteristics are arguably common among almost all deconstructive projects.

In spite of the irrationality and nonsense in form formation and the disregard for the laws of aesthetics and organizational order, deconstructive projects are well accepted and widely spread around the globe. It has also become a leading trend in design, which has raised several questions: since the human brain is prone to seek order and reasoning, why is deconstructive architecture publicly accepted and celebrated? Does deconstructive architecture conceal, either intentionally or unintentionally, some sort of proportional systems in its unexpected and surprising forms and compositions? Therefore, it is necessary to examine the role of the proportional systems in deconstructive architecture.

**Proportional Systems and the Golden Ratio**

Throughout the centuries, human beings are prone to surround themselves with beauty. The ancient Greeks had developed the science of aesthetics as a way to understand and analyze this mysterious, but fascinating, concept. In their attempt to answer the question ‘what makes something beautiful?’ they were inspired by the language of the natural world, where harmony and rhythm are manifested in the form of geometrical proportions. They believed that harmony is the key to beauty and that geometrical proportion is the key to harmony. Plato (360 BC), in one of his dialogues, Timaeus, wrote about the proportional systems and considered them as a key to the physics of the cosmos. Marchant (2013a, p. 34) beautifully highlighted why understanding and capturing proportions matters in our life when he stated, “The universal language of proportion may be seen as the outward reflection of an inner beauty. It is found in the underlying structure of nature, from the smallest to the largest levels of scale, and connects all things of the world to the cosmic order of the universe.” Hence, he argued, shapes designed to harmonious proportions are the most aesthetically pleasing shapes.

The relationship between proportions and architecture is as old as the era of Vitruvius (1st century BC), who described the proportions of the human body and noted that these proportions should have a relation to architecture. In architecture and pattern design, the importance of geometrical proportions is amplified because architecture uses shapes and geometries, and seeks to compile them in the most aesthetically pleasing way. Dabbour (2012, p. 381) stated, “Geometric proportions in architectural patterns represent a design language, as words do in a spoken language. They determine the frameworks within which elements may be arranged into a pattern, a relation between one element and another, and a proportional relation within one element. They address and reflect the natural laws that govern the basic harmonies of nature, being describable by means of mathematics and geometry.” In addition, the use of proportional system in architecture guarantees that each
and every part of the design is correlated (Frings, 2002). This, in turn, results in aesthetically pleasing and workable designs.

In their search for a formula for beauty, the Greek discovered the golden ratio and considered it as a pre-requisite to harmony and beauty. The golden ratio is often denoted by the Greek letter, \( \phi \) (Phi), which is an irrational mathematical constant that can be written algebraically as, \((\sqrt{5}+1)/2\), or approximately 1.6180339887. Zeising (1845) claimed that the beauty of numerous works of art is the result of their components being in the golden ratio. This claim is supported by Fechner’s series of psychological experiments on aesthetics (Fechner, 1865, 1876; Fechner & Höge, 1997).

The golden ratio is manifested in the natural world, in human proportion, and in the growth patterns of many living flora and fauna (Elam, 2011) as well as in the universe (Kapusta, 2004). Arguably, the golden ratio is the most pleasing proportion to the human eye (Akhataruzzaman, et al., 2011). Green (1995), in his review of the historical and contemporary issues related to the alleged aesthetic properties of the golden ratio, found that there are real psychological effects associated with the golden ratio.

Architects in their quest for beauty have been fascinated with the concept of the golden ratio since the ancient times. It was first applied at the Parthenon by Greek sculptor and mathematician, Phidias (and hence the ratio got the initials “Phi” of his name) (Huntley, 1970). It also exists in the design of the Pyramids, which indicates that the Egyptians were also aware of the ratio (Meisner, 2016a). In a literature review on the golden ratio, Shekhawat (2015) found that many key architects in history, such as Palladio, Le Corbusier, Pacioli, and Leonardo DaVinci, favoured the use of the golden ratio in their designs. He summarized several studies showing that many buildings in ancient and contemporary times have been built based on the golden ratio, and that the golden ratio has occurred at different moments in the history of architecture.

However, some authors questioned the relationships associated with the golden ratio and described them as coincidences and exaggerations (Kissing, 2012; Gailiunas, 2015). Others went even further to provide evidence on what they call “misleading” claims of the existence of the golden ratio in famous examples in nature, art, and architecture (Markowsky, 1992). Many of the criticisms were however refuted (Meisner, 2016b). In addition, some psychologists questioned whether the golden ratio is actually associated with people’s preference and choice for aesthetics (Phillips, Norman, & Beers, 2010).

Throughout history, other proportional systems were also used and recommended by architects, philosophers, and mathematicians. Plato, for example, placed great importance on two geometrical ratios: the two times progression of 1:2:4:8; and the three times progression of 1:3:9:27, which are used in musical proportions. In architecture, Palladio used these ratios in the room plans that he advocated (Marchant, 2013a). During the early Renaissance, Pacioli (1447–1517), the Italian mathematician, wrote “Tractato de l’architettura”, which was a part of the 3-part book, “The Divine Proportion”. He recommended – along with the golden ratio – that architects should use simple ratios of integral numbers, such as 1:2, 1:3, 3/4, and 2/3 (Frings, 2002). Root two \((1:\sqrt{2})\), root three \((1:\sqrt{3})\), and root five \((1:\sqrt{5})\) have been also used in art and architecture. Plato described root two and root three equilateral triangles as the most beautiful triangles that are underlying the structures of the universe (Marchant, 2013b). These proportional systems can also be found in the art and design of Islamic architecture (Dabbour, 2012). Marchant (2013a) showed that
$\phi$, $\sqrt{2}$, $\sqrt{3}$, and $\sqrt{5}$ were the underlying geometrical proportions for the designs in Islamic patterns, while $\phi$, $\sqrt{2}$, $\sqrt{3}$, were used in the design of Taj Mahal in Agra, India. These proportional systems, the golden ratio included, were clearly manifested in notable buildings in the history of Islamic architecture, such as the Great Umayyad mosque in Damascus (709-715), Ibn Tulun mosque in Cairo (876-879), Sultan Qaytbay Funerary Complex in Cairo (1472-74), Bu Inaniyya madrasa in Fes (1350-55), and the 19th-century extension of Cordoba mosque (Marchant, 2013a). Although the golden ratio is not the only proportional system that was used, experimented with, and recommended throughout the history of art and architecture, it is indeed the most widespread criterion of beauty that permeates the world of art and architecture (Stakhov & Sluchenkova, 2003).

The use of the golden rectangle by many key architects throughout history is not only driven by cultural and aesthetics reasons, but also by functional needs. Shekhawat (2015) provided mathematical evidences that the golden ratio achieves a great level of connectivity and creates the best-connected rectangular arrangement. Despite criticisms, the golden ratio provides an effective means upon which aesthetics in architecture can be analyzed, evaluated, and compared in a quantitative way.

**Tension Points**

In art and design, Visual Tension is the source of visual interest and vital energy that shape the connection between the art (a building’s form in this study) and the observer (Fennel, 2009). This term is generally defined as “a balance maintained in an artistic work between opposing forces or elements; a controlled dramatic or dynamic quality” (Editors of Encyclopaedia Britannica, 2011). Visual tension is understood in this study as the interplay of conflicting forms that creates a balance between the conflicting visual and physical forces that provoke feelings of uneasiness or suspense. With this understanding, Tension Points are defined as the points of the generative two-dimensional elements of the form at which the composition of a building starts to deform, distort, or fragment to create visual tension, interest, and imbalance. Based on the aforementioned literature and understanding, this paper uses a matrix of multi golden rectangles that are displaced and have variety of scales to explore the degree of correspondence between tension points of famous examples of deconstructive architecture and the golden ratio.

**METHODOLOGY**

**The case studies**

Three famous deconstructive building designs were selected as the case studies for this study. The selection was based on the following criteria:
- The significance of the design in the history of the deconstruction movement;
- The architect should be known for his/her deconstructive approach in design;
- The design is already constructed, occupied, and functioning;
- The popularity of the building among the architecture community;
- The availability of literature, including 2D drawings and 3D models.

Consequently, three building were selected, namely, the 41 Cooper Square, the Cincinnati Contemporary Arts Centre, and the Perot Museum, as shown in Figure 1. The availability of data and drawings had played a major role in the selection process.
Method Development

The golden ratio itself is a property of a one-dimensional (x, y, or z) line segment. A line is thought to achieve the golden ratio when it is divided into two segments in a way that the ratio between the longer segment and the shorter segment equals the ratio between the length of the whole line and the longer segment, as shown in Figure 2. This ratio is always equals to \( \varphi \) (1.6180339887 approx.). The point at which the line is divided to achieve this property is called the golden section, i.e. \( 1/\varphi \).

![Figure 2. One-dimensional representation of the Golden Ratio](Source: Authors)

\[ \frac{AC}{CB} = \frac{AB}{AC} = 1.618033987 \text{ approx.} \]

A line segment, AB, is divided to form a golden ratio at the golden section, i.e. point C.

When expanding the golden ratio into two-dimensional representations (xy, xz, or yz), we get the golden rectangle. A rectangle is said to be a golden rectangle if the ratio between its long side and its short one equals \( \varphi \) (Stakhov & Sluchenkova, 2003). A series of golden rectangles that correspond to Fibonacci numbers can be constructed, as shown in Figure 3 (the golden rectangles in Figure 3 are AFED, BCEF, and GHCE), where \( \frac{AF}{FE} = \frac{BC}{CE} = \frac{HG}{GE} = \varphi \). The process shown in the figure can continue infinitely to create smaller and smaller golden rectangles.

![Figure 3. Steps of constructing a two-dimensional representation of the golden ratio i.e. the Golden Rectangle](Source: Authors)
The two-dimensional golden rectangle has repeatedly appeared in studies that offer analyses of proportions in building designs. Searching the phrase, ‘golden rectangle in architecture’ on Google could yield hundreds of thousands of results. In this type of analysis, the golden rectangle is usually superimposed on plans, sections, or elevations of buildings to show that the exterior dimensions or the arrangements of some architectural elements in buildings correspond to φ, as shown in Figure 4. This method was applied in the visual analysis of the Pantheon in Rome (Doczi, 2005), the Palazzo della Signoria in Florence (Bartoli, 2004), The Great Umayyad mosque in Damascus (Marchant, 2013a), and other traditional and contemporary examples of architecture, art, fashion, and nature.

In spite of the fact that architectural forms are naturally three-dimensional products, to the authors’ best knowledge, the golden rectangle has never been used to analyse the generative two-dimensional elements of the three-dimensional forms of buildings. Almost all analyses in this area were focused on the overall dimensions of the elevation or the arrangements of the two-dimensional elements, while neglecting the third dimension. This has developed a perception that the golden rectangle is restricted to the design of regular and grid-based plans and elevations, and could not be used as a tool to create forms and compositions. Therefore, this study presents a matrix of displaced golden rectangles superimposed on the generative two-dimensional elements of the form that can be used to analyze architectural forms in terms of the degree to which the formation of the composition corresponds to the golden rectangle. The focus is on the analysis of famous examples of deconstruction architecture as previously explained.

Figure 4. Examples of the conventional way of using the golden rectangle to analyze architectural elevations and plans.

Our starting point was a simple 3D cuboid, with the dimensions of 1:1*1:φ, corresponding to the golden rectangle, as shown in Figure 5a. A golden rectangle can be superimposed on any of the elevations creating an extrusion grid as shown in Figure 5b. The designer can opt to use more than one golden rectangle and displace, rotate or rescale them to create a more
complex grid. Then the designer can select any parts of the golden grid and subject them to extrusion procedures in a way that corresponds to the functional requirements of the building, as shown in the example in figures 5c. The extrusion values could also correspond to the golden ratio and can be done either positively (addition) or negatively (subtraction), figures 5d. The resultant form can then be scrutinised against functional, environmental, and structural requirements. The process can be repeated until a satisfactory composition is developed. The final composition should then be subjected to further development and refinement to achieve workable internal spaces. Therefore, this method could help designers to create unlimited aesthetically pleasing novel forms from simple shapes, which in turn allows the designer to explore a whole range of possible compositions that the variability of the initial form allows.

Figure 5. The process of producing compositions that conform to the golden ratio (Source: Authors). a) Start with a simple cuboid, b) superimpose one or more golden rectangles on any of the elevations, c) select areas on the grid for extrusion, and d) extrude these areas.
In this case, the golden rectangle provided a design framework and a systematic method to produce innovative, novel, and unusual compositions that could achieve the aesthetic criteria of the golden ratio. Figure 6 shows a perspective of the resultant form.

![Figure 6. A perspective of the resultant form (Source: Authors).](image)

Architects have the choice to select the number, scale, and location of the golden rectangles from which the two-dimensional shapes would be extruded to create the composition. The selection of the golden rectangles and the extrusion procedures should correspond to a design goal, e.g., functional, environmental, contextual, or structural. In addition, the designer might use the golden ratio to guide the extrusion values in order to produce compositions that are fully conforming to the golden ratio. However, this might be challenging in some cases due to functional or structural constrains. Although this process seems to impose restraints on the design, it actually provides a structure within which unlimited aesthetically pleasing compositions could be created. Then, the designer can select the form that he/she accepts as the most appropriate, and would satisfy the balance between aesthetical, functional, and structural requirements. Figure 7 demonstrates the possibility of producing an unlimited number of compositions that conform to the golden ratio using the method described before.

Similarly, the same method can be used to analyze existing designs by superimposing a displaced matrix of golden rectangles on the elevations of the form of an existing design. The number, scale and position of the different golden rectangles can be modified in an iterative manner to find the best fit between the golden matrix and the tension points of the composition. This assessment method was used in the current study to test the degree of correspondence between the tension points of the selected case studies and the golden rectangle. By doing so, the degree of the composition’s correspondence to the golden ratio can be measured. Subsequently, different compositions can be compared in terms of aesthetics and harmony.
Tension point identification (Delphi Method)

To identify the tension points for each building form, the Delphi method was used. This method was designed to capture the opinions of a selected group of experts in the subject of discussion through a series of structured data-gathering rounds (Kahn, 2006). Typically, participants are anonymous to each other and they are physically isolated. In the first round, each participant is asked to answer a question or a set of questions based on their experience and knowledge. The facilitator would collect, summarize, and present the data as a collective response that combines the answers of all participants. In round two, the participants are presented with the collective answer of the whole group and are given the opportunity to revisit their original answer. This process can be repeated until a consensus is reached. The Delphi method is widely used in researches and practices when a consensus among experts is needed (Abdulrahman, 2010).

In this study, a two-round Delphi survey was conducted with four experienced architects to identify the tension points for each case study. We followed the typical protocol of the method. Each participant was presented separately with 2D and 3D drawings of the three case studies and they were asked to highlight, on the drawings, what they think is a major tension point. It was clarified for them that tension points in this context means “The points of
the generative two-dimensional elements of the form at which the composition starts to
deform, distort, or fragment creating visual tension, interest, and imbalance*. Since the
deformation and fragmentation of the form is better observed in the three-dimensional space,
participants were given the freedom to use the two-dimensional, three-dimensional or both
types of drawings to fully understand the buildings and identify the tension points in a more
accurate and comprehensive manner. The data was then summarized by the researchers
and presented anonymously for each building. Next, the participants were asked to revisit
their answers upon considering the collective answers of all participants. The revised data
were then collected and sent to the participants for a final feedback.

This exercise was limited to two adjacent elevations for each case study due to practicality.
Including more elevations would have resulted in a large number of judgments that
participants should make, which is likely to compromise the quality of the outputs. In addition,
the Delphi method requires the participants to revise their answers in light of the collective
response of the whole group. Including more elevations would have created confusion and
uncertainty in the revised answers. This is an exploratory study that aims to provide initial
evidence that proportional systems are manifested to a varying degree in deconstructive
architecture. Thus, it was concluded that two elevations for each case study would be
sufficient to fulfil the aim of this study.

The degree of correspondence between tension points and the golden
rectangle

To quantify the degree of correspondence between the tension points of the forms of the
case studies and the golden rectangle, Equation 1 was used:

\[ r = \frac{\left( \sum_{i=1}^{n} \frac{x_i}{t_i} \right)}{n} \]  

Equation 1

where \( r \) is the overall degree of correspondence between the form’s tension points and the
golden rectangle, \( n \) is the total number of elevations considered, \( x \) is the number of tension
points on the elevation that conform to the golden rectangle, and \( t \) is the total number of
tension points of the elevation. Upon completing the development of the method, it was
applied to assess the degree to which three famous examples of deconstructive architecture
correspond to the golden rectangle.

RESULTS

Tension Points

As previously explained, tension points identified by a panel of experts were collected using
the Delphi method. Table 1 shows the number of tension points that all participants in the
Delphi method had agreed upon for each building, while Figure 8 maps these tension points
on two adjacent facades of each case study.
Table 1. Number of tension points identified by the Delphi panel in each case study (Source: Authors).

<table>
<thead>
<tr>
<th>Case Study</th>
<th>No. of tension points</th>
<th>Total no. of tension points</th>
</tr>
</thead>
<tbody>
<tr>
<td>41 Cooper Square</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Front view</td>
<td>23</td>
<td>43</td>
</tr>
<tr>
<td>Side view</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Cincinnati Contemporary Arts Centre</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Front view</td>
<td>24</td>
<td>52</td>
</tr>
<tr>
<td>Side view</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>Perot Museum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Front view</td>
<td>17</td>
<td>33</td>
</tr>
<tr>
<td>Side view</td>
<td>16</td>
<td></td>
</tr>
</tbody>
</table>

The table shows that the Cincinnati Contemporary Arts Center has the highest number of tension points with 52 points, followed by the 41 Cooper Square with 43 points, whereas the Perot Museum has the least number of tension points with 33 points. Discussions with the panel of experts have indicated that the form of the Cincinnati Contemporary Arts Center looks and feels more complex and dramatic compared with the other two projects. This could be due to the clear displacement of the elements of the elevations that had resulted in a stronger definition of the forming geometries. Another reason could be that this form consists of a large number of basic geometries that are connected and composed in an unexpected manner, as opposed to the other two projects, where fewer, but more distorted and skewed geometries were used. In addition, the variation in the colours of the Cincinnati Contemporary Arts Centre creates stronger contrasts between the geometrical shapes, resulting in a robust visual tension.

Once the tension points of the form of each case study have been determined, the previously described method was applied to analyze the extent to which the tension points correspond to a selected matrix of displaced golden rectangles. This step allowed the researchers to test the hypothesis underpinning this study; the golden ratio, as a proportional system, is manifested to a varying degree in deconstruction architecture.

Degree of correspondence

Several golden rectangles, with variations in scale, location, and orientation, were tested on two elevations of each case study. Due to the aim of the study, this process was iterative and exploratory in nature. The researchers attempted to test as many golden rectangles as possible to ensure a proper and comprehensive coverage of each elevation. Golden rectangles that overlapped with the tension points were then retained. Figure 9 illustrates the process of applying the matrices of the golden rectangles to the Cincinnati Contemporary Arts Centre.
Figure 8. Tension points of the case studies as identified by the Delphi panel of experts (Source: Authors).
Figure 9. Example of applying the proportional matrix to test the correspondence between tension points and the golden rectangle, Cincinnati Contemporary Arts Centre (Source: Authors).

The results of this exercise are shown in Figure 10, which illustrates the tension points in each project, as identified by the panel of experts, and the corresponding golden rectangles. For each elevation, three golden rectangles were found as “the best fit” for the tension points. The data from this figure were extracted to calculate the degree of correspondence ($r$) using Equation 1, as shown in Table 2.

The results support the hypotheses of this study and show that in all the projects considered for this study, a high degree of correspondence was found between the tension points and the golden rectangles. The highest degree of correspondence was found in the Perot Museum, followed by the 41 Cooper Square, with negligible difference (approx. 0.02%). The Cincinnati Contemporary Arts Centre had shown the lowest degree of correspondence, with a value of 0.56%. A careful examination of Figure 10 shows that the Cincinnati Contemporary Arts Centre has the highest number of tension points that conformed to multiple golden rectangles. This project also had the highest number of total tension points, as shown in Table 1. These two factors have contributed to lower the degree of correspondence of this project.

In conclusion, the results showed that the golden rectangle, as a proportional system, was found to be manifested, to a varying degree, in the three chosen case studies. This observation supports the hypothesis underpinning this study and suggest that the two-dimensional generative elements of the elevations that, when extruded, cause the form to deform, fragment or distort are govern to varying degree by the golden rectangle. Table 3 shows the number of tension points in each case study that conform to multiple golden rectangles. Higher number of these points indicates stronger presence of proportional systems in the case study. The Cincinnati Contemporary Arts Centre has the highest number of tension points that conformed to multiple golden rectangles, indicating a stronger presence of the golden ration.
Table 2. Degree of correspondence between tension points and golden rectangles for each case study, calculated using Equation 1 (Source: Authors).

<table>
<thead>
<tr>
<th>Case study</th>
<th>Elevation</th>
<th>Total number of tension points ((n))</th>
<th>Number of unique corresponding tension points**</th>
<th>Total number of corresponding tension points ((x))</th>
<th>Degree of correspondence of the elevation ((\frac{cx}{t}))</th>
<th>Overall Degree of correspondence ((r))</th>
</tr>
</thead>
<tbody>
<tr>
<td>41 Cooper Square</td>
<td>Front Elevation</td>
<td>23</td>
<td>Red 7</td>
<td>17</td>
<td>0.74</td>
<td>0.77</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Blue 5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green 5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Side Elevation</td>
<td>20</td>
<td>Red 6</td>
<td>16</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Blue 5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green 5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cincinnati Contemporary Arts Centre</td>
<td>Front Elevation</td>
<td>24</td>
<td>Red 8</td>
<td>15</td>
<td>0.63</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Blue 5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Side Elevation</td>
<td>28</td>
<td>Red 10</td>
<td>15</td>
<td>0.54</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Blue 10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green 5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perot Museum</td>
<td>Front Elevation</td>
<td>17</td>
<td>Red 7</td>
<td>12</td>
<td>0.71</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Blue 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Side Elevation</td>
<td>16</td>
<td>Red 5</td>
<td>14</td>
<td>0.88</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Blue 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green 6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* \(n\) is the total number of elevations considered. For all case studies, \(n = 2\).
** If a tension point is overlapped with more than one golden rectangle, it is only counted once.

Table 3. Number of tension points that conformed to multiple golden rectangles in each case study (Source: Authors).

<table>
<thead>
<tr>
<th>Case study</th>
<th>Elevation</th>
<th>Number of tension points that conformed to multiple golden rectangles</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>41 Cooper Square</td>
<td>Front Elevation</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Side Elevation</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Cincinnati Contemporary Arts Centre</td>
<td>Front Elevation</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Side Elevation</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Perot Museum</td>
<td>Front Elevation</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Side Elevation</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
Figure 10. The overlapping matrices of the golden rectangle and tension points. The letters A, B, and C depict the tension points that conform to the red, blue, and yellow golden rectangles, respectively (Source: Authors).
DISCUSSION AND CONCLUSIONS

This study challenges the general understanding among the architectural community, which promotes the idea that deconstructive architecture is based on random compilations of unrelated, displaced, and distorted geometries, resulting in compositions that do not follow traditional design principles, such as proportional systems and harmony. In particular, this study has examined the extent to which forms and compositions in deconstructive architecture are “random”. This focus was motivated by the hypothesis that since seeking patterns and order is an ingrained tendency in human beings, and since architects are trained to capture and apply proportional systems in their designs, then, proportional systems, such as the golden rectangle, are likely to be manifested in the deconstructive designs to varying degrees, whether consciously or unconsciously.

To test this hypothesis, two interrelated methods were used. First, a matrix of displaced golden rectangles was developed to test existing forms for the extent to which they conform to the golden rectangle. This method can also be used as a design tool to develop forms that achieve the golden ratio in their generative elements. Second, a two-round Delphi method was used to identify the tension points of three famous deconstructive projects, namely, the 41 Cooper Square, the Cincinnati Contemporary Arts Centre, and the Perot Museum. The idea of tension points was borrowed from the Visual Tension concept, which is well known in art, and is defined in this study as the points of the generative two-dimensional elements of the form at which the composition of a building starts to deform, distort, or fragment to create visual tension, interest, and imbalance. Then, the tension points were examined to check the degree of correspondence between their locations and selected golden rectangles.

It was found that the tension points of the three case studies conformed, to a varying degree, to the golden rectangles, thus, confirming the hypothesis. This suggests that some of the main generative two-dimensional elements on the examined elevations that, when extruded, caused the form to deform, fragment, or distort correspond to the golden ratio to certain degrees. The highest degree of correspondence was found in the Perot Museum, with 0.79 of the tension points conformed to the golden rectangle. Similar results were found in the 41 Cooper Square, with 0.77 of the tension points conformed to the golden rectangle. The lowest degree of correspondence was found in the Cincinnati Contemporary Arts Centre, with a ratio of 0.56%. However, this particular project has the highest number of tension points that conformed to more than one golden rectangle at the same time, indicating a strong presence of the golden ratio.

This paper uses the concept of tension points to examine the extent to which the forms in deconstructive architecture conform to the golden rectangle as a measure of aesthetics and order. Although tension points have been used in art at a two-dimension level, to the authors' best knowledge, its use in the context of assessing the two-dimensional generative elements of the three-dimensional forms of deconstructive architecture is rather original. For example, in his search for the golden ratio in art work, Kappraff (2004) believed that it is likely that artists have unconsciously built points of tension in their art in ways that correspond to the golden ratio that would result in “the natural state of tension” needed by the human brain to recognize an art work as pleasing. He added, “I, myself, have created a template from which I can measure certain points of tension and focus in many classic paintings and invariably found them to conform to the golden section”. In fact, our findings from analyzing and studying deconstructive architectural forms are aligned with his findings from analyzing paintings.
This study has provided evidence that deconstructive architecture is not as random as it looks to the naked eye, and that it is governed by varying levels of proportional systems. It has shown that deconstructive architecture is not a type of "free-form" architecture, as classified by Wong (2010). The scope of this study did not include determining whether the search for regularities through proportional systems in architecture is a sort of Apophenia, i.e., human tendency to seek patterns in unrelated data or things, or not, and whether researches in this area are "misfits" or informative. The debate in this topic is long-lasting and seems to be endless. Nevertheless, the role of proportional systems, such as the golden ratio, in architectural designs is almost undeniable. In fact, the role of proportional systems in architecture is deeply rooted in human history and in the theory of architecture, as previously explained. This is may be best summarized by Frings (2002), who provided evidence of the value of proportional systems from the ancient work of Vitruvius, who believed that an educated architect has to know arithmetic, geometry, and proportion of the human body; to Leon Battista Alberti in the Renaissance era, who recommended simple numerical proportions to architects; to Serlio, Vignola, and Palladio’s use of simple and commensurable ratios, and to the work of Luca Paccioli, who was a great admirer of the golden ratio in the 19th century, to Adolf Zeising, who arguably discovered the golden ratio for architecture; to Neufert and Le Corbusier’s work on the golden ratio in the 20th century. Our findings extend these works by providing more evidence that proportional systems are manifested in contemporary movements, namely, deconstructive architecture, in the field of architectural design.

Although the design process in architecture is complicated and difficult to understand as it involves some mix of rationalization, intuition, and preference (Alalouch, Aspinall, & Smith, 2015), this study shows that proportional systems, such as the golden ratio, are unavoidably manifested in architectural forms and compositions that are generally accepted and seen as pleasing to the mind. This manifestation could be explicit or implicit, conscious or unconscious.

This paper also contributes to the body of knowledge by introducing a design and analysis method that can be used to develop forms that conform to the golden rectangle. Such a method would increase the freedom of the design, without imposing unnecessary restraints on the process. It could also be used to establish a design language that systematically embraces beauty rather than excludes it. This method can also be used to assess existing forms to determine the extent to which they embrace proportional systems, as shown in this study.

Due to its simplicity and ability to provide variation of forms that conform to the golden ratio, the method can be used in design education as an active-learning mechanism contributing to the knowledge-integrating theory of design education (Salama, 2015). Unconventional and systematic method are not very common in design studio teaching. An exception of this is the method introduced by Alalouch (2018) which uses simple model-making tasks to introduce parametric thinking to novice design students. Similarly, the method could be used as an active- and experiential-learning tool in theory courses that address the proportional systems as part of its syllabus. This aligns with the work of Salama and MacLean (2017) who called for the integration of active and experiential learning into theory courses in architectural education.
One limitation in this study can be associated with the availability of data and drawings of deconstructive projects. Future researches should expand the work presented in this paper to include a larger sample of deconstructive architects, and explore the existence of other proportional systems along with the golden ratio. This work should be combined with subjective observations and data related to the design process that deconstructive architects use in a day-to-day basis. In other words, future researches should explore the design process behind deconstructive architecture in addition to the finished product. This will most likely open a window into how deconstructive architects think, and the role of their education and experience in the manifestation of proportional systems in their designs. In addition, the examination in this study was limited to applying a matrix of displaced golden rectangles on two elevations of each selected project to examine whether the generative two-dimensional elements of the composition conform to the golden ratio. Future work should pursue the development of a three-dimensional presentation of the golden rectangle to better capture the degree of correspondence between the three dimensions of the form and the golden ratio.

Equally important, the design and assessment method presented in this study should be tested in an educational context and examined in terms of process and product. This method should be tested with undergraduate design students to produce simple proportion-friendly forms. The feasibility of this proposed method and its impact on learning domains should be observed and examined.

All things considered, this study has shown that deconstructive architects have applied Aristotle’s statement, beauty is to “maintain the just measure” (Lawlor, 1989, p. 3), which might provide justification to the wide acceptance of the movement. This paper does not aim, however, to glorify the golden ratio nor to examine its accuracy in architecture. It aims to show that designers, whether consciously or unconsciously, do implement some sort of proportion systems in their designs, even in the most extreme architectural style as the deconstructive architecture.

REFERENCES


