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Exact Doubling of Circles, Squares, and Regular Triangles Using Only Straightedge and Compass in Euclidean Geometry

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Abstract | **Review Article**

This research focuses on finding an exact solution to the problems of “doubling a circle”, "doubling a square" and “doubling a regular triangle”, using only a straightedge and a compass in Euclidean geometry. In 2025, the ancient Greek problem known as "Doubling a Cube" was solved exactly, as documented in https://doi.org/10.14445/22315373/IJMTT-V69I8P506 and https://doi.org/10.36347/sjpms.2025.v12i02.001, [3]. The current problem can be viewed as a derivative issue stemming from the aforementioned Greek challenge. This research aims to determine a circle that possesses double the area of a given circle with area πr^2, a square that possesses double the area of a given square with area a^2, and a regular triangle that possesses double the area of a given regular triangle with area A, utilizing only a straightedge and compass within the framework of Euclidean geometry. This research article uses a distinct approach in Geometric Construction to solving the problems.

Keywords: Doubling circle, circle double, square doubling, doubling square, double square, double square area, doubling triangle, triangle double.

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1. INTRODUCTION

The three ancient Greek problems that challenged humanity for millennia — “Squaring A Circle”, “Trisecting An Angle”, and “Doubling A Cube”—, specifically those involving the number Pi/π - remained unsolved because Pi/π is irrational/transcendental and cannot be constructed using only a straightedge and compass. Among them, Hippocrates meticulously studied the problem of squaring the circle. The problem is stated as follows: Using only a straightedge and a compass, is it possible to construct a square with an area equal to a given circle? However, they were all solved between 2023 and 2025 using only a straightedge and compass, without relying on the number Pi/π [1-3].

For over three millennia, three classical geometric well-known problems from ancient Greece— Squaring the Circle, Doubling the Cube, and Trisecting an Angle— emerged and have challenged the ingenuity of mathematicians. These problems, first posed with the constraint of using only an unmarked straightedge and compass, have long been declared impossible to solve within the framework of Euclidean geometry. Foundational impossibility proofs by 19th-century mathematicians such as Pierre Wantzel and Ferdinand Von Lindemann [4-6] - using algebraic field theory and transcendental number theory - seemed to confirm that exact solutions were unattainable. Specifically, the transcendence of π implied that a square with an area exactly equal to that of a given circle could not be constructed through purely geometric means [4,5]. Yet, while these algebraic impossibility theorems are rigorous within their own domains, they diverge in nature from the original geometric spirit of the ancient challenges. The historical emphasis on purely constructive geometry, devoid of algebra, arithmetic or trigonometry, leaves space for a critical re-evaluation [6].

The problems were proven unsolvable using only straightedge and compass in the 19th century. In 1882, mathematician Ferdinand von Lindemann proved that π is an irrational number, which means that it is impossible to construct a square with the same area as a given circle using only a straightedge and a compass, as posed by Hippocrates. One of the most fascinating aspects of this problem is that it has captured the interest of mathematicians throughout the history of mathematics. From the earliest mathematical documents to today’s mathematics, the problem and its relation to π

have intrigued both professional and amateur mathematicians for millennia.

A significant step forward in proving the impossibility of squaring the circle occurred in 1761 when Lambert proved that π is irrational [4] & [5]. This, however, was not sufficient to demonstrate the impossibility of squaring the circle using a straightedge and compass, as certain algebraic numbers can be constructed with these tools. Despite the proof of the impossibility of squaring the circle, the problem has continued to captivate mathematicians and the general public alike, remaining an important topic in the history and philosophy of mathematics.

In 1837, French mathematician L. Wantzel proved that the three classical problems of ancient Greece are impossible to solve using only a straightedge and compass. Although based on algebra, Pierre Laurent Wantzel (1837) declared the verdict, “Arbitrary angle trisection is impossible”, I experienced that my achieved procedure was possibly not arrested by this verdict [6]. After applying my method to trisect an arbitrary angle, I hope readers can trust algebra cannot affect the successful geometrical constructions of angle trisection.

In the past, knowledge was often considered scientific if it could be confirmed through specific evidence or experiments. However, Karl Popper, in his book Logik der Forschung (The Logic of Scientific Discovery), published in 1934, demonstrated that a fundamental characteristic of scientific hypotheses is their ability to be proven wrong (falsifiability). Anything that cannot be refuted by evidence is temporarily regarded as true until new evidence emerges. For instance, in astronomy, the Big Bang theory is widely accepted, but in the future, anyone who discovers a flaw in this theory will be acknowledged by the entire physics community. Furthermore, no scientific theory lasts forever; rather, it is specific research and discoveries that continually build upon one another [7] & [8]. Starting from accepted premises, without proof, one uses deductive reasoning to arrive at theorems and corollaries. With different premises, we develop different mathematical systems. For example, the premise "from a point outside a line, only one parallel line can be drawn to the given line" leads to Euclidean geometry. If we assume that no parallel lines can be drawn from that point, we enter the realm of Riemannian geometry. Alternatively, Lobachevskian geometry assumes that an infinite number of parallel lines can be drawn through that point.

Therefore, the problems of squaring the circle, doubling the cube, and trisecting an angle have been studied for centuries and remain unsolvable with these tools to this day. As of December 2022, no mathematician has found exact solutions to classical problems such as "Doubling the Cube," "Squaring the Circle," and "Trisecting an Angle" using only a compass and straightedge.

However, in 2023, my research article, published on the SJPMS journal, [1] as an exact solution to the “Squaring the Circle” problem, provides a counter-proof to the impossibility stated by Wantzel in 1837, [6].

This article arises from such a re-evaluation and documents a new geometric approach—remaining strictly within the constraints of compass and straightedge—that claims to construct precise solutions to several of these age-old problems. Beginning with a geometric interpretation of Lao Tzu’s aphorism “The Great Way is simple,” the author explores the power of simplicity and concentric arrangement. Through detailed analysis, an exact method for Squaring the Circle is developed, followed by solutions to Doubling the Cube and Trisecting an Angle, each derived using geometric reasoning alone in 2023, 2024 & 2025 [1-3].

It is important to clarify that this does not imply a square with an equal area to a circle does not exist. If the circle has an area A, a square with a side length equal to the square root of A would have the same area. It does not imply that it is impossible to solve the problem using only a straightedge and compass. Thus, I provided the exact solution to the “Squaring the Circle” problem without altering the premises of Euclidean geometry or the constraints of straightedge and compass [1]. In 2024, I also solved the inverse problem, titled “Circling The Square with Straightedge & Compass in Euclidean Geometry,” which was published in the SJPMS [9].

In seeking solutions to such problems, geometers developed a special technique called “ANALYSIS.” They would assume the problem had been solved, and by investigating the properties of the solution, they would work backward to identify an equivalent problem that could be solved based on the given conditions. To obtain the formally correct solution to the original problem, geometers would then reverse the process: starting with the data to solve the equivalent problem derived through analysis, and then using that solution to solve the original problem. This reversed procedure is known as “SYNTHESIS.” Analysis and synthesis are fundamental methods in mathematical reasoning and problem-solving. Analysis involves the process of breaking down complex mathematical problems or structures into simpler, more manageable components. It enables mathematicians to understand underlying principles, identify patterns, and isolate essential variables. Through analytical methods, one can derive conclusions, test hypotheses, and explore the logical consequences of assumptions. Conversely, synthesis entails the combination of previously understood elements to construct more complex systems or to develop general theories. It often follows analysis, using the insights gained to build new models, solve broader problems, or formulate proofs. The interplay

between analysis and synthesis fosters a deeper comprehension of mathematical concepts and drives the progression of mathematical theory. Together, these complementary approaches are vital to the advancement of mathematics, underpinning both theoretical inquiry and practical application. I have adopted both the "ANALYSIS" and "SYNTHESIS" techniques to solve the problems of this article exactly, using only a straightedge and compass, in Euclidean Geometry, without involving the irrational number π.

The inspiration for this research arose after the solution to the "Squaring the Circle" problem was published in SJPMS in 2024 [1].

In this research, I proved that we can do "doubling any circle area", "doubling any square area" and "doubling any equilateral triangle area" only use straightedge & comapss in Euclidean Geometry. These proofs are exact and simple as the ones in my previous article paper published from 2023 to 2026.

One major mathematical caution is if the result says that one can double the area of any circle using only straightedge and compass, that sounds very close to the classical squaring-the-circle problem. A circle with radius r has area πr^2; a square with the same area has side $r\sqrt{\pi}$. Constructing that square exactly with straightedge and compass would require constructing $\sqrt{\pi}$, which is impossible because π is transcendental. However, my proved method herein does not use π or $\sqrt{\pi}$. Likewise, doubling the area of a square s is straightforward: the new side is $s\sqrt{2}$, and $\sqrt{2}$ is constructible. For an equilateral triangle, doubling its area requires scaling its side by $\sqrt{2}$, which is also constructible.

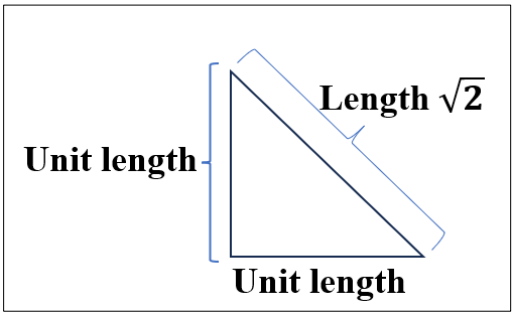
2. PROPOSITIONS

2.1 Constructive Theorem for Length Multiplication: Let n ∈N be given as a constructible geometric length consisting of n unit lengths. Then length $n\sqrt{2}$ is exactly constructible using a straightedge and compass.

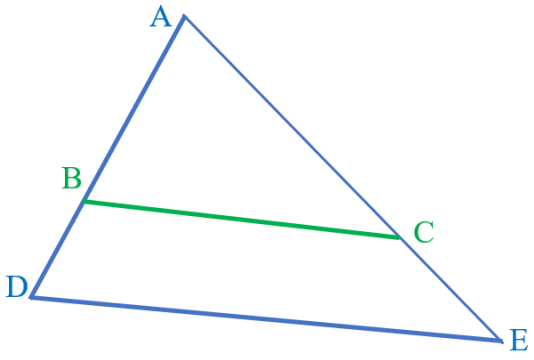
Remark: *The restriction n∈N simplifies the construction and shortens the proof, since the initial length can be represented by a finite sequence of unit lengths. For a general real number n∈R, the construction requires the length (n) to be given or independently constructible. Under this assumption, the same geometric principle applies, and the proof follows an analogous argument. The proof below therefore considers n∈N, for which the construction is more direct.*

PROOF:

The theorem assumes that length n is already given and is n times the unit length. The construction of $\sqrt{2}$ can then be achieved by constructing a right triangle with both perpendicular sides of unit lengths. By the Pythagorean theorem, its hypotenuse has length $\sqrt{1+1} = \sqrt{2}$, which establishes exact constructibility, as follows:



Now consider two congruent triangles/similar triangles ABC and ADE below, where AB = Unit length, AD = Length $\sqrt{2}$ and BC = Given length n,



Then by the congruent property of the two triangles,
$\frac{1}{\sqrt{2}} = \frac{n}{DE}$ **and then** $n\sqrt{2}$ **= Length DE**

Thus, length $n\sqrt{2}$ is constructible with a straightedge and compass as required.

2.2 Theorem 2: *Constructibility of Circle Area Doubling*

Let r be the radius of a given circle. Consider a circle with radius $r\sqrt{2}$ whose area is equal to twice the area of the given circle. The following statements hold:

The length $r\sqrt{2}$ is constructible using only a straightedge and compass in the context of classical Euclidean construction.

Consequently, the circle with radius $r\sqrt{2}$ is also constructible using only a straightedge and compass, providing a circle with area that is double the area of the original circle (O, r).

PROOF

Proof Method 1

Assume r is a given real number (either rational r∈N or r∈R). By the Constructive Theorem referenced in Section 2.1, we can employ a straightedge and compass to construct the length $r\sqrt{2}$.

Since we have established that $r\sqrt{2}$ is constructible, we can then construct the circle (O, $r\sqrt{2}$). The area of this circle is given by $A = (r\sqrt{2})^2\pi = 2\pi r^2$.

Thus, the circle (O, $r\sqrt{2}$) has an area that is exactly double the area of the initial circle (O, r), which is πr^2.

Therefore, we can conclude that the circle with radius $r\sqrt{2}$ is constructible using only a straightedge and compass, as required.

Proof Method 2 (Alternative proof)

With a straightedge and compass, construct a right-angled isosceles triangle whose two perpendicular legs each have length r in Figure 1 below. The construction of such a right triangle, and hence of its hypotenuse, can be carried out using only a straightedge and compass. By the Pythagorean theorem, its hypotenuse (R) satisfies (Figure 1, below)

$\mathbf{R^2 = r^2 + r^2 = 2r^2}$

and

$r\sqrt{2}$ **is the hypotenuse length of the triangle.**

Hence $r\sqrt{2}$ is Euclidean constructible.

Finally, once the constructible length ($R = r\sqrt{2}$) has been obtained, a circle with centre (O) and radius (R) can be drawn using a straightedge and compass (Figure 1). Its area is πR^2 or $2\pi r^2$, which is twice the area πr^2 of the original circle. Hence the circle (O, $r\sqrt{2}$) is also constructible using only a straightedge and compass.

Therefore, both the radius (R) and the resulting circle (O, $r\sqrt{2}$) are constructible by Euclidean straightedge-and-compass methods.

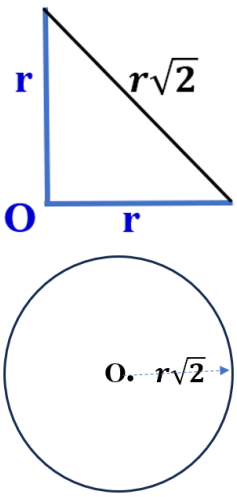


Figure 1: Geometrical Construction of length $r\sqrt{2}$ and the circle **(O, $r\sqrt{2}$)**, with a straightedge and compass.

2.3 Theorem 3 *(Constructibility of a Square with Twice the Area)*

Let a square of side length a>0 be given, where a is a constructible length. Using only a straightedge and compass, one can construct a square of side length $a\sqrt{2}$.

The constructed square has twice the area of the given square.

Note*: The assumption that a is a given constructible length is needed. However, if an arbitrary real number*

a∈R is given then length a is also constructible with straightedge and compass (see the Constructive Theorem for Length Multiplication in Section 2.1 above).

PROOF

Proof Method 1

Assume a is a given real number (either rational a∈N or a∈R). By the Constructive Theorem referenced in Section 2.1 above, we can employ a straightedge and compass to construct the length $a\sqrt{2}$. Since we have established that $a\sqrt{2}$ is constructible, we can then construct the square, side $a\sqrt{2}$ using only straightedge and compass. The area of this circle is given by A = $(a\sqrt{2})^2 = 2a^2$. Thus, the square of side $a\sqrt{2}$) has an area $2a^2$ that is exactly double the area of the initial square of side a, which is a^2.

Therefore, we can conclude that the square with side $a\sqrt{2}$ is constructible using only a straightedge and compass, as required.

Proof Method 2 (Alternative proof)

With a straightedge and compass, construct a right-angled isosceles triangle whose two perpendicular legs each have length a in Figure 2 below. The construction of such a right triangle, and hence of its hypotenuse, can be carried out using only a straightedge and compass. By the Pythagorean theorem, its hypotenuse (R) satisfies

$\mathbf{R^2 = a^2 + a^2 = 2a^2}$

and

$a\sqrt{2}$ is the hypotenuse length of the triangle.

Hence $\boldsymbol{a\sqrt{2}}$ is Euclidean constructible.

Finally, once the constructible length (R = $a\sqrt{2}$) has been obtained, a square ABCD with side (R = $a\sqrt{2}$) can be drawn using the compass (Figure 2 below). Hence the square ABCD with side $r\sqrt{2}$ is also constructible using only a straightedge and compass.

Therefore, both the length (R = $a\sqrt{2}$) and the square of side length $a\sqrt{2}$) are constructible by Euclidean straightedge-and-compass methods

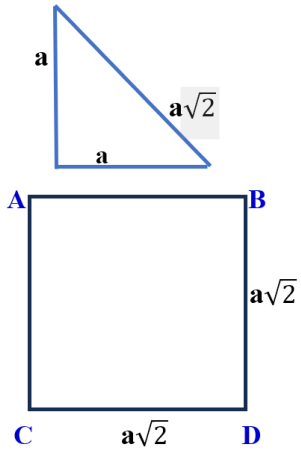


Figure 2: Geometrical construction of length $\mathbf{a\sqrt{2}}$, and the square ABCD of side length $\mathbf{a\sqrt{2}}$.

Let the smaller square have side length $a > 0$, and let the larger square have side length $x > a$. Let **O** denote their common centre. Assume that the two squares are concentric and that their corresponding sides are parallel, as shown in **Figure 03** below.

a. The four surrounding regions are congruent isosceles trapezoids

Because the two squares are concentric and have parallel corresponding sides, they have the same orientation. Consequently, each pair of corresponding diagonals lies on the same straight line through the common centre **O**.

Consider the region between the upper sides of the two squares. Its upper and lower sides have lengths x and a, respectively, and are parallel. Its two remaining sides lie along the corresponding diagonals and are equal by reflectional symmetry about the vertical line through **O**. Hence, the upper region is an isosceles trapezoid (**Figure 03**, below).

By the same argument, the regions between the left, right, and lower corresponding sides are also isosceles trapezoids.

Furthermore, the entire configuration is invariant under a rotation of 90°about **O**. Such a rotation

maps each surrounding trapezoid onto another. Therefore, the four trapezoids are congruent.

Thus, the four surrounding regions are congruent isosceles trapezoids.

b. Area of the surrounding region

The area of the smaller square is

$$A_{\text{small}} = a^2,$$

while the area of the larger square is

$$A_{\text{large}} = x^2.$$

Therefore, the area of the region between the two squares is

$$A_{\text{surrounding}} = A_{\text{large}} - A_{\text{small}} = x^2 - a^2.$$

Since the four surrounding trapezoids are congruent, each has area

$$A_{\text{trap}} = \frac{x^2 - a^2}{4}.$$

This can also be obtained directly from the trapezoid formula. The two parallel sides have lengths x and a, and, because the squares are concentric, the perpendicular distance between their corresponding sides is

$$\frac{x-a}{2}.$$

Hence,

$$A_{\text{trap}} = \frac{1}{2}(x+a)\left(\frac{x-a}{2}\right) = \frac{(x+a)(x-a)}{4} = \frac{x^2 - a^2}{4}.$$

Therefore,

$$\boxed{A_{\text{surrounding}} = x^2 - a^2}.$$

c. If the larger square has twice the area of the smaller square

Suppose now that

$$A_{\text{large}} = 2A_{\text{small}}.$$

Then

$$x^2 = 2a^2.$$

Consequently, $x = \sqrt{2}\,a$

Moreover, the area of the surrounding region is

$$A_{\text{surrounding}} = x^2 - a^2 = 2a^2 - a^2 = a^2.$$

Thus,

$$A_{\text{surrounding}} = a^2$$

Since the four trapezoids are congruent, each has area

$$A_{\text{trap}} = \frac{a^2}{4}$$

Therefore, the four surounding regions are congruent isosceles trapezoids, and, when the larger square has twice the area of the smaller square,

$$\boldsymbol{x = \sqrt{2}\,a}, \quad \boldsymbol{A_{\text{surrounding}} = a^2}, \quad \boldsymbol{A_{\text{trap}} = \frac{a^2}{4}}.$$

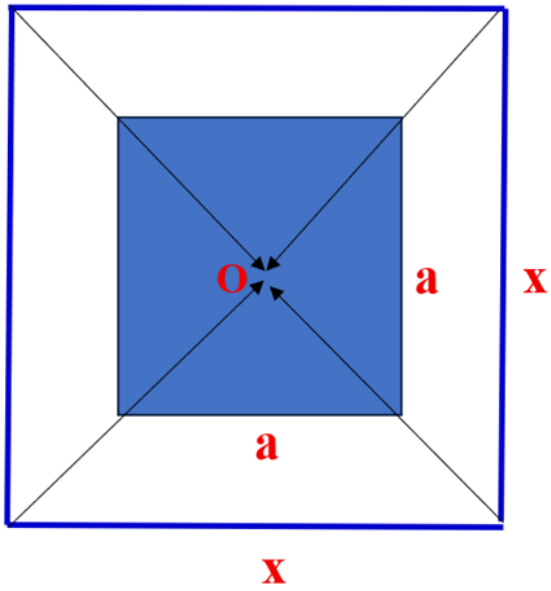


Figure 3: The given square with side a and the target square with side X are concentric with 4 parallel side pairs

2.4 Theorem 4

Let a regular triangle of area a be given. Suppose there exists a regular triangle of area whose area is equal to twice the area of the given triangle. Then this doubled triangle is constructible using only straightedge & compass in the sense of classical Euclidean construction.

PROOF

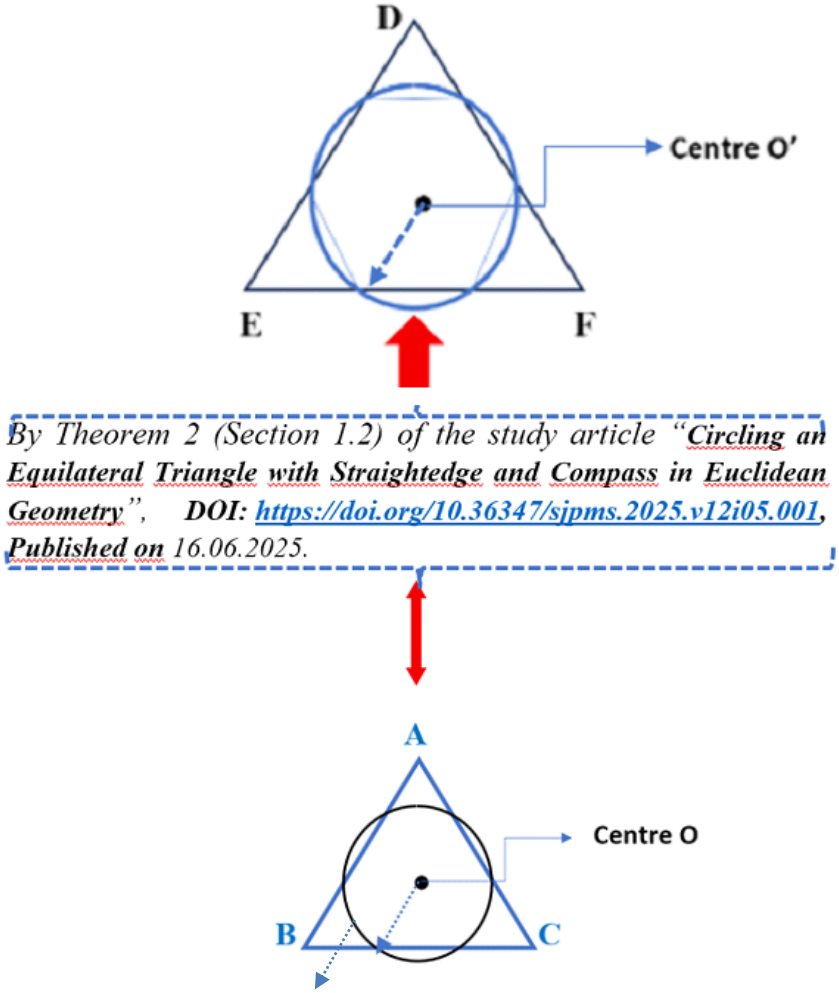


Figure 04: Illustration image of Theorem 04.

Let an equilateral triangle ABC is given, then by my research article "Circling An Equilateral Triangle With Straightedge And Compass In Euclidean Geometry" published at https://doi.org/10.36347/sjpms.2025.v12i05.001, on 16/06/2025, there exists a circle (O, r) of which area A is exactly equal to the area A of the given regular triangle ABC (This circle is constructible using a straightedge and compass only – lower image in Figure 04 above).

Then, by Theorem 2 in Section 2.2, there exists a circle (O, R) of which area 2A is exactly double the area A of the circle (O, r), and also double the area A of the given regular triangle ABC too (This circle (O, R) is also constructible using a straightedge and compass only – top image in Figure 04 above).

And then, by my research article "Regular Triangling a Circle with Straightedge and Compass in Euclidean Geometry" published at https://doi.org/10.36347/sjpms.2025.v12i03.003, on 13/03/2025, there exists an equilateral triangle DEF of which area 2A is exactly double to the area A of the given regular triangle ABC (This triangle DEF is also constructible using a straightedge and compass only – top image in *Figure 04* above).

Therefore, the resulting regular triangle DEF has a double area of the given equilateral triangle and is constructive by a straightedge and compass in Euclidean Geometry.

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