



## Qualitative Study on Application of Mathematical Principles in Architectural Design in Nigeria

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### Abstract

*This paper focused on “qualitative study on application of Mathematical principles in architectural design in Nigeria”. Mathematical principles have played a vital role in architectural design such as the foundation, the columns, beams, slabs, footings, stairs and the roofing. It was recommended that Mathematic curriculum should be design to embrace practical principles to architectural designs.*

**Keywords:** Mathematical Principles & Architectural Design

### Introduction

Every building, be it a place of worship or learning, a grocery store, a mall, a sport arena or perhaps a kiosk, is a product of mathematical principles. Chances are that you are in a building even as you read this paper. Many times, we hear the phrase, "mathematics is the mother of all science and is everywhere, all around us" but how often do we try to find the connection between mathematics and design or mathematics and building design, specifically? There is no one definition of mathematics as various scholars have tried to define mathematics based on their perception of the discipline. According to Merriam Webster Dictionary, mathematics is the science of numbers and their operations, interrelations, combinations, generalizations, and abstractions and of space configurations and their structure, measurement, transformations, and generalizations. Wikipedia defines mathematics as an area of knowledge that includes the topics of numbers, formulas and related structures, shapes and the spaces in which they are contained, and quantities and their changes. This makes the practicality of mathematics even more acceptable. This is because, looking around us, we can so easily identify various shapes of different sizes, we also deal with numbers in counting as well as measurements in our day-to-day tasks and sometimes, apply basic mathematical principles in solving simple problems. Soyemi (2005) noted that everybody uses mathematics in one way or the other in solving life problems. Beyond its application in everyday activities, mathematics can and indeed has been employed to accomplish far greater feats especially in the area of design. Egbe (2016) asserted that mathematics is made up of so many branches like algebra, geometry, trigonometry, statistics, topology, mensuration, etc. These concepts and others such as patterns, symmetry, spaces, arrangement and sequence are so important in design and all stem from mathematics. Dahiru (2016) described geometry as a practical science concerned with surveying, measurement of areas and volumes. He went further to point out that among the notable accomplishments, one can find formulae for lengths, areas and volumes, which can be applied to get the circumference and area of a circle, area of a triangle, volume of a cylinder, sphere and pyramid. According to Meremikwu and Enuokoha (2010), mathematics is one of the formal disciplines that helps man lay a solid foundation for future survival. Mathematics is a universal part of the human culture. It is a tool and language of commerce, engineering and other sciences including physics, computing and biology. It helps in recognizing patterns and to understand the world around us. Taking a look at architecture, the starting point in design, especially that of building designs, one can observe that before construction workers can build any structure, an architect has to design it. Since ancient times, architects have incorporated geometric, algebraic and trigonometric principles to sketch and plan the shapes and spatial forms of buildings. Other mathematical concepts such as probability are also used to predict and calculate the possibility of encountering hazards during and after construction therefore, they design competent structures that can withstand these hazards when brought to three dimensions upon completion. Euclid, the Greek mathematician in 300 B.C., defined a mathematical law of nature called the Golden Ratio, also referred to as the Golden constant. For over two thousand years, architects have used this formula to design proportions in buildings and it still serves as a basic geometric principle in architecture. The Taj Mahal, one of the wonders of the world is known for the golden ratio of its dome. Interestingly, ancient engineers and architects were also mostly mathematicians. Ancient

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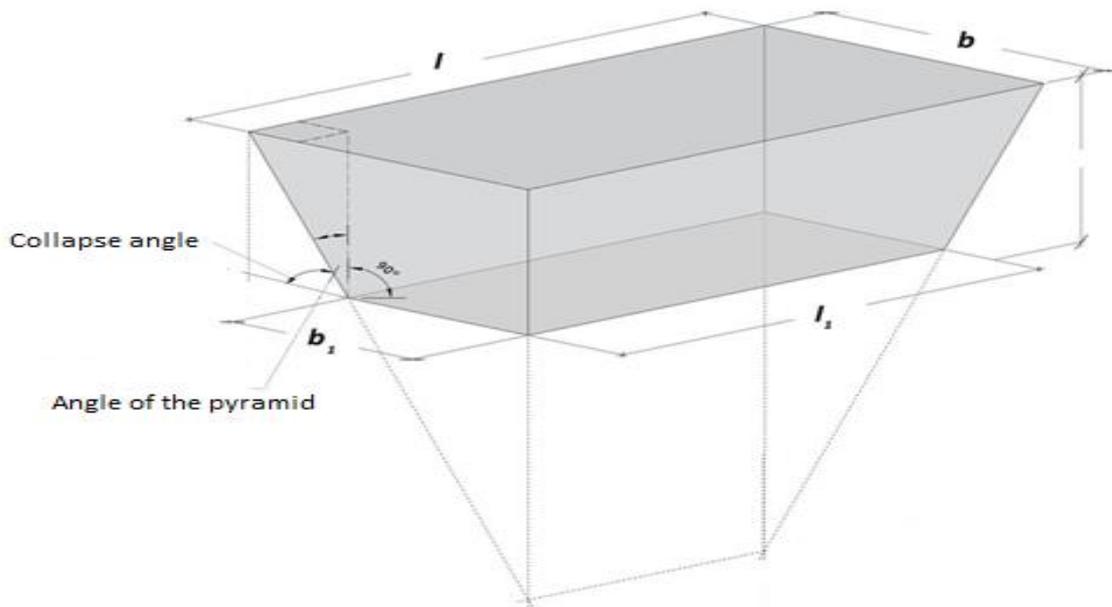
monumental structures such as the great pyramids of Ancient Egypt, magnificent temples and stadiums were built using principles like that of triangles in geometry, calculus and algebra among others. The Pythagorean theorem, formulated in the 6th century B.C., has also been used for centuries to calculate the size and shape of a structure. This theorem enables builders to accurately measure right angles. Truly, the various applications of mathematics and its principles in building design over centuries cannot be exhausted. This paper seeks to explain the interface of mathematics and design. However, the focus will be on the aspect of building design. The areas to be considered include: The building foundation, slabs, beams, columns, and footings, stairs and roofing.

### Objective of The Study

i. To assess the application of Mathematical principles in architectural design in Nigeria

### FOUNDATION PLAN AND MATHEMATICS PRINCIPLES

A building consists of the substructure and the superstructure. The superstructure consists of all the parts above the ground while the substructure is the part of the building that is below the ground. The foundation is a part of the substructure and the first step in building a solid house is the construction of its foundation. The foundation is in direct contact with the soil and transmits the load of the superstructure to the ground. Procedure for construction of foundation starts with deciding its depth and width, and marking layout for excavation and centerline of foundation. Before a foundation can be built, soil extraction has to be done and the total volume of the soil to be extracted must be calculated. Soils come in various forms and can be categorized based on their strength ranging from soft soil to rock formation. Whatever the soil type, the foundation must be firm and solid. Although softer soils cost more when constructing the foundation, rocky soil formation may also require processes like soil blasting or other expensive methods to break the rocks. It is necessary to note the natural collapse angle of the soil in question as it is an important indicator. For instance, on rocky soil it can be vertical at  $90^\circ$ , on regular sand it can vary but it can be at  $30^\circ$ , on quicksand it also varies because runny water takes some soil with it (Pärnumaa, 2020). In a construction drawing, the natural collapse angle is shown either in degrees or ratios.

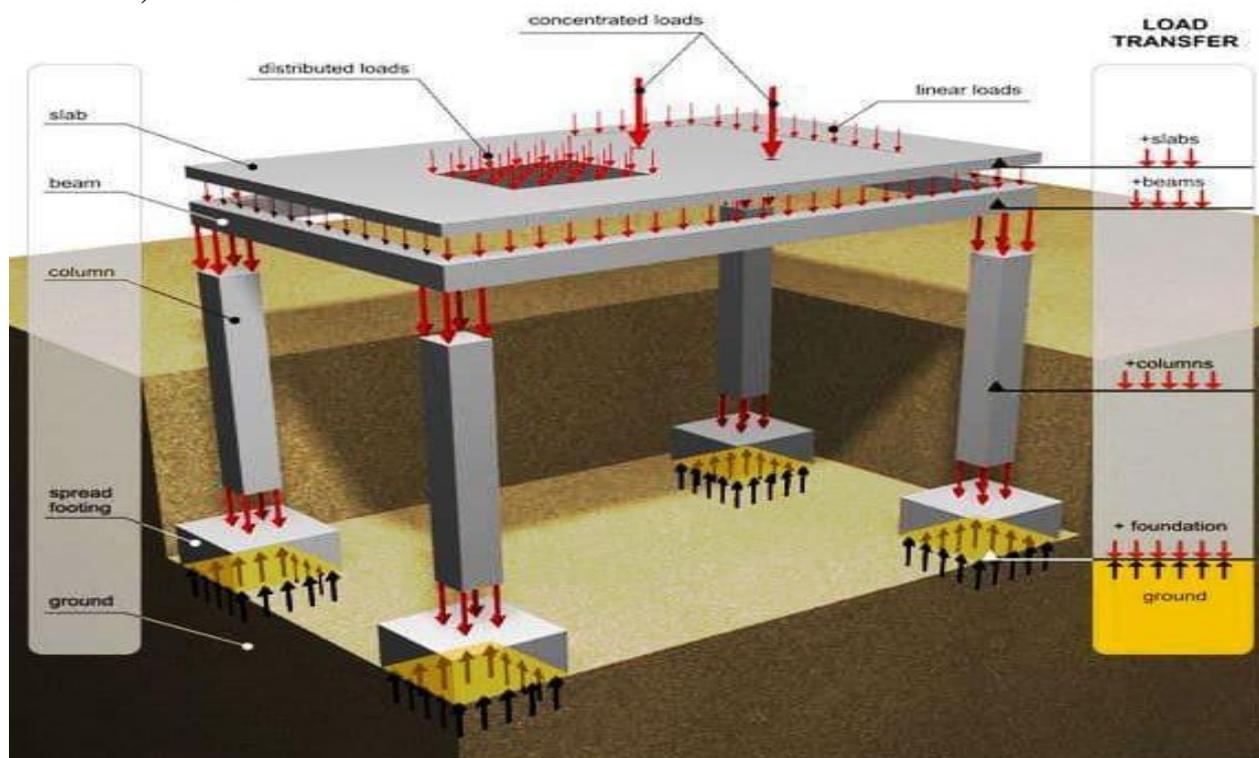


A different formula can also be used, but its result will not be so exact:

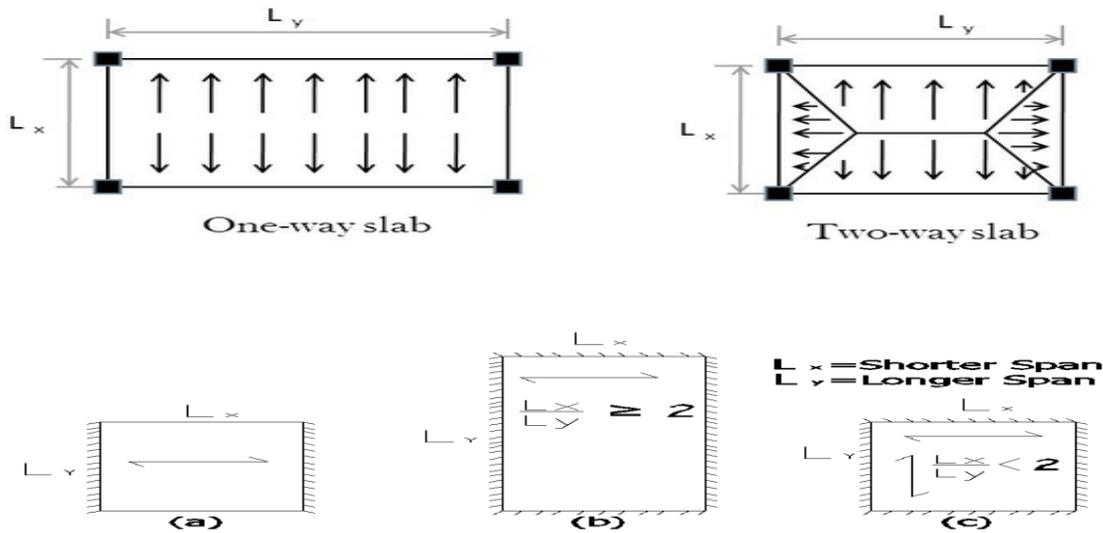
$$V \approx h \cdot \frac{l+l_1}{2} \cdot \frac{b+b_1}{2}$$

Most buildings' foundations, with the exception of fun houses have right angles at their corners. These are referred to as "perfectly square" corners. The closer they look to right angles, the more tightly fit the beams, joists and other structural supports will be. In order to ensure that all the angles are right, that is, 90 degrees, two methods can be employed, Viz: Pythagorean Theorem Method and the 3-4-5 Method which date back to ancient Greece. Although the two methods have different names, they basically mean the same thing and are based on the same theorem- the Pythagorean theorem which states that in a right-angle triangle having three sides with lengths a, b and c, the sum of the square of the shorter sides is equal to the square of the longest side. Mathematically,  $a^2+b^2=c^2$ . Where a and b represent the lengths of the shorter sides and c the length of the hypotenuse (the longest side). The 3-4-5 methods simply assigns real numbers as the values of a, b and c where a is 3, b is 4 and c is 5. Apparently, 5 is the highest value and therefore is the length of the hypotenuse. Practically, applying  $a^2+b^2=c^2$ , we have that  $3^2+4^2=5^2$ . This gives us  $9+16=5^2=25$ . The numbers in the 3-4-5 method provides an easier way to remember the Pythagorean theorem.

#### APPLICATION OF MATHEMATICAL PRINCIPLES IN ARCHITECTURAL DESIGN OF FOOTINGS, COLUMNS, BEAMS AND SLABS



**Slab:** This is a horizontal structural element with top and bottom surfaces parallel or almost parallel to each other. is constructed to create flat surfaces such as floors, roofs, and ceilings. Usually, they are supported by beams, columns (concrete or steel), walls, or the ground. The depth of a concrete slab floor is very small compared to its span (length and width). The forces transfer from slab to beams occur either in one way or in two ways. The total system completely counts on the geometrical dimensions of the slab. Sometimes, slabs are supported by columns only, in this case two way action will prevail. If the ratio of the long side to the short side is less than two, it is referred to as 2-way slab, and if the ratio of the longer side to the shorter side is greater than two, then it is considered as 1-way slab.

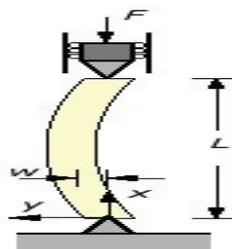


So assuming we have a slab with a thickness of 150 mm, the self-weight of Concrete is around  $2400 \text{ kg/m}^3$ . The slab load will be  $= 0.150 \times 1 \times 2400 = 360 \text{ kg}$  which is equivalent to  $3.53 \text{ kN}$ . \*Total load on slab = dead Load + Live Load + Wind Load + Self-Weight. Dead load = volume of component  $\times$  unit weight of materials.

**Beams:** A beam is also a horizontal structural element. It can withstand vertical loads, shear forces and bending moments. The loads applied to the beam result in reaction forces at the support points of the beam. The total effect of all the forces acting on the beam is to produce shear forces and bending moment within the beam, that in turn induce internal stresses, strains and deflections of the beam. They transfer loads imposed along their length to their end points where the loads are transferred to columns or any other supporting structural elements. Load on Beams = Self Weight per running metre

Example: Each metre of the beam has dimensions of 300 mm  $\times$  600 mm excluding slab thickness, assume each (1m) meter of the beam has dimension. Weight of concrete is around  $2400 \text{ kg/m}^3$ , Self-weight of Concrete is around  $2400 \text{ kg/m}^3$ , which is equal to  $24.54 \text{ kN/m}^3$  and the self-weight of Steel is around  $7850 \text{ kg/m}^3$ . (Note: 1 Kilonewton Is Equal to 101.9716 Kilograms). To calculate the beam load: 300 mm  $\times$  600 mm excluding slab.; Volume of Concrete =  $0.30 \times 0.60 \times 1 = 0.18 \text{ m}^3$ ; Weight of Concrete =  $0.18 \times 2400 = 432 \text{ kg}$ ; Weight of Steel (2%) in Concrete =  $0.18 \times 2\% \times 7850 = 28.26 \text{ kg}$ ; Total Weight of Column =  $432 + 28.26 = 460.26 \text{ kg/m} = 4.51 \text{ KN/m}$ ; So, the self-weight will be around  $4.51 \text{ kN}$  per running meter.

**Columns:** Column is a vertical structural component that carry loads mainly in compression. The column is a very important structure in a building because the safety of a building rests on the column strength. If the strength of the column fails, it could lead to progressive collapse in buildings. Columns transfer vertical loads from a ceiling, floor or roof slab or from a beam, to a floor or foundation. They are mainly subjected to the effective length and axial loads of which exceeds three times its least lateral dimension. They also carry bending moments about one or both of the cross-section axes. The compression component whose effective length is less than three times its least lateral dimension is called Pedestal while the component which is inclined or horizontal and is subjected to axial loads is called Strut.



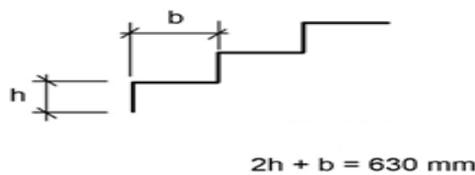
Load on Column = Self Weight  $\times$  Number of floors

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**Footings:** Gopal (2018), in an article, described footing as a structure constructed in brickwork, masonry, or concrete under the base of a wall or column for distributing the load over a large area. Footings are structural elements that transmit the load of the entire building structure to the underlying soil below the building. They are designed to transmit these loads to the soil which is the root support of the footing without exceeding the safe bearing capacity of the soil. All the forces that come in contact with the footings will be transferred to the soil. The bearing capacity changes from one type of soil to another and it is the key factor in estimating the size of footings.

**STAIRS AND MATHEMATICS CONCEPT**

Another part of construction that uses pitch (or slope) calculation are stairs. When constructing stairs, the ratio of the rise to the tread should be taken into consideration so that a proper staircase that can be comfortably used by people will be created. To calculate the height of the stairs a simple formula is used. This formula helps to find the optimal ratio between the rise and tread of the step.  $2h+b=630\text{ mm}$  Where, h = rise of the step; b = tread of the step



The sum of double rise and the tread gives a constant. From there, the pitch can be derived - usually 1:1.5 to 1:2.

To calculate the width of the steps, the formula used is  $h + b = 450\text{mm}$

Additionally, to the pitch, the stairs will have a total rise and total run which are also important measurements.

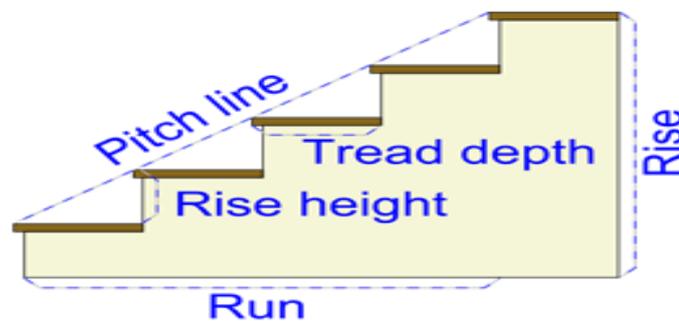
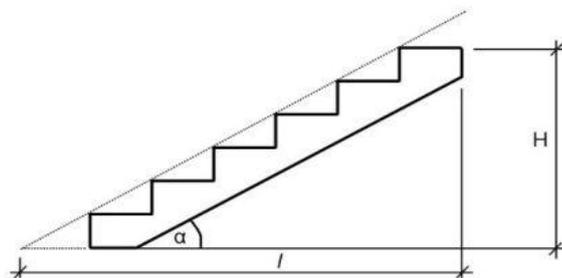


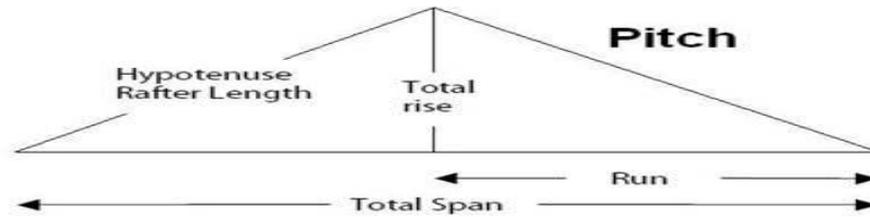
Image: Wikipedia



When building multi-turn stairs, you must also make sure that it has an uneven number of steps otherwise you must change legs when walking up the stairs. All steps must also have the same rise - human brain adapts to a certain rhythm of walking so if one step is of different height then it might cause you to trip on the steps (Pärnumaa, 2020).

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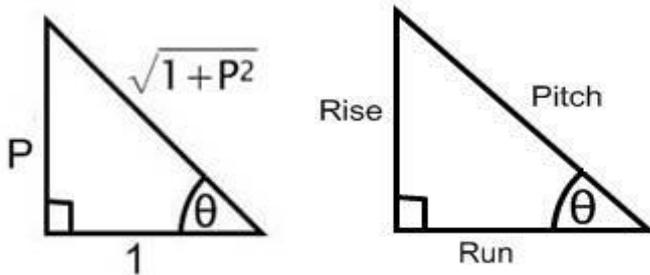
ROOFING AND MATHEMATICS CONCEPT



In roof design of buildings, the Pythagorean Theorem is also applied. There are various kinds of roofing designs. Gable roofs, for example, are made by placing two right triangles together. A Gable is a triangle formed by a sloping roof. A building may be front-gabled or side-gabled. The triangle relationships in roof construction can be explained with the following terms below:

**The span:** This is the length from the outside wall to the outside wall of a building.

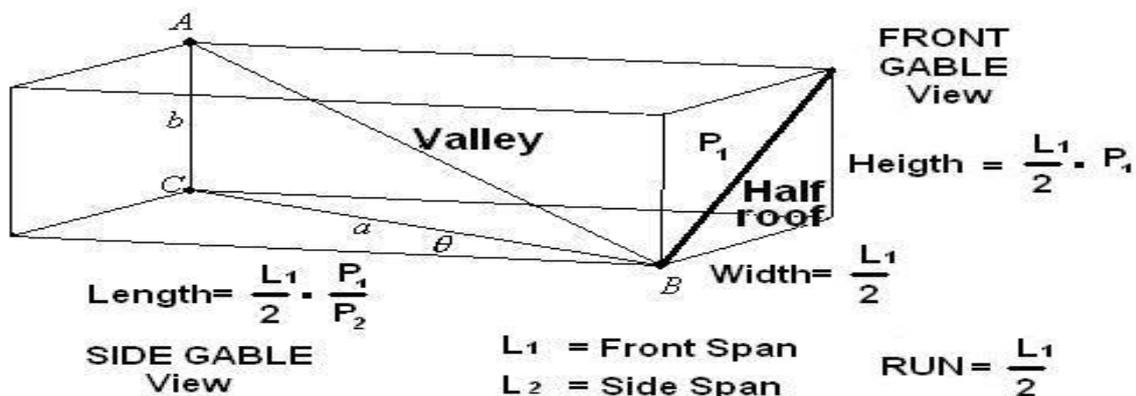
**The run:** The run is one-half the span. Units of run are typically based on 12 inches.



$$run(mm) = \frac{pitch(\text{‰}) * 1000}{rise} \quad rise(cm) = \frac{pitch(\%) * run}{100}$$

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**The pitch:** The roof's pitch is its vertical rise divided by its horizontal span (or "run") -called slope in geometry or the tangent function in trigonometry. It is a ratio of vertical to horizontal measurements. If a plan calls for a 6/12 pitch roof, then the architect wants the slope of the roof to go up six inches for every 12 inches of horizontal run. Carpenters do not refer to the angle of roof as 30° but prefer to use the pitch of the roof. (Grazda et al, 1966)





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## Conclusion

The application of mathematical principles in building design is one that began centuries ago and continues even in contemporary times. Kulbir (2006) observed that mathematics is a universal subject and its history presents a very good picture of the overall development of our civilization. Agwagah (2013) further asserted that mathematics is an indispensable tool in virtually all human endeavours and there is hardly any field where mathematics is not useful. This by implication puts the field of design into the equation which further underscores the universality of mathematics. As long as the human race exists, the need for mathematics will always arise. More building structures will be constructed and so, seeing the importance of mathematics in the world of architecture and engineering as well as in other areas that play a role in building design, mathematics should not be relegated to the background. Adebola (2007) indicated that the roles played by mathematics in the day-to-day activities of man is suggestive of the fact that mathematics is needed by all. Hence, efforts must be strengthened in order to train and help more people around us and all over the globe embrace mathematics and also to realize the indispensability of mathematics in the field of design. This paper has been able to show the interface of mathematics and design in some parts of a building structure which are: the foundation, the columns, beams, slabs, footings, stairs and the roofing.

## Recommendation

Mathematic curriculum should be design to embrace practical principles to architectural designs.

## References

- Adebola, S.I (2007) Mathematics education for sustainable development. *Proceedings of the 50th anniversary conference of Science Teachers Association of Nigeria (STAN) 162-165*
- Agwagah, U. (2013). Improving the teaching of mathematics for attainment of seven-point agenda: Implication of gender parity. *ABACUS. The journal of Mathematical Association of Nigeria* 38(1) 111-121.
- Dahiru, S.M (2016). Strategies for effective teaching/learning differences between pyramid and prism in mathematics education in Nigeria. *Journal of issues on mathematics* 18(1) 164-168.
- Dream box (2019) Architecture and Construction through Mathematics. Retrieved from <https://www.dreambox.com/resources/blogs/architecture-and-construction-through-mathematics>
- Egbe, I. O (2016). Issues and problems facing mathematics education in the society. *Journal of issues on mathematics* 18(1), 67-73.
- Gopal, M (2018) Foundation construction: Depth, width, layout and excavation. Retrieved from <https://theconstructor.org/geotechnical/foundation-construction/1392/?amp=1>
- Grazda, et al (1966) Handbook of Applied Mathematics, D. Van Nostrand Company, Inc.
- Kulbir, S.S (2006). The teaching of mathematics. New Delhi: sterling publishers private Ltd.
- Let's build(2019) What is substructure and superstructure in building. Retrieved from <https://www.letsbuild.com/blog/substructure-superstructure>
- Matthew, L. How to load calculation on column, beam, wall and slab. Retrieved from <https://civiljungle.com/load-calculation-on-column-beam-wall-slab/>
- Meremikwu, A. & Enuokoha, O. (2010). Instructional aids, school variables and pupil's mathematics achievements in primary schools in Cross Rivers state. *Proceedings of the British Congress for Mathematics Education.*
- Pärnumaa, K (2020). Practical Mathematics: Foundations. Retrieved from <https://www.hariduskeskus.ee/pracmath/eng/foundations.html>
- Pärnumaa, K (2020). Practical Mathematics: Roof Pitch. Retrieved from <https://www.hariduskeskus.ee/pracmath/eng/roofpitch.html>
- Soyemi, T. (2005). Into the classroom with behaviour modification. *The school councilor* 110-113.
- The Constructor (2018). What is slab, beam, column and footing construction. Retrieved from <https://theconstructor.org/structural-engg/slab-beam-column-footing-construction/24934/?amp=1>