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RESEARCH ARTICLE

MATHEMATICAL AND NUMERICAL ANALYSIS OF THE HERITAGE ARCHITECTURES OF CHEIKH ANTA DIOP UNIVERSITY

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Abstract

This study explores the integration of educational technologies into STEAM education through the mathematical modeling of historical architectures at Cheikh Anta Diop University of Dakar (UCAD). The approach combines history, culture, mathematics, and engineering by linking real-world experience with digital tools, such as GeoGebra and augmented reality, to analyze the Central Library and the main gate of the pedagogical campus.The project highlights the presence of geometri c principles in the design of these buildings, illustrating how simple forms and proportionsparticularly the Fibonacci spiralstructure the architecture. The pedagogical activities enable students to decompose structures into polygons, apply mathematical rules, and integrate their knowledge into the modeling process.

Introduction:-

Educational technologies serve as a lever to develop complementary approaches in exploring interdisciplinary themes in science, technology, engineering, arts, and mathematics (STEAM). Within the framework of this study, history, culture, mathematics, and engineering are closely intertwined. We combine hands-on experience with mathematical software, which also facilitates the connection between digital and physical dimensions.Through this project, we simultaneously leverage multiple reality technologies to study architectural examples placed within their cultural context. The study focused on representative buildings of Cheikh Anta Diop University in Dakar, notably the central libraryconsidered a major landmark of the campus due to its modernist architectureas well as the entrance gate of the main campus located on the Corniche, whose symbolic and institutional value makes it a significant heritage element.It is conceivable that mathematical principles guided the design of these historical buildings. The process of modeling ancient structures followsthe general mathematical modeling process, i.e., modeling, applying mathematical equations and rules to achieve the final result.All the practices implemented aim to stimulate and enhance the creativity of both teachers and students, enabling them to acquire and apply their knowledge in mathematics and physics through the use of various technologies, applied here in the architectural domain.Our research aims to introduce new mathematical concepts to students and explore their multiple dimensions using physical and digital representations, such as augmented reality. These tools allow for the visualization and better understanding of a wide diversity of forms and spaces.As part of our research, we seek to explore the effect of various digital and physical representations on the modeling of ancient architecture and how new technologies can be applied to connect architectural models to our cultural heritage.

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Objective:-

This article presents an experimental educational program that utilizes the mathematical modeling of historical architectures to enhance learners' mathematical and technical skills, while connecting them to culture and history. The program investigates how students break down architectural structures into simple polygons and integrate their knowledge into the modeling process.The program offers educational activities linking mathematics and technology to architectural modeling. Two elements were selected for their cultural significance and simple geometric forms.

Historical Context:-

Higher education in Senegal dates back to 1916 with the establishment of the Jules Carde African School of Medicine and Pharmacy in Dakar. This institutionmarked the beginning of the first university-level courses taught in French in West Africa.In 1938, the French Institute of Black Africa (IFAN), dedicated to Africanist research, further strengthened this framework. A first cycle in chemistry and biology was opened in 1949, followed by the creation of the Institut des Hautes Études de Dakar in 1950. These milestones laid the foundations of higher education for students from French West Africa.On February 24, 1957, the University of Dakar was officially founded. It was later renamed Cheikh Anta Diop University of Dakar (UCAD) on March 30, 1987. In parallel, the development of documentary collections accompanied this evolution. The earliest collections, intended for medical students and professors, date back to 1916. Soon, the need for specialized libraries expanded to law, humanities, and sciences, with distinct collections established at the Van Vollenhoven High School (now Lamine Guèye High School).

In 1952, a professional librarian was appointed to supervise the three sections of law, humanities, and sciences. A first regulation was adopted in 1953, and a library commission was created in 1954. That same year, the sections were distributed across different premises, and in 1956, the library appeared for the first time in the budget of the Institut des Hautes Études. By the late 1950s, the collections included around 5,000 volumes and 2,000 periodicals.
The growing need for a centralized building led to a project supported by the French Directorate of Libraries. The foundation stone was laid in 1959, and the building was inaugurated in 1965 by President Léopold Sédar Senghor. At the time, the new library offered 350 seats and a capacity of 450,000 volumes.From the 1960s onwards, Senegalese librarians trained at the CRFB (later EBAD) gradually replaced expatriates. In the 1970s and 1980s, the collections grew steadily, reaching 300,000 volumes and nearly 6,000 periodicals by 1983. The library also established exchange networks with institutions in Africa, Europe, and North America, consolidating its scientific and academic role.

The late 1980s were marked by difficulties related to limited resources, the aging of collections, and the rapid increase in student enrollment. However, a modernization program was launched in the 1990s, including renovations, staff training, the integration of digital technologies, and the expansion of research spaces.
In 1995, the library was integrated into the Common Documentation Service, which today federates 18 libraries around the central library. A new modern facility, offering 1,700 seats, was commissioned to provide users with expanded collections and enhanced access to digital resources.Granted university institute status since 1978, the central library is represented on the University Council and remains a key player in higher education and research. From its creation in 1916 to its most recent developments, it has become the oldest and largest French-speaking university library in sub-Saharan Africa, serving as a major scientific, educational, and cultural institution. [2]

Figure 1. View of the library before renovation. [2]

Figure 2. View of the library before renovation. [1]

Modeling Procedure:-

GeoGebra was chosen as the modeling tool because it allows efficient manipulation of mathematical objects in both 2D and 3D, covering various areas of learning. The generated models can be exported in STL format for 3D printing. The application thus helps students gain a better understanding of mathematical representations, whether in the form of algebraic equationsor geometric visualizations. Additionally, its extrusion feature enables the easy transformation of a 2D polygon into a 3D object.

Results:-

This section progressively presents the results obtained from modeling the two buildings. For the evaluation, we specifically considered the coefficient of determination (r^2), defined as the square of the correlation coefficient. This was calculated directly using GeoGebra software through the “RSquare” command.

Table 1. Correlation Coefficient (r) Interpretation Scale

<table>
<tr><td colspan="7">-1 -0,75 -0,5 -0,25 0 0,25 0,75 0,5 1</td></tr>
<tr><td>Strong Negative Correlation</td><td>Moderate Negative Correlation</td><td>Weak Negative Correlation</td><td>Very Weak or No Correlation</td><td>Weak Positive Correlation</td><td>Moderate Positive Correlation</td><td>Strong Positive Correlation</td></tr>
</table>

The coefficient of Determination (r2):-

The coefficient of determination (r^2) is a statistical measure that assesses the quality of a regression model, including quadratic models, by quantifying the proportion of the variance in the dependent variable that is explained by the model. In a quadratic regression (which uses an equation of the form $y=ax^2+bx+c$), r^2 indicates how well the quadratic curve fits the data points, ranging from 0% (the model explains nothing) to 100% (the model explains all the variation). A high r^2 (close to 1) indicates a good fit, whereas a low r^2 (close to 0) indicates a poor fit.

How (r^2) works in a quadratic model:-

r^2 measures the proportion of the variation in the dependent variable (y) that is explained by the quadratic relationship (the curve) between the variables.

Interpretation:-

$r^2 = 1$: The quadratic model explains 100% of the data variability; the points lie perfectly on the curve.
$r^2=0$: The model explains none of the datavariation; the model is useless for describing the distribution of the points.

Goodness of Fit:-

A high r^2 (close to 1) indicates that the quadratic curve fits the data well, whereas a low r^2 (close to 0) means that the points are widely scattered around the curve.In summary, the coefficient of determination (r^2) is a key indicator for evaluating the goodness of fit of a quadratic regression, showing the proportion of the dependent variable's variability that is explained by the curve.

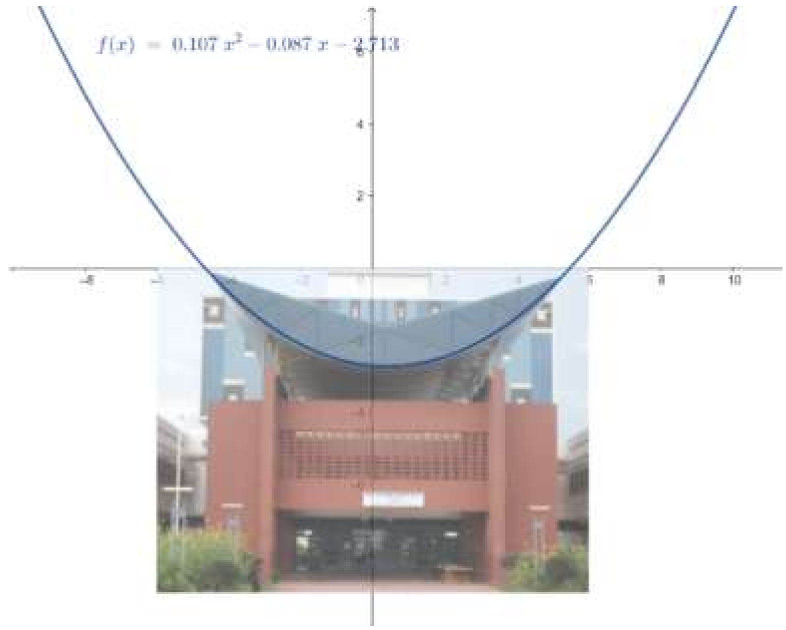

Figure 3. Quadratic curve of the decorative structure above the main entrance (front view).

The function: $f(x) = 0.107x^2 - 0.087x - 2.713$

Coefficient of determination: $r^2 = 0.990$, which means 99% of the variation is explained.

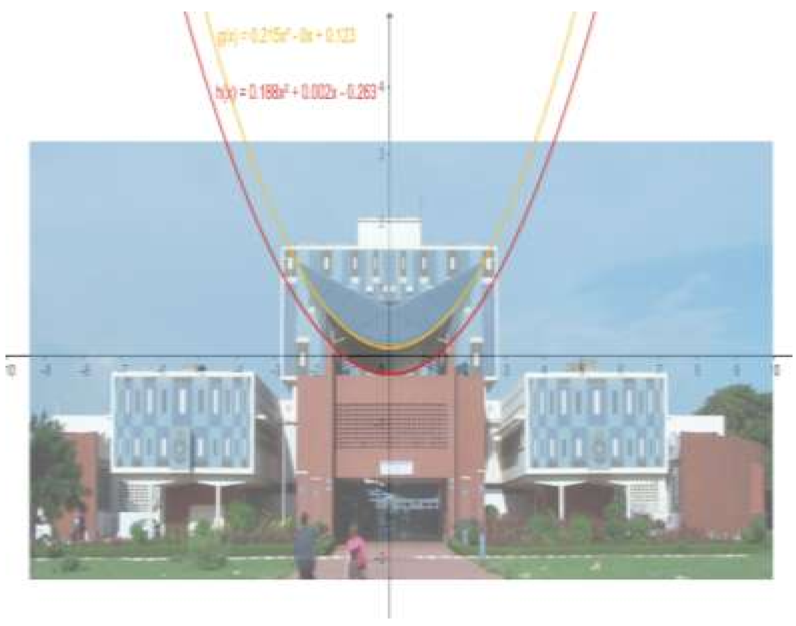

Figure 4. Quadratic curves of the decorative structure above the main entrance (front and rear views).

Thefunctions: $g(x) = 0.215x^2 - 0.x + 0.123$

Coefficients of determination: $r^2 = 0.992$, meaning 99.2%.

The function: $h(x) = 0.188x^2 + 0.002x - 0.263$

Coefficients of determination: $r^2 = 0.997$, meaning 99.7%.

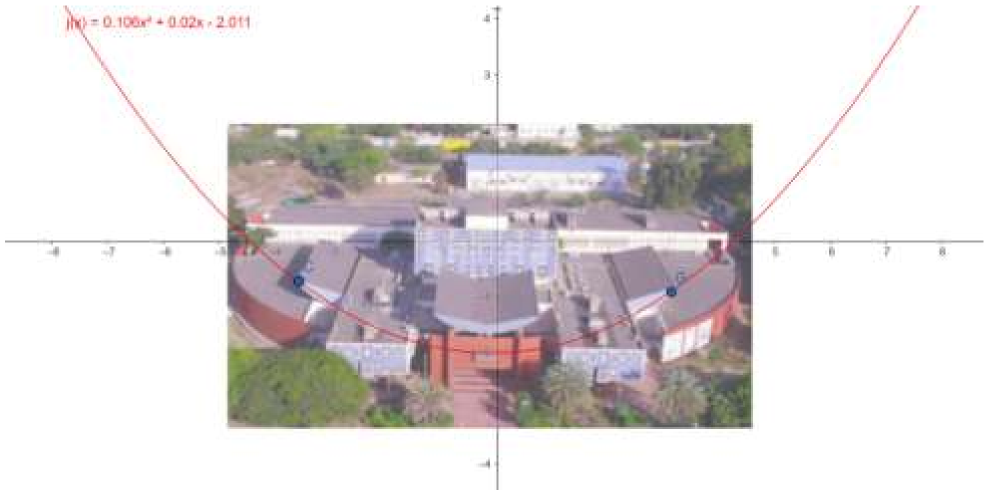

Figure 5. Quadratic curve revealing the symmetry of the outer decorative elements.

The coefficients of determination:$r^2 = 0.982$, meaning 98.2%.

Thefunction: $j(x) = O.106x^2 + 0.02x - 2.011$

This parabola satisfactorily models the curvature of the library's main façade, characterized by its two curved lateral wings. Points C and G correspond to strategic positions on the structure where the quadratic curve closely follows the architectural shape.Figure 6 is an aerial (satellite) view of Cheikh Anta Diop University of Dakar (UCAD). It offers a perspective that clearly highlights the main axis connecting the Monumental Gate (on the left, along the corniche) to the University Library (on the right), which serves as the true backbone of the campus.

Figure 6. The Principal Architectural Axis Linking the Monumental Gate and UCAD's University Library.[4]

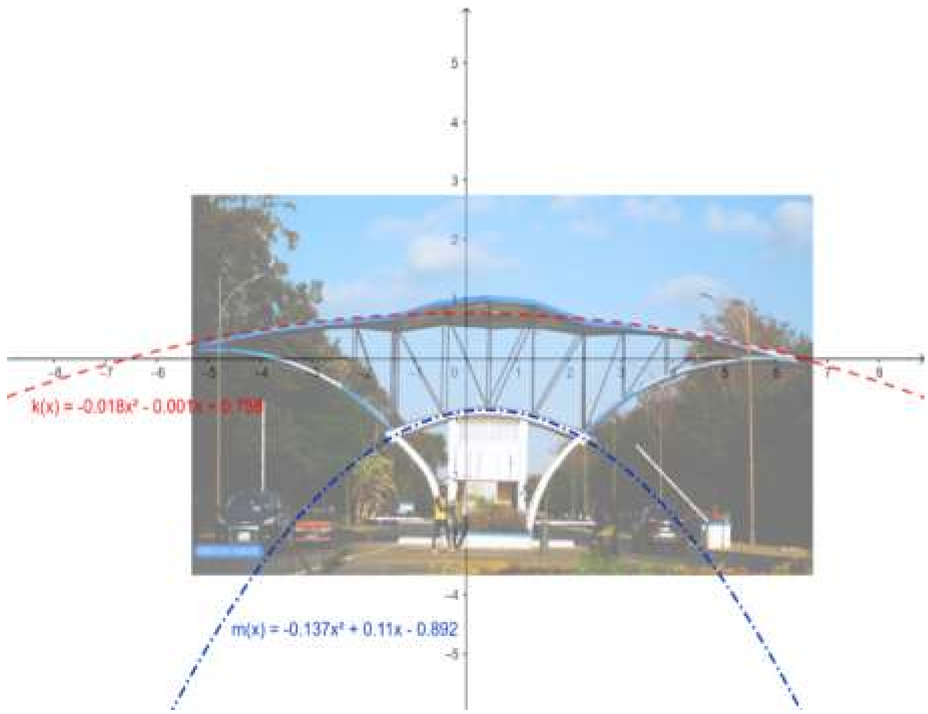

Figure 7. Quadratic Analysis and Modeling of the Roof Arch of the Main Entrance Gate of Cheikh Anta Diop University (UCAD).

The obtained function is :

$$k(x) = -O.018x^2 - 0.001x + 0.758$$

The coefficient of determination is :

r^2 =0.979, corresponding to a 97.9% fit.

The obtained function is:

$$m(x) = -0.137x^2 + 0.11x - 0.892$$

The coefficient of determination is r^2 =0.987,
corresponding to a 98.7% fit

The image shows the monumental gate of UCAD, over which two quadratic curves have been superimposed to model its main shapes:The red curve k(x) corresponds to the rounded roof of the gate. It is a downward-opening parabola with a small curvature, reflecting the slightly domed shape of the metallic roof.The blue curve m(x) models the lower arch. This “tighter” parabola follows the curvature of the central arch that supports the structure.The interpretation shows that the architecture combines simple geometric forms (parabolas) to create an aesthetic and functional construction. By superimposing these quadratic equations on the photograph, we illustrate how mathematics can describe and analyze real architectural structures.This activity could be complemented by a second task highlighting the mathematical presence of the Fibonacci spiral in these buildings.

Harmonious growth of the central library illustrated by the Fibonacci spiral:-

The evolution of the Central University Library is modeled through a Fibonacci spiral, highlighting a dynamic of regular and harmonious growth,similar to structures observed in nature and mathematics.The Fibonacci sequence begins with 1, 1, 2, 3, 5, 8, 13, with each new term being the sum of the two preceding ones. By dividing a term of this sequence by its predecessor, we obtain an increasingly accurate approximation of the golden ratio: between 1 and 2; between 1.5 and 2; between 1.5 and 1.667; between 1.6 and 1.667; between 1.6 and 1.625, and so on. It is important to note that the famous Fibonacci sequence is closely linked to the golden ratio.

Table 2.

Fibonacci sequence: $F_n=F_{n-1}+F_{n-2}$	Golden ratio (divine value)
1	
1	1 /1 =1
2	2/1 = 2
3	3/2 = 1.5
5	5/3 = 1.66
8	8/5 = 1.625
13	13/8 = 1.615
21	21/13 = 1.616
34	34/21 = 1.619
55	55/34 = 1.617

The number is approximately 1.618034… But we can also consider a geometric solution to the puzzle. Let's see what would happen if we superimposed several golden rectangles on the library. The image in Figure 7 was obtained from Google Earth. [3]

Figure 8. The library seen from above. [3]

The first rectangles are arranged at the level of the former central building, and then the subsequent rectangles are added according to a precise geometric progression. Once the entire set is established, the golden spiral can be drawn while respecting the mathematical proportions that define it. In constructing it, one can observe that the spiral passes through the new main entrance, accurately follows the curvature of the new compartments, and then rises to integrate with the upper curve of the library. This configuration reveals a strict geometric continuity and highlights the structural harmony between the contemporary extension and the historic building, while adhering to the proportionalrelationships characteristic of the Fibonacci sequence.

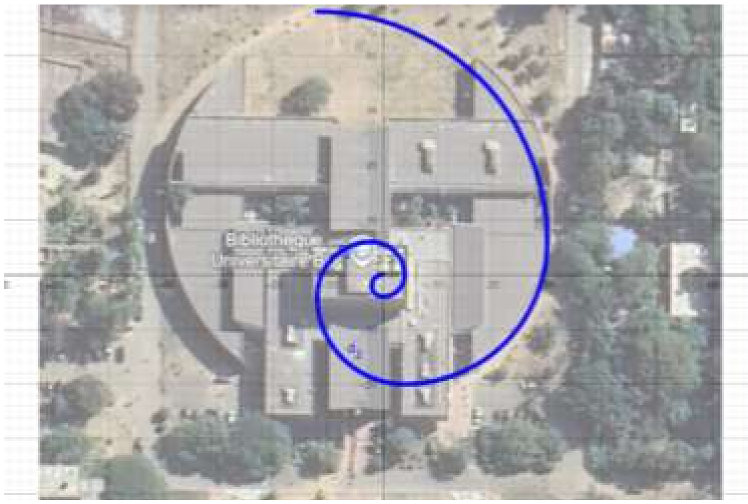

Figure 9. Geometric analysis of the Dakar University Library through the superimposition of a Fibonacci spiral.

Figures 9 and 10 present an aerial view of the University Library of Cheikh Anta Diop University in Dakar, on which geometric elements related to the golden ratio and the Fibonacci sequence have been superimposed. Successive golden rectangles (in yellow) as well as circular arcs (in red and blue) outlining the Fibonacci spiral can be observed. This geometric construction highlights a harmony between the architectural proportions of the building and universal mathematical principles. Thus, the superimposition demonstrates that mathematics is not limited to theoretical abstractions, but also allows for the analysis and understanding of balance and beauty in architecture
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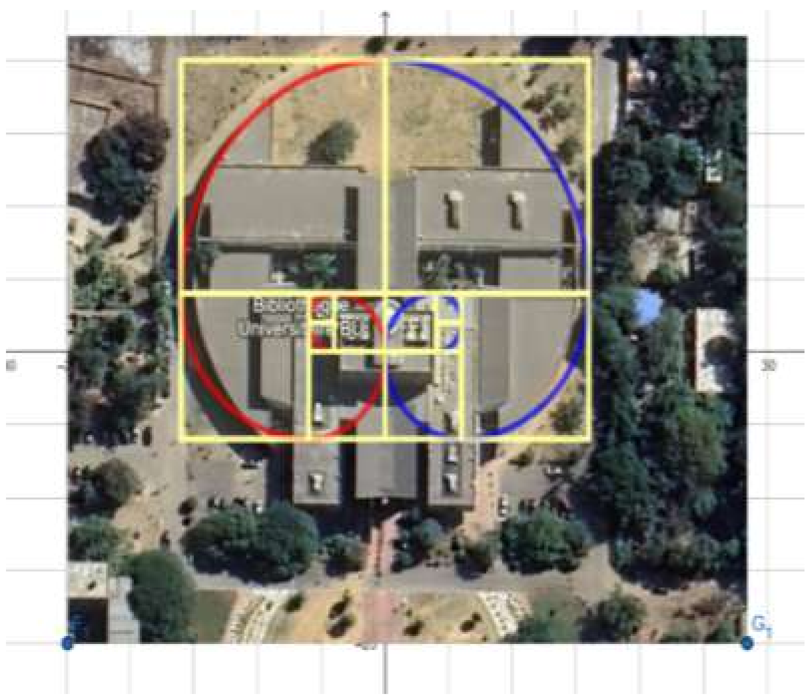

Figure 10. Application of the golden rectangle and the Fibonacci spiral to the structure of the UCAD University Library.

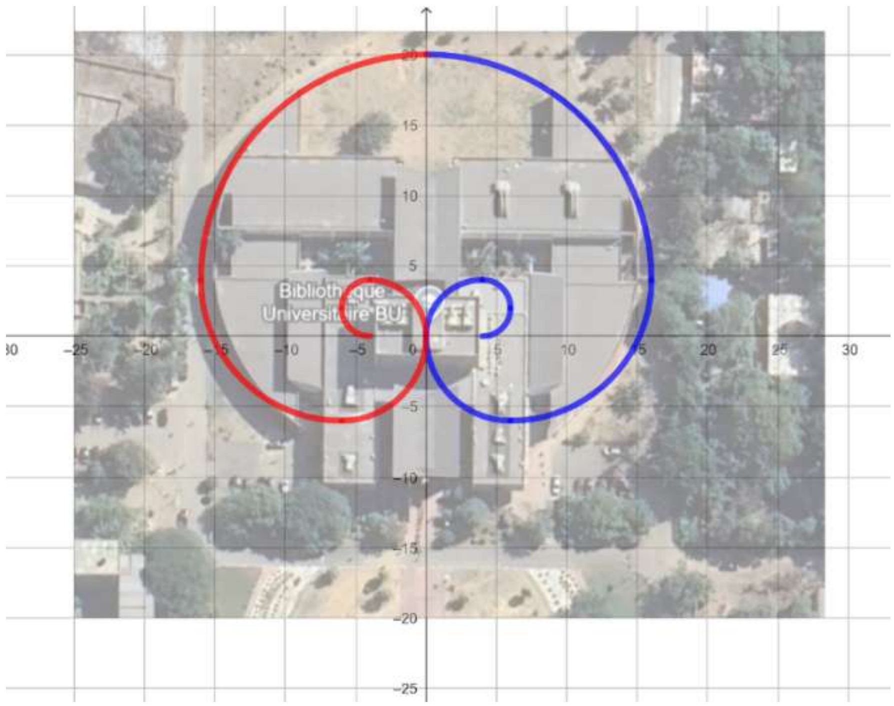

Figure 11. The geometric aspect (reversed spirals) and the architectural framework (Dakar University Library).

The building can be interpreted as a reflection on the passage of time. The new central entrance, precisely sized to align with the axis of the former building, divides the whole into two almost identical volumes. This design ensures not only visual symmetry but also optimal structural balance, while emphasizing the continuity and dialogue between the historic architecture and the contemporary extension. The proportions of the entrance and the correspondence of the surfaces are carefully studied to harmonize perspectives and guide the spatial perception of observers.

Conclusion:-

In sum, while the extension of the building can be seen as the juxtaposition of two identical hemispheres, this modeling primarily highlights the designer's intention to combine geometric rigor with architectural aesthetics. The value of this analysis lies less in the mathematical demonstration itself than in highlighting the importance given to the relationship between forms, proportions, and the visual harmony of the structure.

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