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# ICONIC STRUCTURES: CASE STUDY OF A HISTORIC MUSEUM WITH NOTABLE SPANS DESIGNED IN CONCRETE

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The emergence of iconic structures around the world increased tourism and economic status of the of host cities. Iconic structures stand out and attract the attention of the general public due to their daring structural limits and aesthetic forms. Hence, the design idea of an iconic historic museum is conceptualized in this research. This paper models an art center, analyses and designs the critical elements according to BS 8110, trying to determine the feasibility of a large-cantilevering structure with numerous curves being achieved. The activities carried out in this research involved a systematic modeling of the structure with Building Information Modeling (BIM) tools, analysis and design in reinforced concrete with particular emphasis on the cantilevered wing of about 37.5m. Numerous load combinations were applied, and various member section properties were experimented. The results obtained from the analysis of the designed reinforced concrete model identified the structural efficiency of certain critical members in the west wing of the building and how they were made to adhere to structural limits in the code of practice by ensuring deflections of critical cantilevered members did not exceed the limit. A unique arrangement of structural systems has been combined to solve the problem of deflection of the seemingly impossible cantilever of 37.5m.

*Keywords*: Design and analysis, Deflection, Structural limit, Long cantilever, Reinforced concrete, BIM.

## 1 INTRODUCTION

Various regions and countries have astonishing structures, but a handful have become instantly recognizable and easily symbolize a destination or an epoch in time and a location as they develop the skyline of such areas. Such structures can be classified as iconic structures.

An iconic structure is an architectural masterpiece that stands out and is captivating (Ede 2014a, Ede and Udoh 2015a, 2015b). Numerous structures around the world belong to this category of eye-catching structures. Examples are the Sydney Opera House, Tower of Pisa, Eiffel Tower, the Burj Al Arab, CCTV Headquarters, the Millennium Dome, Pyramids of Egypt, British Airways London Eye and Malaysia's Petronas Towers. These structures are easily recognizable and have come to symbolize their host cities. Their presence has been immensely beneficial to their host cities and nations as they boast the value of tourism and therefore, inspires the design of more outstanding eye-catching structures.

This research considers the structural analysis and design of a proposed museum building according to BS 8110 (1997), conceptualized by architect Tunji. The museum is an ingenious artifice testing the limits of spatial requirements and extents of long-span with a daring curved extensive cantilever. Museums are structures in which historical, scientific, artistic, or cultural objects of interest are stored and exhibited. Other museums buildings across Nigeria, like the National Museum in Lagos and the Civic Centre in Victoria Island, Lagos amongst others, are unique structures and this proposed model is to bring a new touch to the city by exploring new architectural and structural limits.

The economic benefits of the world's most iconic structural wonders have been immensely beneficial to the countries in which they are present. Hence, a ripple effect in the generation of more outstanding structures. If this structure is implemented, it could contribute immensely the value of internal and external tourism in Nigeria as there will be an influx of tourists from within and from other countries of the world.

## 2 METHODOLOGY

Museums buildings serve a large segment of society and therefore, to achieve end-user satisfaction, there is a need to adopt innovative design philosophies as they relate to accessibility and usability requirements (Ibem *et al.* 2017). They require spaces with aesthetic priorities to properly relay the essence of historical objects. Hence the need for open rooms with large areas and spans. The traditional role of museums is to gather and store objects and materials of cultural, religious and historical importance, preserve them and present them to the public for the purpose of education and entertainment (EGMUS 2017).

This museum building consisting of three storey, has a 22m long cantilever, which supports a 488 square meter atrium with a critical wing of 37 m cantilever, children interpretation class, curator's lounge and interpretation space, which carry large significant distributed loads. The approach consisted of the development of the structural computer model, the analysis of the critical wing of the building and the design of selected elements.

Building Information modeling (BIM) tools were adopted for various part of the works. The importance of BIM tools in present day buildings cannot be over-emphasized (Ede 2014b, Ede *et al*. 2017). BIM tools are used to model and manage a whole lot of information; the building teams need to make proper decisions especially in the design process, thereby minimizing errors and enhancing structural qualities. In this museum design, BIM tools were extensively used by the creator of the design and the supervising team of engineers and architects of Covenant University, Ota, Nigeria in order to ensure that the structural model is feasible.

The architectural model was realized in Autodesk REVIT 2017 while Autodesk Robot was adopted for the analysis and design. Studies on the deflection and moment envelopes of the concrete elements of the west-wing of the structure containing the cantilever were meticulously carried out. The west side of the building gradually progresses in height for three levels and then stretched out from this level upwards. The cantilever extended for a distance of 22m about its curved perimeter to the supported end. Based on structural efficiency considerations, tension cables members of 275 MPa were adopted to reduce the deflection of the cantilever. Two Core columns were used to support the cables at each half of the cantilever.

The museum has a spatial requirement of about 450 square meters, which is required on all four floors. The topmost floor consists a curved glazed glass roof, which can be effectively accounted for in numerous iconic structures by application of steel structural systems forming portal frames, space frames, trusses or space trusses. The elevation and skeleton views are shown in Figure 1.

Figure 1a. Architectural model displaying the extensive cantilever (Arc. Tunji 2017).

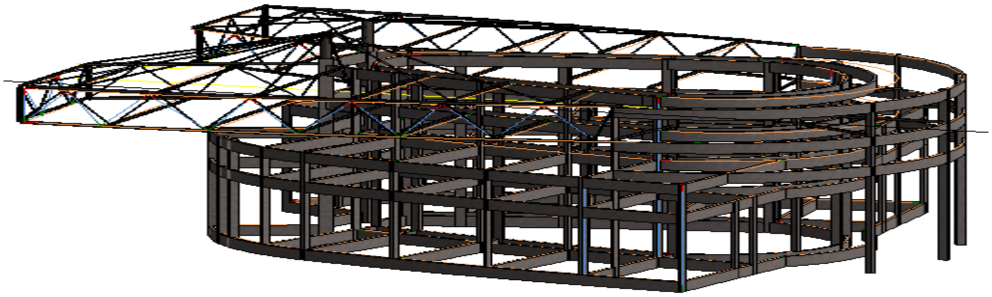


Figure 1b. Skelton of left wing cantilever (Arc. Tunji 2017).

In today's world, being guide by the ever-increasing concern for sustainability, vast combinations of materials are available for construction (Olofinnade *et al*. 2017, Ede *et al.* 2018a). For this project, normal reinforced concrete, strengthened with cables were adopted. The estimated dead and imposed loads values are in accordance with the BS 6399 (1996). Wind load was generated in Autodesk robot in the x and y directions, assuming wind velocity of 25m/s, terrain level one meter above sea level and load generation deviation factor of 0.5%.

The analysis considered the shear stress in beams and columns, bending moment in beams and columns, deflection of cantilever and tension in cables. The analysis was based on the decomposed beam loads since all the slab loads are transferred to the beams. The slabs were defined as the rigid diaphragm while the tension cables were considered as steel full sections.

## 3 RESULTS AND DISCUSSIONS

The works carried out consisted of the architectural modeling of the structure via BIM tools, structural analysis of the model with simultaneous consideration of various load interaction curves of critical elements, with strong consideration of the deflection limits as prescribed in BS 8110 (1997). A sketch of the structure with its least resisting moment compared to the overturning moment is shown in Figure 2.

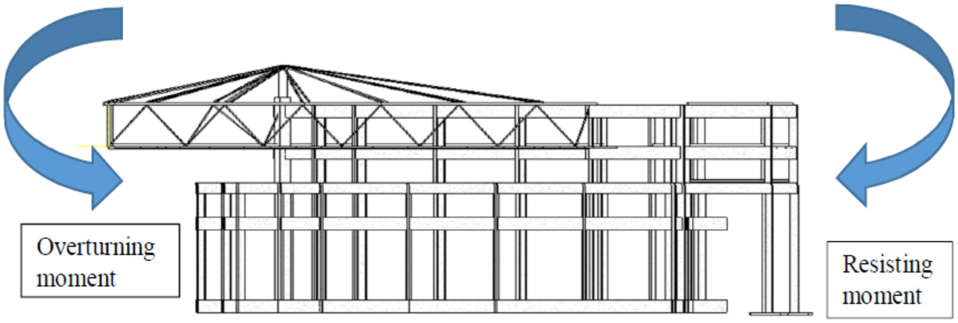


Figure 2. Elevation of building with graphic aids of entire moment directions.

The member sections were selected based on functional and aesthetic feasibility, bearing in mind the best options that will not encroach into functional space. Certain members most susceptible to the effects of the loads were identified and carefully analyzed. A section of the longest cantilever B of daring length is shown in Figure 3.

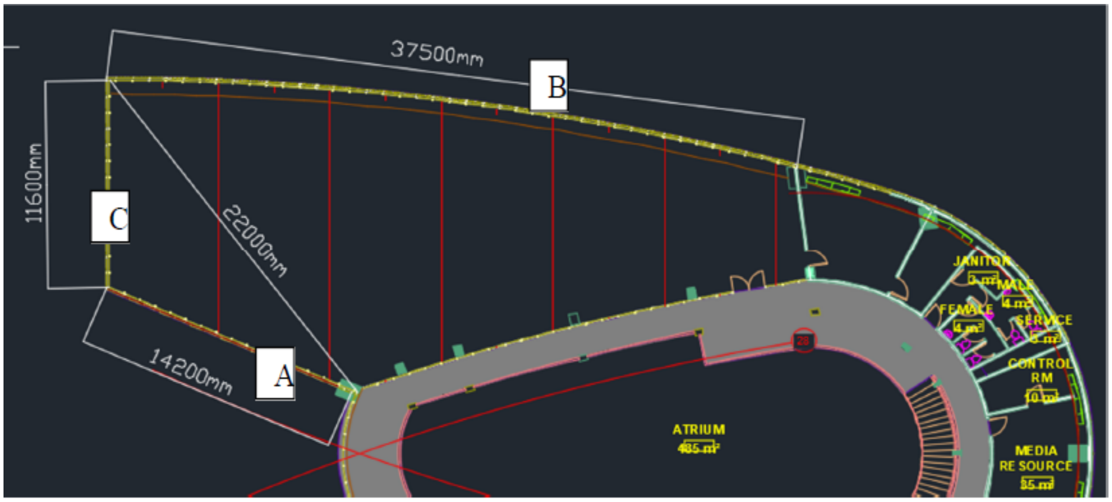


Figure 3. Plan view of cantilever (AutoCAD drawing).

Deflection is an essential criterion to be considered for structural members (especially in a cantilever) due to the risks that excessive deflection may likely lead to damage of finishes, glass panels and unnecessary slope on ground surface. In this research, the deflections of the cantilevers were vigorously analyzed. Numerous concrete sections were experimented on the various cantilevering members during the analysis. It was observed that an increase in member section was directly related to a decrease in deflection but with continuous increase, the self-weight of the steadily increasing members leads to an increase in deflection. Variation of beam A with section sizes is shown in Figure 4.

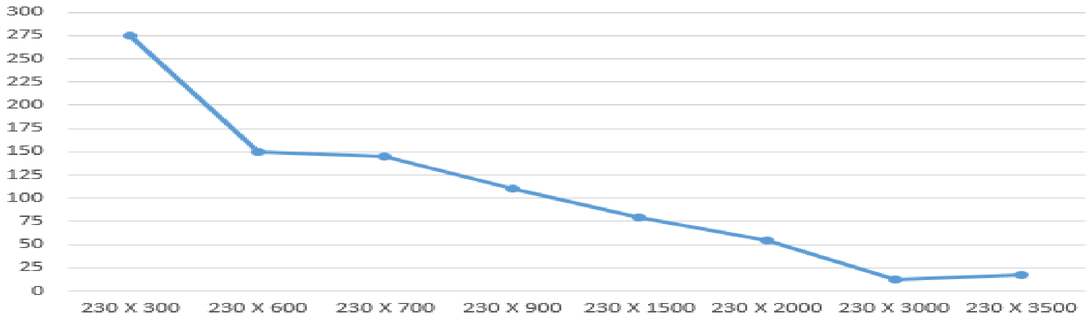
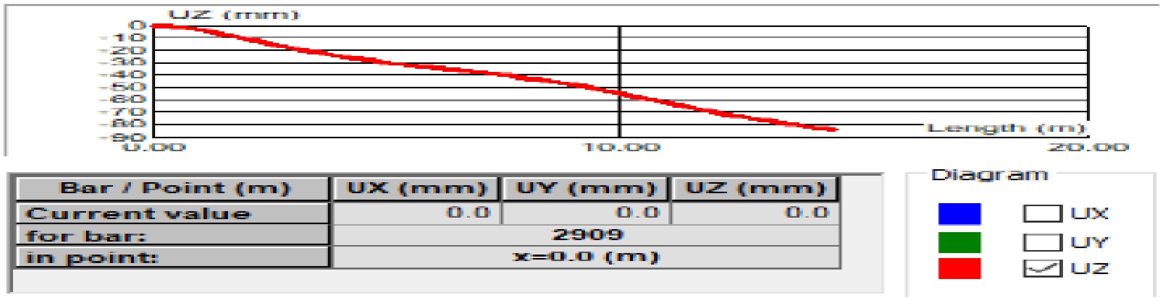


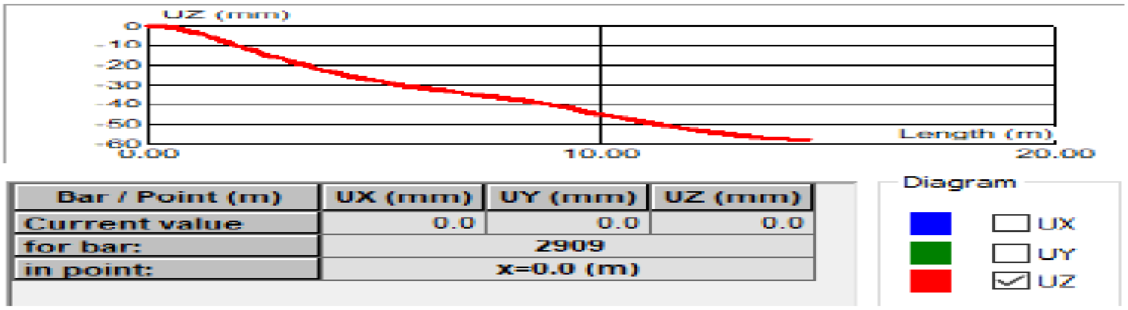
Figure 4. Graph showing variation of beam A with section size.

Two principal types of C35 concrete sections were eventually adopted: a 300X600 mm rectangular section and a T-section with flange breadth of 600mm, flange height of 175 mm, overall height of 900 mm and web breadth of 230 mm. The deflection of beam A for section types 1 and 2 are shown in Figures 5a and 5b.



| Bar / Point (m) | UX (mm) | UY (mm) | UZ (mm) |
|---|---|---|---|
| Current value | 0.0 | 0.0 | 0.0 |
| for bar: | 2909 | | |
| in point: | x=0.0 (m) | | |

Figure 5a. Deflection graphs of members A for section type 1.



| Bar / Point (m) | UX (mm) | UY (mm) | UZ (mm) |
|---|---|---|---|
| Current value | 0.0 | 0.0 | 0.0 |
| for bar: | 2909 | | |
| in point: | x=0.0 (m) | | |

Figure 5b. Deflection graphs of members A for section type 2.

It can be seen that by applying section 2, deflection reduced considerably from 90 mm to 60 mm in beam A.

## 4 CONCLUSIONS AND RECOMMENDATIONS

The structural model of this eye-catching museum building was successfully generated and subjected to various load cases. With the arrangement of structural members, it can be said that the negative outcomes of the actual long cantilever were greatly catered for. The research was tasking and helped to realize systems unique to the structure, which helped to reduce the typical outcome of such complex structure and define the limits of the architect's concept. With further analysis and study of such iconic structures, more efficient solutions may be developed, which will lead to the realization of more amazing structures, which may boost tourism and transform the skylines of Nigeria and other nations of the world. As can be seen, a unique arrangement of structural systems has been combined to solve the problem of the deflection of the seemingly impossible cantilevers, thereby reducing safety risks (Ede *et al.* 2018b). Also, variations of deflection extents with member sizes were studied as member sections were increased. Hence, this work serves as a strong basis for further research into other extensive cantilevering structures.

Based on the challenges encountered in translating the architectural drawing to functional structural model, it is recommended to engage reputable contractors who experienced in complex construction projects. This is particularly important because excessive deflection after installation of finishes, cladding and perimeter glass can lead to cracks and damages to supplementary installations and pose safety risk for the entire structure.

### Acknowledgements

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## References

BS 6399-1, *Loading for Buildings-Part 1: Code of Practice for Dead and Imposed Loads*, British Standard Institute, London. 1996.

BS 8110-1, *Structural use of Concrete-Part 1: Code of Practice for Design and Construction,* British Standard Institute, London. 1997.

Ede, A. N., Building Information Modeling: Case Study of a Duplex Building Project in Nigeria, *International Journal of IT, Engineering and Applied Sciences Research*, 3(4), 25-28, 2014a.

Ede, A. N., Challenges Affecting the Development and Optimal Use of Tall Buildings in Nigeria, *The International Journal of Engineering and Science,* 3(4), 12-20, 2014b.

Ede, A. N., and Udoh, E. G., Modelling, Analysis and Design of a Bottle-Shaped Building, *IISTE Civil and Environmental Research*, 7(1), 114-121, 2015a.

Ede, A. N., and Udoh, E. G., Modelling, Analysis and Design of a Water Drop-Shaped Building, *The International Journal of Scientific and Engineering Research*, 6(4), 14-19, 2015b.

Ede, A. N., Olofinnade, O. M., and Sodipo, J. O., *Use Of Building Information Modelling Tools For Structural Health Monitoring,* Proceedings of the IEEE International Conference on Computing, Networking and Informatics, ICCNI, 1-4, 2017.

Ede, A.N., Olofinnade, O. M., and Awoyera, P. O., Structural Form Works and Safety Challenges: Role of Bamboo Scaffold on Collapse of Reinforced Concrete Buildings in Nigeria, *International Journal of Civil Engineering and Technology,* 9(9), 1675-1681, 2018a.

Ede, A. N., Olofinnade, O. M., Ugwu, E. I., and Salau, A. O., Potentials Of Momordica Angustisepala Fiber In Enhancing Strengths of Normal Portland Cement Concrete, *Cogent Engineering*, 5(1), 1-17, 2018b.

EGMUS - *The European Group on Museum Statistics*, 2017.

Ibem, E. O., Oni, O. O., Umoren, E., and Ejiga, J., An Appraisal of Universal Design Compliance of Museum Buildings in Southwest Nigeria, *International Journal of Applied Engineering Research*, 12(23), 13731-13741, 2017.

Olofinnade, O. M., Ede, A. N., and Ndambuki, J. M., Sustainable Green Environment through Utilization of Waste Soda-Lime Glass for Production of Concrete, *Journal of Material and Environmental Sciences*, 8(4), 1139-1152, 2017.