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Modelling, Analysis and Design of a Bottle-Shaped Building

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Abstract

The emergence of unique structures around the world have turned the points of it location to centers of attraction thereby yielding benefits to the economy of the cities where they are cited. Worldwide, iconic structures stand out, placing its location on the map. Hence, the idea of bottle-shaped building was birthed trying to put bottle to tension. This research models, analyses and designs a bottle-shaped structure according the British Standard. The works carried out in this research consisted of step by step generation of a three dimensional computer models of the bottle shaped super- structure, analysis and design of critical members for various combination of dead load, live load and the wind load and the critical analysis of the results obtained. The results of the nonlinear finite element analysis carried out for different ranges of loading scenarios were so exiting. It confirmed the validity of the approach adopted for the model and showed that the realization of the structure is very feasible.

Keywords: Bottle-Shaped Building, Iconic Building, Reinforced Concrete, Structural Analysis and Design,

1. Introduction

An iconic structure can be regarded as an architectural masterpiece that is beautiful in form, serves a useful purpose and creates a sense of place by contributing to the public realm (Etheridge, 2007, Ede, 2014). The world is full of impressive and incredible structures, but there are those that have become instantly recognizable, those that have come to symbolize a destination or even a period of time. Over time, these buildings become the defining pinnacle of the greatness of their city as they improve the skyline of such areas. Such structures are truly iconic structures. The tower of Pisa, Eiffel Tower, the Sydney Opera House, the Burj Al Arab, and the Beijing National stadium (the Birds nest Stadium), Beijing Water Cube, the Flatiron Building, the London Tower Bridge and Big Ben, the Pyramids of Egypt, British Airways London Eye and the Millennium Dome are amongst such buildings. Everywhere in the world, iconic structures stand out, placing its location on the map. Hence, the idea of bottle-shaped building was birthed trying to put bottle to tension. This research presents the structural modelling, analysis and design of a bottle-shaped building to be realized in reinforced concrete. The design is in accordance with the British Standards (BS 8110). The shape of the building was originally inspired by the coca cola bottle (Adegbayi, 2009), and then successively upgraded to more innovative models (Udoh, 2012) and it stands at 112m above ground with 28 floors to accommodate offices. The conceptual shape of the building suggests an attempt at creating an iconic structure. What inspired this design is that Nigeria needs some eye catching unique structures that will put her on the global map just as the Burj Al-Arab has for the U.A.E, the Sydney Opera House for Australia, and the Eiffel Tower for France, the Big Ben for the UK and the Statue of Liberty for the USA, just to mention a few. If this structure is built, it will add a touch of the extraordinary to the skylines of Nigeria. Among the benefits include changing of the location into a holiday resort and point of continuous influx of tourist which could then trigger off the boom in the tourism sector in Nigeria and spinoff for other businesses.

A structure is an assembly of members each of which is subjected to various kind of stresses. It involves the arrangement and proportioning of the members in such a way that the assembled structure is capable of supporting the design loads within the allowable limit states (Wai-Fah, 1999). Every structure that must withstand loads, such as buildings, bridges, vehicles, machinery, furniture, soil strata etc. can be subjected to structural analysis to determine its ability to support the loads. Unique structures are those that are different from other regular structures as a result of certain characteristics peculiar to them.

This research looks into the modelling, structural analysis and design of a building in the shape of a bottle to be constructed in reinforced concrete based on BS 8110 code. The research tries to provide a unique-shaped building that could improve the Nigerian skyline and be a center of attraction. The research will consist of creation the architectural design and generation of the aesthetics of the model through AutoCAD and structurally analyses and design through Orion.

2. Literature Review

.2.1 Similar Unique Shaped Structures

This section will present a review of similar buildings, materials, theories and analysis to be carried out in this research. It considers the theories and codes employed in the design and analysis of the structure through computer soft wares and the effects of unique buildings on the economy.

Iconic structures that have been built over time that have common features comparable to bottle-shaped structure are those of curvilinear shape, of approximately circular floor plans and of varying sizes of floor plans in the direction of the height. Among the unique-shaped buildings around the world that share these same features are Burj Al Arab in Dubai UAE; Torre Agbar in Barcelona, Spain; 30 St Mary Axe in London, UK; Capitol Records Tower in in Hollywood Los Angeles, USA, Adegbayi's bottle-shaped building and the innovative variations preceding the Udoh,s water drop-shaped building.

Burj Al Arab is a luxury hotel located in Dubai, UAE. It stands on an artificial island 280 m from Jumeirah beach and is connected to the mainland by a private curving bridge. The shape of the structure is designed to mimic the sail of a ship (Wikipedia, 2015). At a height of 322m, construction started in 1994 and ended 1999 at a cost of about $650 million. The architectural design was by Tom Wright of WKK Architects while the structural design was by Rick Gregory of WS Atkins where as Jumeirah was the developer. The client wanted a building that would become an iconic or symbolic statement for Dubai and he truly got it. An incredible 70,000 cubic metres of concrete, more than 9,000 tons of steel were employed in the construction of the tower and 43,446 square metres of glass panels were used for the exterior of Burj Al Arab.

The Torre Agbar is a 38 story skyscraper/tower built in Barcelona, Catalonia, Spain. It was constructed between 2001 and 2003 for office building and realized in reinforced concrete. The architectural concept was by French architect Jean Nouvel with the Spanish firm b720 Fermine Vasquez Arquitectos whereas the structural engineering aspects was taken care of by Robert Brufau y Asociados while Dragados handle the construction. The tower occupies a space of 50693m2 and cost 130 million Euros to build.

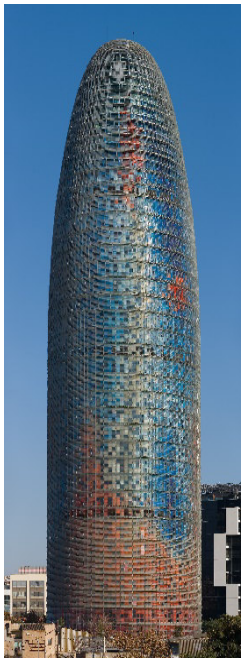
30 St Mary Axe, informally known as "The Gherrkin" is a commercial skyscraper in London. With 41 storeys, it is one of London's landmarks, standing at 180m above the City of London and was designed by Foster and partners for architectural concept while Arup Group was in charge of structural modelling and design whereas the main contractor was Skanska starting from 2001 to 2003 with a contract sum of about180 million pounds. The building has become an iconic symbol of London and is one of the city's most widely recognised examples of contemporary architecture and is a very environmentally progressive skyscraper (Tanya Barnes, 2008). The round glass walls consist of thousands of flat triangular panes of glass, which allow a 360-degree view across London. Only in the lens at the top of the building is there a single piece of rounded glass.

The Capitol Records building opened in 1956 and was easy to spot from the nearby. The cylindrical design for the building, by Welton Becket and Louis Naidorf, played beautifully to its mobile audience and that wide-open urban landscape. The result was a 13-story tower with the confidence and allure of a major skyscraper. Though Hollywood has changed a great deal in the recent years, the tower on Vine Street just north of Hollywood Boulevard continues to stand out as the symbol for anyone on arrival to Hollywood. Figure 1 shows these four famous iconic buildings.

In 2009, Adegbayi Adeola Oluwaseyi, a graduate of Covenant University, Ota, Nigeria analysed and designed a unique shaped building in the shape of a coca cola bottle. Though the building has not been constructed, but full analysis and design was carried out. The structure had 28 floors and a roof floor. The building has circular floors whose dimensions vary from floor to floor. The largest floor had a diameter of about 45m and the least floor 19.5m. It stands tall at 112m from the mean sea level. The Adegbayi bottle-shaped building was cylindrical with contours on the exterior and with varying interior diameter. The wide and symmetric circular base of the shape means the centre of gravity of the structure is symmetrically placed therefore it can resist tilting. Udoh's model took off from Adegbayi's model and brought in a lot of innovations.

Burj Al Arab

30 St Mary Axe



Torre Agbar

Capitol Records building

Figure 1: World famous iconic buildings

2.2 Intricate Design Considerations

Major consideration of the structure is the aesthetics of the structure, the assigning of dimensions in order to get the shape of the structure. The curvilinear shape of the structure is similar to that of the 30 St Mary axe and the Torre Agbar and as such shares the same concept of varying circular floor dimensions. In the determination of the dimensions, care had to be taken because the height is interlinked with the width of each floor. So an increase in the floor to floor height requires a corresponding increase in the diameter of the floors.

2.3 Materials

Concrete, arguably the most important building material playing a major part in the construction of all types of building structures, is adopted for this research. Its virtue of versatility and the ability to be molded to take up the shapes required for the various structural forms makes it a good choice. When combined with steel reinforcement, we obtain reinforced concrete which is a strong durable composite material per excellence (Ede and Agbede, 2015) as concrete and steel complements the weakness of each other and create a synergy that none of them can offer alone. Reinforced concrete structures are typified by their strength and durability and is a material of choice for many complex structures such as Burj Al Arab in Dubai and Torre Agbar in Barcelona.

2.4 Structural analysis and design assumptions

The structural form of this building is inherently three dimensional. The development of efficient methods of analysis for tall structures like this is possible only if the usual complex combination of many different types of structural members can be reduced or simplified whilst still representing accurately the overall behavior of the structure. A necessary first step is therefore the selection of an idealized structure that includes only the significant structural elements with their dominant modes of behavior. Achieving a simplified analysis of a large structure such as this is based on two major considerations. 1) The relative importance of individual members contributing to the solution; this allows a member stiffness to be taken as infinity if the associated mode of behavior is expected to yield a negligible deformation relative to that of other members in the structure while elements of minor influence on the final results given zero stiffness. 2) The relative importance of modes of behavior of the entire structure; it is often possible to ignore the asymmetry in a structural floor plan of a building, thereby making a three-dimensional analysis unnecessary.

3. Methodology

This section gives an overview of the steps and approaches adopted for the development of the structural model,

the analysis and design the members. The bottle image was imported into AutoCAD and scaled. Dimensions were gotten; these dimensions were used to produce the architectural plans. The plans were taken to Orion and analysis and design was carried out. The structure was designed for dead load, imposed and wind load as prescribed in BS codes (BS8110, 1997, BS6399, 1996, BS6399, 1997).

3.1 Super structures dimensions

An image of the bottle was gotten and inserted into AutoCAD. Measurement were taken of the bottle form on the image from edge to edge such as to represent the diameter of the building. The image was segmented into different horizontal partition. Each partition represents the floors, the dimension were magnified in order to get the final diameter of each floor. The architectural design is similar in all the floors. Approaches used on the ultimate editions of the bottle shaped building have been readily applied to other innovative creations like the water drop building. The development of a 3D computer model of the structure for analysis was achieved in AutoCAD and then replicated in Orion software. The building have shear walls in the core which acts as the elevator shaft. Figure 2 shows some modelling examples along the height and on a typical floor.

3.2 Analysis and design

The analysis of the model was carried out using Orion obtaining shear stress in beams and columns, and bending moment in slabs, beams, columns and walls. The slabs were analyzed using finite element method. The loads were transferred to the supporting beams. The beams were then designed by Orion in accordance with BS 8110. The walls were analyzed and designed considering gravity and lateral loads. The columns under uniaxial and biaxial bending were designed by Orion in accordance with BS 8110. The structural design philosophy of ultimate limit state was employed to guarantee safety and strength against failure while the serviceability limit state was employed to ensure satisfactory behavior under service load relating to the prevention of excessive deflection, drift, excessive cracking and excessive vibration (Arya 2009; Chen, 1999; MacGinley and Choo, 1990 and Mosley, 1999). The analysis and design of the bottle-shaped building was carried out by the use of Orion R14 and was the basis that inspired this research. After the initial model by Adegbayi, many innovative version of the bottle-shaped building were produced by Udoh which formed the precursor to the water drop-shaped building. Orion provides a unique central 2D/3D modelling environment for modelling, analysis and design that replicates the true physical model. The dedicated reinforced concrete finite element package allows detailed assessment of the floors based on the load cases as stipulated in clause 2.4.1 of BS 8110-1 code.

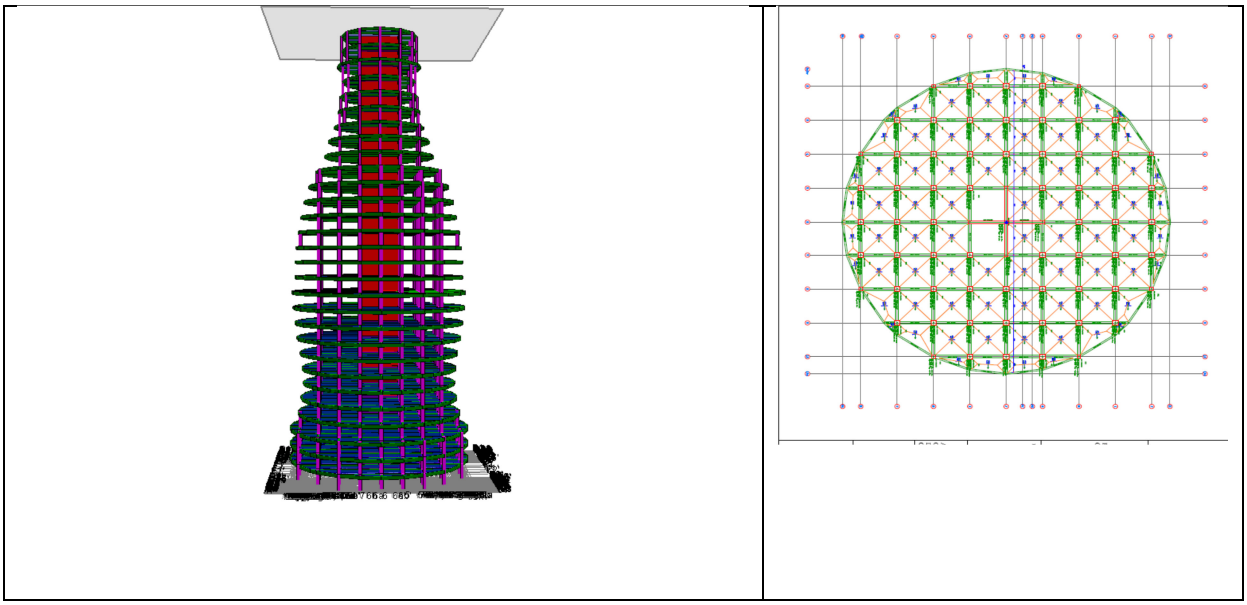


Figure 2: modelling along the height and on a typical floor.

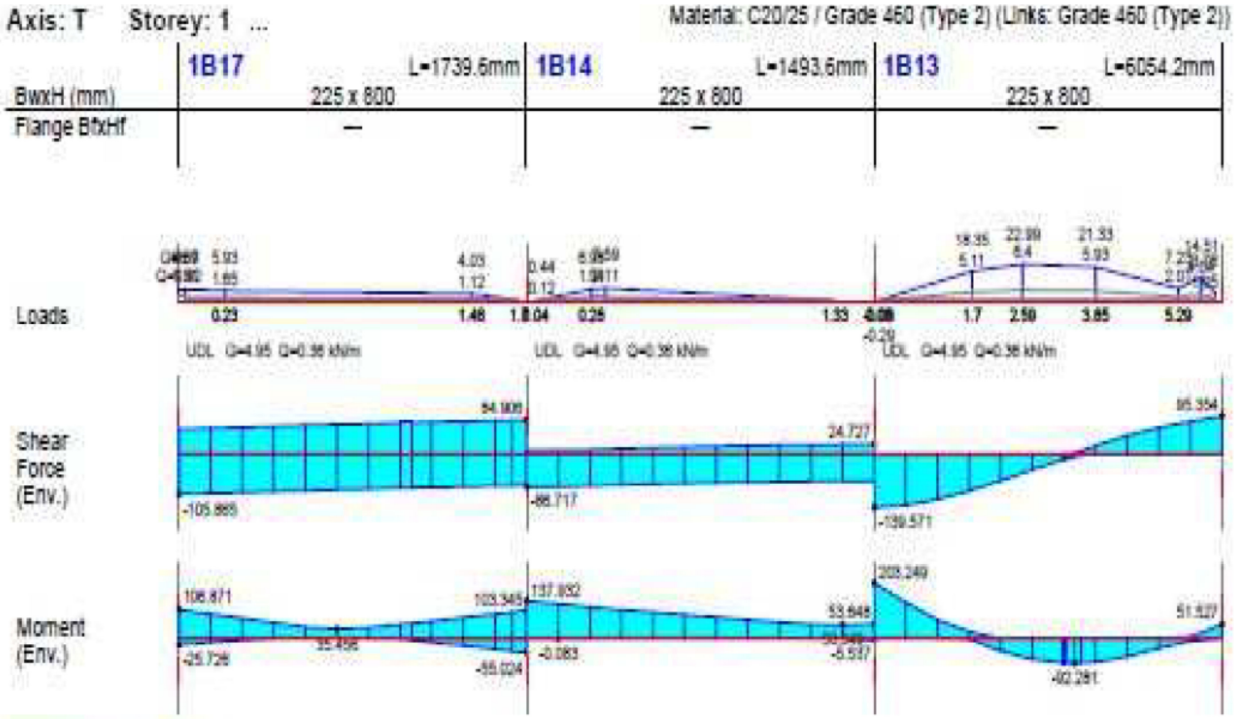


Figure 3: typical bending moment diagram of a beam

4. Results and Discussion

This section presents the result of the work carried out in the actualization of the aims of the research. Some of such work include: architectural design, modelling, floor plan, structural analysis and design. The modelling underwent several phases.

Modelling began from the initial Adegbayi model of bottle shaped building model to the ultimate models of bottles-shaped building. The step by step improvements now follows. Figure 3 shows typical bending moment diagram obtained for an element. Figure 4 contains the initial work showing the façade of the first bottle shaped structure and the corresponding structural frame. Figure 5 shows a rendered image of the structural frame and the solution after the installation of the windows and doors. Figure 6 shows the final solution with the immediate environment using AutoCAD.

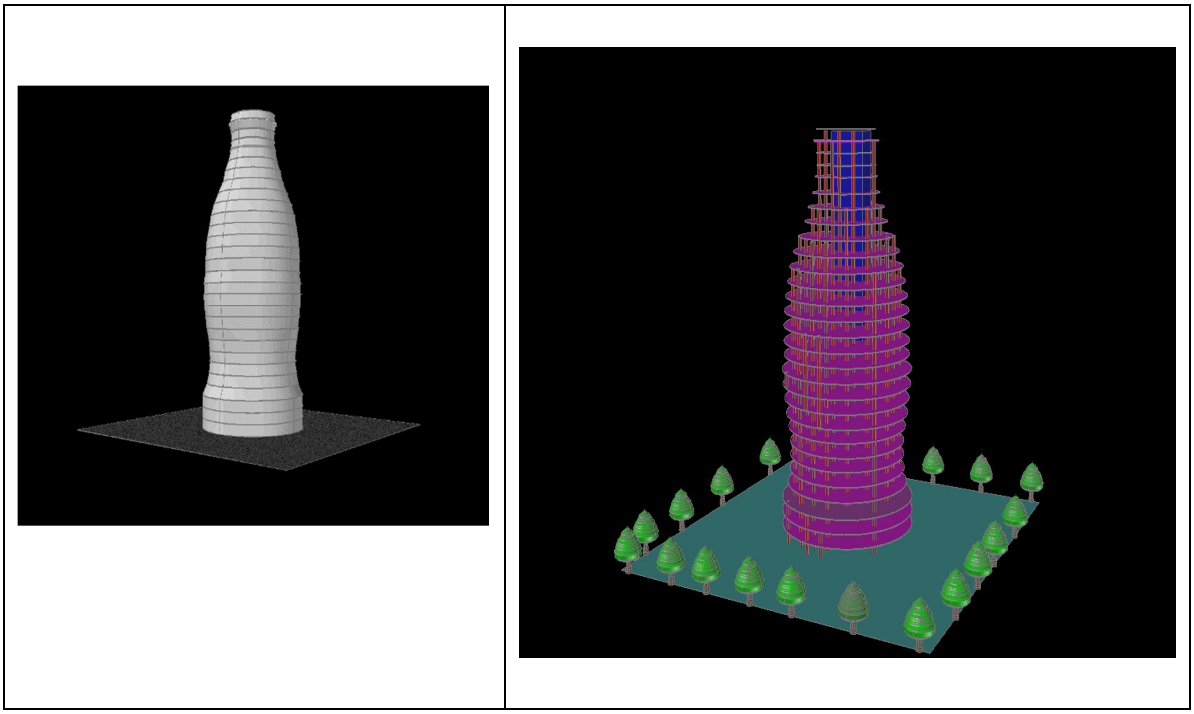


Figure 4: the façade of the first bottle shaped structure and the corresponding structural frame.

5. Conclusion

A new unique building design that was proposed was successfully modelled, analysed and designed. From the design result of the first floor structural elements, it can be said that the sections and the loading conditions adopted are valid as all sections passed and the lateral drift for each floor was acceptable. Difficulties encountered were limited examples to use as guide, dissimilar floors, and irregular shape but the end result justifies the research. This iconic structure that have been proposed and successfully designed will place the host city on the map of the world and boast the tourism of the city just as the iconic structures cited at the beginning have done for their respective cities.

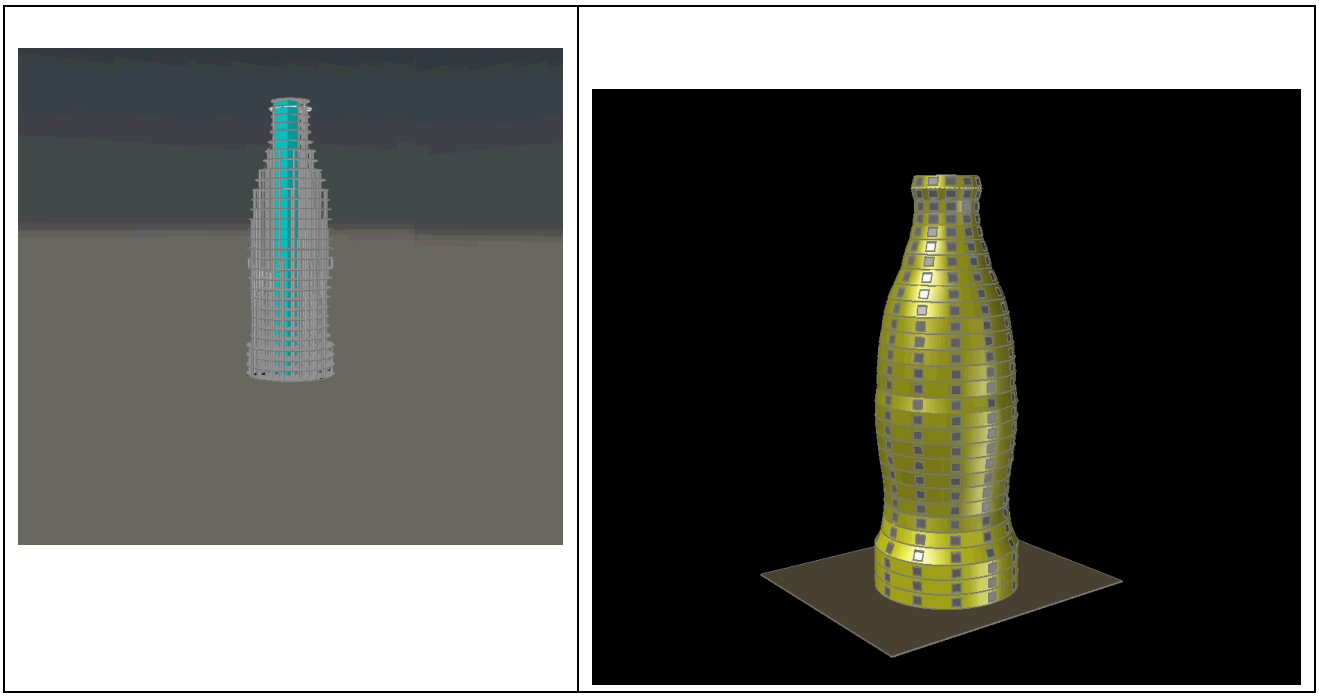


Figure 5: a rendered image of the structural frame and the solution after windows and doors are installed

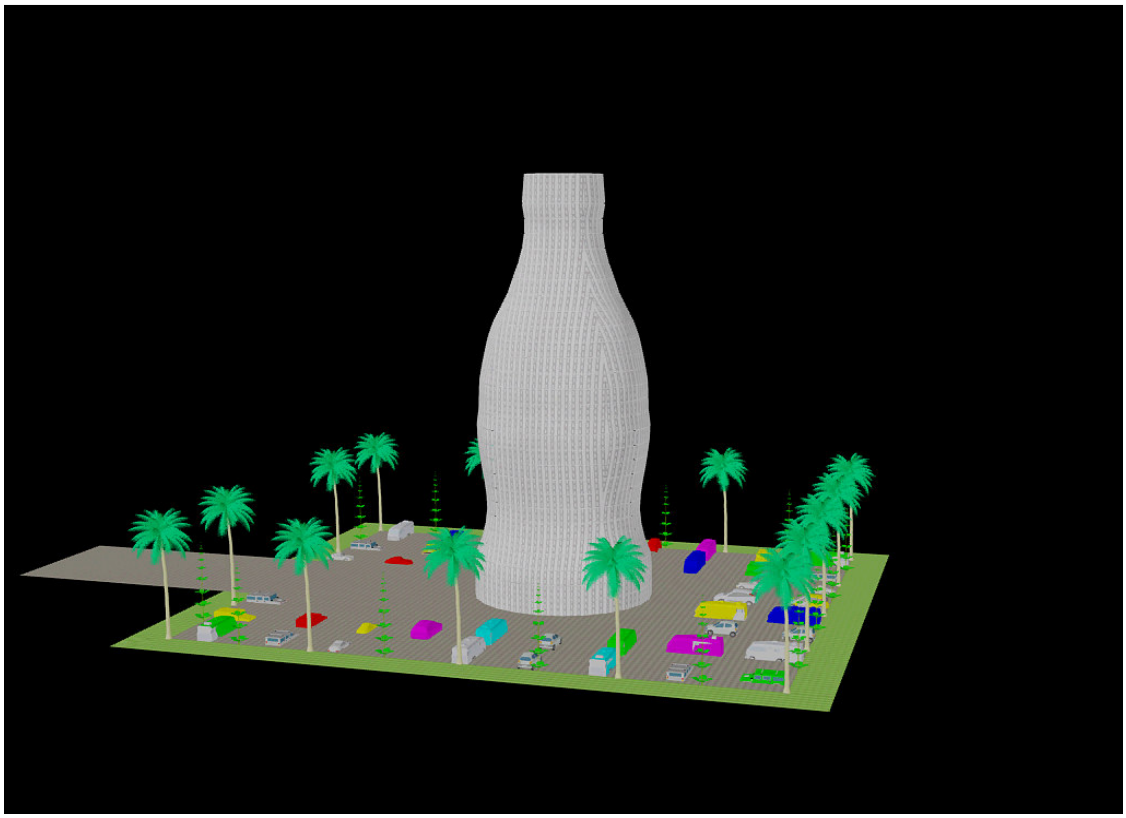


Figure 6: Image showing the rendered image with immediate environment using AutoCAD.

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