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Automated Structural Health Monitoring System for Mitigating Building Collapse in Nigeria: A Mobile App Approach

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Abstract: Building collapses have become a distressing and recurring issue in Nigeria, necessitating urgent action to mitigate their occurrence. This paper introduces an innovative approach to address this challenge by developing an Automated Structural Health Monitoring System (ASHMS) utilizing a mobile app. Focusing on major cities like Lagos and Abuja, the proposed system employs strategically placed sensors to gather data from various structural elements of buildings. The collected information, encompassing seismic activity, vibrations, bending moments, shear forces, and other key parameters, is wirelessly transmitted to the cloud where it can then be accessed and visualized using mobile app.

The system offers real-time insights into the structural integrity of buildings and provides early warnings, thereby contributing significantly to reducing the risk of building collapses. Key findings show that when incorporated into an automated Structural Health Monitoring (SHM) system, the user's mobile app offers essential structural insights, capturing values such as a 0.5-unit vibration level, 20 units of shear force, 50 units of bending moment, and an 89-degree vertical wall angle. The app's user-friendly interface improves the effectiveness of monitoring and overseeing structural health, in line with the overarching objective of promoting safety in construction practices.

Keywords: Automated Structural Health Monitoring System, Building Collapse, Nigeria, Mobile App, Sensors, Cloud Service, Structural Integrity.

I. INTRODUCTION

In recent years, Nigeria's construction industry has witnessed significant growth attributed to urbanization and population expansion [1]. However, this development has been accompanied by a disturbing rise in building collapses, posing severe threats to life, property, and economic stability.

The construction sector in Nigeria, involving architects, governments, private developers, landlords, and users, confronts a substantial challenge [4]. Notably, Abuja and Lagos have experienced a disturbingly high frequency of building collapses, exemplified by incidents like the Nigeria Industrial Development Building (NIDB) in Lagos in 2006 and a two-storey market plaza in Oshodi, Lagos, in 2010 [5]. A particularly alarming case unfolded in Surulere, Lagos State, in July 2006, where three buildings collapsed, resulting in at least 29 deaths and severe injuries to 48 others [6]. Another tragic incident occurred in Lagos in 2006, claiming 37 lives in a four-storey building mishap in Ebute Meta [6].

In September 2014, over 118 worshipers lost their lives in a collapsed six-storey building at the Synagogue Church of All Nations (SCOAN) in Lagos State [8]. Additionally, in 2011, a collapse in Gimbiya Street, Area 11 Garki, Abuja, resulted in the deaths of five people, including a pregnant woman, with over 40 squatters trapped in the house. Another two-storey building collapse occurred in Abuja, Nigeria [9]. The scenes of building collapses are disheartening and tragic (refer to Figures 1.1-1.2 below), often associated with the loss of life, investments, time, equipment, and waste of building materials. Furthermore, it adversely affects the reputation of the construction industry in the area.

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Figure 1.1: School Building Collapse in Lagos, Nigeria 2019

Source; [10]

Figure 1.2: Two -Storey Building that collapsed in Abuja, Nigeria (2023)

Source: [9]

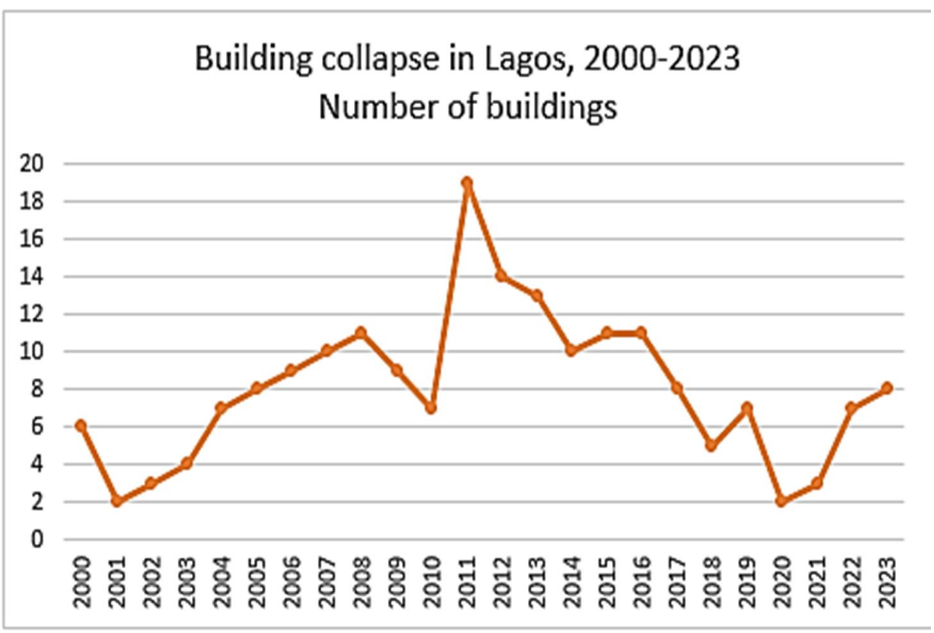

Figure 1.3: Source: Lagos State Fire Service, authors' calculations.

These incidents not only resulted in the loss of lives and property but also caused significant economic setbacks (Ibidun, 2020). The absence of effective tools for detecting and preventing building collapses impedes sustainable development and safety practices. The building collapse crisis in Nigeria is attributed to factors such as poor construction practices, inadequate supervision, the use of substandard materials, and a lack of maintenance.

In contrast to manual methods prone to human error, this study advocates for automation in structural monitoring. An automated system, equipped with strategically placed sensors within the structure, can continuously collect data, providing real-time insights into its health. This shift towards automation aims to enhance the effectiveness and reliability of structural health monitoring, ultimately contributing to the prevention of building collapses in Nigeria.

Recognizing the necessity for Structural Health Monitoring (SHM), this study underscores SHM as a crucial solution to prevent building collapses. By continuously assessing and analyzing the structural condition of buildings, SHM allows for early detection of potential issues, facilitating timely interventions and maintenance. Cloud services and mobile app technology have transformed SHM into a scalable and accessible solution. With the widespread adoption of mobile devices, mobile apps can serve as user-friendly interfaces for building owners and regulatory authorities to monitor and manage structural health efficiently.The pursued specific objectives include:

- Identifying the primary reasons for building collapses in cities in Nigeria;
- Creating a network of compact sensors to capture crucial structural data;
- Establishing wireless communication between the sensors and cloud services;
- Establishing a cloud service for the storage and processing of sensor data;
- Creating a mobile app for visualization and analysis of reports.

II. RELATED LITERATURE

In 2019, Fidelis O.A and Colleagues Combining multicriteria decision analysis with GIS for suitably siting landfills in a Nigerian state, to enhance building safety in Nigeria through the integration of GIS data with structural health monitoring. The results showcased improved visualization and analysis of building health data using GIS [11].

However, a research gap was identified: there's inadequate exploration of the potential of GIS in predicting and preventing building collapses. Moving to 2021, P. Mehta and Friends conducted a study on " Building MedVenture – A mobile health application to improve adolescent medication adherence in Nigeria." Their goal was to evaluate the usability and acceptance of a mobile app-based monitoring system among Nigerian professionals [12]. Positive feedback on usability and acceptance emerged from the results, but a research gap was identified: insufficient exploration of user preferences and challenges that might affect widespread adoption.

In the same year, Ebekozien and colleagues delved into the "Social Sustainability of Building Failures in Lagos, Nigeria: A Structural Health Monitoring Perspective." Utilizing economic analysis and interviews, they aimed to assess the socioeconomic impact of building collapses in Nigeria and the potential contribution of structural health monitoring [7]. The results revealed significant economic and social consequences, but a research gap was identified: a limited understanding of how monitoring systems can effectively mitigate these consequences. Fast-forwarding to 2023, M. Oni and Colleagues focused on "Challenges and Opportunities in Implementing Automated Structural Health Monitoring in the Nigerian Construction Industry." Through literature review and case studies, their aim was to identify challenges and opportunities associated with adopting automated monitoring systems in Nigerian construction [13]. The results highlighted barriers and potential strategies for successful implementation. However, a research gap was identified: insufficient exploration of the socio-economic implications of these challenges. In 2024, O. Olushina with Friends conducted research on "Machine Learning Applications in Building Collapse Prediction: A Nigerian Perspective," employing machine learning algorithms and historical data analysis [14]. Their aim was to develop predictive models for early detection of building collapse risks in Nigeria. The results demonstrated high accuracy in predicting potential building collapse risks, yet a research gap was noted: limited exploration of the model's performance in diverse Nigerian geographical and structural settings. R. Katam and two others, in 2023, did "Review on Structural Health Monitoring in Nigerian Buildings," using data fusion algorithms and simulation [15]. Their aim was to enhance the accuracy and reliability of structural health monitoring. The results demonstrated enhanced precision in health assessments, but a research gap was identified: insufficient exploration of the impact of diverse building materials on data fusion accuracy.

Finally, in the same year, A. Adefemi and Colleagues explored "Community Engagement and Participatory Structural Health Monitoring for Building Safety in Nigeria," utilizing surveys, focus groups, and participatory methods [16].

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Their aim was to understand the role of community engagement in the successful implementation of structural health monitoring systems. The results highlighted the importance of involving local communities, but a research gap was recognized: a limited understanding of the scalability of community engagement models.

The traditional method was to carry out visual inspection and calculation as detailed below:

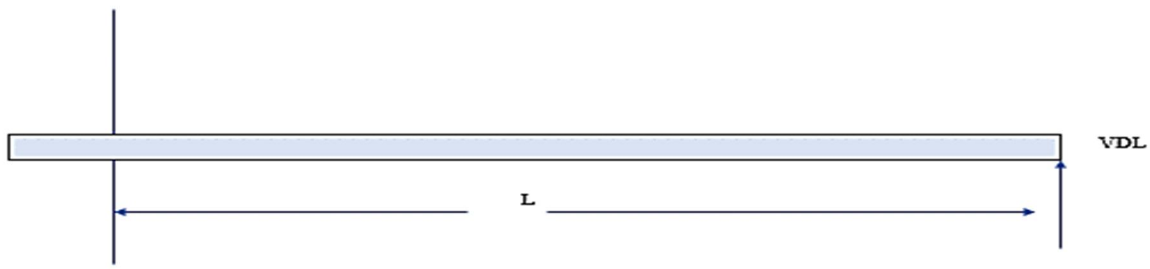

Figure 2.1: Beam of a building [2]

The general equation for moment M in the context of structural Engineering is represented by M = $\beta\omega l^2$,
2.1

where:

M is the moment applied to the structure,

β is a constant,

ω is the angular velocity of the structure, and

l is the length or dimension of the structural element.

For instance, For Simply Supported Slabs

When the slab does not have adequate provision to resist tension at the corners and to prevent the corners from lifting.

The maximum moments per unit width for non-restrain slab given as:

$$M_{sx} = \alpha_{Sx}\ \omega\ l_x^2 \text{ for short span} \qquad 2.2$$

$$M_{sy} = \alpha_{Sy}\ \omega\ l_x^2 \text{ for long span} \qquad 2.3$$

$$\alpha_{Sx} = \frac{K^4}{8(1+K^4)} \qquad 2.4$$

$$\alpha_{Sy} = \frac{K^2}{8(1+K^4)} \text{ where } k = {l_y}/{l_x} \qquad 2.5$$

(Mahyar et al, 2015)

The maximum moments per unit width for restrain slab given as:

$$M_{sx} = \beta_{Sx}\ \omega\ l_x^2 \text{ for short span} \qquad 2.6$$

$$M_{sy} = \beta_{Sy}\ \omega\ l_x^2 \text{ for long span} \qquad 2.7$$

Deflection equation of a structural Element

Deflection refers to the deformation of a member under load @ x section of structure

$$M_x = EI\frac{\delta^2 y}{\delta x^2}, \frac{\delta^2 y}{\delta x^2} = \frac{M}{EI} \qquad 2.8$$

M_x = Bending Moment at section x, and $EI = Moment\ of\ rigidity$

$E = Elastic\ Modulus\ of\ Material\ used$

$$I = Moment\ of\ inertial = \frac{bd^3}{12} \qquad 2.9$$

The deflection is maximum when $x = \frac{l}{2}$,

After derivation, the maximum deflection $= y = \frac{5\omega L^4}{384EI}$ 2.10

Where:

$\omega = weight\ on\ structure$

$L = Length\ or\ span$

In the traditional methods of structural health monitoring, Engineers often rely on visual inspections and manual calculations to assess the condition of a building's structural elements, including beams. This involves physical examinations, measurements, and calculations to estimate the structural integrity and potential risks of collapse.

Now, in the context of this paper, "Automated Structural Health Monitoring System for Mitigating Building Collapse in Nigeria: A Mobile App Approach," the traditional inspection methods would be significantly enhanced and replaced by an innovative mobile app-based approach. Reasons includes:

Real-Time Monitoring:

Traditional Method: Visual inspections are periodic and may not capture real-time changes in the structure's health. Whereas a mobile app can continuously collect and analyse data from various sensors, providing real-time insights into the structural health. This allows for early detection of potential issues

Automation and Accuracy:

Traditional Method: Manual calculations based on equations such as $M = \beta\omega l^2$ may be prone to human errors, and visual inspections may overlook subtle structural changes. But Automation through the mobile app ensures accurate calculations and continuous monitoring, eliminating the limitations associated with manual methods

Community Engagement and Awareness:

Mobile App Approach: The mobile app can serve as a tool for community engagement, providing residents with real-time updates on the structural health of buildings. This fosters awareness and proactive involvement in maintaining the safety of structures.

In summary, the mobile app approach to structural health monitoring enhances the traditional inspection methods by providing real-time, accurate, and continuous monitoring. It not only improves the efficiency of structural assessments but also allows for proactive measures to mitigate potential building collapses, contributing to the safety and stability of structures in Nigeria. The aforementioned then serves as the motivation for this research work.

III. METHODOLOGY

The research process commences with problem identification, recognizing the alarming rate of building collapses in Nigeria and the need for advanced monitoring systems. The literature review follows, delving into existing technologies, methodologies, and best practices in structural health monitoring. Subsequently, the methodology is developed, outlining the integration of various sensors into building structures, data collection through a mobile app, and the application of advanced analytics for real-time structural assessments. The results phase involves implementing the mobile app approach in a pilot study, analysing data, and assessing the system's effectiveness in early detection of structural issues. Finally, the conclusion synthesizes findings, discusses the implications for mitigating building collapses, and suggests potential enhancements or further avenues for research in this critical area of infrastructure safety in Nigeria as shown in figure 3.1

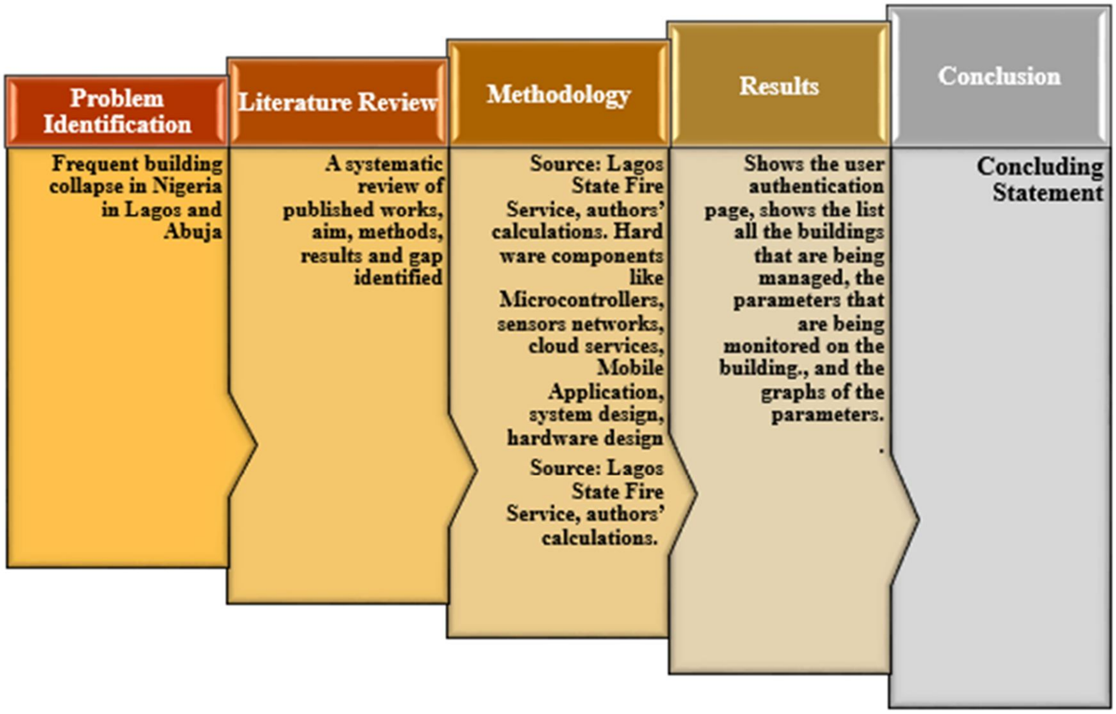

Figure 3.1: Workflow of the research process

To describing the research process with a focus on addressing the frequent building collapse issue in Nigeria, particularly in Lagos and Abuja. Here's a breakdown of the workflow based on the stages mentioned:

Problem Identification:

Define the problem: Clearly articulate the issue of frequent building collapses in Nigeria, focusing on Lagos and Abuja.

Identify factors: Understand and identify the factors contributing to building collapses, such as structural issues, environmental conditions, or other relevant aspects.

Literature Review:

Systematic review: Conduct a thorough review of published works related to building collapses, with an emphasis on systematic analysis stating the aim, methods, results and identifying research gaps.

Methodology:

Design Methodology: Explain the approach to be used for solving the identified problem.

Hardware components: Specify the hardware components involved, such as Microcontrollers, sensor networks, cloud services, and a Mobile Application.

System design: Detail the overall architecture and design of the proposed solution, including user authentication, building management, and parameter monitoring.

Hardware design: Describe the specific design of the hardware components and their integration.

A. Design Methodology

The design methodology involves the conceptualization of miniaturized sensors, selection of suitable wireless communication protocols, selection and setup of a suitable cloud services and the development of an intuitive mobile app interface. The system is designed to be user-friendly, cost-effective, and capable of seamless integration with existing building structures. The block diagram is as shown below.

Figure 3.2: Block diagram of the design methodology

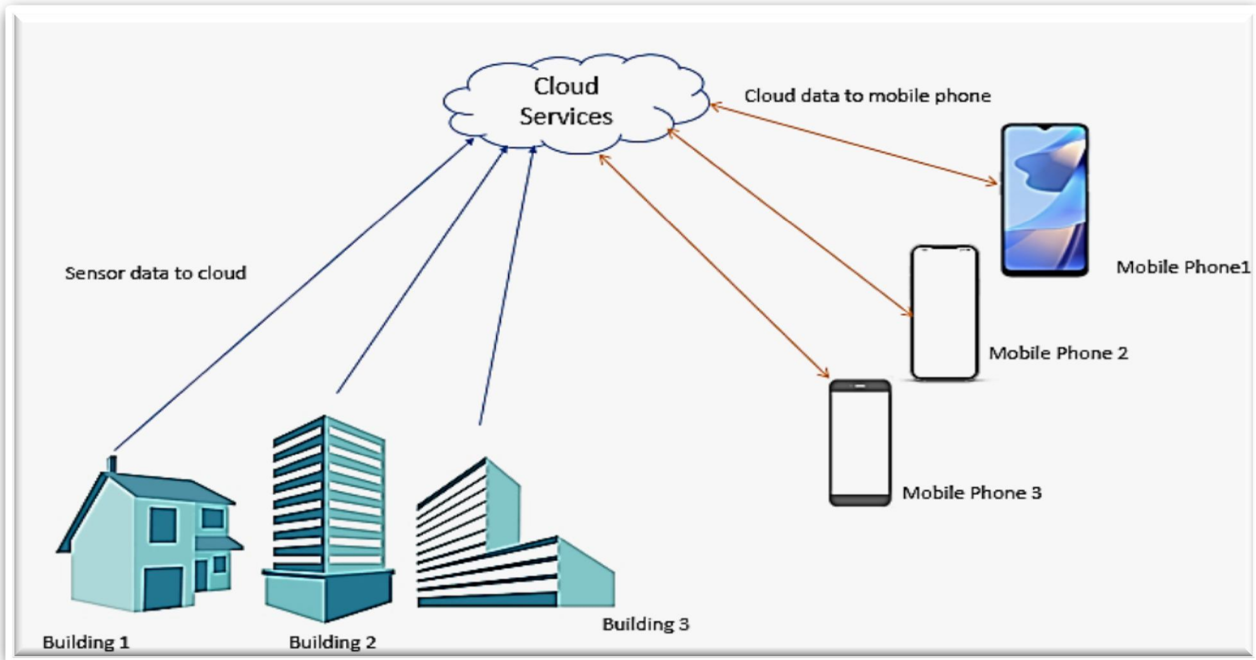

Figure 3.3: The System Diagram

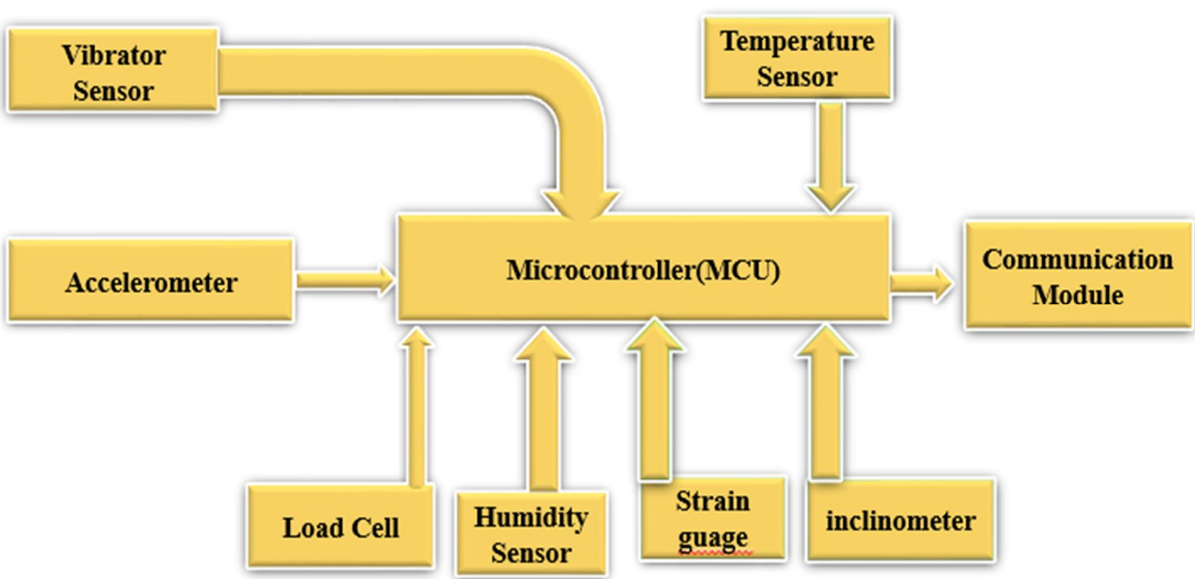

Figure 3.4: The Hardware design block Diagram

B. Hardware Design

The hardware of ASHMS consists of sensors, a microcontroller and a wireless communication module.

1) Proposed Sensors

The proposed sensors that can be used for the Automated Structural Health Monitoring System for mitigating building collapse in Nigeria, utilizing a mobile app approach are as follows:

- Accelerometers: Measure acceleration forces caused by vibrations or movement, helping detect structural shifts or potential collapses.
- Strain Gauges: Monitor strain or deformation in building components to identify overstressed areas.
- Temperature Sensors: Detect temperature variations that could lead to material degradation or weakening.
- Humidity Sensors: Monitor humidity levels to prevent moisture-related deterioration and corrosion.
- Load Cells: Measure loads or weights applied to structural elements to ensure they're within safe limits.
- Inclinometers: Determine tilting or leaning of structures, indicating potential instability.
- Vibration Sensors: Detect vibrations caused by external factors or structural issues that could lead to collapse.

2) The Microcontroller (MCU)

The microcontroller to be used in the ASHMS hardware must have the required computation capacity and speed to handle all the sensor inputs and send the data to the communication module in real-time. STM32F4 series of microcontrollers is recommended as they are 32bit MCUs with good performance. An ESP32 series from Expressif can also be used. The later comes with extra advantage as it has inbuilt communication module based on Wi-Fi and Bluetooth.

3) Communication Module

The recommended communication module for ASHMS is one internet capability. A Wi-Fi based module is a good choice. GSM/3G modules form SIMCOM (e.g SIM800) are also good choices as eliminate the need for Wi-Fi routers and communicate directly with the internet.

4) Cloud Service Design

The cloud services recommended for this project is a serverless function. This can be gotten from the major cloud services providers (e.g. AWS, Azure, GCP, DigitalOcean etc). The serverless function will run custom logic to process the data from the sensors and store it to the database and also process the data for inferences and easy visualization before sending it to the mobile app. User authentication is also performed in the serverless function. Recommended storage solution is a InfluxDB which is a time-series database. This provides the advantage of easy storage and fast query of data based on time and other properties.

5) Mobile Application

For best performance on the mobile application, native development is recommended. The Android application will be developed using the official Android SDK. This will help to take advantage of all the native visualization libraries (AAChartCore, HelloCharts, etc) with very responsive user interaction.

IV. RESULTS

The results of the suggested mobile app display a user authentication page, prompting users to log in with a username and password. Subsequently, it presents a comprehensive list of managed buildings and the monitored parameters within each building. Following this, graphical representations of the monitored parameters (refer to Figures 3.5-3.8) are showcased below.

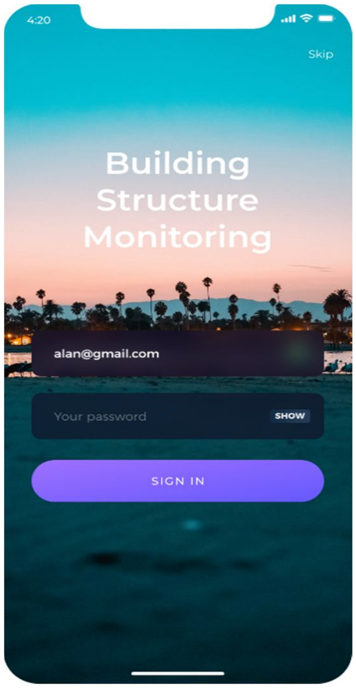

Figure 3.5: User Authentication Page

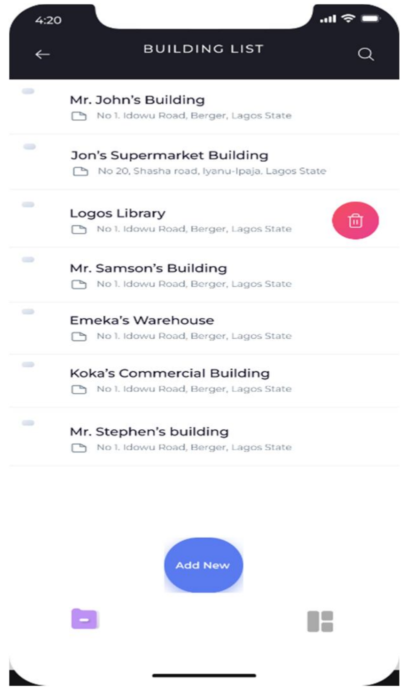

Figure 3.6: List of Managed Buildings

The user authentication page is the initial screen users encounter upon launching the mobile application. It includes fields for entering credentials such as username and password as shown in Figure 3.5. Whereas upon successful authentication, users would be directed to a screen displaying a list of all buildings being managed. Each building entry could include relevant details such as building name, location, and a status indicator to quickly identify any potential issues. Users might have options to select a specific building to view more detailed information as presented in Figure 3.6.

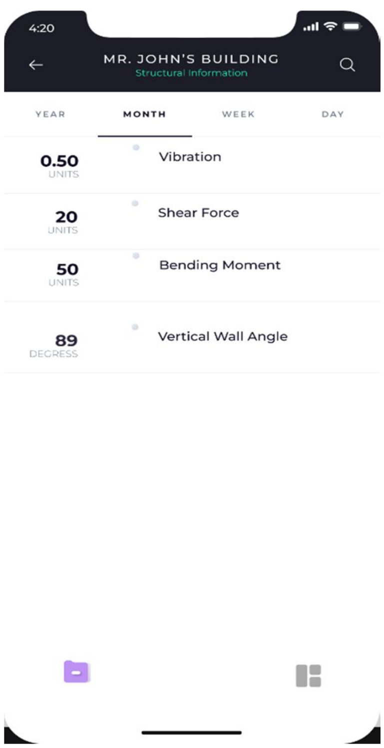

Figure 3.7: Monitored Parameters

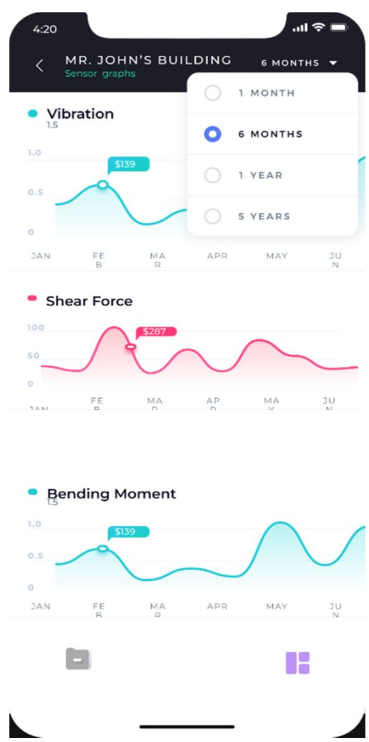

Figure 3.8: Graphs of Monitored Parameters

Figure 3.7 shows the Monitored Parameters that upon selecting a particular building, users would navigate to a screen showing the parameters being monitored for that specific building. Parameter include structural conditions, environmental factors, or any other relevant metrics contributing to the risk of building collapse. The information presented in a good format with clear labels and values. Whereas the graphs of monitored parameters screen presents graphical representations of the monitored parameters for enhanced data visualization. Graphs are line chart showing the trends and fluctuations of the parameters over time. Users can interpret the graphs to identify patterns or anomalies that might indicate potential risks or issues with the building's structural integrity as shown in Figure 3.8. Overall, these screens collectively provide users with a comprehensive tool for monitoring and managing buildings, aiming to address the frequent building collapse issue in Nigeria, especially in Lagos and Abuja. The design prioritizes user authentication, building management, and detailed monitoring of key parameters to ensure a holistic and effective solution.

V. DISCUSSION

The results on the user's mobile app reveal vital structural indicators for an automated Structural Health Monitoring (SHM) system. Recorded values encompass a vibration level of 0.5 units, shear force at 20 units, bending moment reaching 50 units, and a vertical wall angle measuring 89 degrees. These readings are pivotal in evaluating the structural integrity of buildings. A vibration level of 0.5 units implies a fairly stable structure, while a sheer force of 20 units and a bending moment of 50 units highlight the exerted forces, requiring attention to ensure they fall within safe limits. The 89-degree vertical wall angle offers insights into structural alignment, with any deviation potentially indicating an issue.

The mobile app's capability to instantly showcase and assess these parameters is a fundamental aspect of an automated SHM system. This method enables early identification of anomalies or potential structural concerns, allowing for prompt interventions and preventive actions to mitigate the risk of building collapses in Nigeria. The app's user-friendly interface facilitates effective monitoring and management of structural health, contributing to the overarching objective of enhancing safety in construction practices.

VI. CONCLUSION

This paper addresses the alarming issue of building collapses in Nigeria by introducing an innovative Automated Structural Health Monitoring System (ASHMS) utilizing a mobile app. Focused on major cities like Lagos and Abuja, the system strategically places sensors to collect data on various structural elements, transmitting the information wirelessly to the cloud for real-time access and visualization through the mobile app. The findings indicate that the mobile app, integrated into an automated Structural Health Monitoring (SHM) system, provides crucial structural insights, including vibration level, shear force, bending moment, and vertical wall angle. These indicators play a vital role in evaluating structural integrity, with the app's user-friendly interface facilitating effective monitoring and management. The methodology involves problem identification, literature review, sensor integration, data collection, and real-time assessments, leading to promising results in early detection of structural issues. The implications suggest that this approach contributes significantly to mitigating the risk of building collapses in Nigeria, with potential enhancements and further research avenues outlined for the critical area of infrastructure safety.

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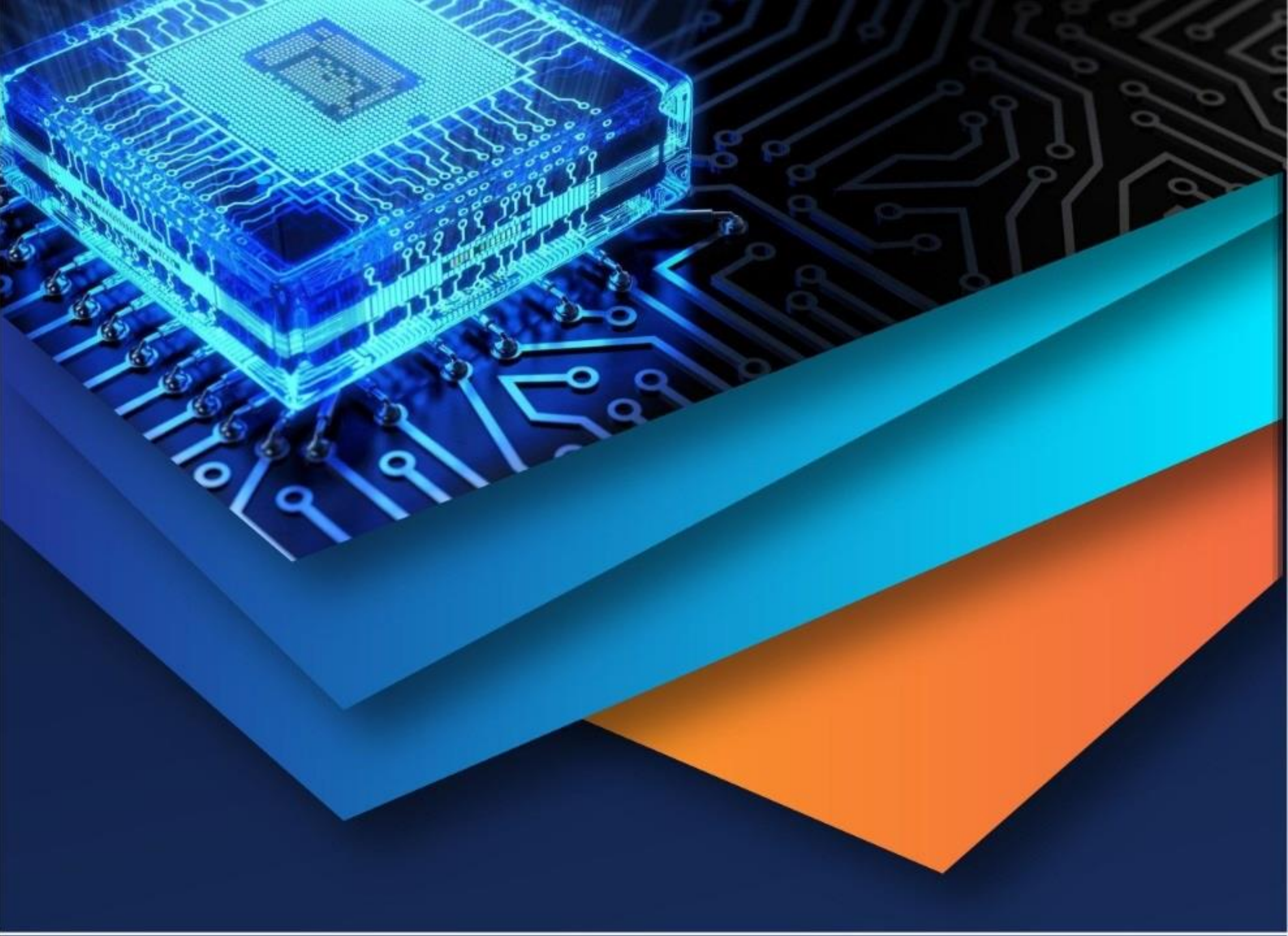

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