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Correlation Analysis and Air Quality Index for CO_2 and TVOC in Downtown San Salvador, El Salvador

***Abstract*—This study utilized a mobile station to analyze air quality AQI, focusing on CO_2 and TVOC concentrations, and examined the correlation between these two variables. The data analyzed were collected between 5:00 a.m. and 8:00 p.m. along an urban route that covered areas with sensitive populations, such as hospitals, clinics, schools, universities, and public spaces. Statistical analysis revealed a strong positive correlation, confirming a direct relationship between CO_2 and TVOC concentrations. This correlation suggests that both variables share familiar emission sources, i.e., vehicle emissions. This is particularly relevant given the 8.1% increase in the number of vehicles by 2024, which contributes to the deterioration of air quality. Although most CO_2 concentrations remain within a "regular" range (50-100 on the AQI) with no significant impact on health, data mapping identified areas with higher concentrations of pollutants, such as the Rosales National Hospital, where the use of heavy machinery during renovation is a contributing factor. Despite these concentrations, the study concluded that, for the most part, the air quality index values for CO_2 and TVOC do not represent a significant impact on human health.**

***Index Terms*—Air quality, Analysis, AQI, CO_2, Concentration, TVOC, Volatile organic compounds.**

I. INTRODUCTION

The air quality index (AQI) indicates the state of the air and associated health risks based on the obtained value. The AQI ranges from 0 to 500, meaning that the lower the value, the less contamination there is. The pollutants regulated by the Clean Air Act are [1]: ozone (O_3), carbon monoxide (CO), nitrogen oxide (NO), suspended particles (PM_{10} and $PM_{2.5}$), and sulfur dioxide (SO_2). Similarly, in the country there is a regulation regarding the concentration and measurement period, the air pollutants of study in the country, which are the following: SO_2, CO, NO_x, O_3, Pb, total suspended particles (PM_{10} and $PM_{2.5}$) [2]. The Ministry of Environment and Natural Resources has three air quality monitoring stations, and only one of them is in operation [3]. This station monitors air quality by recording variations in the concentrations of the pollutant $PM_{2.5}$, without measuring other kinds of concentrations. This is insufficient to carry out air quality studies, which is why the creation of a station to measure these missing concentrations is necessary.

This project proposes to reinforce the mobile stations previously built, adding new sensors to expand their study. The study variables selected are CO_2 and TVOC, which, although not identified as primary pollutants in the country, also affect people's health. Therefore, the objective of this project is also to investigate a correlation between the concentrations of CO_2 and TVOC due to urban dynamics [4], as well as an analysis of the air quality index based on these concentrations.

This document is organized as follows: Section III presents a description of the mobile station device, Section IV describes the process and treatment of the measurements, Section V presents the results and analysis of the research; ending with Section VI with its due conclusions.

II. RELATED WORK

Proposals for the creation of low-cost air quality measurement systems have increased over the years [5] [6] [7] [8], in these stations different sensors have been used to measure $PMS_{2.5}$ and PMS_{10} concentrations [9], TVOC [10], CO_2 [11], O_3 [12], CO [13], HCHO [14], displays for the visualization of concentrations in real time [15], using developer boards such as ARDUINO UNO [16] and ESP32 [17], being also these mobile stations [18].

III. MATERIALS AND METHODS

A. Equipment for measurement.

Data collection will be performed using a low-cost mobile station that has undergone significant development. In version 1.0 [19], the device measured suspended particles (PM) and temperature, which were visualized and stored on a web platform. In version 2.0 [20], the device incorporates GSM connection, in addition to measuring $PM_{1.0}$, $PM_{2.5}$, PM_{10} and formaldehyde (HCHO) concentrations, temperature and humidity by means of advanced sensors. In version 3.0 [21], geolocation (GPS) and air quality heatmap generation were introduced for mobile monitoring. In version 3.5 [22], a centralized IoT platform (Thingsboard) was implemented for real-time tracking. Now in version 4.0, seeks to improve the technological and analytical capabilities of the previous systems, in addition to integrating new sensors to measure ozone (O_3), carbon monoxide (CO), carbon dioxide (CO_2) and total volatile organic compounds (TVOC), as well as the sensors previously used in the others' version.

TABLE I: Sensor specification table

Sensor	Magnitude	Measuring range	Accuracy
PMS5003ST	PM1.0, PM2.5 y PM10.0	0 – 500 μg/m^3	±10 μg/m^3
	Formaldehyde	0 – 1 μg/m^3	±0.05 μg/m^3
	Temperature	-20 – 99 °C	±0.5 °C
	Humidity	0 – 99 %	±5 %
MEMS Gas Sensor	CO	1 – 1000 ppm	±10 %
Ozone Sensor	O_3	0 – 10 ppm	±15 %
ENS160 + BME280 Environmental Sensor	CO_2	400 – 65000 ppm	±50 ppm
	TVOC	0 – 65000 ppb	±15 % of lecture

With this version, the quality of the sensors was improved by reducing the uncertainty they presented, while maintaining a low cost compared to sensors of similar accuracy. Therefore, the technical specifications of the sensors used are listed in Table I.

B. Structure of the mobile station

The hardware of the mobile station consists of the four sensors listed above, which enable the measurement of different pollutant concentrations. Additionally, it includes a GPS antenna that facilitates the location of the measurement and provides the GTM time in UTC+0. Then, the board is the LilyGO T-SIM7000G, which helps in the collection and processing of data. Finally, there is an LTE antenna that enables sending data to the online platform ThingsBoard®.

Algorithm 1: Mobile Station Operating Procedure

Outcome: Data collection and air quality index calculation. Include libraries to be used. Prepare UART port for PMS5003ST, and I2C port for OLED, MEMS Gas, Ozone Sensor, ENS160, and BME280; Initialize variables; Configure the GPS connection. Configure APN connection; Establish a connection with the Thingsboard®platform; Execute sensor warm-up phase.

while *Station* == *on* **do**

  Read the system date and time; Read GPS coordinates; Acquire sensor data: O_3, CO_2, CO, TVOC, HCHO, PM, humidity; Process the data. Calculate the Air Quality Index (AQI) from the
19 measured concentrations. Display on screen: measured concentrations and their AQI value; Format the data as a JSON payload. Send the payload to the FastAPI endpoint via an HTTP POST request.

  while *Server* == *on* **do**

    FastAPI receives and validates the payload; FastAPI stores the data in PostgreSQL. FastAPI forwards the payload to Thingsboard via HTTP API for visualization. FastAPI sends a reception confirmation to the IoT device.

  Wait 4.5 seconds;

C. Mobile station processes

35 The operating steps of the mobile station are as follows: first, when the device is turned on, the development board is initialized, which turns on the screen that displays the processes being carried out. Then, it proceeds to warm up the sensors, which are ready to take measurements after three minutes have passed. Next, the Internet connection is established through the APN, and then the positioning process begins with the nearby satellites. The measurements are taken at an interval of 4.5 seconds and then sent to ThingsBoard®, where the data is displayed and stored. The process described before is shown in Algorithm 1.

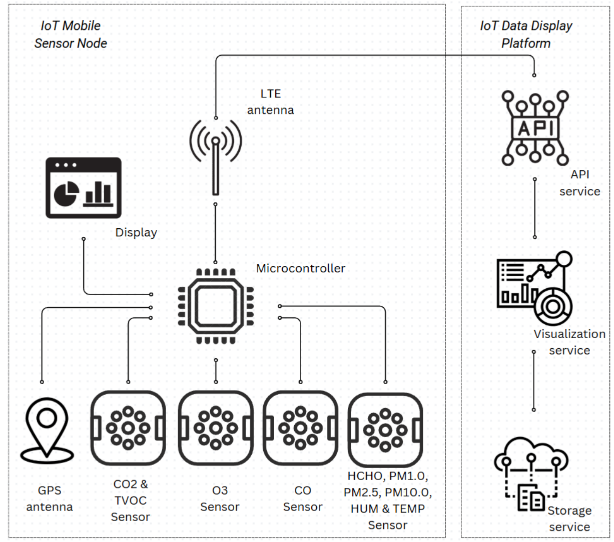

Fig. 1: Schematic of mobile station.

IV. MAPPING, HYPOTHESIS FORMULATION AND METHOD DEFINITION

A. Delimitation of the cases to be analyzed

The variables to be used in the study will be the concentrations of carbon dioxide and total volatile organic compounds. Measurements will be taken between 5:00 a.m. and 8:00 p.m., encompassing both peak and off-peak traffic hours. The area of interest for this study was spaces such as hospitals, clinics, and health centers, where people with vulnerable health are found, and where these concentrations are detrimental to their well-being and recovery. Additionally, it included areas of public spaces, such as squares. The route starts at the Benjamin Bloom Children's Hospital following 25th North Avenue until it reaches the Rosales National Hospital, where different hospitals and clinics are located, then the route continues along Rubén Darío Street until it arrives at the Libertad square, then it continues along 6a South Avenue until reaching 1st East Street, finally the route ends arriving at the intersection with the España Avenue, as shown in the Fig. 2 [1].

B. Processing of collected data

A total of 31 complete measurements are available, of which twelve samples will be analyzed over a day, to be used in the correlation study. Additionally, an analysis of all the data collected will be carried out by means of the Air Quality Index (AQI), with the objective of normalizing the values and facilitating the interpretation of air quality.

$$AQI = \frac{AQI_{Hi} - AQI_{Lo}}{C_{Hi} - C_{Lo}} \cdot (C_x - C_{Lo}) + AQI_{Lo} \quad (1)$$

Where:

- AQI_{Hi}:Upper value of the range.
- AQI_{Lo}:Lower value of the range

[1]The coordinate system used in the maps of Fig. 2 and Fig. 3 is WGS84

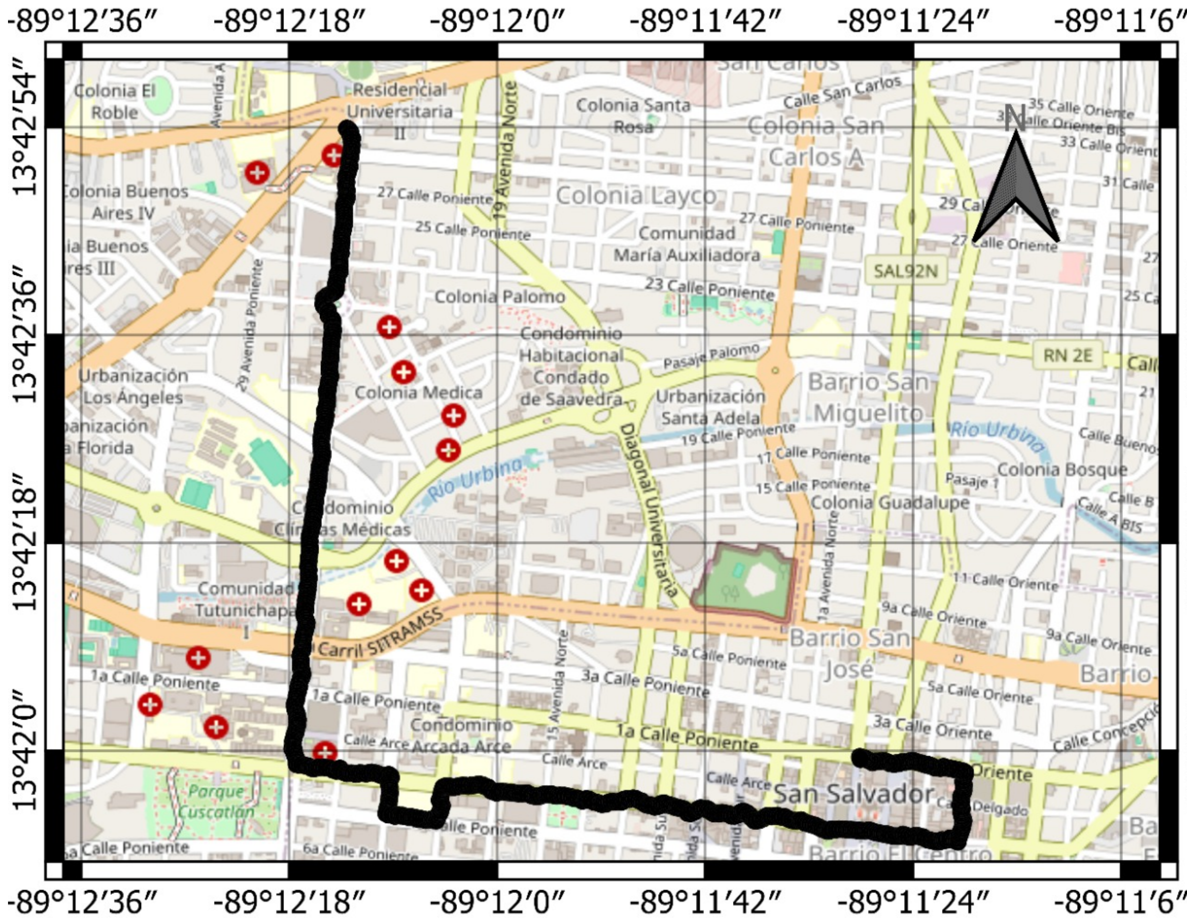

Fig. 2: Data collection route in downtown San Salvador

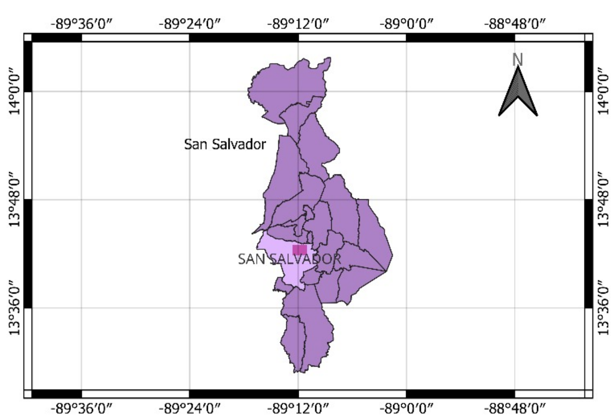

Fig. 3: Location of San Salvador city in the department of San Salvador, in reference to the area of the figure 2.

- C_{Hi}:Upper value of the concentration range.
- C_{Lo}:Lower value of the concentration range.
- C_X: Measured concentration value.

The formula (1) will be used [23], and the tables II [24] and III [25], for the calculation of the AQI for both concentrations.

TABLE II: AQI classification and CO_2 concentrations.

AQI range	Air Quality	CO_2 [ppm]
0–50	Good	0–400
50–100	Moderate	400–1000
100–150	Unhealthy for sensitive groups	1000–1500
150–200	Unhealthy	1500–2000
200–300	Very unhealthy	2000–5000
300–500	Hazardous	5000+

TABLE III: AQI classification and TVOC concentrations.

AQI range	Air Quality	TVOC [ppb]
0–50	Good	0–220
50–100	Moderate	221–660
100–150	Unhealthy for sensitive groups	661–1430
150–200	Unhealthy	1431–2200
200–300	Very unhealthy	2201–3300
300–500	Hazardous	3301–5500

C. Hypothesis Statement

To determine whether there is a significant statistical correlation, an analysis must be performed to calculate this correlation and ensure its validity. For this purpose, the correlation hypothesis test was used [26].

We begin with the hypothesis statement:

- H_0 (Null hypothesis): There is no characteristic correlation between carbon dioxide concentration levels and total volatile organic compound concentration levels.
$$H_0 : r = 0$$
- H_A (Alternative hypothesis): There is a characteristic correlation between carbon dioxide concentration levels and total volatile organic compound concentration levels.
$$H_A : r \neq 0$$

To test the hypothesis, the p-value method will be used, which consists of calculating the probability of obtaining results that could reject the null hypothesis or assume that it is true [26]. In this case, for a we use a set value of 0.05.

- If $p < a$ and the correlation is strong, the null hypothesis is rejected, meaning that there is a correlation between the variables.
- If $p >= a$, the null hypothesis is accepted, which means that there is no significant correlation between the variables.

For the calculation of Pearson's coefficient, a mathematical software will be used to measure the statistical summary between the carbon dioxide variable and the total volatile organic compounds.

Pearson's coefficient is represented by an "r" which ranges from +1 to -1, meaning the following:

- If it has a correlation coefficient greater than zero, and this value is as close to +1, it means that there is a direct correlation.
- If it has a correlation coefficient less than zero, and this value is as close to -1 as possible, it means that there is an inverse correlation.
- And if it has a correlation coefficient equal to zero, it means that there is no linear correlation.

Following the p-value method, the formula for the t-statistic test will be used:

$$t = \frac{r\sqrt{DF}}{1 - r^2} = \frac{r\sqrt{n-2}}{1 - r^2} \tag{2}$$

Where:

- DF is the degrees of freedom.
- n is the number of measured values.

For the calculation of the p-value, mathematical software will be used again.

V. CORRELATION ANALYSIS AND RESULTS

By employing mathematical software (Power Bi), the calculation of Pearson's coefficient value was performed, the results obtained are shown in the table (IV), and its due interpretation in the table [27].

Following the p-value method, to determine whether the null hypothesis is true or false, the p-value is calculated using the support of code in the Python programming language and recorded in Table (V).

TABLE IV: Pearson correlation coefficients by time period.

Measurements	Hour	Pearson's Coefficient	Interpretation
1	5:01:17 AM – 5:42:45 AM	0.64	Strong positive
2	6:41:45 AM – 7:28:59 AM	0.73	Strong positive
3	8:06:06 AM – 8:51:55 AM	0.70	Strong positive
4	8:36:02 AM – 9:22:33 AM	0.68	Strong positive
5	9:42:02 AM – 10:31:17 AM	0.74	Strong positive
6	10:51:47 AM – 11:41:21 AM	0.76	Strong positive
7	12:07:54 PM – 1:00:54 PM	0.93	Very Strong positive
8	1:06:28 PM – 2:12:40 PM	0.83	Very Strong positive
9	2:07:55 PM – 2:57:15 PM	0.79	Strong positive
10	4:12:21 PM – 4:58:17 PM	0.65	Strong positive
11	5:24:43 AM – 6:13:24 AM	0.72	Strong positive
12	7:20:19 PM – 8:07:27 PM	0.68	Strong positive

TABLE V: Results of the p-value analysis for each case.

Measurements	DF	t	p-value	Null hypothesis
1	521	19.0119	0.000000	Rejected
2	588	25.9004	0.000000	Rejected
3	570	23.4019	0.000000	Rejected
4	576	22.2582	0.000000	Rejected
5	617	27.3283	0.000000	Rejected
6	619	29.0936	0.000000	Rejected
7	664	65.1988	0.000000	Rejected
8	670	38.5182	0.000000	Rejected
9	619	32.0580	0.000000	Rejected
10	578	20.5637	0.000000	Rejected
11	612	25.6664	0.000000	Rejected
12	584	22.4123	0.000000	Rejected

By making the comparison with the a value, we confirm a strong correlation and reject the null hypothesis, since all sample values confirm $p < a$.

The AQI was applied according to the formula (1) for CO_2 concentration values as shown in the graph in Figure 4 and TVOC as shown in the graph in Figure 5.

For a better understanding of the colometry of the heat maps in Figure 4 and Figure 5, the table VI is taken as a reference.

TABLE VI: Color classification of heatmaps.

Color	Classification	AQI Value
Green	Good	0-50
Yellow	Moderate	51 - 100
Orange	Unhealthy for Sensitive Groups	101 - 150
Red	Unhealthy	151 - 200
Purple	Very Unhealthy	201 - 300
Maroon	Hazardous	301 - 500

VI. CONCLUSION

According to the statistical analysis, the Pearson coefficient with the lowest correlation value was 0.64, a strong correlation,

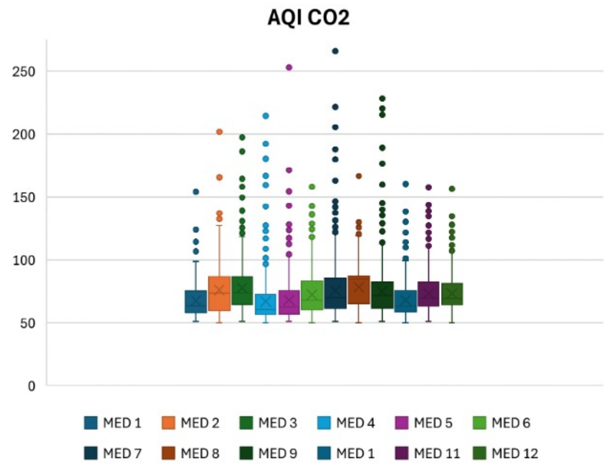

Fig. 4: Box plots comparative of AQI-CO_2.

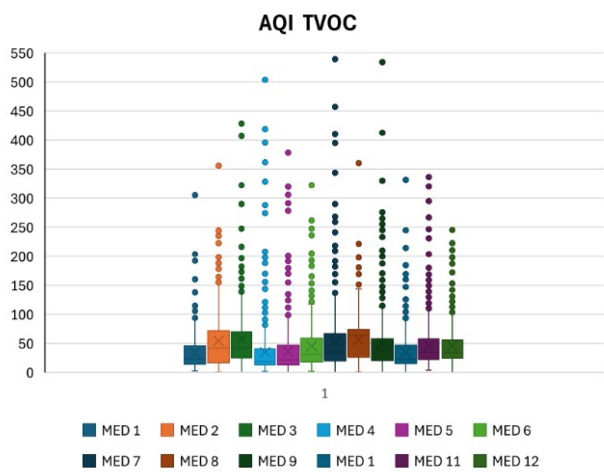

Fig. 5: Box plots comparison of AQI-TVOC.

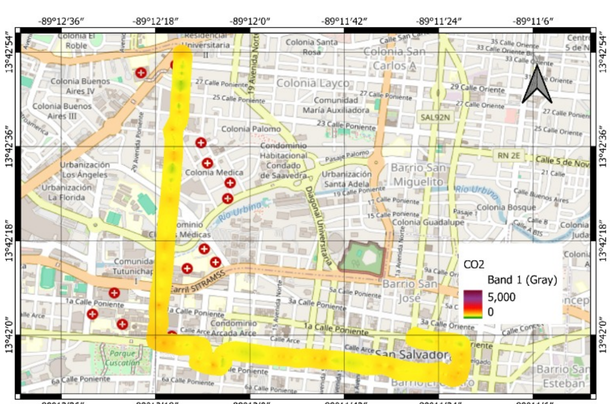

Fig. 6: CO_2 heatmap from measure 3.

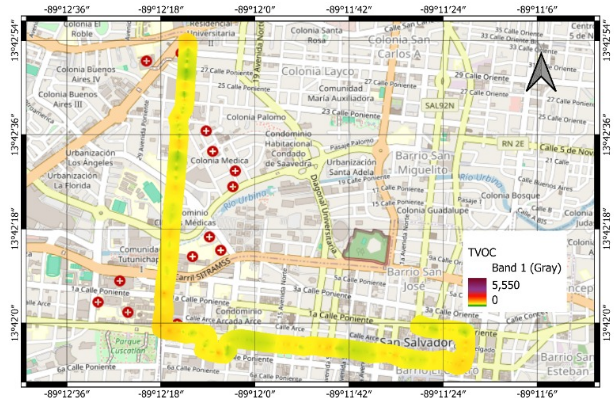

Fig. 7: TVOC heatmap from measure 3.

and the highest correlation value was 0.93, a very strong correlation, so it was found that there is a strong correlation between the levels of CO_2 and TVOC, suggesting that both variables have common sources of emissions, one of which could be vehicle emissions, which are the leading cause of carbon dioxide emissions, and the release of hydrocarbons when incomplete combustion is carried out.

According to ONASEVI (National Road Safety Observatory), there was an increase of 8.1% in the number of vehicles in 2024 [28], which indicates that vehicle emissions have increased and, consequently, air quality deterioration has also increased.

In the graph of Figure 4, it can be seen that CO_2 concentrations are primarily within the range of 50 to 100 according to the AQI, which is at a regular level and does not have a significant impact on people's health.

By capturing the measurements on a map (figures 7 and 6), a better observation of the data was achieved, the orange areas show a higher concentration of these pollutants, as was the case of the Rosales National Hospital (figure 8), which due to a remodeling process makes use of heavy machinery, which is known to emit higher contractions of these pollutants compared to a standard vehicle [29].

VII. ACKNOWLEDGMENTS

We would like to express our sincere gratitude to the University of El Salvador for the invaluable technical, academic, and financial support it has provided. The commitment has been essential to our development, providing us with the necessary technological tools, exceptional academic guidance, and crucial financial assistance that have enabled us to focus entirely on our studies. This comprehensive support has not only facilitated our educational journey but has also enriched our university experience in countless ways. We are deeply grateful for your trust and investment in our future.

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Fig. 8: On May 23 at 17:44, the Rosales National Hospital was undergoing remodeling

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