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Monitoring and analysis of air quality and meteorological parameters on the construction site by the IoT

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Abstract:

Introduction/purpose: The construction industry is one of the main producers of dust, greenhouse gases and air pollutants. Effective operation and management of construction site operations can significantly reduce projects' carbon footprints and other environmental impacts. Through the cooperation of a scientific and research institution and a construction company, the real-time monitoring of air quality at a construction site was implemented using IoT technologies.

Methods: An IoT-based system framework that integrates a distributed sensor network to collect real-time data and demonstrates air quality at a construction site was implemented. Different types of sensors were used to collect data related to NO2, PM2.5, and PM10 particles, as well as meteorological parameters – wind speed and direction, humidity, pressure, and temperature.

Results: The results of real-time measurements provide a picture of the state of air pollution at the construction site and the connection with construction activities that can be managed in order to reduce the concentration of polluting gases and suspended particles. Through on-site monitoring of a construction site in Belgrade City, this study found that the dust level due to construction activities is relatively high.

Conclusion: It can be concluded that the construction activity had a significant impact on the air quality in the construction surrounding areas. Regarding the main factors affecting the building construction dust emission, the correlations show that building construction dust emission was not significantly correlated with meteorological factors.

Key words: construction site, PM concentration, correlation, meteorology.

Introduction

With the looming consequences of climate changes, sustainability measures, including quantifying the amount of air pollution during various types of activities, have become an important goal in all branches of the economy, including the construction industry. All construction sites generate high levels of pollution over a long period of time. The construction industry is one of the main producers of greenhouse gases (GHG) with a share of about 12% of the total world emissions. According to official figures from the Delhi Pollution Control Committee (DPCC), 30% of air pollution by dust is caused by emissions from construction sites. Various construction activities such as excavation, diesel engine operation, demolition, burning and working with toxic materials contribute to air pollution. The main factor that contributes to air pollution with nitrogen and sulfur oxides during construction projects is the use of heavy equipment, ie., machines (excavators, loaders, bulldozers, etc.) as a result of burning the fuel used by these machines. PM pollution is mainly attributed to excavation work. A significant source of PM 2.5 particles on construction sites are exhaust gases from diesel engines and diesel generator sets, vehicles and heavy equipment. Harmful substances from oils, glues, solvents, paints, treated woods, plastics, cleaning agents, and other hazardous chemicals widely used on construction sites also contribute to air pollution.

In the Balkans, Serbia is the leader in the construction industry which is growing year by year. In August 2022, 2,562 building permits were issued. This construction trend promises a further significant increase in the concentration of greenhouse gases and other pollutants. For these reasons, it is primarily necessary to introduce monitoring of polluting gases and PM particles in real time in order to propose measures to reduce the concentration of polluting gases and PM particles through insight into the amount of pollution present and depending on the atmospheric conditions.

Although emissions of harmful substances in the construction industry are becoming more and more significant due to the accelerated trend of construction in Serbia, a real-time emission monitoring tool, essential to help construction teams avoid excessive emissions of harmful substances, has not yet been introduced to the construction sites in the Republic of Serbia. The considerable importance of the application of this system and the implementation of this type of research is for the health of employees at construction sites who often have health problems due to the working conditions, i.e., the poor air quality at construction sites, which sometimes reaches such a bad quality that it endangers the lives of workers.

Particulate matter (PM) is one of the most common air pollutants globally as well as nitrogen oxides (NOx), photochemical oxidants including ozone (O3), carbon monoxide (CO), lead (Pb), and sulfur dioxides (SO2). (EPA, 2022)

In the last few years, research has been done on the effects on dust concentration at construction sites, with a focus on PM10 and PM2.5 (De Moraes et al, 2016; Hassan et al, 2016; Yan et al, 2019). It was found that there are a number of factors that influence the concentration of PM particles at construction sites. Certainly, the surroundings of construction sites represent a source of certain emissions that are transported and registered on construction sites themselves, independently of the activities on construction sites. These are so-called background emissions. When it comes to meteorological factors, several studies have been done on the connection between meteorological parameters and the concentration of polluting substances (including PM particles), and there are conflicting views on that topic. Some authors (Araújo et al, 2014) believe that meteorology has an extremely important influence on the concentration of PM particles at the construction site, although due to the lack of concentration data, they failed to develop a model for the dependence of PM particle concentrations on meteorological parameters. According to some other authors (Zhang et al, 2010), dust emissions from construction sites have significant seasonal changes, which was also confirmed by other researchers in their research (Zhao et al, 2010). This again indicates a strong relationship between the concentration of PM particles and meteorological parameters. In some research (Luo, 2017; Wei et al, 2022) that also studied the relationship between construction works and meteorological parameters, it was concluded that PM particles are highly positively correlated with wind speed and relative air humidity, and weakly with temperature. In addition to excavation work, internal works on buildings also have a certain contribution to emissions. Kinsey et al (2004) found that vehicles leaving a construction site can carry a large amount of dust and sediment to nearby roads, leading to the rise of secondary dust. Azarmi et al (2014) carried out a detailed monitoring of certain phases of work on the construction site, such as concrete mixing, drilling and cutting. PM10, PM2.5, and PM0.1 concentrations of PM particles during drilling and cutting activities were up to 14 times higher than background concentrations. Moraes et al. (2016) focused on monitoring the concentration of particulate matter (PM10) generated from concrete and masonry in construction activities. These and similar studies have shown that certain phases and activities during work on construction sites are an important factor that affects the concentration of PM particles. (Font et al, 2014).

The goal of this research is a deeper and more detailed analysis of the relationship between the concentrations of PM particles on the construction site that are emitted due to excavation work and meteorological parameters. The data analysis was done to check the possibility of applying artificial intelligence to predictions of the concentration of PM particles depending on weather conditions.

Materials and methods

The experiment, which consisted of measuring the concentrations of suspended particles PM2.5 and PM10, then NO2, as well as meteorological parameters (pressure, temperature, humidity, speed and wind direction) was carried out at one construction site in Belgrade (Fig. 1) during 15 days in July 2022, from the first to the fifteenth of July. The excavation zone is located west of the location of the measuring station, while additional sources of emissions on the construction site, such as waste, carpentry and reinforcement works, are placed on the north from the monitoring device on the constructin site. Fig. 1 shows the distances of individual emission sources from the measuring station. Emissions from other sources come from the south and east direction and can be treated as background emissions.

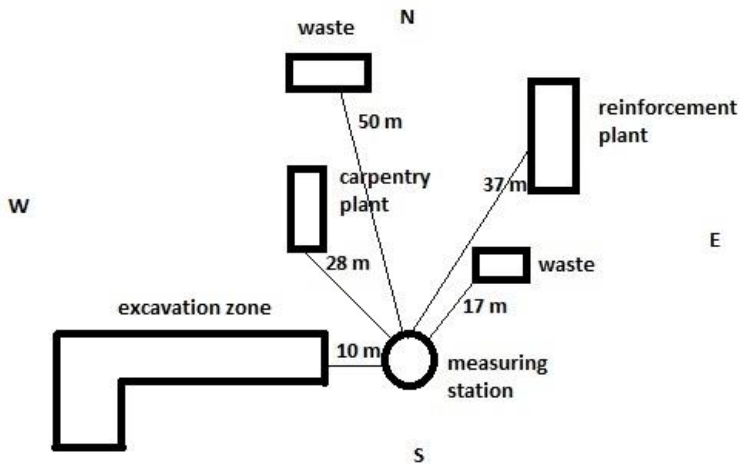

Figure 1 – Sketch of the construction site with the marked positions of the measuring device, the excavation zone, as well as other potential sources of emissions
Рис. 1 – Эскиз строительной площадки с отмеченными местами расположения измерительного прибора, зоны выемки грунта, а также других возможных источников выбросов
Слика 1 – Скица градилишта са обележеним положајима мерног уређаја, зоне ископа, као и других потенцијалних извора емисија

During all fifteen days, two electrically-powered machines were working in the excavation area. All days except Sunday, work was done from 13:00 to 17:00. The waste was taken away by truck every day.The devices used were of a sensor type and the results were recorded every 5 minutes. The RS-MG111-WIFI-1 is an air environment multi-element transmitter. It is used to detect NO2, PM2.5, and PM10. The transmitter adopts the original imported sensor and control chip, which has the characteristics of high precision, high resolution, and good stability. Using WIFI network transmission, it is directly connected to the on-site WIFI network, and the connection is convenient. With the free monitoring platform software or the free IoT cloud platform, it directly formed an online Integrated air environment monitoring system, widely used in building HVAC, building energy saving, smart home, schools, hospitals, airport stations, and other places. Another device is the CC-M12 weather station: an anemometer (WD, WS), temperature, pressure and humidity with RH&T and 4G communication. The devices are portable (with the possibility of installation outdoors and indoors). Such a system allows the manager of the construction site and the company to have a detailed insight into the quality of the environment in real time. In doing so, sources of harmful gas emissions are identified from three main activities in construction: earthworks, transport, and interior works. Different types of sensors were used to collect data related to NO2, PM2.5, PM10 particles, as well as data related to meteorological parameters – wind speed and direction, humidity, pressure and temperature. The web and mobile application provides data visualization (map, list, chart), notifications/alarms when values are outside the defined range, algorithms for data processing, export to csv file. SPSS 23.0 statistical software was used for data analysis in this study.

Results and discussion

The measurement results are shown in Table 1. The results are given as Full Day results (FD), measurement results during the total time, 24 hours a day, for all 15 days, as well as Working Hours results (WH) that show the separated working hours from 7 a.m. to 5 p.m. on weekdays (Monday to Saturday).

By monitoring the concentration of polluting substances, three sets of data were obtained, including PM2.5, PM10, and NO2.

From the results shown, it can be seen that the PM2.5 concentrations ranged from 1 to 133 μg/m^3 throughout the day, i.e., in a period of 24 hours a day, while during working hours they ranged from 1 to 71 μg/m^3. The

average value of the PM2.5 concentration for all 15 days was 15.301 μg/m^3 during the whole day's observation, while during working hours it was 14.66 μg/m^3. For all 15 days, the average daily concentrations of PM2.5 were, respectively: 26.46, 14.69, 21.06, 26.87, 27.09, 15.76, 15.16, 16.55, 11.66, 7.26, 5.75, 9.38, 8.36, 10.20, and 15.26 μg/m^3.

Table 1 – Basic statistical analysis of the measured parameters
Таблица 1 – Базовый статистический анализ измеряемых параметров
Табела 1 – Основна статистичка анализа мерених параметара

	PM2.5 (μg/m^3)	PM10 (μg/m^3)	NO2 (μg/m^3)	p (kapa)	T (°C)	hum (%)	v (m/s)
FD av	15.301	16.811	94.243	1004.78	25.192	51.030	0.354
FD SD	9.5752	11.155	131.989	2.618	6.401	18.534	0.698
FD min	1	1	0	999	12.4	18.1	0
FD max	133	143	510	1010	46.2	98.3	17.8
WH av	14.660	16.0597	167.741	1004.977	28.600	20.2	0.467
WH SD	9.147	10.577	144.859	2.835	5.556	13.749	0.574
WH min	1	2	0	999	15.2	91.1	0
WH max	71	82	510	1010	41.1	40.696	3.2

From the results shown, it can be seen that the PM2.5 concentrations ranged from 1 to 133 μg/m^3 throughout the day, i.e., in a period of 24 hours a day, while during working hours they ranged from 1 to 71 μg/m^3. The average value of the PM2.5 concentration for all 15 days was 15.301 μg/m^3 during the whole day's observation, while during working hours it was 14.66 μg/m^3. For all 15 days, the average daily concentrations of PM2.5 were, respectively: 26.46, 14.69, 21.06, 26.87, 27.09, 15.76, 15.16, 16.55, 11.66, 7.26, 5.75, 9.38, 8.36, 10.20, and 15.26 μg/m^3.

The PM10 concentrations ranged from 1 to 143 μg/m^3 throughout the day, i.e., in a period of 24 hours a day, while during working hours they ranged from 2 to 82 μg/m^3. The average value of the concentration for all 15 days was 16.811 μg/m^3 during the whole day of observation, while during working hours it was 16.06 μg/m^3. For all 15 days, the average daily concentrations of PM10 were, respectively: 29.18, 16.22, 23.05, 30.21, 30.15, 16.97, 16.04, 17.50, 12.69, 7.98, 6.48, 10.55, 9.11, 11.08, and 16.94 μg/m^3.

It can be noted that the highest values of PM10 and PM2.5 particle concentrations were during the night hours, which can be attributed to stabilization of the atmosphere.

According to the WHO limits, PM2.5 should not exceed 5 μg/m3 annual mean, or 15 μg/m3 24-hour mean while PM10 should not exceed 15 μg/m3 annual mean, or 45 μg/m3 24-hour mean. Analyzing the average 24-hour values for PM2.5 and PM10, it can be concluded that PM2.5 represents a far greater health hazard due to far higher values compared to the prescribed daily limits. It can be observed that more than 50% of days, including non-working days, PM2.5 exceed the permissible 24-hour value according to the WHO standards, which is not the case with PM10.

The NO2 concentrations ranged from 0 to 510 μg/m^3 throughout the day, that is, during the 24-hour period, as well as during working hours. The average value for all 15 days was 167.741 μg/m^3 during the whole day of observation, while during working hours it was 94.243 μg/m^3. A significant increase in NO2 concentration can be observed at the construction site during working hours. About 70% is a higher average daily value during 10 working hours compared to all 24 hours.

The impact on the concentration of NO2 can be explained by the transport of waste that was taken to the construction waste disposal site by truck every day, but also by the impact of traffic from nearby roads.

By monitoring meteorological data, five sets of meteorological data were obtained, including wind speed and direction, temperature, humidity, and atmospheric pressure.

The pressure ranged from 999 to 1010 kPa throughout the day, i.e., in a period of 24 hours a day as well as during working hours. The average value for all 15 days was 1004.977 kPa during whole-day observation, while during working hours it was 1004.78 kPa.

Humidity ranged from 18.1 to 98.3% throughout the day, i.e., in a period of 24 hours a day, while during working hours it ranged from 40.696 to 91.1%. The average value for all 15 days was 51.03% during whole-day observation, while during working hours it was 20.2%.

The temperature ranged from 12.4 to 46.2°C throughout the day, i.e., in a period of 24 hours a day, while during working hours it ranged from 15.2 to 41.1°C. The average value for all 15 days was 25.192 °C during whole-day observation, while during working hours it was 28.6°C.

The wind speed ranged from 0 to 24.8 m/s throughout the day, i.e., in a period of 24 hours a day, while during working hours it ranged from 0 to

3.2 m/s. The average value for all 15 days was 0.354 m/s during the whole day of observation, while during working hours it was 0.467 m/s.

Apart from the basic statistical analysis (Table 1), a correlation analysis was done between the PM concentration and the meteorological data. Table 2 shows that the concentrations of PM10 and PM2.5 were not significantly correlated with any meteorological factor.

Table 2 – Values of the linear correlation coefficient among the measured parameters
Таблица 2 – Значения коэффициента линейной корреляции между измеряемыми параметрами
Табела 2 – Вредности линеарног коефицијента корелације између мерених параметара

	PM2.5	p	hum	T	v
PM10	0.987	-0.092	0.299	0.201	0.003
PM2.5	1	-0.103	0.297	0.236	0.008
p		1	0.053	-0.416	-0.989
hum			1	-0.660	-0.030
T				1	0.326

A very high correlation between PM2.5 and PM 10 can be observed, indicating their same origin. The correlation between PM particles and the meteorological parameters shows a small value that is insufficient for the application of meteorological parameters for predictive purposes using some form of artificial intelligence such as ANN. The highest correlation, although lower than 0.3, is between PM particles, humidity, and temperature.

The reasons that led to this result could be that construction dust is affected by many factors. Construction activities are a direct factor that creates construction dust and have a major impact on construction dust much more than meteorological factors. During the monitoring period, meteorological factors did not change too much; in this way, the influence of meteorological factors on construction dust can somewhat be eliminated. Precipitation is the main factor influencing dust. Therefore, it can be considered that the emission of construction dust is not significantly related to any meteorological factor when it does not change too much. To some extent, it is in accordance with the conclusions of the urban PM10 and PM2.5 research (Tian et al, 2014).

Fig. 2 shows the relationship between the concentration of PM10 and PM2.5 particles and the direction of wind. The Figure shows the wind directions in degrees from 0 to 360° on the x-axis. On the y-axis, PM2.5 and PM10 are represented by two different colors. A high degree of correlation between PM particles can be observed, but also that the concentrations of PM2.5 and PM10 particles are increased when the wind takes the direction of 0°, i.e., blows from the north, then 90°, from the east, while other wind directions are followed by lower concentrations of PM10 and PM2.5 particles. These facts coincide with the position of waste dosposal.

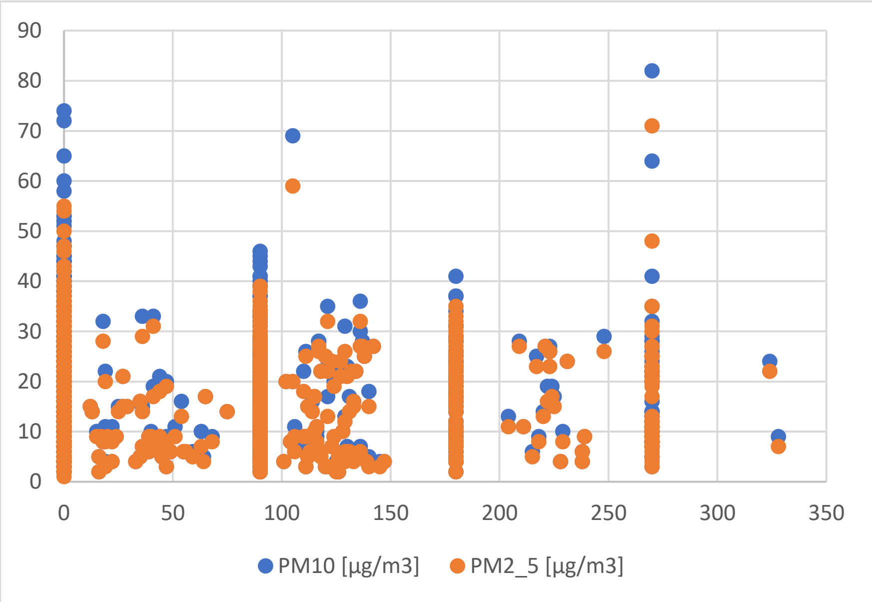

Figure 2 – Dependence of the concentration of PM10 and PM2.5 particles on the construction site on the wind direction
Рис. 2 – Зависимость концентрации частиц PM10 и PM2,5 на строительной площадке от направления ветра
Слика 2 – Зависност концентрације честица ПМ10 и ПМ2,5 на градилишту од правца ветра

Conclusion

The data of meteorological and construction intensity were collected to determine the main factors affecting the construction dust emission, which can provide a basis for reducing the impact of dust generated by construction activities on the surrounding area. The main conclusions of the article are as follows:

Through on-site monitoring of a construction site in Belgrade City, this study found that the dust emission level of construction activities is relatively high. The average PM10 concentration was 16.42 µg/m^3 and the PM2.5 concentration was 8.37 µg/m^3. Analyzing the average 24-hour values for PM2.5 and PM10, it can be concluded that PM2.5 represents a far greater health hazard due to far higher values compared to the prescribed daily limits. In addition, compared with the upwind direction concentrations, the construction site makes PM10 and PM2.5 downwind direction concentrations increased by around 70% and 35%, respectively, which indicates that the construction activity had a significant impact on the air quality in the construction surrounding areas.

Regarding the main factors affecting the building construction dust emission, the results show that building construction dust emission was not significantly correlated with any single meteorological factor when it did not change too much.

Considering a very low correlation between the concentration of PM particles and the meteorological parameters, the possibility of applying ANN for the purpose of creating a prediction model is excluded. A further subject of research will be the application of machine learning in the development of a predictive model that would aim at smart management of the construction site while taking into account the quality of the working and living environment.

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Мониторинг и анализ качества воздуха и метеорологических параметров на строительной площадке с помощью интернета вещей

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РУБРИКА ГРНТИ: 28.23.00 Искусственный интеллект,
67.21.25 Строительная климатология, метеорология
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Строительная отрасль является одним из основных источников пылевыделения, парниковых газов и загрязнителей воздуха. Эффективная эксплуатация и управление операциями на объекте могут значительно снизить углеродный след проекта и другие воздействия на окружающую среду. При сотрудничестве научно-исследовательского *учреждения со строительными компаниями был проведен мониторинг качества воздуха на строительной площадке в режиме реального времени с использованием технологий Интернета вещей.*

Методы: Была внедрена системная платформа на основе Интернета вещей, которая интегрирует распределенную сенсорную сеть для сбора данных в режиме реального времени и демонстрации качества воздуха на строительной площадке. В ходе исследования использовались различные типы датчиков для сбора данных, относящихся к частицам NO2, PM2.5 и PM10, а также метеорологическим параметрам – скорости и направлению ветра, влажности, давлению и температуре.

Результаты: Результаты оперативных измерений дают представление о состоянии загрязнения атмосферного воздуха на строительной площадке, вызванного строительными работами, которыми можно управлять с целью снижения концентрации выхлопных газов и взвешенных частиц. В результате мониторинга строительных площадок в городе Белград выявлено, что уровень запыленности при строительстве относительно высок.

Выводы: На основании результатов исследования можно сделать вывод, что строительная деятельность оказывает значительное воздействие на качество воздуха вблизи строительной площадки. Что касается основных факторов, влияющих на выделение строительной пыли, корреляции показывают, что выделение строительной пыли не имеет значительной корреляции с метеорологическими факторами.

Ключевые слова: строительная площадка, концентрация ТЧ, корреляция, метеорология.

Мониторинг и анализа квалитета ваздуха и метеоролошких параметара на градилишту уз помоћ IoT технологија

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ОБЛАСТ: рачунарске науке, грађевинарство
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Грађевинска индустрија је један од главних произвођача прашине и гасова стаклене баште који загађују ваздух. Ефикасним функционисањем и управљањем операцијама на градилишту може се знатно смањити угљенични отисак пројекта, као и други *утицаји на животну средину. Сарадњом научноистраживачке установе и грађевинске компаније реализовано је праћење квалитета ваздуха на градилишту у реалном времену коришћењем IoT технологија.*

Методе: Имплементиран је системски оквир заснован на IoT технологијама који интегрише дистрибуирану сензорску мрежу за прикупљање података у реалном времену и демонстрирање квалитета ваздуха на градилишту. Различити типови сензора коришћени су за прикупљање података који се односе на NO2 и честице PM2,5, PM10, као и на метеоролошке параметре – брзину и смер ветра, влажност, притисак и температуру.

Резултати: Резултати мерења у реалном времену приказују слику стања загађености ваздуха на градилишту и повезаност са грађевинским активностима којима се може управљати како би се смањила концентрација загађујућих гасова и суспендованих честица. Праћењем градилишта у Београду утврђено је да је ниво прашине услед грађевинских активности релативно висок.

Закључак: Грађевинска активност имала је значајан утицај на квалитет ваздуха у околини грађевинског подручја. Што се тиче главних фактора који утичу на емисију грађевинске прашине, корелације показују да емисија грађевинске прашине није у значајној корелацији са метеоролошким факторима.

Кључне речи: градилиште, концентрација PM, корелација, метеорологија.

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