sustainability

MDPI

Review

Measurement and Monitoring of Particulate Matter in Construction Sites: Guidelines for Gravimetric Approach

Ingrid Priscylla Silva Araújo * and Dayana Bastos Costa

Department of Structural and Construction Engineering, School of Engineering, Federal University of Bahia, Aristides Novis, 2, Federação, Salvador 40210-630, Brazil; dayanabcosta@ufba.br
* Correspondence: ingrid_psa@hotmail.com

Abstract: Studies on particulate matter (PM) from construction activities are still at an early stage. Thus, there is still no consensus on standardized experimental methods for monitoring PM in construction sites, which impedes the advancement of knowledge on this subject. This work proposes guidelines for measuring and monitoring the concentration of suspended PM and the annoyance generated by sedimented particles on construction sites in urban areas. These guidelines aim to reduce the variability and uncertainties that exist during the PM sampling processes at construction sites. This study adopts a literature review strategy in order to update the available scientific literature based on empirical evidence obtained in experimental PM studies and relevant documents from government agencies. The proposed guidelines were applied in a study protocol for gravimetric monitoring PM and annoyance tracking generated by sedimented particles using sticky pads. As a result, this article details sampling techniques, procedures, and instruments, focusing on gravimetric sampling, highlighting their characteristics compared to other monitoring approaches. Additionally, it points out a series of parameters for the measurement and monitoring of PM. This paper seeks to support future researchers in this area, inform decision making for experimental sampling, and provide a benchmark for measuring and monitoring PM at construction sites.

Keywords: air pollution; particulate matter; measurement and gravimetric monitoring; annoyance tracking; construction site

Citation: Araújo, I.P.S.; Costa, D.B. Measurement and Monitoring of Particulate Matter in Construction Sites: Guidelines for Gravimetric Approach. *Sustainability* **2022**, *14*, 558. https://doi.org/10.3390/su14010558

Academic Editors: Baojie He, Ayyoob Sharifi, Chi Feng and Jun Yang

Received: 18 November 2021
Accepted: 14 December 2021
Published: 5 January 2022

1. Introduction

Most of the world's population experiences long-term exposure to environments with various air pollutants, such as ozone, nitrogen dioxide, carbon monoxide, and particulate matter (PM) [1]. Among these air pollutants, PM is linked to a series of respiratory and cardiac problems, in addition to its detrimental effects on flora and fauna, soil, water, and air quality [2]. Moreover, PM in the air directly contributes to the global climate imbalance [3].

PM is a set of air pollutants consisting of solid or liquid particles [4]. These particles are suspended in the atmosphere, but they can also be sedimented on surfaces [5]. Despite a number of differences, PM is mainly classified by its aerodynamic diameter into three groups: (1) fine or breathable particles ($PM_{2.5}$) with aerodynamic diameter up to 2.5 µm, (2) coarse or inhalable particles (PM_{10}) with an aerodynamic diameter up to 10 µm, and (3) total suspended particles (TSP) that have a wide particle size range, typically with an equivalent aerodynamic cutting diameter of 100 µm.

In addition to these, there are sedimented particles, which are particles of different sizes that, in turn, are sedimented or deposited on surfaces [5]. The settlement times of particles $PM_{0.5}$, PM_1, PM_3, PM_{10}, and PM_{100} are 41 h, 12 h, 1.5 h, 8.2 min, and 5.8 s, respectively [6]. Thus, larger-sized particles have a shorter residence time in the atmosphere, having deposition closer to their sources, while smaller-sized particles have a longer stay in the atmosphere and, consequently, increase the risks to human health [7–9].

Construction sites are considered to be one of the main emitters of particulates in the environment, owing to the nature of their work procedures and the recurrent use of heavy machinery and equipment [1,10]. These particulates are released during the various construction operations, such as loading and unloading activities, earthmoving, transportation of bulk material, exhaust of diesel equipment, storage of materials outdoors, and during the various stages of construction—from the execution of structures, fences, and masonry, to the finishing stage [11–14].

According to Sa'adeh et al. [15], the effects of construction on the atmosphere are distressing and more apparent in urban areas. Despite the significant impacts caused, there is still a lack of scientific literature on PM in construction sites, although the number of publications has increased since the middle of the last decade [10]. At the international level, one could highlight the studies published by Chiang and Kuo [16] in Taiwan and Feliciano et al. [17] in Portugal, who investigated the concentration of PM from the activities of construction sites; Li et al. [18] in Singapore and Azarmi et al. [19] in England, who assessed air quality by monitoring in the areas surrounding construction sites; Ahmed and Arocho [20,21] in the United States, who compared the PM concentration produced from two construction systems, i.e., wooden panels (cross-laminated timber, CLT) and steel frames; and Sa'adeh et al. [15] in Jordan, who assessed the impact of construction work on fine particulate matter. In Brazil, Araújo et al. [12] and Moraes et al. [13] evaluated the concentration of PM from the activities of construction sites and identified that the activities of construction release particles of various sizes into the environment.

The mentioned scientific studies focused on the characterization of several factors that contribute to PM pollution from construction sites. However, it was observed that researchers have not been using correlatable monitoring and sampling protocols. The lack of systematized procedures means that more variables are added to an already existing set of multiple factors, making it even more difficult to assess conformities and compare the different scientific works available. The lack of homogeneity in the experimental methods clearly indicates a large research gap, showing the need for methods and procedures for measuring PM that can ensure more correlatable results, despite their applicability in different construction sites.

In addition to studies in construction sites under local conditions, Cheriyan et al. [22,23] carried out a series of laboratory experiments to evaluate the propagation of the different PM sizes (PM_{10}, $PM_{2.5}$, and PM_1) away from a construction source. The authors argued that a location-based real-time PM monitoring system could provide accurate measurements, as it considers the distributional characteristics of the different PM sizes [22,23].

In this context, this article proposes guidelines for measuring and monitoring the concentration of suspended PM and the annoyance generated by sedimented particles on construction sites in urban areas. These guidelines aim to contribute to the identification of research variables in order to reduce the variability and uncertainties that exist during the PM sampling processes in construction sites. The proposition of these guidelines is based on empirical evidence available in the literature and recommendations from relevant government agencies. For knowledge consolidation, the guidelines were applied in a PM study protocol for gravimetric monitoring PM and annoyance tracking in construction, thus adapting to the local context in order to identify real benefits for the construction site.

2. Legislation on Suspended and Sedimented Particulate Matter

To control air pollution and avoid irreversible damage to the environment and health of the population, specific pollutant limits are determined to differentiate a polluted atmosphere from an unpolluted one [24].

The World Health Organization (WHO) established consultative air quality guidelines for environmental concentrations of PM (and other pollutants) based on scientific evidence related to air pollution and its health risks [3]. These values are guidelines to be adopted by countries [3]. In 2005, the WHO established reference values for $PM_{2.5}$ at 10 μg/m^3 (annual) and 25 μg/m^3 (24 h), and for PM_{10} at 20 μg/m^3 (annual) and 50 μg/m^3 (24 h) [25]. After more than 15 years, in 2021, the OMS updated these reference values, introducing the level proposed in 2005 as an interim target [3]. The established WHO air quality guideline levels were updated for $PM_{2.5}$ to 5 $\mu g/m^3$ (annual) and 15 $\mu g/m^3$ (24 h), and for PM_{10} to 15 $\mu g/m^3$ (annual) and 45 $\mu g/m^3$ (24 h) [3].

The European Union (EU) established values for $PM_{2.5}$ at 25 $\mu g/m^3$ (annual) and for PM_{10} at 40 $\mu g/m^3$ (annual) and 50 $\mu g/m^3$ (24 h) [26]. Compared with the WHO reference values, the standards by the EU are less restrictive.

Resolution No. 491/2018 from CONAMA (National Council of Environment—Conselho Nacional do Meio Ambiente) defines intermediate air quality standards, in which standards are established with temporary values to be met in stages until the final air quality standard is reached [27]. Currently, CONAMA Resolution No. 491/2018 sets the Brazilian standards for $PM_{2.5}$ at 20 $\mu g/m^3$ (annual) and 60 $\mu g/m^3$ (24 h), PM_{10} at 40 $\mu g/m^3$ (annual) and 120 $\mu g/m^3$ (24 h), and TSP at 80 $\mu g/m^3$ (annual) and 240 $\mu g/m^3$ (24 h) [27]. The authors adopt the national standards of Brazil (Resolution No. 491/2018) and the reference values established by the WHO, which are more restrictive, for comparison purposes with the concentration levels obtained in the monitored construction sites.

The OSHA (occupational safety and health administration of the USA) determines the occupational PM_{10} exposure in a working day (8 h/day) as 50 $\mu g/m^3$ [8]. This same value was adopted as the WHO reference value for PM_{10} (24 h) in 2005. The Health and Safety Commission defined standards (mg/m^3) for inhalable and respirable levels of Portland cement and silica (crystalline), with Portland cement inhalation at 10 mg/m^3 and respirable at 4 mg/m^3 and for crystalline silica inhalation at 6 mg/m^3 and respirable at 2.4 mg/m^3 [28].

Currently, there are no established international standards for sedimented particles [29]. According to Vallack and Shillito [30], the absence of standards for sedimented particles is due to the fact that its impact is related to the annoyance perceived by the people exposed, thus introducing subjective characteristics. Despite this subjectivity, it is understood that the investigation of environmental exposure to sedimented particles is necessary to support the development of reference standards, as filling this gap becomes essential to support regulations for the mitigation of this annoyance [31].

Regions in Europe (Great Britain, Finland, Germany, and Spain), USA (North Dakota, Kentucky, Louisiana, Maryland, Mississippi, Montana, Pennsylvania, Washington, Wyoming, and New York), Canada (Alberta, Manitoba, Newfoundland, Ontario, and Vancouver), western Australia, Argentina, and some states in Brazil (Rio de Janeiro, Amapá, Minas Gerais, and Espírito Santo) have reference standards for the limit value of the deposition rate of these particles that, according to these laws, can cause annoyance if exceeded [29]. The standards adopted by these countries vary from 2.4 to 20 g/m^2 (30 days), with most of the limit values being between 3 and 15 g/m^2 (30 days) [29].

According to the presentation of the regulations, it is clear that the established parameters cover only the mass concentrations of the PM and do not consider its chemical compositions. However, without chemical characterization, there is no way to deepen the understanding of the toxic potential of these particles. For example, the mineral or metallic dust particles can cause several pneumoconioses, the dust of quartz and other silicates can cause silicosis, the asbestos fibers can cause asbestosis with fatal health effects for both construction workers and residents in the vicinity [32]. Therefore, there is a need for physical-chemical analysis to estimate the risk of environmental exposure to the concentrations and chemical agents of the particles [12,33,34].

3. Equipment and Methods for Measuring Particulate Matter in Construction

This section presents a set of equipment, filters, and experimental studies identified for measuring and monitoring PM in construction.

3.1. Equipment and Filters for Measuring Suspended Particulate Matter

There are several types of equipment available for monitoring suspended PM at construction sites. To date, the scientific literature has not established standard monitoring equipment or methods for measuring suspended PM [10]. Cheriyan and Choi [8] point out two main approaches: gravimetric monitoring and real-time monitoring.

Gravimetric sampling through filters is considered as a reference monitoring (Tables 1 and 2); it allows the investigation of collected particles by providing samples for subsequent physicochemical laboratory analyses. In this way, promoting investigations of the concentrations and chemical agents of particles [9]. On the other hand, gravimetric sampling does not consider the real-time PM dispersion [9].

Real-time monitoring is considered a modern and low-cost method. It allows for understanding the distributional characteristics of different PM sizes produced and discharged from construction activities. These sensors present a high correlation of measurements with reference PM monitors [8,35,36]. However, sensors for real-time PM monitoring that analyze the chemical composition and toxic substances of particles are not available [8,9]. Another obstacle to real-time monitoring concerns the fact that these sensors are not fully adapted to field conditions at construction sites [8].

Khamraev et al. [9] recommended joint monitoring using gravimetric samplers and real-time monitoring sensors to conduct a health risk assessment. However, Zheng et al. [37] ponder the obstacles that can be encountered for joint monitoring, such as different sampling periods, the performance of different instruments facing saturation (high and low-concentration), and environmental conditions. Furthermore, an estimated cost of a sensor for real-time PM monitoring, such as Alphasense OPC-N2 (OPC), is around 500 USD [8], while the MiniVol gravimetric sampler is around 2500 USD.

Table 1. Equipment and techniques for gravimetric monitoring PM [38].

Equipment	Advantages	Disadvantages	Applications
Gravimetric sampler using filters	This is a sampler that monitors the TSP, PM_{10}, and $PM_{2.5}$ fractions using a suction pump; They usually provide average concentrations over 24 h and require laboratory determination to identify the mass of the filters; The concentrations obtained can be associated with air quality limit values; Reference methods for monitoring suspended particles are based on gravimetric samplers.	High operating costs; Care must be taken with the selection, storage, handling, and weighing of the filters; Results not available in real time.	It is unlikely to be applicable in most situations, as there are delays between the sampling period and the availability of results; Although some types of samplers are small and battery-powered, they do not provide real-time information.

Table 2. Most used types of filters in gravimetric monitors and their characteristics.

Filters	Characteristics	References
Glass fiber filters	Filters that show resistance to high temperatures, low reaction to corrosive material, and high efficiency. They do not break easily with handling, and are recommended for gravimetric processes. They can be used for elementary analysis if their chemical composition is known (typically Al and Si, with large and variable amounts of Na). Recommended by the United States Environmental Protection Agency (EPA).	[39,40]
Polycarbonate filters	Filters that present low thickness, smooth surface, and vitreous aspects. Recommended for performing elementary analysis of the samples, owing to their low blank levels and inertness to gas adsorption. These filters contain carbon, which makes them difficult to use in certain research applications. Widely used in monitoring particulate matter.	[40–42]
Teflon filters	These filters have an irregular, porous, and chemically inert structure. They contain carbon, which makes them difficult to use in certain research. Recommended when characterizing the sampled particles using analytical techniques. Recommended by 40 CFR Part 50—Appendix L and O.	[40–45]
Cellulose filters	These are highly hygroscopic filters, not recommended for accurate analysis. They are difficult to handle. These filters are necessary for sampling where there is no possibility of using other filters owing to the chemical equivalence between their compositions and the monitored particles.	[39,46]
Quartz filters	Filters with generally high collection efficiency. They are spectral quality filters, that is, more refined filters, with low contents of organic and inorganic contaminants. Highly recommended for carbon analysis. Recommended when chemical analyses are required.	[39,40,46,47]

The choice of collection equipment must consider this prior knowledge, as well as the monitoring objectives of each survey. Table 1 presents a summary of the applicability of the gravimetric samplers, as well as their advantages and disadvantages [38]. For further details on other equipment and their applicability, the reader is referred to IAQM [38]. The IAQM [38] presented a summary of the main dust-monitoring equipment identified in the literature.

Table 2 presents a summary of the most used filter types for gravimetric sampling and their characteristics.

3.2. Equipment and Methods for Measuring Sedimented Particles

According to the Environment Agency (United Kingdom) [48], the monitoring of sedimented particles can be performed by two classes of methods, the first through analyses of the gravimetric, physical, and chemical characteristics of the collected particles, and the second through analyses of potential loss of amenity in sensitive receptors, in which the annoyance generated by the sedimented particles can be analyzed. The Environment Agency [48] presents that these monitoring methods can be carried out individually or complementarily, depending on the research objective.

The quantification of particle deposition rate, expressed in (g/m^2 30 days), can be performed using direct and/or indirect techniques [31]. The former is carried out by experimental methods, and the latter by theoretical calculations [49].

For experimental methods, it is necessary to use substitute surfaces or collecting devices [31]. The following can be used for the replacement surfaces: plastic material, absorbent material, sticky surfaces, wetted paper filter, paper, glass, metal, etc. [31]. For the option of collecting devices, there are several models that can be applied; however, the most frequently used is the cylindrical container standardized by ASTM D 1739-98: Standard Test Method for Collection and Measurement of Dust-fall (Settleable Particulate Matter) [50].

To track the effect of sedimented particle annoyance on receivers (surroundings, properties, equipment, materials, fauna, flora, water, soils, among others), sticky pad adhesive collectors can be used [48]. Sticky pads are 31.7 cm × 14.8 cm collectors. When installed horizontally on flat surfaces, sticky pads are intended to assess the annoyance caused by the deposition of particles and, when installed vertically on cylindrical surfaces, they function as a directional flow meter [48]. Table 3 presents a summary of the applicability of sticky pads, as per the IAQM [38].

Table 3. Characteristics and applicability of sticky pad collectors [38].

Equipment	Advantages	Disadvantages	Applicability
Sticky Pads	Relatively low cost; Can be easily installed; No electricity required; The analysis of the percentage of effective area coverage (% EAC) considers the color of the particle; Can be used to quantify the flow of dust; Subsequent analyses can be performed to determine the chemical composition and morphology of the particles.	Requires subsequent laboratory analysis of the percentage of effective area coverage (% EAC) and/or percentage of absolute area coverage (% AAC); Limited time resolution, does not provide daily information; Intensive use of resources.	Provides useful information to complement the monitoring of PM concentrations; Provides an indication of the potential loss of amenity; Provides information on the effectiveness of mitigation measures.

3.3. Experimental Studies on Measuring Particulate Matter in Construction

Table 4 presents 14 experimental studies from the literature focused on identifying the concentration of PM in construction sites (field studies) and focused on understanding spatiotemporal variations of different PM sizes from construction activities (laboratory studies).

Table 4. Experimental studies applied to construction sites (field and laboratory studies).

Authors/ References	Monitoring and Sampling Protocols	Sampling Information (Fraction/Filter/Equipment)	Location
Chiang and Kuo [16]	Monitoring was carried out during excavation, template marking, and concreting. The sampling periods were 8 h (active work) and 24 h (background). In total, 15 samples per activity and 3 background samples were collected. The monitoring points were located close to the activities. Chemical analyses were carried out.	TSP, glass fiber filters, HiVol	Taoyuan County, China
Feliciano et al. [17]	Monitoring was carried out during several activities at the construction site. The sampling period was 24 h for 10 monitoring campaigns. Total of 32 samples for each monitored fraction. The location of the monitoring points was changeable due to factors of a different nature (the authors indicated that the most suitable locations from a scientific point of view were not always chosen). No chemical analyses were carried out.	TSP, PM_{10}, and $PM_{2.5}$, MiniVol	Bragança, Portugal
Araújo et al. [12]	Monitoring was carried out during activities in the earthwork, structure, and finishing phases. The sampling period was 8 h (active work) and 10 h for 9 days. In total, 54 samples per activity phase (8 h) and 24 samples for 22 h were collected. The monitoring points were located in favor of and against the prevailing wind. Chemical analyses were carried out.	TSP, PM_{10}, and $PM_{2.5}$, polycarbonate and Teflon filters, MiniVol	Salvador, Brazil
Li et al. [18]	Monitoring was carried out during the construction activities of a building and after the completion of the work. The total sampling period was 35 h during working hours of 5 consecutive days. The measurements were performed in an adjacent building, based on its ground floor and its covering floor, with height difference between the floors equivalent to 20 m. Chemical analyses were carried out.	$PM_{20–35}$, $PM_{8.1–20}$, $PM_{4–8.1}$, $PM_{2–4}$, $PM_{1–2}$, $PM_{0.5–1}$, and $PM_{0.25–0.5}$, glass slides, Naneum Nano ID Select™	Singapore
Azarmi et al. [19]	Analyses were carried out during various activities of three construction sites. The sampling period was 10 h (active work; daytime monitoring) and 14 h (stopped work, nighttime monitoring) during weekdays and weekends. The collection period was approximately 4000 days for approximately 12 years. The measurements were carried out in favor of and against the wind in the areas surrounding the selected sites. No chemical analyses were carried out.	PM_{10} and $PM_{2.5}$, TEOM 1400 and Turnkey Osiris (model 2315)	London, England
Moraes et al. [13]	Monitoring was carried out during activities in the structure and masonry phases. The sampling period was 8 h (active work) and 8 h (Sunday or other holidays) for 11 days + 1 day (Sunday or holiday). Four sites were analyzed, plus a reference site. In total, 252 samples were collected, including 52 for construction site 1, 60 for construction site 2, 56 for construction site 3, 48 for construction site 4, and 36 for the reference construction site. The monitoring points were located in favor of and against the prevailing wind. Chemical analyses were carried out.	TSP and PM_{10}, polycarbonate and Teflon filters, MiniVol	Salvador, Brazil
Payus et al. [51]	Analyses were carried out during preliminary service activities, site preparation, and structure activities. Sampling was carried out during working hours, over 4 working days in the dry season and another 4 working days in the rainy season. The fractions were monitored for 20 min/day, continuously. No chemical analyses were carried out.	$PM_{0.3}$, $PM_{0.5}$, PM_1, and PM_2, Particulate Counter (model GT-321)	Kota Kinabalu, Malaysia
Ahmed and Arocho [20]	Analyses were carried out at two construction sites to compare the PM concentration of two construction systems: wooden panels (CLT) and steel. There was no specific monitoring time, as the researchers gave priority to the activities. The measurement occurred for 15 min/day for each fraction of PM in the period of 5 days. In total, 600 data points were collected, i.e., 300 for each construction site. Measurements were taken close to the activities (350 feet). No chemical analyses were carried out.	PM_1, $PM_{2.5}$, PM_4, and PM_{10}, DustTrak	Oregon, USA
Ahmed and Arocho [21]	Extension of the study of Ahmed and Arocho [20]. The two sites previously studied were compared with a third site (external area without construction). Measurements were performed following the same procedures at the three monitoring sites. There was no specific time for monitoring, as the researchers gave priority to the activities. The measurement took place for 15 min/day for each fraction of PM in the period of 5 days. Measurements were taken close to the activities (350 feet). Regarding the reference site (without construction), the authors reported only the movement of students. In total, 900 data points were collected, i.e., 300 for each monitoring location. No chemical analyses were carried out.	PM_1, $PM_{2.5}$, PM_4, and PM_{10}, DustTrak	Oregon, USA

Table 4. *Cont.*

Authors/ References	Monitoring and Sampling Protocols	Sampling Information (Fraction/Filter/Equipment)	Location
Rahman et al. [52]	Analyses were carried out during the activities of masonry, plastering, and concrete mixing. Correlations were investigated between PM concentrations found in these activities and the performance of pulmonary function (peak expiratory flow, PEF) of construction workers. The sampling period was 8 h (active work) for a period of 6 days per activity, during a total of 18 days. The PEF test was performed at a fixed time of day (9:30 a.m. to 11:30 a.m.). In total, 54 concentration data points and 80 workers were tested. No chemical analyses were carried out.	$PM_{2.5}$, DustTrak	Klang, Malaysia
Sa'adeh et al. [15]	Monitoring was carried out before and during construction activities of an educational building in three sampling periods: "No Construction", "Pouring Concrete", and "Bleaching". The measurements were performed on a rooftop of an adjacent building. The sampling period was 24 h, with 2–3 samples per week. Total of 60 sampling days, 20 samples for each sampling period. Chemical analyses were carried out.	$PM_{2.5}$, Teflon filters, ISAP® 1050e sampler	Amman, Jordan
Yan et al. [53]	Analyses were carried out in the areas surrounding seven construction sites during the execution of activities. The measurements were carried out in favor of and against the wind in the vicinity of the borders of the flowerbeds. Each construction site was monitored continuously for 2 to 3 days. No chemical analyses were carried out.	TSP, PM_{10}, and $PM_{2.5}$, air/smart integrated sampler (2050)	Qingyuan, China
Cheriyan et al. [22]	Systematic experimental assessments were carried out during construction activity, concrete mixing activity in an area of 3 × 4 m, using a location-based PM monitoring approach. Three PM monitoring points were installed (Alphasenses sensors, with 2 s sampling times) and arranged between them (horizontal distances of 1 m and 1.5 m and vertical distances of 0.8 m and 1.3 m) and at an angle of 120°. No chemical analyses were carried out.	PM_{10}, $PM_{2.5}$, and PM_1, Alphasense OPC-N2	Laboratory
Cheriyan et al. [23]	This study adopted a location-based real-time PM monitoring system proposed by Cheriyan et al. [22] with Alphasense OPC-N3 sensors. The authors also installed the Hexoskin wearable monitor to identify (IR) inhalation rate real-time variation. The real-time PM and IR sensor data were collected simultaneously to assess the drilling, cutting, concrete mixing, mortar mixing, sanding, and gypsum activities, performed with different materials. No chemical analyses were carried out.	PM_{10}, $PM_{2.5}$, and PM_1, Alphasense OPC-N3 and Hexoskin wearable monitor	Laboratory

By analyzing Table 4, it is observed that the authors have not been using standardized and/or homogeneous field monitoring methods. This lack of a standard method means that more variables are added to an existing set of multiple factors, making it difficult to assess conformities in different scientific works.

As an example of an additional variable, the different monitoring periods in the mentioned studies stand out, which include 8 h/day, Li et al. [18], Moraes et al. [13], and Rahman et al. [52]; 8 and 24 h/day, Chiang and Kuo [16]; 24 h/day, Feliciano et al. [17] and Sa'adeh et al. [15]; 8 and 22 h/day, Araújo et al. [12]; 10 and 14 h/day, Azarmi et al. [19]; 20 and 15 min/day, Payus et al. [51] and Ahmed and Arocho [20,21]; and consecutive days, Yan et al. [53]. In addition, only Araújo et al. [12], Moraes et al. [13], Azarmi et al. [19], and Yan et al. [53] make it clear that they installed monitoring points in favor of and against the prevailing wind.

Regarding the equipment used, Chiang and Kuo [16] used HiVols; Yan et al. [53] used air/smart-integrated samplers (2050); Feliciano et al. [17], Araújo et al. [12], and Moraes et al. [13] used MiniVols; Ahmed and Arocho [20,21] and Rahman et al. [52] used DustTrak; Payus et al. [51] used a particulate counter model GT-321; Li et al. [18] used Naneum Nano ID Select™, Sa'adeh et al. [15] used ISAP® 1050e sampler; and Azarmi et al. [19] used TEOM and Turnkey Osiris. Finally, it is clear that studies have rarely considered the characterization of the chemical composition. Among the mentioned scientific studies in Table 4, Chiang and Kuo [16], Araújo et al. [12], Li et al. [18], Moraes et al. [13], and Sa'adeh et al. [15] are the only ones that focused on the chemical investigation of the particulate matter.

In general, the research results contribute relevant information for the definition of study variables in the face of PM exposure and bring significant results to the construction sector, thereby providing a database. However, the lack of homogeneity in experimental methods highlights the need to develop standard, clear, and globally applicable methods in construction sites. Figure 1 identifies a set of investigation variables considered significant to collect information concerning PM in construction sites, aiming to further investigate their polluting potential and, consequently, to support management plans and control the generation of PM in construction.

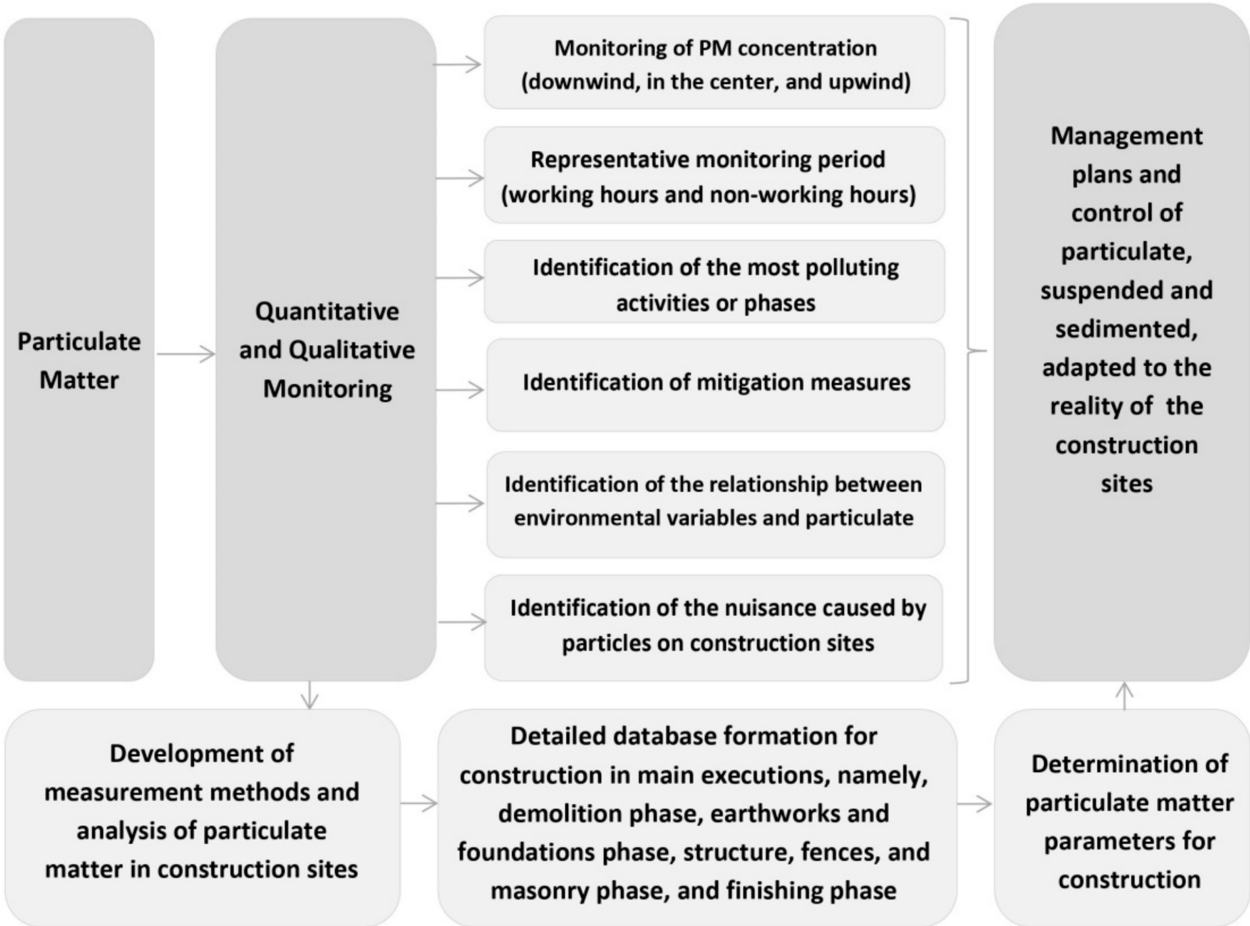

Figure 1. Investigation variables to collect information about PM from construction sites.

4. Research Method

This study adopts a literature review strategy, based on the available scientific literature to update empirical evidence obtained in experimental PM studies and relevant documents from government agencies, such as the Code of Federal Regulations—CFR (United States of America) [43], Canadian Council of Ministers of the Environment—CCME (Canada) [54], Environment Agency (United Kingdom) [48], Greater London Authority—GLA (England) [55], Institute of Air Quality Management—IAQM (United Kingdom) [56], United States Environmental Protection Agency—EPA (United States of America) [57], and Institute of Air Quality Management—IAQM (United Kingdom) [38].

The proposed guidelines are based on the protocol for measuring and gravimetrically monitoring PM in construction developed by Resende et al. [58] and applied by Araújo et al. [12] and Moraes et al. [13] in five residential construction sites in the city of Salvador, Brazil. From these applications, the positive points, opportunities for improvement, and limitations of the guidelines were identified. The update of the guidelines is detailed in Section 5.

To consolidate knowledge, these guidelines were applied in a new study protocol started in 2019 in a residential project with seven construction sites in the metropolitan region of Salvador, Brazil for measuring the TSP and PM_{10} fractions and sedimented particles, in three phases, namely, Phase 1: Execution of Earthworks and Foundations (24 April 2019–14 June 2019), Phase 2: Execution of Structures, Fences and Masonry (17 December 2019–04 February 2020), and Phase 3: Finishing Execution (15 December 2020–04 February 2021).

5. Guidelines for Measuring and Monitoring Particulate Matter at Construction Sites

This section presents six guidelines for measuring and monitoring PM that aim to support the establishment of procedures and recommendations to reduce the variability and uncertainties in the sampling processes at construction sites, focusing on gravimetric sampling and its subsequent analysis. The guidelines are presented in Figure 2 and described below.

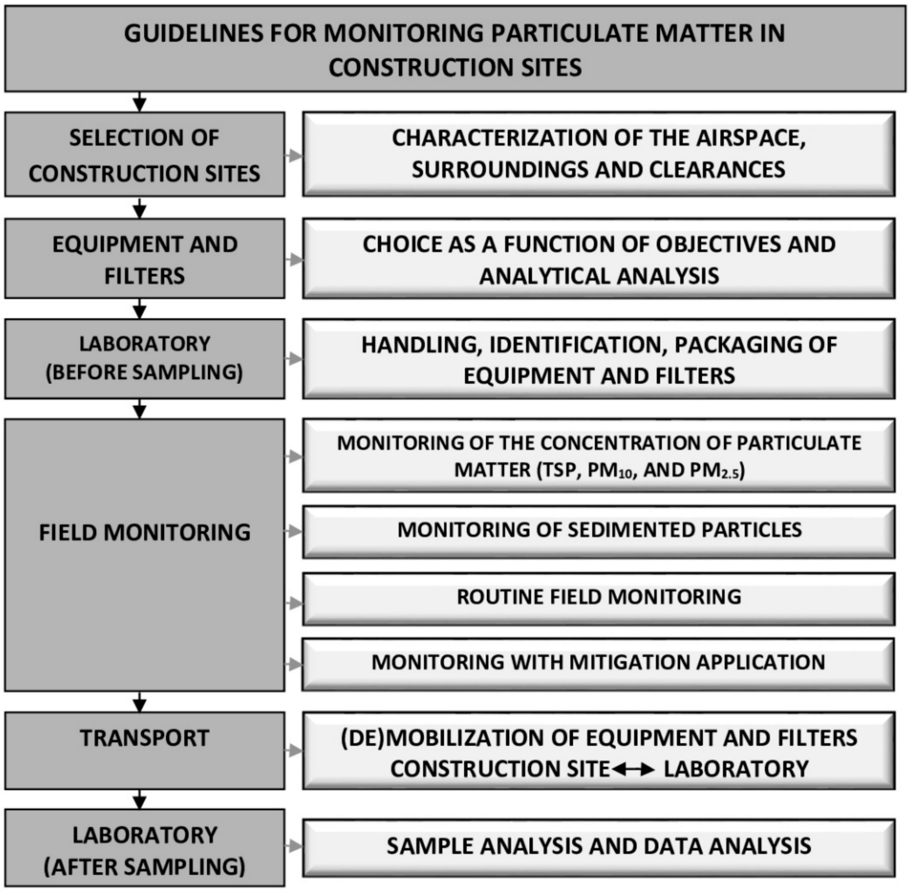

Figure 2. Guidelines for monitoring PM in construction sites.

5.1. *Selection of Construction Sites and Characterization of the Micro-Region*

This guideline aims to guide the characterization of airspace, surroundings, and clearances for carrying out PM monitoring. The recommendations for the selection of the construction site are intended for academic studies, as construction companies can apply these recommendations in their construction sites, independently.

In the selection, construction sites that present less external interference should be considered. It is necessary to characterize the occupation of the surrounding area on a spatial scale of 100 m to identify other construction sites in the vicinity and/or other primary sources of particles (industrial activities, fires, etc.). The proximity of the construction site to sensitive receptors and areas with a highly concentrated population should also be analyzed [55]. Finally, attention should be paid to the proximity of traffic routes and airports, as they enhance the concentration and resuspension of particles [54].

5.2. Equipment and Filter Selection

This guideline aims to make recommendations on the selection of equipment and filters to meet the objectives of monitoring, as detailed in Tables 1 and 2 in Section 3.

One selection criterion can be based on the cost of the equipment and, consequently, a greater or lesser number of sampling stations can be installed, depending on the available resources. Another criterion is to choose, according to the need for more detailed and conclusive analyses, gravimetric samplers, which are more expensive and complex, but which yield samples suitable for carrying out analytical methods [48].

As for the filter media to be used, there is no ideal filter for all gravimetric samplers and individual objectives of sampling and analysis [40,57]. For the most appropriate choice of filters, evaluations are recommended with respect to certain aspects, such as characteristics of the particles to be monitored, equipment flow rate, collection methods, and subsequent analyses (physical and/or chemical) [57]. The filter media can be made of polycarbonate, Teflon, cellulose, quartz fiber, and glass fiber, among other materials [46].

Among the most recommended filters, we highlight Teflon and polycarbonate filters for monitoring at construction sites, as these filters do not contain silica, which is the most abundant component of the inputs used in construction. However, attention is needed, as these filters contain carbon, which makes it difficult to use them in certain investigations at construction sites. According to Galvão et al. [40], polycarbonate and Teflon filters are highly recommended in cases where elementary characterization of the samples is required.

Instead of gravimetric sampling, one can choose sensors for real-time PM monitoring, which is an alternative with low-cost and high agreement compared to reference monitors [8,35,36]. However, any new real-time air monitors must be previously validated, as Fisher et al. [35] suggested, especially in real scenarios.

Finally, the consolidation of the approaches (hybrid monitoring) can be accomplished, exploring information and details not explored in construction sites from one or another isolated monitoring. However, this last recommendation may lose strength as it raises costs for its consolidation.

5.3. Laboratory Activities Prior to Monitoring

This guideline aims to provide guidance on the proper handling, identification, and packaging of filters in the laboratory.

The filters must be separated and stored in identified Petri dishes, with unique identification for recording information [43]. According to EPA [57] and CFR [43], the equilibrium conditions of the environment must have a temperature between 20 and 23 °C, which does not vary by more than ±2 °C over 24 h, and the relative humidity must be between 30 and 40%, without varying by more than ±5% for 24 h. Before any weighing, the filters must remain in the desiccator with silica in the same environment as the balance, under the conditions mentioned above, for at least 24 h.

The filters must be weighed before and after collection in the field, using a microanalytic balance with a nominal precision of 1 µg. Before inserting the filters in the balance, it is necessary to pass them through a load elimination system where they are electrostatically discharged by means of a static charge neutralizer.

Field blank filters and laboratory blank filters should be considered. These filters are used to control contamination and identify research uncertainties [40,57].

Field blank filters are unsampled filters, which are taken to the sampling locations and returned to the packaging conditions. These filters should not vary by more than 30 µg [57]. If the measurements indicate this variation, the EPA [57] advises that, before automatically invalidating any filters, one should try to find the source of the problem and apply corrective measures, that is, weigh the filters again, weigh the adjustment patterns of the scale again, check the temperature and humidity conditions, or have the scale checked by a technician, among other possibilities.

Laboratory blank filters are unsampled filters used to determine possible contamination during weighing and packaging processes in the laboratory. These filters should not have a variation greater than 15 µg [57]. In cases of such variation, the EPA [57] recommends measures similar to those mentioned above.

All filters must be visually inspected before their initial weighing, and those found to be defective are rejected [57]. The inspection should preferably be carried out against a flat light source, and it is recommended to look mainly for the following defects: holes, loose material that must be removed before weighing the filter, discoloration that may be evidence of contamination, nonuniformity of the filter, and other imperfections [57].

The filters must be handled with vinyl gloves (free of dust) and with the aid of tweezers, always avoiding contact with the sampled area. All material used for PM collection must be previously sanitized with a detergent solution and nitric acid and subsequently with distilled and deionized water [57].

Weighing the filters (µg) must follow two procedures in order to standardize the step and reduce the variability, namely: (1) procedure for the scale and (2) procedure for the filters.

1. Procedure for the scale:
    - Check that the scale is clean and remove any filter or object in the surroundings, leaving the environment clean;
    - Check the scale level and adjust if necessary;
    - Switch on the balance and let it stabilize for 3 h;
    - Place the silica gel immediately after turning it on;
    - Try to make the internal adjustment, then weigh and record the reference weight value for the blank of the scale;
    - After 3 h, start weighing.
2. Procedure for the filter:
    - Tare the balance;
    - Pass the filter through the load elimination system;
    - Place the filter on the scale;
    - Record the weight after the scale stabilizes;
    - Remove the filter and wait for the balance to return to zero;
    - Repeat the weighing (µg) "n" times, passing the filter through the load elimination system again until, in two consecutive measurements, there is variation only in the sixth decimal place (i.e., 0.00000Y, 0.00000X). In this way, the average filter mass in µg is obtained according to Section 5.6.

5.4. Field Monitoring

This guideline aims to provide guidance in the parameter selection for field monitoring, namely, the positioning of equipment, choice of monitoring periods, identification of the most polluting activity phases, identification of applied control measures, identification of the influence of environmental variables, and finally, identification of the annoyance generated and perceived.

5.4.1. Monitoring of Suspended Particles

This monitoring aims to measure and characterize the concentration and chemical composition of particles (TSP, PM_{10}, $PM_{2.5}$, and PM_1) in the different phases of the work (earthworks and foundations phase, structure, fences, and masonry phase, and finishing phase). Although PM_1 is commonly investigated as part of $PM_{2.5}$ and sometimes $PM_{2.5}$ as part of PM_{10}, it is important to investigate them separately. Smaller particles have different characteristics than larger ones, i.e., different settlements and distributional characteristics, physicochemical properties, toxicity, emission, impact on human health, health risk, and others [7–9,35]. Similarly, this reasoning should be extended to other PM fractions, confirming, therefore, that the more details investigated of the different PM sizes, the more information is reached for more effective monitoring and controls [22,59].

As a recommendation, Chow [33] highlights the importance of dividing field monitoring into daytime and nighttime periods, as, according to the author, the sources, concentrations, and behavior of particles differ during the day and night. It is recommended, therefore, that the gravimetric monitoring of suspended PM be carried out during the period of 24 h per day, and these 24 h are divided into intervals of effective activity at the construction site (5:00 a.m. to 5:00 p.m.; local time) and periods of stopped work (5:00 p.m. to 5:00 a.m.; local time) [19].

The suggested monitoring period is 10 working days and another day off work (Sunday or other holiday) [13]. The latter is used as a reference, being a day without activities at the construction site [13].

It is suggested to measure fixed points for gravimetric monitoring inside the construction site by installing at least two monitoring points, following the prevailing wind direction, and installing the points in favor of and against the wind [53,55]. In addition, the installation of background monitoring stations close to the urban area under evaluation must be considered.

According to the Environment Agency [48], when locating the fixed points for successful measurements, it is necessary to pay attention to the objectives proposed in the research. Therefore, when choosing the location of the equipment, requirements that interfere with the measurement results must be observed: physical barriers, terrain topography, local infrastructure, and safety for storing the equipment. According to EPA criteria [47]:

- The construction site must generally be downwind, and the emitting activities at the construction site must guarantee the period of exposure to prevailing wind conditions and pollution plumes;
- The equipment must be in an open and flat area with structural similarity and absence of proximity to skyscrapers in at least three directional quadrants of the equipment;
- The airflow around the sampler must be free from any obstruction over a range of at least 270°;
- The entrance of the equipment must be at least 2 m from the entrance of any other equipment;
- For samplers rented for simultaneous sampling (comparative evaluations), the entries must be, at most, 4 m from each other.

According to the CCME [54], distances must be observed and guaranteed to reduce interference, according to the guidelines below:

- It is recommended to keep heavy activities and other major sources of emission of primary particles, according to the road parameters, a distance/volume of at least 25 m from the main arterial circulation routes;
- Vertical and horizontal barriers (vegetation, trees, buildings, walls, among other obstacles) that can impede the normal wind flow around the sampler or monitoring path must be observed;
- The sampler must be at least 90% of the monitoring path, with free airflow, and be away from vertical obstacles, so that the distance between the capture point is at least twice the maximum height of the obstacle, above the sampler path;
- The equipment must be at least 2 m away from any obstacle; it is noteworthy that the fence of the construction site can be a restriction on installation; in this case, it is recommended to position it above the siding;
- The sampler must be at least 20 m away from trees, buildings, or other major obstacles;
- The height of the stations must be at least 2 m above the ground or the height of the breathing zone.

In turn, a location-based monitoring method is suggested for an approach that reinforces the accuracy of measured PM distributional characteristics in their real configurations on construction sites. The real-time PM monitors must be installed from horizontal and vertical distances defined from closer to the investigation sources, with careful investigations of the coexisting activities in the surroundings [9,22].

Attention is needed when locating the sensors in outdoor environments for success regarding the objectives proposed in this type of monitoring. According to Han et al. [59], it is challenging to accurately characterize personal PM exposure in outdoor environments because of the resources required to build and maintain an adequately dense network.

In addition, Venkatram et al. [60] highlight the need for investigation considering meteorological parameters, namely turbulence, direction, and wind speed in the surroundings of monitored sources. Han et al. [59] highlight the importance of investigating the effects of relative humidity in the face of monitoring (and monitors) and its results.

It is necessary to consider that, during environmental monitoring at a construction site with routine works, it is not easy to monitor a specific activity since the various activities are carried out in parallel using different materials and different sizes. For this reason, there is a need for more studies to clarify existing doubts in real configurations by monitoring with low-cost sensors (price below 2000 USD).

Finally, the GLA [55] points to the importance of evaluating the PM throughout the progress of the work in order to monitor the main phases of the work:

- Demolition Phase: characterized by a need to demolish buildings that will not be maintained on the ground;
- Earthworks and Foundations Phase: characterized by a wide-open area at the construction site;
- Structures, Fences, and Masonry Phase: characterized by the elevation of the building with emissions at and above ground level;
- Finishing Phase: characterized by final activities in external and internal environments.

5.4.2. Monitoring of Sedimented Particles

This monitoring aims to identify the sedimented particles according to the evolution of the production phase and seasonality. The installation of a collection monitoring network is suggested to identify the most critical areas within the construction site. This methodology consists of demarcating a monitoring network with equidistant radii at the construction site and installing sedimented particle collectors at strategic points within the construction site (Figure 3).

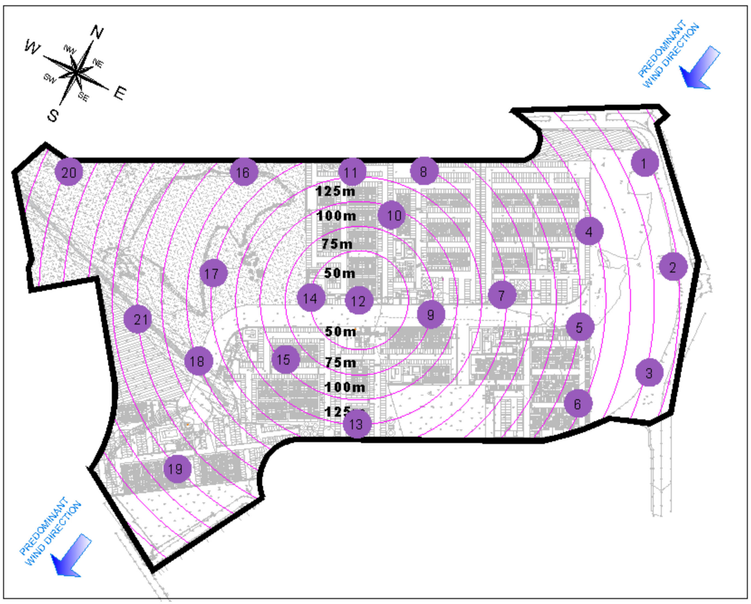

Figure 3. Monitoring network with radii at 25 m intervals, and 20 monitoring points.

For the identification of the monitoring points, it is necessary to support the location and layout plan of the construction sites in order to identify the focus areas for investigation. Collectors can be easily applied at different points on the construction site over a long period of time per job, precisely because they have a relatively low cost [56]. The monitoring periodicity should be from two days to a month, depending on the chosen particle collector [38].

Particle sedimentation can be investigated using a variety of techniques using collector devices, substitute surfaces, and sticky pad collectors, among others [38,48,50], as presented in Section 3.2.

Considering collection devices, it is suggested to use the cylindrical container standardized by ASTM D 1739-98: Standard Test Method for Collection and Measurement of Dustfall (Settleable Particulate Matter). These collectors must remain in the field for a period of 30 days. It is suggested to position the collectors 2 m above the ground [50].

Considering substitute surfaces, care must be taken with respect to the loss of particles in periods of rain and strong winds. In addition, attention must be paid to the monitoring period; if the collector is exposed for too long, it can become saturated with dust, as new dust will not adhere to the dust already trapped. To minimize particle overlap, monitoring over a 10-day period is suggested [39,61]. Collectors should not be positioned directly on the ground; the suggested minimum height above the ground is 1.5 m [39,48]. This height is a characteristic of surfaces in daily use on construction sites, such as machinery, equipment, vehicles, windows, window sills, work surfaces, etc.

It is recommended to use sticky pads when trying to track the effect of the sedimentation of particles [48]. For each exposure period, collection between 2 to 7 days is recommended [62]. It is also suggested to keep the collectors elevated with respect to the ground, locating them at strategic points of the construction site, such as roofs, walls, containers and, in the absence of such supports, facilities must be built with wooden beams to keep sticky pads 2 m above the ground.

For analysis of sticky pad collectors, readings must be performed using a portable reader (sticky pad reader, SPR) or by computerized image processing [38,48,62]. The loss of reflectance of the sticky pads is expressed as the percentage of effective area coverage (% EAC) per day [48]. The % EAC can be interpreted as an annoyance measure [48]. The annoyance levels are shown in Table 5.

Table 5. Sticky pads: annoyance level [48].

% EAC/day	Response
0.2	Noticeable
0.5	Possible complaints
0.7	Objectionable
2.0	Probable complaints
5.0	Serious complaints

From the optical digitalization of the sticky pads followed by computerized image processing, it is possible to obtain one more measure for the analysis of the collectors, the percentage of absolute area coverage (% AAC). The % AAC allows the collected particles to be analyzed, regardless of the color of the dust and the reflective characteristics [38]. However, there are still no published limits for the levels of annoyance according to % AAC, which demonstrates the need for more research to correlate the observed measurements and the levels of complaints from the population [48].

To complement the monitoring of sedimented particles, questionnaires can be applied to investigate the perceived annoyance by construction workers and the residents of the neighborhood. This opinion survey can be carried out concurrently with the collection of particles to capture associations between the measurements of sedimented particles and the complaints of workers and the neighborhood regarding the perceived annoyance [29].

5.4.3. Routine Field Monitoring

After installing the equipment at the construction site, a set of procedures for routine monitoring must be carried out, which can be daily or not, depending on the experimental plan, its level of detail and expected conclusions, and the manufacturers' recommendations for maintenance and calibration of the instruments.

When using samplers with filters to collect PM in suspension, it is necessary to check and adjust the flow of the equipment with each filter change. Routine monitoring starts with the removal of the filters, and it is necessary to transport them horizontally to avoid the loss of collected materials. The next step is to pack the filters and install new ones. This step must be carried out in a suitable place, such as the construction office, so that there is no contamination. The entire filter handling process must be carried out using tweezers and gloves.

When using real-time sensors, these devices provide almost instantaneous data without the need for the researcher to remove the sample for further laboratory analysis [8,9,37]. The collected data can be transmitted using a USB port or Bluetooth, for example.

Finally, it is recommended that the production activities on the monitoring days be investigated, as well as complications that may interfere with the sampling results during the collection period. As part of the investigation of activities, it is suggested to analyze the work diary and the work schedule, as well as identify the daily production activities for each monitoring day [58].

5.4.4. Monitoring with Mitigation Application

At this stage, the intervention of mitigating alternatives in the activities or phases of activities with the most impact on the construction site is suggested, providing a later comparison of data with and without mitigation. Cheriyan et al. [23] point out the importance of finding the most polluting activities in construction sites to implement the main control measures. Here, it should be noted that the more details are investigated in light of the different PM sizes and their distributional characteristics, the more subsidies are reached for more effective monitoring and controls [22,23].

The results of the experiments by Cheriyan et al. [22] showed that PM_{10}, $PM_{2.5}$, and PM_1 have different distributional characteristics depending on measurement location from the source. PM_1 tended to propagate exponentially away from the source from higher heights and remained suspended for a prolonged period, while $PM_{2.5}$ and PM_{10} propagated away from the source, with $PM_{2.5}$ gradually moving upwards, while PM_{10} particles moved towards ground level as they moved away from the PM source [22].

According to Xing et al. [14], there are still certain obstacles to implementing mitigating activities at construction sites. As one of the main obstacles, the authors pointed out the increase in the cost of construction. This is usually one of the main reasons why construction companies do not adopt mitigations or adopt them incompletely. Xing et al. [14] also highlighted the need for greater government participation to control PM in construction, whether by legislation, inspection, or even the imposition of fines upon recurrences.

Zuo et al. [63] showed that there is an urgent need for behavioral changes while pointing out that one of the alternatives to improve environmental awareness would be the self-responsibility of the managers of the works. Noh, Lee, and Yu [64], Li et al. [32], and Cheriyan and Choi [10] showed that it is still difficult to achieve an optimal and healthy level of PM exposure on construction sites. However, the control of the PM already allows fewer interruptions in the daily life of the surrounding area, reduces the risks to the health of workers, and reduces the damage caused to the machinery used on the construction site, in addition to reducing pollution in the air, water, fauna, and flora [32,55,65].

It is understood that it is essential for construction companies to effectively apply the mitigating measures in a continuous way and adapt to the reality of emissions in their construction sites. However, before adopting the measures, it is recommended to carry out a cost-benefit analysis to include them in the budget. Similarly, it is also necessary to consider the training and awareness of professionals, such that managers have sufficient support to make coherent and, if possible, low-cost decisions.

5.5. Transport

This guideline aims to present a recommendation for the transport of equipment and filters after gravimetric monitoring. After finishing the measurements at the construction sites, the equipment must be disassembled and stored in their respective containers:

- Care must be taken when transporting equipment and filters to the construction site/laboratory in order to avoid contamination and loss of characteristics;
- Samples must be stored immediately after collection in order to avoid contamination and hydration of the filter surface.

5.6. Laboratory Activities after Sampling

According to Heal et al. [66] and Galvão et al. [40], analytical techniques for the physical and chemical characterization of PM samples are available. However, Galvão et al. [40] question the ability to make the appropriate choice of technique in the research, stating that researchers are usually limited to the techniques available in their laboratories.

For gravimetric equipment that requires laboratory steps, it is suggested to weigh the filters using an electronic microanalytical scale with a nominal precision of 1 μg. The filter mass is determined gravimetrically by the difference between the final average mass (post-sampling) and the initial average mass (pre-sampling). Next, consider Equation (1):

$$M\ (\mu g) = M2 - M1, \tag{1}$$

where M (μg) = filter mass, M1 = initial average filter mass, and M2 = final average filter mass.

To calculate the gravimetry of the filters, one can consider the measurements of the blank filters, that is, consider the difference between the final mass of the sampled filters and the average mass of the blank filters. In this situation, field blank filters can be used to correct possible contamination during the handling, transport, and sampling process (Equation (2)). The EPA [57] points out the mandatory use of blank filters to control possible contamination; however, it does not require the correction of the gravimetry of the sampled filters to the detriment of the measurements of the blank filters. Next, consider Equation (2):

$$G\ (\mu g) = \text{total } M\ (\mu g) - \text{Xblanks}\ (\mu g), \tag{2}$$

where G(μg) = filter gravimetry, M total = filter mass, and Xblanks = average blank filters mass.

To calculate the concentration, it is first necessary to find the flow and volume of air used in the collection of each filter. Next, consider Equation (3):

$$C\ (\mu g/m^3) = G\ (\mu g)/V\ (m^3), \tag{3}$$

where C($\mu g/m^3$) = concentration of each filter, G = gravimetry of each filter, and V = total volume of sampled air.

For chemical analyses to be applied to filters and samples, there are options for analytical techniques, such as mass spectrometry, optical emission spectrometry, X-ray diffraction, X-ray fluorescence, scanning electron microscopy, among several others. The technique to be applied must be associated with the previous choices, such as the equipment and filters used in sampling, for example. In addition, it is necessary to consider the prior knowledge (or lack thereof) of the particles, the response required from the analysis, the destructive nature of the technique, and the need to preserve (or not) the sample for further analysis, among others [40]. For further details on choosing the most appropriate analytical technique for a given study, the reader is referred to Galvão et al. [40], who presented an analytical map with a step-by-step approach to support the researcher in the selection of the most appropriate technique for specific experimental tasks.

For data analysis, it is suggested to consider tabulation and extensive understanding of data, identification of appropriate statistical techniques for the treatment of qualitative and quantitative data, analysis of normality, analysis of measures of central tendency, and dispersion for a correct interpretation, with representativeness and precision. It is recommended to use descriptive statistical analyses to obtain an overview of the dataset and the use of inferential statistics to draw conclusions that can be expanded.

6. Application of Guidelines for Monitoring Particulate Matter at Construction Sites

The proposed guidelines were applied in a study protocol for gravimetric monitoring of PM, and annoyance tracking in construction started in 2019 in a residential project with seven construction sites in the metropolitan region of Salvador, Brazil, located at latitude 12°53′30.9′′ South and longitude 38°18′40.3′′ West. The construction site has an area of 154,366.06 m^2. Data on particulate concentrations (TSP and PM_{10}) were collected for 10 days and another Sunday or other holiday in the main phases of construction: (a) earthworks and foundations phase (24 April 2019–14 June 2019), (b) structures, fences, and masonry phase (17 December 2019–04 February 2020), and (c) finishing phase (15 December 2020–04 February 2021). The annoyance generated by the sedimented particles inside the construction site was also assessed to verify its relationships with the activity phases during the construction.

The initial results showed high levels of PM (PM_{10} and TSP) regardless of the phases of construction. Preliminary data showed that the daily average concentrations, monitored during working hours, were 70.35 $\mu g/m^3$ (PM_{10}) and 118.65 $\mu g/m^3$ (TSP) in the earthworks and foundations phase; 56.11 $\mu g/m^3$ (PM_{10}) and 155.86 $\mu g/m^3$ (TSP) in the structures, fences, and masonry phase; and 44.19 $\mu g/m^3$ (PM_{10}) and 76.10 $\mu g/m^3$ (TSP) in the finishing phase. In addition, critical levels of annoyance were found during the execution of the different phases of the construction (% EAC/day $\geq$ 5.0).

For monitoring the PM concentration, the MiniVol (Airmetrics) was chosen, as it is a portable instrument, which is easy to handle and transport, and because it allows monitoring in multiple locations owing to its battery-powered operation (autonomy of approximately 24 h). MiniVols were also chosen because they favor the analytical analysis of samples, as physicochemical characterizations are considered necessary to deepen the understanding of the toxic potential of the particles [12,33,34].

The MiniVols are calibrated to operate at a flow rate of 5.0 L/min at standard conditions; the corrected calibration must be adjusted to account for different air temperatures and atmospheric pressures. These samplers allow the separate collection of particles by size (TSP, PM_{10}, and $PM_{2.5}$) according to the use of the impactor (particle size separator). It is necessary to consider that MiniVols have limitations for determining the analytical technique to be used, as the samples collected by this instrument are small in mass and volume.

In this experimental study, twelve MiniVol instruments were used, which were divided into three monitoring groups, with each group consisting of one instrument for PM_{10} and one for TSP, both monitoring from 5:00 a.m. to 5:00 p.m. (local time), and one instrument for PM_{10} and one for TSP, both monitoring from 5:00 p.m. to 5:00 a.m. (local time), accounting for a total of 24 h of daily monitoring for each fraction of PM studied (Figure 4).

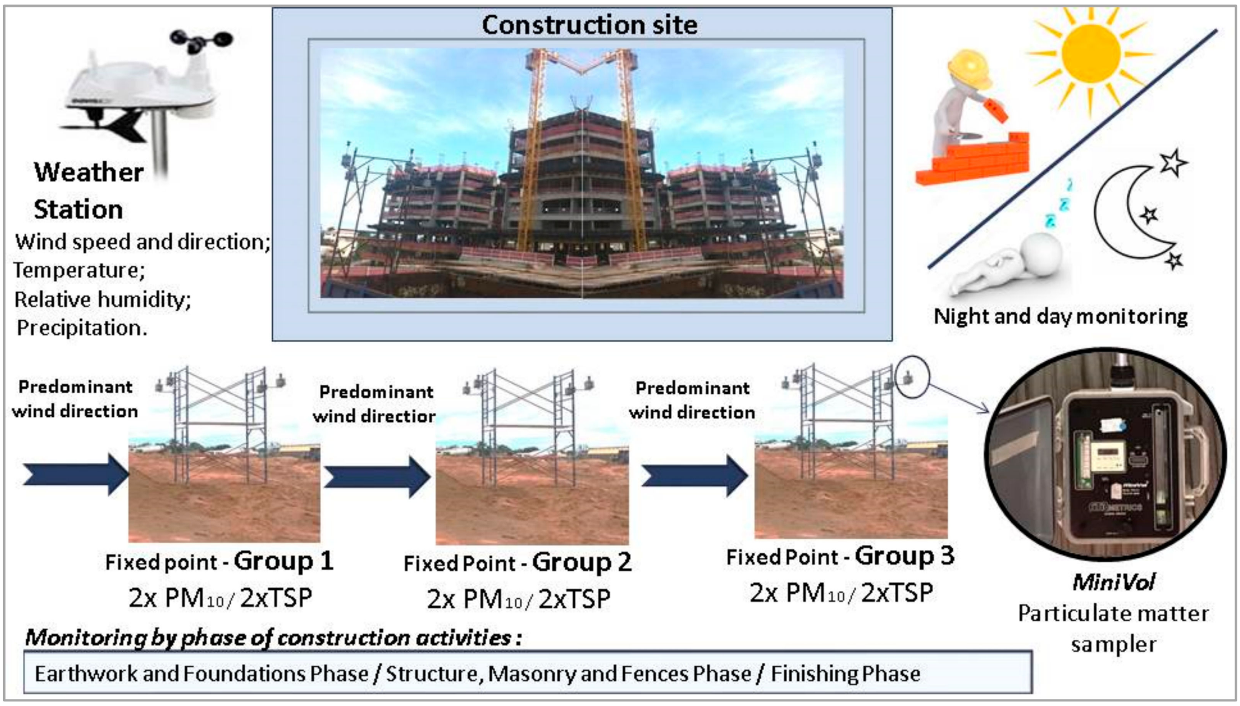

Figure 4. Scheme for monitoring PM concentration in construction sites.

In this research, the PM_{10} and TSP fractions were chosen for monitoring at the expense of the $PM_{2.5}$ fraction, which was not monitored owing to the limitation of twelve available devices. This choice was based on the recommendations of the Institute of Air Quality Management [38], which presents the fraction of PM_{10} as a priority for monitoring particles in suspension at construction sites, followed by TSP and, finally, $PM_{2.5}$. The IAQM points out that the particulate emissions of construction are predominantly coarse [38].

Monitoring groups were installed in opposite positions (downwind and upwind) and one more in the central area of the studied area on the construction site. The additional monitoring point located in the center of the studied area allowed us to investigate activities at the heart of production. In terms of location, this point is the most difficult to meet the proposed guidelines regarding observing and ensuring adequate distances from obstacles, mainly in the monitoring of the structure and finishing phases. This is because the shapes and sizes of buildings change, creating new obstacles and new interactions with environmental variables [12,67].

As for the filter media used, Teflon filters were chosen for monitoring TSP and polycarbonate filters for monitoring PM_{10}. These filters are widely used in PM monitoring [40–42,44,45,68]. To monitor climatic conditions, the Davis Vantage Vue meteorological station was chosen, which records temperature, humidity, pressure, wind speeds and directions, dew point, precipitation, solar and UV radiation every 30 min (24 h/day).

Sticky pad collectors were chosen for monitoring the sedimented particles, as they allow the investigation of the annoyance generated by sedimented particles inside the construction site. These collectors have practicality, ease of installation, low cost, and simple and fast analysis processes. In addition, they can be installed at various points in the construction site without harming the construction activities.

In this experimental study, radii at 25 m intervals were demarcated with the aid of the construction site location plan, and 21 collecting points with sticky pads were horizontally installed (per monitoring round/month) in strategic locations, such as on roofs, walls, containers, and, when there was no such support, installations with beams were built (Figure 3 previously presented and Figure 5). For the purpose of this study, the sticky pad monitoring points were placed, whenever possible, in the same positions. The maintenance of the same or similar locations aims to identify the evolution of data in view of the progress of activities in the construction site. The chosen collection period was four full days (Monday–Tuesday, Tuesday–Wednesday, Wednesday–Thursday, and Thursday–Friday), one week per month. With this monitoring method, due care must be taken owing to its susceptibility to loss of particles in the rain and in the presence of strong winds.

Figure 5. Scheme for monitoring sedimented particles on construction sites.

Finally, as part of data collection, the work diary and work schedule were investigated, and the production activities and mitigating activities were applied as identified from the checklist.

The routine of laboratory analyses involves the characterization of samples through physical-chemical analysis. The physical analysis is carried out with Mettler Toledo's 1 µg nominal precision microanalytical electronic balance, following an extensive laboratory routine. Weighing protocols, as presented in Section 5.3, are followed precisely to ensure data reliability. For chemical analysis, the analytical technique chosen to determine the elemental composition was energy-dispersive X-ray fluorescence (EDXRF). EDXRF was chosen for its nondestructive multi-element analytical ability to determine qualitatively and quantitatively the elemental composition of the samples. The initial results showed corroboration regarding the constitution of PM (PM_{10} and TSP) in the three monitored production phases, confirming the presence of Na, Al, Si, S, Cl, K, Ca, Ti, and Fe, with the most abundant percentages for Na, Al, Si, Cl, and Ca.

The readings of the adhesive sticky pads (%EAC/day) were acquired from the SPR.

7. Limitations and Recommendations for Future Research

Given the set of recommendations, the authors monitored the PM from the activities of construction sites from gravimetric sampling. The authors considered that information on PM concentration and chemical composition is necessary to understand the samples and conduct the risk assessment of toxic substances. These analyses will be presented in future publications. As a limitation of this choice, there was no possibility to investigate the distributional characteristics of the different PM sizes.

For future research, the authors recommend joint monitoring based on gravimetric monitoring and real-time monitoring (optical particle counter sensors (OPC)) at construction sites. In addition, the authors encourage the use of other low-cost monitors (see EPA [36]) to be validated and applied at construction sites (see Kelly et al. [69] and Zhang et al. [70]). Therefore, it is necessary to consider the weighting of Zheng et al. [37] regarding the need for a greater understanding of the low-cost PM sensors under field conditions. For this choice, it is necessary to pay attention to those devices with a high saturation level because large amounts of PM are generated in construction works, as pointed out by Cheriyan and Choi [8]. In addition, it may be necessary to develop an appropriate correction factor to compare the results, as recommended by Kelly et al. [69].

Despite these challenges, the consolidation of monitoring practices can provide information and details not explored from a single isolated monitoring type. However, this recommendation loses strength when raising the necessary costs for such joint monitoring events. Thus, as a conclusion, it is recommended, following the details presented in this article, to conduct primarily joint monitoring and, if this is not possible, the choice of the monitoring approach should be according to the objectives of each study, whether focused on the spatiotemporal variations or physicochemical analysis to identify toxic substances. In monitoring, investigations to reduce the health risk of construction workers should not be neglected.

8. Conclusions

The guidelines proposed in this study detailed recommendations, procedures, sampling instruments, and their main applications to support future researchers in this area; thus, directing decision making for experimental sampling and providing a benchmark for measuring and monitoring PM in construction sites.

The main contribution of this study is the consolidation of the limited knowledge about suspended and sedimented particulate material monitoring in construction. This study allowed the understanding of a set of variables that effectively interfere with measuring and monitoring PM at construction sites, namely, the location of sampling stations, equipment heights, monitoring periods, choice of equipment, and filters according to the research objectives. This work made efforts to provide scientific evidence for measuring and monitoring particulate matter on construction sites to promote construction workers' and neighborhood residents' safety and health.

Finally, it is understood that in order to further improve construction sites, it is necessary to consider training to raise awareness among professionals through lectures, courses, seminars, and meetings, among others, so that they have sufficient support to execute plans for monitoring, mitigating, and managing suspended and settled particles on their construction sites. This can be done including, for example, by registering complaints regarding dust and local air quality, attending regular meetings to discuss the efficiency of applied control activities, inspections of the most polluting activities, inspections of the impact on the surrounding area, among others. From this set of integrated actions, it becomes possible to increasingly reduce the environmental impact resulting from the detachment of PM during the execution of construction works.

Author Contributions: Conceptualization, I.P.S.A. and D.B.C.; methodology, I.P.S.A. and D.B.C.; validation, I.P.S.A. and D.B.C.; investigation, I.P.S.A. and D.B.C.; writing—original draft preparation, I.P.S.A.; writing—review and editing, I.P.S.A. and D.B.C. All authors have read and agreed to the published version of the manuscript.

Funding: This study was supported by the Brazilian construction company MRV Engineering and the Ministry of Education of Brazil through CAPES PrInt/CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Acknowledgments: The authors would like to acknowledge MRV Engineering and CAPES PrInt/CAPES.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Jung, S.; Kang, H.; Sung, S.; Hong, T. Health risk assessment for occupants as a decision-making tool to quantify the environmental effects of particulate matter in construction projects. *Build. Environ.* **2019**, *161*, 106267. [CrossRef]
2. Wang, L.K.; Pereira, N.C.; Hung, Y.T. *Air Pollution Control Engineering*; Human Press: Totowa, NJ, USA, 2004.
3. World Health Organization. WHO Global Air Quality Guidelines. *Global Update 2021. Particulate Matter ($PM_{2.5}$ and PM_{10}), Ozone, Nitrogen Dioxide, Sulfur Dioxide and Carbon Monoxide.* 2021. Available online: https://apps.who.int/iris/bitstream/handle/10665/345329/9789240034228-eng.pdf?sequence=1&isAllowed=y (accessed on 11 December 2021).
4. World Health Organization. *Ambient Air Pollution: A Global Assessment of Exposure and Burden of Disease*; World Health Organization: Geneva, Switzerland, 2016. Available online: https://apps.who.int/iris/bitstream/handle/10665/250141/9789241511353-eng.pdf;jsessionid=26F10218EBA7462EF0C07364E9FB34E4?sequence=1 (accessed on 18 November 2021).
5. Machado, M.; Reisen, V.A.; Santos, J.M.; Reis, N.C., Jr.; Frère, S.; Bondon, P.; Ispány, M.; Aranda Cotta, H.H. Use of multivariate time series techniques to estimate the impact of particulate matter on the perceived annoyance. *Atmos. Environ.* **2020**, *222*, 117080. [CrossRef]
6. Baron, P.; Generation and Behavior of Airborne Particles (Aerosols). Center for Disease Control and Prevention, NIOSH. 2010. Available online: https://www.sdpt.net/rd/Aerosol_101.pdf (accessed on 18 November 2021).
7. Tian, G.; Wang, J.; Lu, Z.; Wang, H.; Zhang, W.; Ding, W.; Zhang, F. Indirect effect of PM_1 on endothelial cells via inducing the release of respiratory inflammatory cytokines. *Toxicol. Vitr.* **2019**, *57*, 203–210. [CrossRef]
8. Cheriyan, D.; Choi, J. Estimation of particulate matter exposure to construction workers using low-cost dust sensors. *Sustain. Cities Soc.* **2020**, *59*, 102197. [CrossRef]
9. Khamraev, K.; Cheriyan, D.; Choi, J. A review on health risk assessment of PM in the construction industry–Current situation and future directions. *Sci. Total Environ.* **2020**, *758*, 143716. [CrossRef]
10. Cheriyan, D.; Choi, J.H. A review of research on particulate matter pollution in the construction industry. *J. Clean. Prod.* **2020**, *254*, 120077. [CrossRef]
11. Lipfert, F.W. Filter artifacts associated with particulate measurements: Recent evidence and effects on statistical relationships. *Atmos. Environ.* **1994**, *28*, 3233–3249. [CrossRef]
12. Araújo, I.P.S.; Costa, D.B.; Moraes, R.J.B. Identification and characterization of particulate matter concentrations at construction jobsites. *Sustainability* **2014**, *6*, 7666–7688. [CrossRef]
13. Moraes, R.J.B.; Costa, D.B.; Araujo, I.P.S. Particulate matter concentration from construction sites: Concrete and masonry works. *J. Environ. Eng.* **2016**, *142*, 05016004. [CrossRef]
14. Xing, J.; Ye, K.; Zuo, J.; Jiang, W. Control dust pollution on construction sites: What governments do in China? *Sustainability* **2018**, *10*, 2945. [CrossRef]
15. Sa'adeh, H.; Aburugia, S.; Chiari, M. An assessment of the impact of construction work on fine particulate matter in the University of Jordan: A PIXE study. *X-Ray Spectrom.* **2019**, *48*, 569–578. [CrossRef]
16. Chiang, Y.C.; Kuo, C.C. Characteristics of suspended particulate matter emitted from various stages of construction works. *J. Aerosol Sci.* **2004**, *35*, S995–S996. [CrossRef]
17. Feliciano, M.; Gonçalves, A.; Gomes, P.; Cardoso, A.; Araújo, R. Partículas em Suspensão na Praça Camões (Bragança), durante a Construção do Parque de Estacionamento. In Proceedings of the Conferência Nacional De Ambiente, Lisboa, Portugal, 27–29 October 2004. (In Portuguese)
18. Li, H.; Fang, C.H.; Shi, W.; Gurusamy, S.; Li, S.; Krishnan, M.N.; George, S. Size and site dependent biological hazard potential of particulate matters collected from different heights at the vicinity of a building construction. *Toxicol. Lett.* **2015**, *238*, 20–29. [CrossRef] [PubMed]
19. Azarmi, F.; Kumar, P.; Marsh, D.; Fuller, G. Assessment of the long-term impacts of PM_{10} and $PM_{2.5}$ particles from construction works on surrounding areas. *Environ. Sci. Process. Impacts* **2016**, *18*, 208–221. [CrossRef] [PubMed]
20. Ahmed, S.; Arocho, I. Characteristics of the emission of particulate matters in construction site: A comparative study on a timber and a steel construction project. In Proceedings of the CSCE Annual Conference, Laval, QC, Canada, 12–15 June 2019.
21. Ahmed, S.; Arocho, I. Emission of particulate matters during construction: A comparative study on a Cross Laminated Timber (CLT) and a steel building construction project. *J. Build. Eng.* **2019**, *22*, 281–294. [CrossRef]
22. Cheriyan, D.; Hyun, K.Y.; Jaegoo, H.; Choi, J.H. Assessing the distributional characteristics of PM_{10}, $PM_{2.5}$, and PM_1 exposure profile produced and propagated from a construction activity. *J. Clean. Prod.* **2020**, *276*, 124335. [CrossRef]
23. Cheriyan, D.; Khamraev, K.; Choi, J.H. Varying health risks of respirable and fine particles from construction works. *Sustain. Cities Soc.* **2021**, *72*, 103016. [CrossRef]
24. Araújo, I.P.S.; Costa, D.B.; Moraes, R.J.B. Boas práticas para redução da emissão de material particulado proveniente dos canteiros de obras. In *Tecnologias Para o Canteiro de Obras Sustentável*; Serra, S.B., Costa, D.B., Saurin, T.A., Cardoso, F.F., Eds.; FINEP: São Carlos, Brazil, 2017. [CrossRef]
25. World Health Organization. Air Quality Guidelines. *Global Update 2005. Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide.* 2006. Available online: https://apps.who.int/iris/bitstream/handle/10665/107823/9789289021920-eng.pdf?sequence=1&isAllowed=y (accessed on 18 November 2021).
26. European Union. European Union: Standards Air Quality Environment European Commission. 2008. Available online: http://ec.europa.eu/environment/air/quality/standards.htm (accessed on 18 November 2021).

27. Conselho Nacional do Meio Ambiente. Resolução 491. Brasília: Ministério do Meio Ambiente. 2018. Available online: http://conama.mma.gov.br/?option=com_sisconama&task=arquivo.download&id=766 (accessed on 18 November 2021).
28. Health and Safety Commission. Table 1: List of Approved Workplace. 2005, pp. 9–15. Available online: https://www.chemeng.upatras.gr/sites/default/files/users/site/health-Safety/04ENG.ListOfApprovedWorkplaceExposureLimits.pdf (accessed on 18 November 2021).
29. Machado, M.; Santos, J.M.; Reisen, V.A.; Reis, N.C., Jr.; Mavroidis, I.; Lima, A. A new methodology to derive settleable particulate matter guidelines to assist policy-makers on reducing public nuisance. *Atmos. Environ.* **2018**, *182*, 242–251. [CrossRef]
30. Vallack, H.W.; Shillito, D.E. Suggested guidelines for deposited ambient dust. *Atmos. Environ.* **1998**, *32*, 2737–2744. [CrossRef]
31. de Melo, M.M. Correlação Entre Percepção do Incômodo e Exposição ao Material Particulado Presente na Atmosfera e Sedimentado. Ph.D. Thesis, Espírito Santo University, Vitoria, Brazil, 2015; p. 272. (In Portuguese)
32. Li, C.Z.; Zhao, Y.; Xu, X. Investigation of dust exposure and control practices in the construction industry: Implications for cleaner production. *J. Clean. Prod.* **2019**, *227*, 810–824. [CrossRef]
33. Chow, J.C. Measurement Methods to Determine Compliance with Ambient Air Quality Standards for Suspended Particles. *J. Air Waste Manag. Assoc.* **1995**, *45*, 320–382. [CrossRef]
34. Maioli, B.G. Quantificação e Caracterização do MP Fino (MP2,5) na Região Metropolitana da Grande Vitória-ES. Master's Thesis, Espírito Santo University, Vitoria, Brazil, 2011; p. 118. (In Portuguese)
35. Fisher, J.; Friesen, M.; Kim, S.; Locke, S.; Kefelegn, Y.; Wong, J.; Albert, P.S.; Jones, R.R. Sources of variability in real-time monitoring data for fine particulate matter: Comparability of three wearable monitors in an urban setting. *Environ. Sci. Technol. Lett.* **2019**, *6*, 222–227. [CrossRef]
36. United States Environmental Protection Agency. Evaluation of Emerging Air Pollution Sensor Performance. 2021. Available online: https://www.epa.gov/air-sensor-toolbox/evaluation-emerging-air-sensor-performance (accessed on 18 November 2021).
37. Zheng, T.; Bergin, M.H.; Johnson, K.; Tripathi, S.N.; Shirodkar, S.; Landis, M.S.; Sutaria, R.; Carlson, D.E. Field evaluation of low-cost particulate matter sensors in high- and low-concentration environments. *Atmos. Meas. Tech.* **2018**, *11*, 4823–4856. [CrossRef]
38. Institute of Air Quality Management. Guidance on Monitoring in the Vicinity of Demolition and Construction Sites. 2018. Available online: http://iaqm.co.uk/text/guidance/guidance_monitoring_dust_2018.pdf (accessed on 18 November 2021).
39. Alves, M.R. Estudo do Fluxo de Deposição de Partículas Para a Região Metropolitana da Grande Vitória Usando Dados de PTS. Master's Thesis, Espírito Santo University, Vitoria, Brazil, 2011; p. 147. (In Portuguese)
40. Galvão, E.S.; Santos, J.M.; Lima, A.T.; Reis, N.C., Jr.; Orlando, M.T.D.A.; Stuetz, R.M. Trends in analytical techniques applied to particulate matter characterization: A critical review of fundaments and applications. *Chemosphere* **2018**, *199*, 546–568. [CrossRef] [PubMed]
41. Alves, D.D.; Osório, D.M.M.; Rodrigues, M.A.S.; Schuck, S. Morfologia e composição do material particulado atmosférico da bacia hidrográfica do Rio dos Sinos (RS) analisados por microscopia eletrônica de varredura. *Geochim. Bras.* **2015**, *29*, 45–57.
42. Nascimento, A.P. Influência da Poluição Atmosférica por SO_2, MP_{10}, $MP_{2.5}$ e sua Composição Elementar na Incidência de Doença Respiratória Aguda em Crianças. Ph.D. Thesis, Espírito Santo University, Vitoria, Brazil, 2015; p. 166. (In Portuguese)
43. Code of Federal Regulations. Title 40, Chapter I, Part 50, Appendix L e O. Office of the Federal Register. 2011. Available online: https://www.epa.gov/laws-regulations/regulations#find (accessed on 18 November 2021).
44. Phung, T.; Zhang, Y.; Dunlop, J.; Dalziel, J. Bilayer lipid membranes supported on Teflon filters: A functional environment for ion channels. *Biosens. Bioelectron.* **2011**, *26*, 3127–3135. [CrossRef]
45. Khuzestani, R.B.; Schauer, J.J.; Wei, Y.; Zhang, Y.; Zhang, Y. A non-destructive optical color space sensing system to quantify elemental and organic carbon in atmospheric particulate matter on Teflon and quartz filters. *Atmos. Environ.* **2017**, *149*, 84–94. [CrossRef]
46. Martin, S.S. El Aerosol Particulado en Telde, Gran Canaria (España), Durante 2002/03. Ph.D. Thesis, Las Palmas de Gran Canaria Univ., Las Palmas, Spain, 2008; p. 445. (In Spanish)
47. United States Environmental Protection Agency. *IO Compendium Method IO-3.1: Compendium of Methods for the Determination of Inorganic Compounds in Ambient Air: Selection, Preparation and Extraction of Filter Material*; EPA/625/R-96/010a; United States Environmental Protection Agency: Cincinnati, OH, USA, 1999. Available online: https://www.epa.gov/sites/default/files/2015-07/documents/epa-io-3.1.pdf (accessed on 18 November 2021).
48. Environment Agency. Monitoring of Particulate Matter in Ambient Air Around Waste Facilities: Technical Guidance Document (Monitoring) M17. 2013. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/301206/TGN_M17_-_Monitoring_of_particulate_matter_in_ambient_air_around_waste_facilities.pdf (accessed on 18 November 2021).
49. Sow, M.; Goossens, D.; Rajot, J.L. Calibration of MDCO dust collector and of four versions of the inverted Frisbee dust deposition sampler. *Geomorphology* **2006**, *82*, 360–375. [CrossRef]
50. *ASTM D 1739-98*; Standard Test Method for Collection and Measurement of Dustfall (Settleable Particulate Matter). American Society for Testing and Material: West Conshohocken, PA, USA, 2017.
51. Payus, C.; Mian, L.Y.; Sulaiman, N. Airborne fine particulate emissions from construction activities. *Int. J. Environ. Sci. Develop.* **2017**, *8*, 526–529. [CrossRef]

52. Rahman, S.A.A.; Yatim, S.R.M.; Abdullah, A.H.; Zainuddin, N.A.; Samah, M.A.A. Exposure of particulate matter 2.5 ($PM_{2.5}$) on lung function performance of construction workers. *AIP Conf. Proc.* **2019**, *2124*, 020030-1–020030-7. [CrossRef]
53. Yan, H.; Ding, G.; Li, H.; Wang, Y.; Zhang, L.; Shen, Q.; Feng, K. Field evaluation of the dust impacts from construction sites on surrounding areas: A city case study in china. *Sustainability* **2019**, *11*, 1906. [CrossRef]
54. Canadian Council of Ministers of the Environment. *Ambient Air-Monitoring Protocol for PM2.5 and Ozone Canada-Wide Standards for Particulate Matter and Ozone*; Canadian Council of Ministers of the Environment: Winnipeg, MB, Canada, 2011.
55. Greater London Authority. The Control of Dust Emissions during Construction and Demolition—Supplementary Planning Guidance. 2014. Available online: https://www.london.gov.uk/sites/default/files/gla_migrate_files_destination/Dust%20and%20Emissions%20SPG%208%20July%202014_0.pdf (accessed on 18 November 2021).
56. Institute of Air Quality Management. Guidance on the Assessment of dust from Demolition and Construction. 2014. Available online: http://iaqm.co.uk/text/guidance/construction-dust-2014.pdf (accessed on 18 November 2021).
57. United States Environmental Protection Agency. *Monitoring PM2.5 in Ambient Air Using Designated Reference or Class I Equivalent Methods*; EPA-454/B-16-001; Research Triangle Park: Research Triangle, NC, USA, 2016. Available online: https://www3.epa.gov/ttn/amtic/files/ambient/pm25/qa/m212.pdf (accessed on 18 November 2021).
58. Resende, F.; Cardoso, F.F.; Costa, D.B.; Melo, A.; Araújo, I.P.S.; Moraes, R.J.B.; Porfiro, A. Metodologia para medição da concentração de material particulado em canteiros de obra. In Proceedings of the Simpósio Brasileiro de Gestão e Economia da Construção, Salvador, Brazil, 19–20 November 2013. (In Portuguese)
59. Han, I.; Symanski, E.; Stock, T.H. Feasibility of using low-cost portable particle monitors for measurement of fine and coarse particulate matter in urban ambient air. *J. Air Waste Manag. Assoc.* **2017**, *67*, 330–340. [CrossRef]
60. Venkatram, A.; Isakov, V.; Yuan, J.; Pankratz, D. Modeling dispersion at distance of meters from urban sources. *Atmos. Environ.* **2004**, *38*, 4633–4641. [CrossRef]
61. Conti, M.M. Caracterização Química e Morfológica de Partículas Sedimentadas na Região Metropolitana da Grande Vitória-ES. Ph.D. Thesis, Espírito Santo University, Vitoria, Brazil, 2013; p. 124. (In Portuguese)
62. Hanby, I. Airborne Dust Monitoring Equipment. 2019. Available online: http://www.hanby.co.uk/CAL%20&%20USE%20SPR.htm (accessed on 18 November 2021).
63. Zuo, J.; Rameezdeen, R.; Hagger, M.; Zhou, Z.; Ding, Z. Dust pollution control on construction sites: Awareness and self-responsibility of managers. *J. Clean. Prod.* **2017**, *166*, 312–320. [CrossRef]
64. Noh, H.; Lee, S.; Yu, J. Identifying effective fugitive dust control measures for construction projects in Korea. *Sustainability* **2018**, *10*, 1206. [CrossRef]
65. Giunta, M. Assessment of the environmental impact of road construction: Modelling and prediction of fine particulate matter emissions. *Build. Environ.* **2020**, *176*, 106865. [CrossRef]
66. Heal, M.R.; Kumar, P.; Harrison, R.M. Particles, air quality, policy and health. *Chem. Soc. Rev.* **2012**, *41*, 6606–6630. [CrossRef] [PubMed]
67. United States Environmental Protection Agency. *Integrated Science Assessment (ISA) for Particulate Matter. EPA/600/R-19/188*; Research Triangle Park: Research Triangle, NC, USA, 2019. Available online: https://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=347534 (accessed on 18 November 2021).
68. Diapouli, E.; Manousakas, M.; Vratolis, S.; Vasilatou, V.; Maggos, T.; Saraga, D.; Grigoratos, T.; Argyropoulos, G.; Voutsa, D.; Samara, C.; et al. Evolution of air pollution source contributions over one decade, derived by PM_{10} and $PM_{2.5}$ source apportionment in two metropolitan urban areas in Greece. *Atmos. Environ.* **2017**, *164*, 416–430. [CrossRef]
69. Kelly, K.E.; Whitaker, J.; Petty, A.; Widmer, C.; Dybway, A.; Sleeth, D.; Martin, R.; Butterfield, A. Ambient and laboratory evaluation of a low-cost particulate matter sensor. *Environ. Pollut.* **2017**, *221*, 491–500. [CrossRef]
70. Zhang, H.; Srinivasan, R.; Ganesan, V. Low Cost, Multi-Pollutant Sensing System Using Raspberry Pi for Indoor Air Quality Monitoring. *Sustainability* **2021**, *13*, 370. [CrossRef]