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Research paper

CONSTRUCTION MATERIALS HANDLING SIMULATION – EFFECT ON PARTICULATE MATTER EMISSIONS

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Abstract

Airborne particulate matter, particularly PM10 represents a significant environmental and occupational health concern on construction sites. The research explores how different construction materials effects PM10 generation during handling activities. In the absence of field measurements, a simulation-based approach was applied using emission factors defined by authoritative sources, including the EMEP/EEA Guidebook and USEPA AP-42 methodology. Seven widely used materials were selected to represent diverse physical properties and usage profiles: Portland cement, gypsum board, sand, aerated concrete blocks, clay bricks, polystyrene insulation, and gravel. For each material, multiple simulations were performed under controlled assumptions, incorporating realistic background PM10 levels to replicate urban construction site conditions. A PM10 Emission Index was defined to normalize emission potential per unit mass of material handled. Results indicate that fine, low-density materials such as Portland cement and gypsum board exhibit the highest emission intensities, while coarse, dense materials such as gravel and clay bricks contribute significantly less to airborne particulate concentrations. The findings highlight the substantial variability in emission potential across materials and emphasize the importance of material selection in sustainable construction planning. These insights can guide policymakers and construction professionals in adopting low-emission materials and better on-site dust control strategies.

Key words: *PM10, Construction Site, Material Selection.*

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1. INTRODUCTION

Construction activities are among the most significant contributors to ambient air pollution in urban environments, especially in rapidly developing regions [1], [2]. Recent researches show that construction sites actively participate in particle pollution around 20% [3]. Among the various pollutants emitted, particulate matter with an aerodynamic diameter of 10 micrometers or less marked as PM10 is specific concern due to its adverse effects on both environmental quality and human health. PM10 can easily due to its size penetrate into the respiratory system, intensify chronic diseases, and reduce air quality far beyond the construction site perimeter [4], [5], [6], [7]. While legislative attention is traditionally focused on traffic, industry, and residential heating, recent studies underscore the growing role of construction sites as localized "hotspots" of dust and airborne particulate emissions [1], [8].

PM10 emission generated on construction sites has a wide range of sources: excavation, demolition, vehicle movement, and handling and processing of construction materials. Despite the availability of general emission factors and occupational exposure studies, relatively few researches have observed how the type of construction material itself affects dust emissions under typical site conditions. The lack of specificity limits the ability of planners and regulators to implement effective source-based mitigation strategies. The growing need to quantify and compare the emission potential of different materials, especially those commonly used in urban constructions across Central and Eastern Europe is essential for prevention model development.

The research addresses the gap by evaluating the influence of material choice on PM10 emissions during manual handling activities. The primary focus is on identifying which materials contribute most significantly to airborne PM10 concentrations in realistic site scenarios. The practical and logistical challenges of measuring emissions directly on active construction sites - especially those with high variability in operation, weather, and equipment indicated the utilization of a simulation-based approach grounded in internationally recognized emission modeling frameworks.

1.1. Material PM Emission Potential

Construction materials vary in their physical and chemical characteristics, which influence how easily they generate dust. Finer materials with low cohesion, such as cement and dry sand, are inherently more susceptible to wind erosion and mechanical disturbance. Equally, bulkier materials with larger particle sizes, such as gravel and solid bricks, tend to exhibit lower dusting potential due to their mass and structure [9], [10].

Recent researches have often addressed PM generation in the context of specific processes (e.g., concrete mixing, demolition), rather than attributing emissions to the material itself ([11], [12]). The researches rarely normalize emissions by the quantity of material handled, which limits comparability. As such, construction planners lack an evidence-based metric to assess the PM potential of materials when evaluating procurement options or preparing environmental impact assessments.

1.2. Limitations of Existing Data and the Role of Simulation

Field data on particle matter emissions from specific materials are scarce due to both technical and practical barriers. Construction sites are dynamic environments, with constantly changing activities, machinery, and meteorological conditions. Instrumentation capable of distinguishing emissions from a single material amidst multiple sources is not only expensive but also requires specialized expertise. The challenges make field studies difficult to replicate and limited in scope.

In order to overcome mentioned limitations, simulation-based modeling has become an increasingly accepted method for emission estimation, particularly in planning and policy contexts. Emission models, such as those proposed by the U.S. Environmental Protection Agency [10] and the European Environment Agency [13] provide structured methodologies for determining emissions based on activity type, material properties, and environmental conditions.

2. MATHERIALS AND METHODS

2.1. Selection of Construction Materials

Seven construction materials commonly used in Central and Southeastern European building projects were selected based on their physical characteristics and relevance to typical construction phases (e.g., structural work, interior finishing, and insulation). The materials include:

- Portland cement (CEM I 42.5 R)
- Gypsum board (12.5 mm thick)
- Dry sand (0–2 mm)
- Aerated autoclaved concrete (AAC) blocks
- Clay bricks (standard perforated)
- Expanded polystyrene insulation (EPS)
- Gravel (16–32 mm aggregate)

The materials were chosen to reflect a range of particle sizes, densities, handling mechanisms, and application domains. All materials were assumed to be dry and handled in an open environment under typical dry-weather conditions, without mechanical dust suppression.

2.2. Simulation Design and Framework

Due to the lack of accessible, site-specific empirical measurements of PM10 emissions in Serbia and similar contexts, a simulation approach was implemented. The method allows for controlled, repeatable estimates of particulate emissions based on established emission factors and assumed conditions. It also aligns with recognized methodologies such as those in the EMEP/EEA air pollutant emission inventory guidebook [9] and the USEPA AP-42 Compilation of Air Pollutant Emission Factors (US EPA, 2011).

The simulation was built on the following steps:

- Baseline Background Concentration

The typical urban background PM10 level was assumed to be 75 μg/m³, with a standard deviation of ±5 μg/m³, based on regional urban measurements near construction sites [1], [14], [15], [16].

- Activity Scenario

Each material was modeled under a standardized manual handling event (e.g., lifting, dumping, or pouring), replicating activities such as material transfer from pallet to site or from bag to mixer.

- Simulated PM10 Emissions

For each material, three simulated measurements were generated, incorporating variability due to handling intensity, particle cohesion, and environmental micro conditions. Values were generated based on known emission behavior (e.g., cement as a high-dust material) and informed by literature estimates where available [12], [17], [18], [19], [20], [21], [22].

- Net PM10 Concentration

The net PM10 contribution of each material was calculated (1) as the difference between the simulated measured concentration and the background value:

$$\text{Net PM10} = \text{Measured PM10} - \text{Background PM10} \tag{1}$$

- Normalization via Emission Index (EI)

To enable meaningful comparison across different material masses, a Particle Matter Emission Index (EI) was defined as:

$$EI = \frac{\text{Net PM10}(\mu\text{g}/m^3)}{\text{Mass handled (kg)}} \tag{2}$$

The index (2) expresses emission potential per kilogram of material and facilitates cross-material comparison.

Assumptions and Constraints were defined in order to provide case efficient modeling results:

- Dry Handling: All materials were assumed to be handled in dry conditions, maximizing potential dust generation (i.e., worst-case scenario).
- Open Site Conditions: Emissions were simulated for open-air handling with no dust suppression (e.g., no water spraying or enclosures).
- Short-Term Exposure: Simulations reflect momentary concentration spikes during material handling rather than long-term average exposure.
- No Wind or Atmospheric Dispersion Effects: Since the goal was relative comparison of emission potential, atmospheric dispersion modeling was not included.

Data simulation was carried out using custom scripts developed in Python, using pseudo-random number generation to represent variability in measured values. Mean and standard deviation parameters were assigned per material category based on review of prior literature and expert judgment. Each simulation consisted of three iterations per material to reflect handling variability.

3. RESULTS AND DISCUSSION

The simulation results revealed significant differences in PM10 emissions across the seven selected construction materials. Both the mean PM10 concentration during handling and the emission index (EI)—representing normalized emissions per kilogram—varied widely, reflecting distinct material characteristics and handling behavior (Table 1.).

Table 1. Modeling results for seven selected materials

Material	Mean PM10 (μg/m³)	SD PM10	Handled Mass (kg)	Mean EI (μg/m³*kg⁻¹)	SD EI
Portland cement	306,70	8,34	10,00	30,67	0,84
Gypsum board	135,28	15,22	12,00	11,27	1,27
Dry sand	116,26	10,31	15,00	7,75	0,69
AAC blocks	93,45	6,98	20,00	4,67	0,35
Clay bricks	60,94	9,55	30,00	2,03	0,32
Polystyrene (EPS)	47,90	47,90	5,00	9,58	0,67
Gravel (16–32 mm)	33,86	33,86	25,00	1,35	0,25

Portland cement simulation produced the highest mean PM10 concentration (306.70 μg/m³) and the highest emission index (30.67 μg/m³*kg⁻¹), defining its status as a primary source of airborne particulate matter on construction sites. The fine powdery texture and dry handling conditions make it highly susceptible to becoming airborne during mixing and transfer operations.

Gypsum board and dry sand also exhibited elevated emissions, with mean PM10 concentrations of 135.28 μg/m³ and 116.26 μg/m³, respectively. Their emission indices were substantial, emphasizing that not only fine powders, but also granular and friable materials, contribute to particulate release. Notably, gypsum board emissions likely result from mechanical degradation during cutting and fitting, which can vary depending on the condition and density of the material.

Surprisingly, polystyrene (EPS)—despite its low bulk density—exhibited a relatively high emission index, due to its tendency to fragment into micro-sized particles during trimming and installation. While the total PM10 concentration was modest (47.90 μg/m³), this finding supports concerns raised in recent literature regarding polymer-based materials as a source of non-mineral PM and microplastics in the air [23].

On the other end of the spectrum, gravel, clay bricks, and AAC blocks were found to emit the least particulate matter. Gravel's coarse particle size and cohesive structure contributed to its low mean PM10 concentration and the lowest EI making it an environmentally favorable material from an air quality perspective. Similarly, clay bricks and AAC blocks produced moderate absolute emissions but low emission indices suggesting they are relatively stable during handling.

The standard deviations in both concentration and EI highlight the variability introduced by material form and handling method. Materials with uneven surfaces or brittleness, such as gypsum board and bricks, showed greater variability in emissions, which could reflect differences in breakage or dust dispersion during handling (figure 1.).

These results highlight a few critical patterns. The most prominent is that emissions correlate strongly with material friability, particle size, and dryness rather than just the quantity handled. High EI materials pose significant environmental risks even at low usage volumes (e.g., EPS), whereas bulk materials like gravel or bricks contribute far less PM per unit mass. The emission index (EI) serves as a valuable normalization tool, enabling comparisons across diverse materials and facilitating more accurate planning and mitigation strategies.

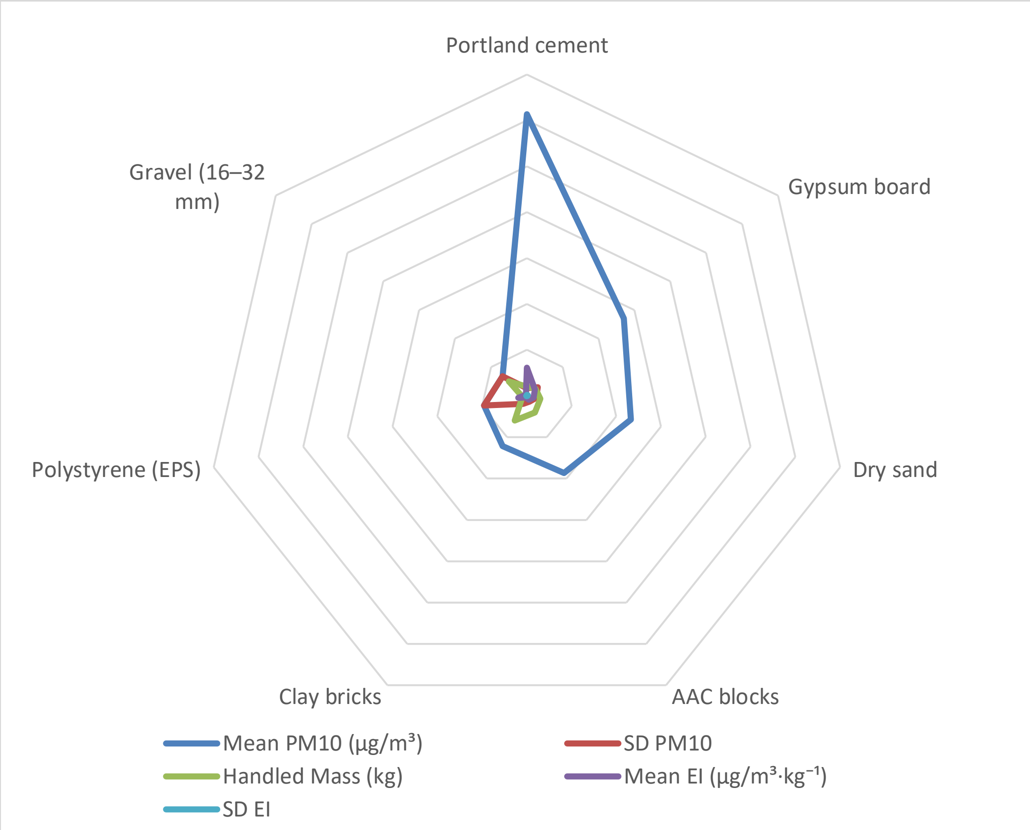

Figure 1. Selected materials modeled comparison.

The simulation model, although idealized, offers practical insights where empirical monitoring is constrained. It allows researchers and experts to estimate material-level impacts and prioritize dust control strategies based on simulated behavior.

4. CONCLUSION

The research demonstrates how the choice of construction materials significantly influences PM10 emissions during site handling operations. Fine-grained, dry, and friable materials such as Portland cement and gypsum board are major contributors to particulate pollution, whereas denser, coarser, and more cohesive materials like gravel and clay bricks pose a substantially lower emission risk.

The introduction of a simulated emission index (EI) provides a practical and scalable tool for comparing emission potential per kilogram of material, offering new insights for environmental impact assessments and construction site planning. While further validation against field data is needed, these results underscore the importance of integrating material-based emission factors into sustainable construction management and urban air quality mitigation efforts.

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