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EVALUATING ENVIRONMENTAL SUSTAINABILITY AND ECOSYSTEM DISRUPTION CAUSED BY CONSTRUCTION DEMOLITION WASTE IN A UNIVERSITY PRECINCT: A CASE STUDY FROM MALANG, SOUTHEAST ASIA

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This research focuses on evaluating the ecological potential of reusing construction and demolition waste (CDW) from brick wall debris in Malang City, East Java, Indonesia, as a sustainable substitute for natural fine aggregate in construction. The problem addressed is the increasing volume of CDW driven by rapid urban growth, especially in student-dominated districts, which poses environmental risks through landfill overuse, and soil degradation. The study employs field surveys, structured interviews, SEM-EDX analysis, and gradation testing to assess the physical and chemical suitability of recycled CDW. The results demonstrate that brick-based CDW exhibits stable particle gradation, an acceptable fineness modulus, with approximately 12.71% of the material passing through the 0.075 mm sieve, and contains no hazardous levels of leachable chemicals, making it suitable for reuse as a construction sand substitute.

These findings are explained by the inherent mineral stability of fired clay bricks and the controlled processing methods used, which reduce impurities and optimize particle distribution. A distinctive feature of the results is the integration of chemical safety verification via SEM-EDX with practical gradation analysis, ensuring both environmental safety and material performance in a single evaluation framework. The results can be practically applied in the manufacture of urban construction materials under conditions where local CDW. Implementation is most effective in medium-sized cities with high construction activity and limited natural sand resources, particularly where municipal waste management systems can support material sorting and processing. By applying these findings, urban areas can reduce environmental pressure from CDW, promote circular economy practices, and advance sustainable construction technology

Keywords: waste management, sustainable material, urban ecosystem, soil hazard, circular construction

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1. Introduction

The rapid growth of urbanization worldwide has intensified the generation of construction and demolition waste (CDW), which is now recognized as one of the largest waste streams contributing to ecological degradation, soil contamination, and resource depletion. Uncontrolled disposal of CDW threatens urban ecosystems by altering soil chemistry, polluting groundwater, and accelerating landfill overuse, making its sustainable management a critical global challenge. International research highlights the importance of circular construction practices, where CDW is revalued as a resource to reduce dependence on natural aggregates and mitigate ecosystem disruption. Within this broader context, campus area provides a representative case of a rapidly urbanizing academic hub where student-driven development has accelerated building expansion, renovation, and demolition. These processes generate significant volumes of brick- and mortar-based CDW, posing risks not only at the local scale but also offering insights applicable to other fast-growing cities across Southeast Asia and beyond. By focusing on the ecological potential of CDW recycling in campus area, this study contributes to the global discussion on sustainable material substitution, ecosystem protection, and the advancement of circular economy principles in urban environments.

International studies about ecology underscore the urgency of improving CDW forecasting and recycling practices. In China [1], urban renewal projects driven by limited land supply have produced substantial demolition waste, yet prediction remains inefficient due to a lack of standardized data. Meanwhile, Korean research [2] reveals that recycling potential varies significantly by building type and demolition method, with waste management spanning demolition, collection, transportation, and disposal stages. Malaysian experience further emphasizes that effective CDW reduction must begin at the planning and design phase linking ecological sustainability with urban policy [3]. As Malang continues to urbanize under the influence of its student-driven demand, the city faces both a challenge and an opportunity: to turn CDW from an environmental burden into a sustainable resource. This study contributes to that goal by evaluating the potential of CDW recycling as a substitute for natural sand, supporting circular construction practices that protect ecological balance.

The reuse of construction and demolition waste (CDW) as fine aggregate plays a vital role in advancing sustainable construction technology. It encourages the development of eco-friendly materials, reduces dependence on non-renewable natural resources like river sand, and promotes circular economy practices. Moreover, it supports innovation in material science, especially in modifying concrete mix designs and improving the mechanical performance of recycled aggregates, paving the way for greener, more resilient infrastructure. Therefore, research on the development of sustainable CDW recycling technologies and their ecological integration is highly relevant for addressing the environmental challenges of rapidly urbanizing academic cities.

2. Literature review and problem statement

The paper [4] presents a systematic review of chemicals of concern in fine residues of construction and demolition waste (CDW), showing that hazardous elements such as heavy metals, sulfates, and chlorides can leach into soil and water, posing ecological risks. While the review offers valuable insight into chemical hazards, it lacks experimental validation in specific urban contexts such as Southeast Asian cities. Unresolved questions remain on how these hazards behave in tropical climates with high rainfall and varied soil pH. This gap may stem from difficulties in replicating local environmental conditions in controlled experiments and the high cost of long-term leachability monitoring. A possible solution is to combine laboratory leaching simulations with in-situ field monitoring at CDW disposal sites.

The paper [5] investigates leaching toxicity and deformation of phosphogypsum-based cemented paste under chemical erosion, demonstrating that binder–solution interactions significantly influence mechanical and environmental performance. However, it is uncertain how similar degradation patterns occur in CDW materials exposed to tropical acidic rain or alkaline soils, since phosphogypsum findings cannot be directly applied to heterogeneous CDW compositions. Adapting their long-term erosion testing methods to CDW with varied binder types could help address this.

The paper [6] examines the long-term geo-environmental behavior of CDW in cemented paste backfill, showing that composition and curing conditions affect leachate characteristics. However, the behavior of untreated CDW aggregates for direct use in concrete or road bases remains unclear due to the focus on bound waste forms. Extending tests to untreated or minimally processed CDW fractions, as explored in [7] for earth-based mixtures, could close this gap.

Taken together, these studies highlight the need for localized chemical resistance testing of campus area's CDW-particularly untreated fine brick–mortar aggregates to ensure environmentally safe reuse and support sustainable material substitution. The paper [7] analyzes how incorporating CDW affects both environmental and mechanical performance of earth-based mixtures, showing that microstructure improvement and pre-treatment reduce leaching risks and enhance strength. However, unresolved questions relate to the specific mineralogical and chemical differences in fired-clay CDW from Southeast Asia, which could influence pre-treatment efficiency. This is likely due to the absence of regional material databases and differences in firing temperature and clay composition. The paper [8] presents experimental data on chemical and leaching behavior of CDW and recycled aggregates, confirming that certain treatments reduce contaminant release. However, unresolved aspects concern scaling these treatments for cost-effective application in low- to middle-income urban contexts. An option is to combine SEM-EDX mineral profiling with targeted pre-treatment trials, as in [9], which tested finely ground brick powder. This approach, applied to Malang's CDW, could ensure both ecological safety and structural performance.

The paper [9] evaluates the use of finely ground brick powder in lightweight concrete, demonstrating improvements in microstructure and reductions in porosity. However, unresolved questions remain regarding the ecological performance of such modified concretes, particularly in terms of leachate quality and soil impact. This gap may exist because mechanical optimization often takes precedence over environmental testing in material studies. A possible solution is to adapt low-energy treatment techniques and incorporate readily available additives, as demonstrated in [10] with eco-cement pastes. This approach is especially relevant for cases in campus area where recycling infrastructure is limited.

The paper [10] investigates the properties of eco-cement pastes incorporating recycled concrete powder, showing that appropriate mix design can maintain strength despite higher water absorption. The unresolved issue is whether similar adjustments would be effective for brick-based CDW, which differs significantly in absorption capacity and mineral composition. These differences in material characteristics between recycled concrete and recycled brick mortar present a key challenge. An option to address this is to integrate leachability assessment into mechanical performance trials, as partially implemented in [11] for clay brick waste reuse. So, overall, these findings suggest that CDW-derived materials from campus area should be tested simultaneously for mechanical performance and ecological impact to ensure both structural suitability and environmental safety.

The paper [11] demonstrates that clay brick waste can be effectively reused in mortar and concrete when properly processed. However, unresolved questions remain regarding how local brick properties – shaped by variations in firing temperatures and clay sources – affect both structural performance and ecological safety. This gap exists due to the principal material differences between recycled concrete and recycled brick mortar. A potential solution is to adapt the mix proportioning methods from [12] and apply them to building's brick-based aggregates in campus area.

The paper [12] examines waste management incentives during wartime, highlighting systemic barriers to effective CDW management. While this policy-oriented approach is valuable, an unresolved issue is how to translate such emergency-driven strategies into the context of peacetime urban growth. This challenge is compounded by the lack of localized brick characterization in previous studies. The approach used in [13], which integrates material flow analysis with life-cycle assessment, could be adapted to create a campus area-specific material database.

The paper [13] presents an integrated method for planning waste management based on material flow analysis and life-cycle assessment, demonstrating how data-driven strategies can optimize resource use. However, an unresolved aspect is the incorporation of ecological risk assessment – particularly leachability and ecosystem toxicity – into these planning tools. Addressing this gap by integrating environmental impact parameters into the existing model would enhance its relevance for sustainable urban CDW management in campus area.

The reviewed studies consistently emphasize that CDW generation is not random but strongly influenced by urban growth patterns, land-use functions, and building characteristics. However, unresolved issues remain regarding how these mechanisms operate in rapidly growing academic cities such as Malang, where student-driven development accelerates both construction and demolition. Moreover, while previous research has evaluated CDW recycling potential and ecological risks, limited attention has been given to linking spatial distribution of CDW with its chemical and ecological impacts in a tropical context. Addressing this gap requires a scientific approach that identifies the regularities of CDW generation, determines the factors influencing its toxicity and reusability, and develops a model for sustainable material substitution.

All this allows to argue that it is appropriate to conduct a study devoted to linking CDW material suitability testing with ecological risk assessment and urban planning integration, as is being done in campus area. This approach directly addresses the unresolved intersection between material reuse potential and ecological safety in tropical, rapidly urbanizing contexts.

3. The aim and objectives of the study

The aim of this study is to establish the spatial distribution and generation patterns of construction and demolition waste (CDW) in Malang City, with a focus on identifying the mechanisms by which urban growth and land-use functions influence CDW volume and its potential ecological impacts, particularly soil hazards. Achieving this aim will contribute to the development of predictive models for CDW generation and provide a scientific basis for sustainable recycling strategies.

To achieve this aim, the following objectives were accomplished:

– to collect and analyze quantitative data on CDW generation across districts and subdistricts, identifying spatial and functional drivers of waste production;

– to determine the chemical and mineralogical composition of CDW using SEM-EDX analysis, with particular attention to elements that may contribute to soil and ecological hazards;

– to evaluate the physical and gradation characteristics of brick-and-mortar CDW and establish its suitability as a fine aggregate substitute in construction.

4. Material and methods

4. 1. The object and hypothesis of the study

The object of the study is construction and demolition waste (CDW) generated in Malang City, with particular attention to its spatial distribution, chemical composition, and potential reuse as a substitute for natural fine aggregate.

The main hypothesis of the study is that recycled CDW, particularly brick and mortar debris containing residual cementitious material, can be processed into fine aggregates with adequate physical and chemical properties to serve as a sustainable replacement for natural sand while reducing ecological risks to soil and groundwater.

In research examines the ecological implications of construction and demolition waste (CDW) in Southeast Asia through a case study in Malang City, Indonesia. It identifies the growing CDW volumes generated by educational infrastructure development and renovation and applies quantitative surveys and conversion models to estimate waste output by project type.

Assumptions made in the study are:

a) the largest CDW volumes are generated not strictly by population density but by areas of high building turnover, such as campus districts and industrial zones;

b) hazardous chemical elements in CDW, including heavy metals and silica, present ecological risks if unmanaged;

c) the cement content in CDW enhances the mechanical properties of recycled aggregates compared to natural sand.

Simplifications adopted in the study include focusing primarily on brick and mortar waste as the dominant CDW fraction in Malang, using laboratory-based SEM-EDX and gradation analyses as representative of field conditions, and limiting the scope of ecological evaluation to soil and leachability impacts rather than broader ecosystem dynamics.

4. 2. Statistical identification of quantitative analysis of construction and demolition waste in Malang city

To verify the primary data, this study used two data collection methods: primary and secondary. Field sampling was conducted in several villages within each sub-district. For secondary data, it is possible to request information and data from the Malang City Statistics Agency (BPS) on the population of each village and sub-district in Malang City. This study was conducted in Malang City, which has up to twelve sub-districts spread across five districts. Prior to the study, a statistical data survey was conducted and presented in Table 1, a map of each district was created as shown in Fig. 1. The map shows that many large campuses are in Lowokwaru District, which borders Blimbing, Klojen, and Sukun. Kedungkandang District is located far from Lowokwaru. The city center is in Klojen District, and large malls are in this district.

From statistical data – Lowokwaru District is the center of large campuses gathering from Universitas Brawijaya, UM, UMM, Widyagama, ABM, ITN, UNISMA. Therefore, student learning activities will gather in this area. Students in Southeast Asian campuses choose to find residential areas or boarding houses in places closer to campus, making Lowokwaru District a favorite location option for boarding houses. Blimbing District is the center of Malang's economic turnover, making it home to several factories and warehouses that were built decades ago and are still standing today. There are no plans to change the function or urban layout of this district. Sukun District is a center of private and elite housing for families of native Malang City residents and is rarely used for student boarding houses. Klojen District is an iconic area of Malang City that is unlikely to be changed or reconstructed. Kedungkandang District is an agricultural area that in the future will slowly change its function into subsidized housing for middle-income families. Malang City has five districts with very different characteristics and land uses.

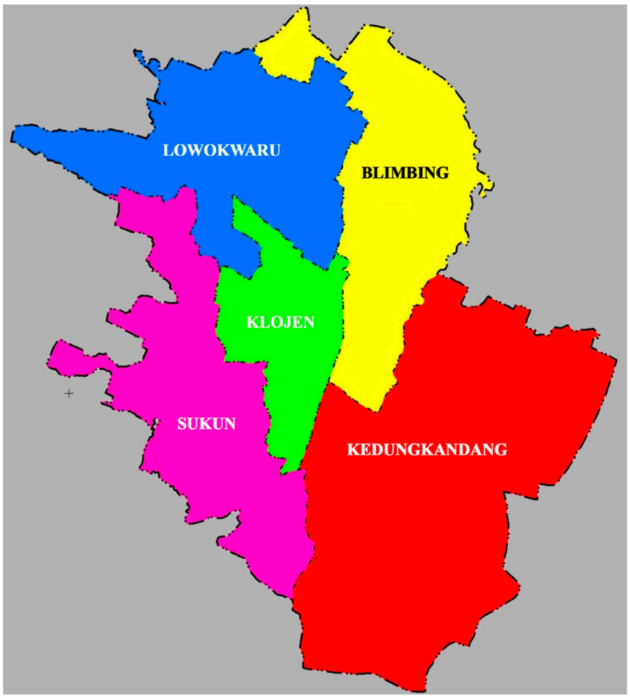

Fig. 1. Geographic characteristics of each district in Malang city

Table 1

Land use characteristics of each district in Malang city

District	Land use characteristics	Population density (people/km^2)
Lowokwaru	Lowokwaru district is the campus center of Malang city, home to numerous student boarding houses. Post-COVID-19, this area has also become home to numerous cafes, shops, and study spaces	6895
Blimbing	Blimbing district is the largest economic area in Malang city, home to numerous business buildings, markets, and factories. The area also boasts a campus in an elite residential area to the north	10313
Klojen	Klojen district is home to ancient buildings and houses, which have become symbols of Malang. Many iconic city landmarks are located in this district. Several small campuses are located here, as are several malls, shopping centers, and entertainment venues	10646
Sukun	Sukun sub-district is mostly made up of housing and private residences. This area has one campus	9435
Kedung-kandang	Kedungkandang District is the largest area in Malang city. Most of this area is vacant land and still consists of agricultural and plantation land. Currently, this area is being developed as an alternative housing option for the lower middle class	5254

Quantitative data collection in the form of total CDW volume in each sub-district, then the amount will be totaled at the station in the next district using the proportion method to obtain the CDW production level in each district at Malang city. To record the amount of demolition waste in each sub-district and district in Malang City, researchers measured the amount of demolition waste in each sub-district and surveyed the demolition waste material in each sub-district, which includes several sub-districts. The sub-districts that produced the most demolition waste were then identified and measured. People who perform home renovations or demolitions and reuse the demolition materials as building materials make up the study's population. With a sample size of 100 individuals in the vicinity of the demolition sample collection, the sample is drawn using a random sampling technique, which involves all members of the current population. To ensure the accuracy of the sample data according to time and location, documentation of sampling and location points must be completed according to coordinates.

4. 3. Construction and demolition waste in Malang city analyzed using SEM-EDAX

The metal tube that contains the X-ray detector is placed within the SEM chamber so that it is near the SEM column's last aperture and aimed at the specimen's surface. As a result, some of the X-rays that are released will reach the detector's surface through the thin polymer window. A silicon semiconductor doped with lithium makes up the detector. The semiconductor generates an electrical charge when exposed to X-rays. To ascertain the X-ray energy and the quantity of X-rays being released, this charge is further examined. Scanning Electron Microscopy (SEM) using FEI brand with Inspect-S50 type from Universitas Malang laboratory Fig. 2.

Fig. 2. The SEM-EDAX unit for identifying the chemical of concern (COC)

The procedure:

1. It is presumed that a region of interest has been identified, the accelerating voltage is on, and a sample has been correctly placed into the microscope.

2. Generally speaking, use an accelerating voltage for X-ray analysis that is at least twice the greatest expected X-ray peak energy. For instance, the minimum kV should be around 14 or 15 if iron has the highest energy peak at 6.39.

3. The sample was situated about 10 mm away from the operator. The position for the EDS detector is 9.8 to 9.9 mm. There will be significantly fewer X-rays striking the detector if the sample is above or below this point.

4. 4. Recycling methods for construction and demolition waste are evaluated as natural sand

The recycling method of construction and demolition waste (CDW) was investigated to assess its feasibility as a replacement for natural sand in construction. CDW materials including brick, concrete, and mortar debris were collected from demolition sites, sorted to remove contaminants, and then crushed using a portable mechanical crusher Fig. 3. The resulting material was saved to isolate sand-sized particles. The recycled fines were then tested for key physical and chemical properties such as particle size distribution, specific gravity, water absorption, and mineral composition to evaluate their compliance with fine aggregate construction standards.

a *b*

Fig. 3. Portable machine for recycling the CDW into fine aggregate: *a* – right side; *b* – left side

After going through the crushing process to become fine aggregate, the next stage is to test the quality of the material, one of which is the gradation and modulus of material fineness. The fineness modulus and gradation of fine aggregate are determined through a sieve analysis. A dry sample of the fine aggregate is passed through a standard set of sieves (typically 4.75 mm to 150 μm). The weight of material retained on each sieve is recorded, and the percentage retained is calculated. The cumulative percentages retained on each sieve are then summed and divided by 100 to obtain the fineness modulus (FM). This value indicates the average particle size and helps assess the suitability of the sand for concrete mix design.

5. Result research of environmental impacts of construction and demolition waste campus area

5. 1. Identifying construction and demolition waste volume using a new quantitative planning model

The findings emphasize that a significant proportion of CDW particularly from brick walls, plaster, and concrete debris comes from the periodic renovation and demolition of aging academic buildings Fig. 4, *a* for the campus building demolition debris and Fig. 4, *b* for the housing renovation. The article underscores the lack of a structured waste management system on campuses and the urgent need for segregation, reuse, and recycling strategies. The article also recommends integrating CDW monitoring into green campus initiatives to support environmental sustainability.

This study contributes to regional data on CDW production and serves as a basis for urban waste planning and policy development, particularly in developing academic cities like Malang.

In campus-dense cities across Southeast Asia, such as Malang City, Indonesia, construction and demolition waste (CDW) is largely driven by university infrastructure development and renovation projects. Using the CDW ratio method, which compares waste volume to build area or demolished volume, researchers have identified the dominant contributors of CDW in these environments.

Key findings indicate that the highest CDW ratios come from:

1. Demolition of academic buildings, especially those built before 1990, which tend to use high volumes of clay bricks and cement mortar.

2. Dormitory and housing renovations, which frequently generate brick wall, concrete, and plaster debris.

3. Campus facility upgrades (e.g., libraries, labs, canteens), contributing significantly to finishing material waste, such as ceramics, wood, and gypsum board.

The CDW ratio in Malang's campus zones is notably higher than in residential districts, largely due to dense institutional development cycles, frequent refurbishments, and limited waste reuse strategies. The study suggests implementing building material audits and selective demolition practices to reduce waste generation in campus centers.

A recent survey of construction and demolition waste (CDW) ratios in Malang City (Fig. 5) revealed that Lowokwaru District is the largest contributor to CDW. This is primarily due to its role as the city's academic center, home to several renowned universities and colleges. The high volume of renovations, demolitions, and building expansions within campus facilities significantly increases CDW generation in this area. After Lowokwaru, Blimbing District ranks second in terms of CDW generation. As Malang's economic and commercial center, Blimbing experiences constant structural changes to shops, offices, and mixed-use buildings, driving substantial demolition and construction activity.

According the statically data, Sukun District ranks third, with CDW generation largely related to its status as a private and elite residential area. Frequent renovations and reconstructions of luxury homes in this district contribute to the city's overall CDW volume. Based on the construction and demolition waste (CDW) ratio survey in Malang City, it was found that 40% of the total CDW volume is concentrated in five key sub-districts: Lowokwaru, Blimbing, Sukun, Klojen, and Kedungkandang. These areas reported estimated CDW volumes of 250 m^3, 200 m^3, 170 m^3, 140 m^3, and 100 m^3 respectively.

The survey results underscore a clear relationship between urban function and CDW generation, indicating that academic, commercial, and high-income residential areas are the primary CDW hotspots in Malang. These findings provide a valuable basis for targeted CDW management strategies in urban planning and environmental policy.

a *b*

Fig. 4. Sample construction and demolition waste raw material: *a* – building demolition; *b* – house renovation

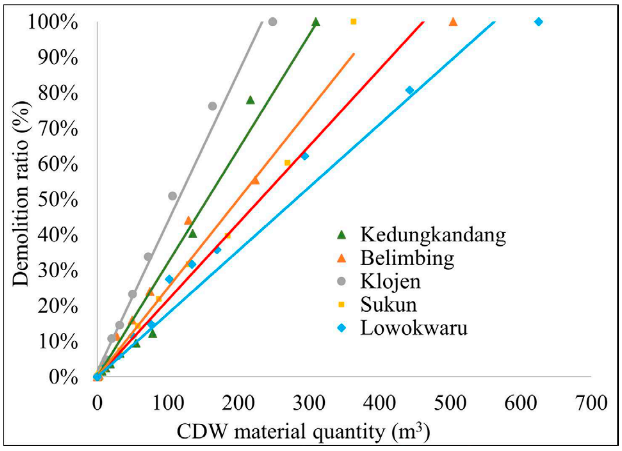

Fig. 5. Total demolition for each district of Malang city

5. 2. Chemical identification of concern (COC) of brick wall demolition waste using SEM-EDAX Analysis

To better understand the material composition and microstructural characteristics of the demolition waste samples, a detailed analysis was carried out using Scanning Electron Microscopy (SEM) combined with Energy-Dispersive X-ray Analysis (EDAX). The SEM-EDAX images provided high-resolution insight into the surface morphology, as well as the elemental composition of the CDW. These results serve as a foundation for identifying Chemical Constituents of Concern (COC) and assessing their potential environmental impact when released into the soil.

The SEM-EDAX micrographs reveal a heterogeneous and porous surface morphology typical of construction and demolition waste (CDW), particularly from materials like brick-and-mortar debris (Fig. 6). At lower magnification (200x, 1000x), the samples display irregular particle sizes and rough textures, indicating mechanical degradation during demolition. At higher magnifications (5000x and 10,000x), the presence of micro-granular particles and fine crystalline structures becomes more evident.

These microstructural features suggest that fine particulate matter (PM) from CDW may have high surface reactivity, increase the risk of chemical leaching when dispose into soil or exposed to moisture. The porous texture may also facilitate heavy metal mobility and pollutant retention, potentially contributing to soil contamination if not properly managed. The results support the need for monitoring of chemical constituents of concern (COC) and environmentally responsible recycling or disposal practices.

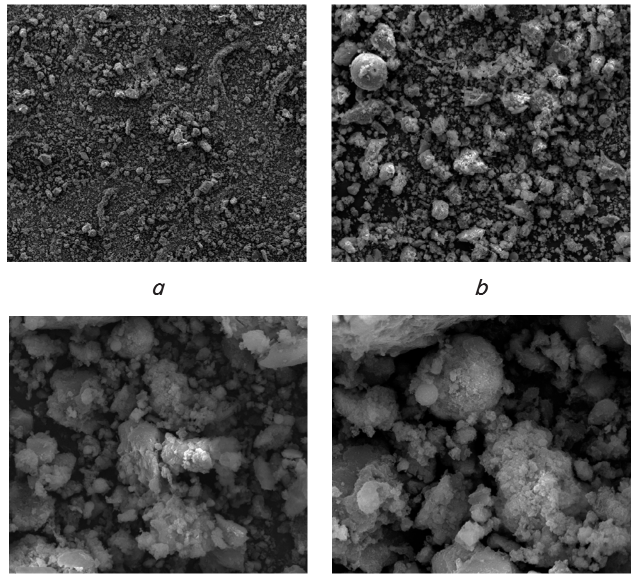

Fig. 6. SEM EDAX image result: *a* – 200x; *b* – 1000x; *c* – 5000x; *d* – 10.000x

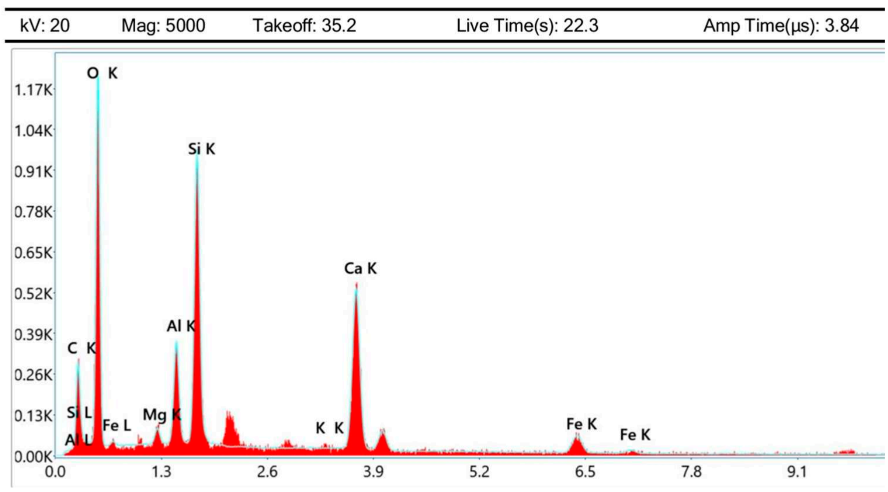

Fig. 7. SEM-EDAX spectrum for chemical of concern

From the results of the SEM EDX test Fig. 7 and Table 2, it is found that the chemical element content was obtained:

1. C – Carbon: 19.8% (weight), 30.1% (atomic).
2. O – Oxygen: 46.2% (weight), 52.6% (atomic).
3. Mg – Magnesium: 1.4% (weight), 1.1% (atomic).
4. Al – Aluminum: 4.4% (weight), 3.0% (atomic).
5. Si – Silicon: 6.3% (weight), 7.3% (atomic).
6. Ca – Calcium: 16.1% (weight), 7.3% (atomic).
7. Fe – Iron: 5.8% (weight), 1.9% (atomic).

Table 2

Chemical of concern percentage

Element	Weight (%)	Atomic (%)
C	26.2	36.5
O	49.1	51.3
Mg	0.6	0.4
Al	3.1	1.9
Si	8.1	4.8
Ca	10.4	4.3
Fe	2.6	0.8

From the result it is possible to obtain some conclusion. There are:

1. Calcium (Ca) – 10.4% (weight):

– ecological impact: high calcium content from cementitious materials can increase soil alkalinity, disturbing the pH balance necessary for plant and microbial life;

– environmental risk: alkaline leachate may lead to the formation of hardpan soil layers, reducing permeability and vegetation growth.

2. Silicon (Si) and Aluminum (Al) – 8.1% and 3.1%:

– while generally non-toxic in natural form, excessive aluminosilicates from CDW can alter soil mineralogy, reduce nutrient availability, and influence clay formation, affecting root penetration and water retention;

– Al in mobile form (e.g., under acidic conditions) can become toxic to plant roots, inhibiting growth.

3. Iron (Fe) – 2.6%:

– iron compounds can undergo oxidation-reduction reactions in moist soils, affecting soil chemistry and contributing to iron toxicity under waterlogged conditions;

– high Fe presence near water bodies may lead to discoloration and precipitation of iron oxides, impacting aquatic life.

4. Carbon (C) – 26.2%: a high carbon presence may reflect organic residue, unburnt material, or carbonates. Some forms, especially fine carbon particles, may influence soil respiration, adsorb pollutants, or block pore spaces, disrupting natural filtration.

5. Magnesium (Mg) – 0.6%: at low levels, Mg is a micronutrient, but if leached excessively, it may contribute to soil hardness and alkalinity, and in sensitive environments, affect soil microbial diversity.

5. 3. Developing sustainable sand alternatives by recycling construction and demolition waste (CDW) materials

To promote sustainable resource use and reduce the environmental pressure caused by construction and demolition waste (CDW), a simple yet effective recycling process has been introduced, as illustrated in Fig. 8. The process begins with the manual collection and sorting of mixed CDW materials, including brick, concrete, and mortar debris. These materials are then air-dried and partially crushed to remove large debris. The waste is then further processed using a mechanical grinder, producing a fine recycled aggregate. The final product is a granular material suitable for use as a sand replacement, offering a promising alternative that supports circular economy principles and minimizes ecological disruption.

Based on the recycling results, it is discovered that CDW may be processed into fine aggregates and used in mortars. The latter can be used to replace sand, while the former demonstrates pozzolanic activity to produce a denser combination. Prior research has examined the durability and mechanical characteristics of mortar.

Brick from South Asia utilizing burned clay that might not be pozzolanic. The crystalline minerals quartz and feldspar, which do not create active chemicals, make up a large amount of clay. Clay cannot, therefore, be regarded as a pozzolan. However, the crystal structure of the silicate will frequently shift into an amorphous compound that reacts with lime at room temperature if clay is heated to 600–1000°C. Thus, CDW reuse can only be used in place of fine aggregate; it cannot be used in place of cement. From Table 3 it is possible to found that the particle size distribution of the recycled fine aggregate, derived from construction and demolition waste (CDW), indicates a well-graded material with a broad range of particle sizes from 2.00 mm to below 0.075 mm. The highest percentage of material is retained on sieve No. 40 (0.42 mm) and No. 50 (0.3 mm), contributing significantly to the total retained weight, suggesting that the material lies within the mid-to-fine sand range.

Fig. 8. Sand substitutes aggregate process from CDW: *a* – raw debris; *b* – debris after crushing by hammer; *c* – aggregate crusher machine; *d* – sand material for reuse

From the data it is possible to found form gradation analysis that:

– well-graded distribution: with retention spread across multiple sieve sizes (notably between No. 20 to No. 100), the material shows a continuous gradation. This supports good workability, packing density, and reduced void ratio when mixed in concrete;

– finer content consideration: around 12.71% of the material passes through the 0.075 mm sieve, indicating a moderate presence of fines. This may slightly affect the water demand or workability but is still within acceptable limits for many concrete mixes;

– fineness modulus: this FM value of 3.36 falls within the standard range for natural fine aggregates (typically 2.3–3.6), indicating that the material has appropriate coarseness for use in concrete.

Table 3

Sieve analysis of sand for substitute aggregate quality

Sieve		Indiv. WT retained (gram)	Acc. WT retained (gram)	Retained (%)	Finer (%)
Sieve No.	Diameter (mm)				
4	4.75	0	0	0.0	100
10	2	3.88	3.88	1.19	99
20	0.84	0.38	4.26	1.31	98.69
40	0.42	135.87	140.13	43.03	56.97
50	0.3	37.37	177.50	54.50	45.50
80	0.18	56.03	233.53	71.71	28.29
100	0.15	18.69	252.22	77.45	22.55
200	0.075	32.07	284.29	87.29	12.71
Pan		41.38	325.67	100	0.00

6. Discussion of evaluating environmental sustainability and ecosystem disruption caused by construction demolition waste

The analysis of CDW in Malang City reveals a clear correlation between urban function, land use intensity, and waste generation volume. Lowokwaru District home to the largest concentration of academic facilities produced the highest CDW volume (250 m^3), followed by Blimbing (200 m^3) and Sukun (170 m^3). This distribution can be explained by differences in land use function, building activity intensity, and population density (Table 1, Fig. 1 of the study). In Lowokwaru, continuous renovation and expansion of academic facilities directly contribute to high CDW volumes, while in Blimbing and Sukun, commercial development and high-end residential projects play similar roles. This spatial pattern mirrors findings from [1], where high-density renewal zones in China generated more waste due to population concentration and modernization pressure. Similarly, [2] demonstrated that CDW output in South Korea is influenced by building age, structure type, and zoning classification variables also reflected in Malang's urban layout. The SEM-EDX results (Fig. 6) reveal that Malang's CDW is primarily composed of Ca, Si, and Al, with minor S, Fe, and trace heavy metals. These elements originate from cement paste, mortar, and brick composition, and their presence explains both the material's suitability for recycling and its potential ecological risks. The detection of sulphates and silicates also explains the potential for soil pH alteration and nutrient imbalance when the waste is disposed of untreated.

Material characterization through SEM-EDX revealed that Malang's CDW predominantly contains Ca, Si, Al, with smaller amounts of S, Fe, and trace heavy metals. This composition is consistent with findings by [4, 8], who reported similar elemental profiles in fired clay and cementitious demolition waste. The presence of sulphates and silicates explains the leaching potential that could alter soil pH and disrupt ecosystems, as highlighted by [5, 6]. Gradation and fineness modulus testing (Table 3) shows that sieved and crushed brick/mortar CDW matches the particle size distribution of natural sand, explaining its mechanical compatibility as a fine aggregate substitute. Fineness modulus and gradation testing indicated that processed brick-and-mortar CDW meets size distribution standards comparable to natural sand. This mechanical compatibility is in line with the observations of [9, 10], who reported that recycled fine aggregates from demolition waste can perform well in concrete with proper mix design adjustments.

Compared to previous works, this study is distinctive in integrating urban-scale CDW mapping with detailed chemical and physical testing. While studies in China [1] and Korea [2] have addressed prediction models and waste volume determinants, they did not directly connect spatial waste data to material suitability testing. Similarly, Malaysian research [3] emphasized planning strategies but lacked material science validation. This study's combination of district-level CDW quantification, SEM-EDX chemical risk assessment, and aggregate suitability testing allows for simultaneous ecological risk evaluation and technological application potential – a methodological advantage not found in earlier research. The applicability of results is limited to brick-and-mortar dominated CDW streams, typical of Malang's demolition profile, and may not translate to regions with concrete- or steel-heavy demolition waste. The leaching analysis was qualitative; long-term leachability under varying environmental conditions (acidic soils, fluctuating moisture, tropical rain exposure) was not tested. Waste volume estimation relied on survey-based data, potentially underrepresenting informal or undocumented demolition activities. Reproducibility of aggregate performance results depends on controlled processing conditions industrial scale recycling may introduce variability in particle size distribution and contaminant removal.

A key disadvantage is the absence of durability testing for concrete incorporating Malang's CDW, particularly in parameters like sulfate resistance, chloride penetration, and shrinkage behavior. These tests are essential to validate long-term performance in tropical climates. Another drawback is the lack of economic feasibility assessment, which is critical for policymaker and contractor adoption. These could be addressed in future studies through pilot projects, cost-benefit analyses, and life-cycle assessments like those in [13].

The future developments are creating GIS-based CDW prediction models integrating building age, function, and demolition trends, drawing from methods in [1, 2, 13]. After that, to expand CDW reuse into eco-cement production [10] and earth-based composites [7], with pre-treatment to minimize leaching risks. The development can be to establish district-level CDW management policies linked to zoning and urban planning, following Malaysia's strategy-based approach [3]. So, Possible challenges that can be reached include developing accurate predictive models that requires high-resolution spatial and building lifecycle data in mathematical, Standardizing CDW sampling and testing methods across diverse building types, Scaling chemical stabilization methods for mass application while maintaining cost-effectiveness, Coordinating multi-stakeholder participation across municipal agencies, contractors, and academic institutions. By addressing these challenges, Malang City could become a model for integrating ecological sustainability and technological innovation in CDW management for Southeast Asia.

7. Conclusions

1. There is a moderate correlation between population density and CDW volume. Densely populated areas typically experience more construction activity to accommodate housing and infrastructure needs. However, land use often plays a more significant role. For example, the central campus district area generated more CDW, at 360 m^3 at a 60% ratio, not only due to population density but also due to the intensive educational and development activities concentrated there.

2. The chemical composition indicates that improperly managed demolition waste can cause pH imbalance, metal ion leaching, and microbial disruption in the soil. Potential accumulations of Ca, Fe, and Al range from 10.4%, 2.6%, and 3.1%, respectively, which in the long term can reduce soil fertility and harm sensitive vegetation. Without proper handling or recycling, runoff from this material can impact surface water ecosystems, contributing to sediment contamination.

3. The recycled CDW sand exhibits a good gradation profile and an acceptable fineness modulus of 3.36, which is

within the standard range for natural fine aggregates, aligning with the characteristics required for fine aggregates in concrete. This indicates that the material can be safely reused as a sustainable replacement for natural sand, supporting environmental conservation while maintaining structural integrity in construction applications.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this study, whether financial, personal, authorship or otherwise, that could affect the study and its results presented in this paper.

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Data availability

Manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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