

# **Ceramic Waste in NYC: Beneficial Use Potential**

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## **Introduction/Scope**

### **Ceramic Tiles in NYC:**

Ceramics are one of the most visible and consistently utilized materials within New York City, appearing in both public and private settings. In buildings, ceramic tiles are widely used for interior designs such as walls, floors, and facades due to their high functionality as well as their aesthetic flexibility. Across the city's horizontal infrastructure, ceramic tiles are used on the walls, platforms, and tunnels of the subway station, where their durability and ease of maintenance are essential under heavy public use. Their widespread usage is driven by their material properties which offer them high mechanical strength, low porosity, and resistance to moisture and degradation. These characteristics have shaped how ceramic tiles are incorporated into the city environment and provide a basis for examining their performance, limitations, and potential beyond conventional applications.

### **NYC Quantity Estimate:**

The monthly production of masonry product waste in New York City and Long Island is estimated to be approximately 40,000 tons, which is equivalent to 480,000 tons per year (McKay et al., 2021). On a global scale, ceramic tiles make up 48% of the ceramic industry (Ceramic Tiles Market, 2024), which translates to approximately 230,000 tons of ceramic tile waste entering the NYC C&D waste stream annually.

### **Ceramic Tiles in the NYC C&D Stream:**

Due to their higher presence in building interiors, ceramic waste enters the waste stream through partial interior demolition or full building demolition. This waste is often left to pile up in open air or be dumped into landfills. This has an inevitably negative effect on the environment. Ceramic tile waste shows great potential for improving infrastructure and providing sound barrier qualities. This provides a useful way to redirect this waste. Moreover, as the growth of the construction industry gradually depletes natural resources, the question of alternative materials arises. In this context, ceramic waste is a particularly attractive substitute for aggregate in concrete. An increasing necessity to redirect waste production through more efficient means, paired with the potential of ceramic waste in improving infrastructure, shows that the ceramic industry will likely play a significant role in future sustainability efforts.

### **New York City / New York State Policies:**

In New York City, efforts to redirect ceramic tile waste have already been taken. According to New York Codes, Rules, and Regulations parts 360.12 and 360.13, ceramic tile waste or “masonry products” may be designated to Beneficial Use Determination (BUD). (New York State Department of Environmental Conservation, n.d.).

## **Material Properties**

### **Composition and Properties:**

Ceramic tiles are widely used in residential, industrial, and infrastructure projects for their mechanical, thermal, and chemical properties. These properties originate from their mineralogical composition and the high-temperature firing processes used during manufacturing, which produce a dense, inert, and durable material. Although ceramic tiles vary in composition due to their extensive applications, most compositions consist of the same essential components: silica, alumina, feldspar, clay minerals, and minor oxides. Clay minerals serve as the primary source of alumina which is essential for the development of mullite during firing. Mullite forms through the calcination and reaction of aluminosilicate materials at high temperatures and is responsible for the high mechanical strength, thermal stability, and chemical durability characteristic of ceramic tiles. During firing at approximately 1200–1250 °C, clay minerals decompose and react to form mullite, silica partially dissolves into molten feldspar to generate a vitrified aluminosilicate glass matrix, and the residual silica remains in a crystalline structure as quartz (Ismail et al., 2022). The vitrified aluminosilicate glass matrix binds the ceramic body, reduces porosity, and improves chemical, mechanical, and thermal durability. Residual quartz, with its ordered crystal lattice and high melting point, provides hardness and dimensional stability to ceramic tiles.

The vitrified structure of ceramic tiles is one of their most notable advantages, as it imparts chemical inertness. This is due to the manufacturing process where the material is fired at extremely high temperatures, causing it to become vitrified and nonreactive. As a result,

ceramic tiles do not rust, corrode, or chemically degrade under normal environmental exposure, remaining stable when subjected to moisture, heat, or environmental pollutants. Chemical inertness is a major reason that ceramic tiles are a highly desirable material for hygienic surfaces such as kitchens and bathrooms as it prevents the material from interacting with bacteria or contaminants, making it easier to clean and more sanitary. This is also a major factor contributing to why ceramic waste forms well as a recycled aggregate: ceramic particles do not participate in unwanted chemical reactions and instead act as stable fillers. This chemical stability makes ceramic tile waste particularly suitable for reuse as aggregate in concrete, alkali-activated mortars, and fill materials, where long-term durability and resistance to environmental exposure are critical.

Ceramic tiles are highly stable materials, exhibiting exceptional thermal stability, due to the extreme temperatures used during the manufacturing process. The ionic and covalent bonds of the materials in ceramic tiles such as the quartz ( $\text{SiO}_2$ ) contribute to the material strength as well as the thermal stability. The strong atomic bonds limit electron movement, and lack of free electrons make ceramic tiles poor conductors of heat and excellent insulators. This makes them highly effective materials for reducing heat transfer and heat gain, allowing them to maintain stable environments. They do not ignite, propagate flames, produce toxic smoke, or degrade structurally when exposed to high thermal loads. The material properties of ceramic tiles are maintained despite exposure to heat as they remain chemically unchanged when heated (Sudha et al., 2018). These thermal properties support the reuse of ceramic tile waste in fire-resistant building linings, infrastructure protection systems, and other applications where other conventional materials may fail under elevated temperatures.

The low porosity of ceramic tile is an important factor that influences its durability. Low porosity means that the material has very few voids or pores, limiting the amount of moisture that can penetrate the ceramic tile. The vitrified structure of ceramic tile closes internal pores and makes the material dense and produces a solid, non-porous network. The feldspar also acts as a flux, fusing the other materials together and helps fill the voids between the solid particles. As a result, ceramic tiles are highly resistant to freeze-thaw damage as there is minimal expansion due to the freezing of water as there is very little absorbed. Additionally, the dense, low-porosity structure of ceramic tiles allows them to reflect sound effectively, and coarse, low-porosity materials can also reduce sound transmission compared to finer, more porous materials. Low porosity and moisture resistance are particularly advantageous for pavement subgrades, sound barriers, and outdoor infrastructure applications, where repeated wetting, freeze–thaw cycling, and long-term exposure are expected.

The table below summarizes the key material properties of ceramic tiles, their effects, and links them to their reuse pathways, some of which will be discussed in more detail in subsequent sections.

<b>Property</b>	<b>Effects</b>	<b>Reuse Options Impacted</b>
Chemical inertness	Prevents unwanted chemical reactions with binders, moisture, and environmental contaminants; improves long-term durability	Concrete aggregate replacement; alkali-activated mortars; fill and embankments
High hardness and compressive strength	Enables load-bearing performance and contributes to strength in structural applications	Concrete aggregate; pavements; foundations
Low porosity	Improves freeze-thaw resistance and durability in outdoor applications	Pavements; sound barriers; infrastructure concrete

Thermal stability and non-combustibility	Maintains structural integrity at elevated temperatures; does not ignite or emit toxic fumes	Fire-resistant linings; infrastructure protection; building safety applications
Mineralogical stability	Provides resistance to chemical, thermal, and physical degradation over time	Long-term infrastructure applications; fill and soil stabilization

Table 1. Material properties and their effects on ceramic tiles.

**Waste Conditions:**

Ceramic tile waste often consists of off-cuts and broken pieces generated during manufacturing, installation, and demolition. The variety of applications from which waste is derived creates a diverse range of waste conditions that needs to be considered before ceramic tile waste can be reused. Ceramic tiles often are glazed to improve their durability and resistance to water and stains, as well as for aesthetic purposes. The glassy glazed surface is less porous and smoother than the ceramic body, which can reduce mechanical interlock and weaken bonding between ceramic particles and cementitious paste when used as an aggregate. Ceramic tile waste also commonly contains grout, mortar, and adhesive residues, due to their applications as wall or floor tiling. These residues can introduce surface roughness and porosity of ceramic particles, which can raise water absorption and demand in concrete or mortar mixes (Li et al., 2023). Beyond usage contamination, a variety of variables can be introduced into ceramic tile waste due to the demolition method, material age, prior site use, and waste separation practices. When ceramic tiles are crushed, the ceramic tile aggregate has different gradation and size distribution compared to natural sand or gravel. The artificial ceramic aggregate tends to have greater surface areas due to their angular shapes created by the ceramic tiles brittle nature and the crushing process (Akshahwany et al., 2024). These variabilities can lead to highly different properties,

causing inconsistent mechanical performance, durability, and chemical stability in reused materials. As a result, screening, sorting, testing, and processing are necessary to ensure suitability for beneficial reuse.

### **Environmental and Health Considerations:**

Although ceramic tiles are generally considered stable during use, their processing and reuse can introduce health and environmental hazards. When the ceramic is crushed, grinded or cut, crystalline silica dust is often released, as silica is a primary constituent in the makeup of the ceramic tile body as well as the glaze. This respirable crystalline silica dust poses potential health hazards, as chronic inhalation of silica dust can cause silicosis, chronic obstructive pulmonary disease, and increased risk of lung cancer without proper practices such as wet cutting, or respiratory protection (United States Department of Labor, 2024). Heavy metals such as lead, cadmium, chromium, and nickel are also present in the ceramic body and glaze and can be exposed when the ceramics are crushed and fragmented. When ceramics are crushed for use as aggregate or fill, the exposure risks increase as the surface area is increased, potentially mobilizing the trace heavy metals present. The aggregate or fills prolonged contact with rainwater or groundwater may also result in leaching of these elements, potentially contributing to soil and groundwater contamination. Heavy metal contamination is toxic in water and can also disrupt nutrient cycles, reduce soil fertility, inhibit plant and microbe growth, and degrade the physical structure of the soil (Nyiramigisha et al., 2021). This can lead to many ecological impacts, such as the bioaccumulation of toxins in plants and microorganisms, and eventually impacting humans as well through biomagnification. The presence of alkaline oxides in the ceramic tile body and glaze may also alter local soil or runoff pH, which can affect microbial

activity, plant growth, and aquatic systems. Although leaching levels are often below regulatory hazardous thresholds, these risks are highly dependent on tile source, age, degree of fragmentation, and environmental exposure conditions. With proper processing of ceramic tile waste, these risks can also be minimized as studies show that heavy metal leaching from thermally treated waste materials generally decreases with higher firing temperatures (Latosińska et al., 2023).

## **Beneficial Use Options**

### **Ceramic Waste as Coarse Aggregate in Concrete:**

Concrete is generally composed of 60 to 70 percent natural aggregate, most of which is sourced nonrenewably. As a result, natural reserves from which crushed concrete is sourced are slowly being depleted. A remedy to this gradual depletion and its negative effect on the environment is to use ceramic waste as a substitute for aggregate. Due to its brittle nature, large amounts of ceramic are broken during processing and must be redirected as waste. Additionally, the durable, chemically inert, insulating, and degradation resistant nature of ceramic raises potential for ceramic aggregate to improve the strength and properties of conventional structural concrete. However, efforts to take advantage of the low thermal conductivity of ceramic materials faces the challenge of increased porosity, which leads to a decrease in strength and frost resistance. Generally, materials with lower thermal conductivity have a higher porosity, which in turn lowers its strength and frost resistance.

Under current New York City Beneficial Use Determination, masonry product waste may be used as filler in concrete if it is uncontaminated, contains minimal amounts of wood or soil, and are separated from other products prior to processing in the original processing site. Unless there is no indication that the site of waste collection is contaminated, and the site does not have any history of spill events or visual indicators of contamination, a sample of the waste material must be chemically analyzed (New York State Department of Environmental Conservation, n.d.). Waste may be exempt from analysis if less than 10 cubic yards are produced from one site. Prior to reincorporation into concrete filler, ceramic waste may be too large to be fed into crushing machines and must be manually broken into pieces. Moreover, the target properties of the resulting concrete may require the ceramic glaze on concrete to be removed, which is a rather labor intensive process and is difficult to do on a large-scale level.

Using ceramic waste as replacement for conventional aggregate for Portland cement concrete, experiments have shown that 20 percent replacement of conventional aggregate produced an increase in compressive, split tensile, and flexural strength in structural concrete at 28 days of curing (Bommisetty et al., 2019).

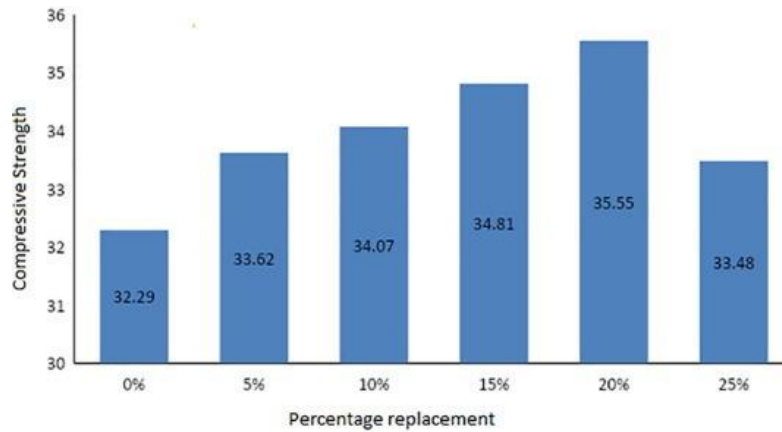


Figure 1. Reduction in compressive strength after 20% replacement. (Bommisetty et al., 2019)

At 0 percent replacement, the conventional concrete possessed 32.29 N/mm<sup>2</sup> in compressive strength, which increased linearly at 5 percent replacement intervals up to 35.55 N/mm<sup>2</sup> at 20 percent replacement. Average strength then dropped to 33.48 N/mm<sup>2</sup> at 25 percent replacement (Figure 1).

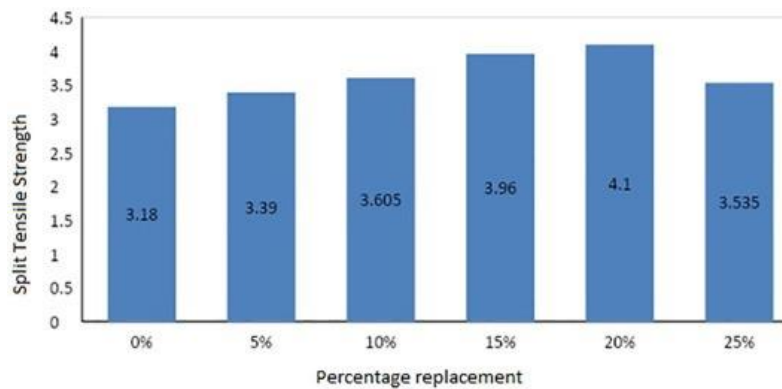


Figure 2. Reduction in split tensile strength after 20% replacement. (Bommisetty et al., 2019)

Split tensile strength saw less of a dramatic shift after ceramic incorporation, with the concrete's average split tensile strength beginning with 3.18 N/mm<sup>2</sup> at 0 percent replacement and gradually increasing up to 4.1 N/mm<sup>2</sup> at 20 percent replacement. Split tensile strength, like compressive strength, dropped to 3.535 N/mm<sup>2</sup> at 25 percent replacement (Figure 2).

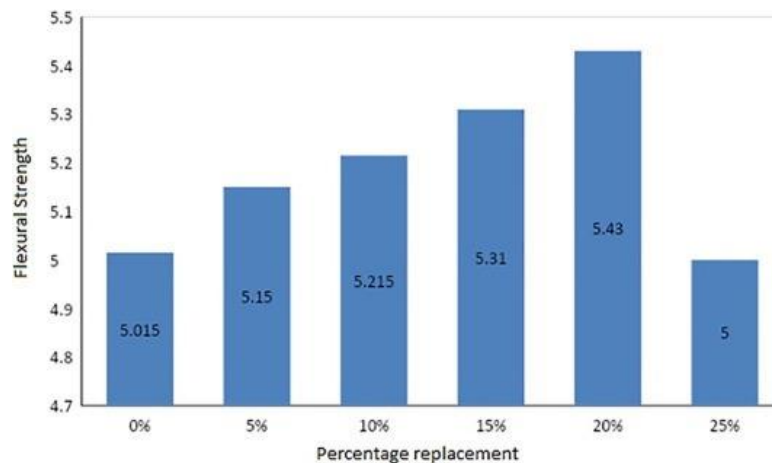


Figure 3. Reduction in flexural strength after 20% replacement. (Bommisetty et al., 2019)

Flexural strength followed a similar pattern, beginning at 5.015 N/mm<sup>2</sup> and increasing in a linear manner up to 5.43 N/mm<sup>2</sup> at 20 percent replacement before dropping dramatically to 5 N/mm<sup>2</sup> at 25 percent replacement (Figure 3).

This shows the improvements that incorporating 20 percent of ceramic tile waste would have on the strength of conventional Portland cement concrete. At 20 percent replacement compressive, split tensile, and flexural strength saw 10.09, 28.9, and 8.27 percent increase to the conventional Portland cement concrete, respectively. Additionally, using ceramic tile waste as aggregate replacement proves economical due to its abundance.

*Senthamarai and Manoharan (2005)* conducted a study investigating the full replacement of crushed stone aggregate with ceramic waste aggregate in Portland cement. It was found that properties between the two were comparable.

Properties of ceramic waste coarse aggregate concrete and conventional concrete mixes at 28 days

Mix	w/c	Cement content (kg/m <sup>3</sup> )	Ceramic waste coarse aggregate concrete								Conventional concrete							
			Slump (mm)	Compressive strength		Splitting tensile strength		Flexural strength		Modulus of elasticity (GPa)	Slump (mm)	Compressive strength		Splitting tensile strength		Flexural strength		Modulus of elasticity (GPa)
				Mean (MPa)	C.V	Mean (MPa)	C.V	Mean (MPa)	C.V			Mean (MPa)	C.V	Mean (MPa)	C.V	Mean (MPa)	C.V	
1	0.35	531	13	51.0	3.28	4.5	6.00	6.9	4.35	22.2	10	53.0	2.79	5.5	4.36	7.0	4.57	25.1
2	0.40	465	24	45.8	4.17	4.3	6.51	6.1	3.93	20.3	18	46.0	2.35	5.0	4.00	6.4	3.44	23.5
3	0.45	413	45	40.0	4.05	3.8	6.87	5.6	2.86	19.0	35	40.0	3.18	4.5	4.06	5.8	3.10	21.3
4	0.50	372	64	37.0	2.46	3.6	4.72	5.3	2.45	17.9	48	38.0	2.29	4.4	3.18	5.5	2.91	20.5
5	0.55	338	99	34.0	2.44	3.5	3.71	5.0	3.00	17.5	80	35.0	2.03	4.1	3.42	5.3	2.64	18.3
6	0.60	310	155	30.0	2.73	3.2	5.63	4.7	2.55	16.1	148	31.0	1.77	3.9	3.59	5.0	3.40	16.5

Note: C.V is Coefficient of variation.

Table 2. Differences in types of strength between ceramic waste aggregates concrete and conventional concrete. (Senthamarai & Manoharan, 2005)

Table 2 demonstrates that the greatest difference between the ceramic waste aggregate concrete and conventional concrete is the means of splitting tensile strength with different water content ratios. On average, the splitting tensile strength of ceramic waste aggregate concrete is 16% lower compared to the conventional concrete.

Ceramic waste is an effective addition for natural concrete aggregates. While it cannot fully replace natural aggregates, it can replace a portion of the aggregates needed while making concrete. In projects where splitting tensile strength is less of a factor, ceramic waste aggregates are a viable alternative to natural aggregates. The recommended replacement for ceramic waste is 20 percent. A drawback of using ceramic waste as aggregates is that there is a certain level of cleanliness necessary before usage. Ceramic waste should not contain dust, organic matter, or

excess clay. These factors prevent aggregates from adhering to the cement, reducing the strength of the concrete. These extra cleaning requirements are more time consuming. Currently, New York Codes, Rules, and Regulations (360.12, 360.13) states that concrete produced using ceramic waste as filler may be used under foundations and pavements above the seasonal highwater table, or for embankments or subgrade in transportation corridors, or on sites where site materials contain higher levels of contaminants than masonry filler (New York State Department of Environmental Conservation, n.d.). Under NYSDEC code 360.12, ceramic tiles are approved as aggregates in concrete as a beneficial use.

One way that New York City could use this in infrastructure is for foundations. There are thousands of construction sites throughout New York City at any given time. With the properties of a 20 percent replacement ceramic waste concrete being stronger in compressive, splitting tensile, and flexural strength, it can be readily used all throughout the city. Ceramic tiles being a beneficial use allows for the widespread use of ceramics as aggregates without needing preapproval.

### **Ceramic Tiles in Infrastructure Improvement:**

Due to their strong resistance to heat, fire, thermal degradation, ceramic tile waste could potentially be repurposed as highly effective protective linings and thermal barriers. Their insulating properties also make them effective in reducing fire damage and improving building safety, as they do not contribute to fire propagation. Traditional interior design often utilizes cheap and affordable composites, such as synthetic organic polymers, to achieve their objectives in providing aesthetics, comfort, storage, and functionality to residents. However, these plastics

tend to degrade with temperatures that exceed 100°C, while also releasing smoke and toxic fumes. This creates additional risks for occupants, reducing visibility, increasing toxicity, and impeding safe evacuation, as such materials contribute fuel to fire spread and growth. Ceramic tiles present a viable alternative to polymer materials, as they do not exhibit adverse fire-related behaviors. They will be able to resist temperatures much higher than those in which the plastics begin to fail, while still satisfying aesthetic requirements due to the long-standing use of ceramic tiles in decorative applications. Their use could potentially extend evacuation times and lower the risk of collapse due to structural damage during fire events.

One study found that, in structural ceramic brick, a composition of 35 percent clay and 65 percent foam concrete was able to reduce the thermal conductivity coefficient by 23 percent and to increase coefficient of constructive quality by 22 percent when compared to a composition that contained 70 percent clay and 30 percent sand (Maslennikova et al., 2020). While not directly sourced from ceramic waste, this composition of raw material ceramics raises new avenues for research into the possibility of converting already-used ceramic waste into structural concrete that provides insulation.

Repurposing ceramic tile waste for structural applications would require cutting or sizing the material for installation as wall, floor, or ceiling linings. The tiles would also need to be thoroughly cleaned to remove surface contaminants from prior use. Beyond these general preparation steps, the material would be required to undergo a series of standardized tests to verify its fire-resistance performance. This includes compliance with established standards such as ASTM E84 for surface flame spread characteristics and ASTM E136 for verification of non-combustibility. Further performance evaluations in thermal conductivity across elevated temperatures, specific heat capacity measurement to assess heat absorption behavior, and fire

exposure testing to confirm non-combustibility and structural stability would also be required to confirm the effectiveness of ceramic tile as a replacement for traditional materials.

Tests were conducted comparing the thermal properties in ceramic tiles to a variety of insulation materials such as spray-applied fire-resistive materials (SFRMs) and synthetic organic polymers (SOPs) which were observed in other studies (Naser & Thavarajah, 2021).

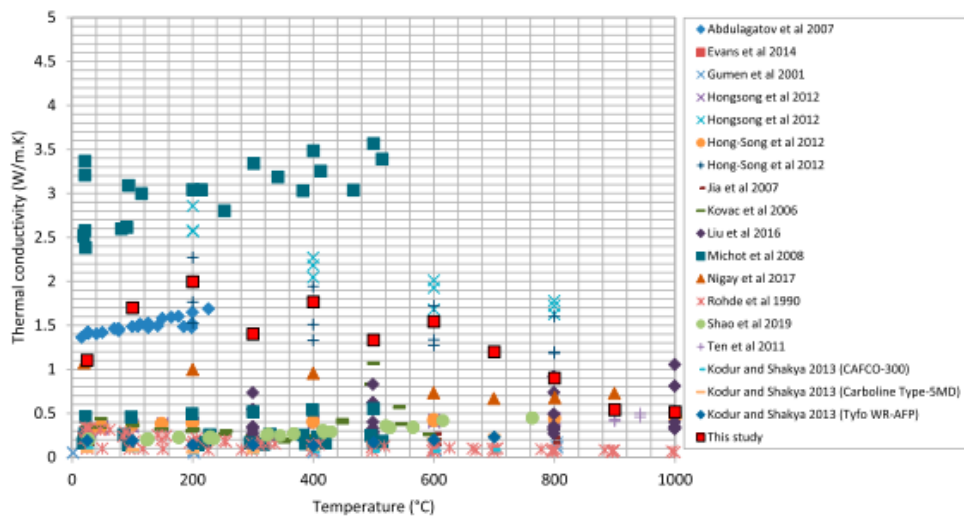


Figure 4. Thermal conductivity of ceramic tiles compared to other insulating materials. (Naser & Thavarajah, 2021)

Figure 4 indicates that ceramic tiles exhibit higher thermal conductivity than SOPs and SFRMs but it is only indicating the material's thermal properties as the temperature increases, not the direct function of the material at that temperature. It does not directly account for the fact that those materials also begin to fail once temperature exceeds 100°C, and that the material will no longer insulate as intended and will not provide reliable coverage. Although ceramic tiles

exhibit higher thermal conductivity than those materials, it is still superior to many others indicated on the graph. Additionally, ceramic tiles perform better in the aforementioned ASTM E136 non-combustibility test and ASTM E84 flame spread test compared to SOP materials. Under ASTM E136, materials are heated to 750 °C and assessed for non-combustibility based on their ability to limit temperature rise, prevent flame development, and avoid excessive mass loss, ensuring that the material does not contribute to fire growth. Ceramic tiles are able to pass due to their inorganic, thermally stable composition, while SOPs often fail due to their tendency to ignite or lose mass. Ceramic tiles are also able to pass the ASTM E84 tests while SOPs are not suitable for the testing methods as the plastic simply melts before the fire can take anywhere else. The results show that ceramic tiles have superior thermal properties to that of SOPs making it a suitable material for constructions as finishing or lining materials. Ceramic tiles also share the same characteristics of SFRMs, as they are both fire-resistive, but ceramic tiles are much more durable and do not decompose or undergo significant degradation under fire conditions, unlike SFRMS.

Despite their advantages, ceramic tiles also have some limitations when compared to other materials. Their higher thermal conductivity at ambient temperatures when compared to traditional insulation materials means that they are less effective for everyday heat retention, but would theoretically prove superior for extreme cases. Ceramic tiles can be reused if they do not need to be decontaminated upon use. The tiles should not leach harmful chemicals when exposed to high temperatures (New York State Department of Environmental Conservation, n.d.). There would be more time required to determine whether different ceramic tiles would be viable for fire resistance infrastructure. The study also acknowledges that the lack of expertise, standardized testing methods and equipment make it difficult to conduct studies of high-

temperature performance. Ceramic tiles may not be used as a beneficial use under code 360.12 as there is concern that due to high temperatures it may leach chemicals (New York State Department of Environmental Conservation, n.d.).

New York City responded to over 36,000 fires in 2024, with around 24,000 of them being structural fires. The first Uniform Fire Prevention and Building Code first took effect in 1984 (New York State Department of State, 2019). With over 85 percent of buildings being built before the 1980s, many of the buildings in New York City may not fully be up to fire codes (Koursaros, 2022). To protect from further damages of prehistoric buildings, the usage of ceramic tiles within the renovation of these buildings can prevent potential fire damage and save lives.

### **Ceramic Tiles in Alkali Activated Mortars:**

Ceramic tile waste is utilized as a replacement for natural fine aggregates (river sand) in alkali-activated mortars, which are cement-free binders produced using industrial by-products such as ground blast furnace slag (GBFS) and fly ash activated with alkaline solutions. The primary purpose is to reduce landfill disposal of ceramic waste, conserve natural aggregates, and lower the carbon footprint associated with conventional cement-based mortars, while maintaining adequate mechanical and durability performance. Ceramic tiles can have a higher strength in comparison to river sand as fine aggregates, due to its crystalline minerals.

Prior to incorporation into alkali-activated mortars, ceramic tile waste must undergo appropriate preprocessing to ensure performance and compliance with material standards. The waste tiles are crushed and sieved to meet ASTM C33 grading requirements, with particles

passing the 4.75 mm sieve and retained on the 75  $\mu\text{m}$  sieve. Physical characterization, including specific gravity and water absorption testing, is conducted to verify suitability as a fine aggregate replacement and to ensure consistency with conventional mortar mix designs.

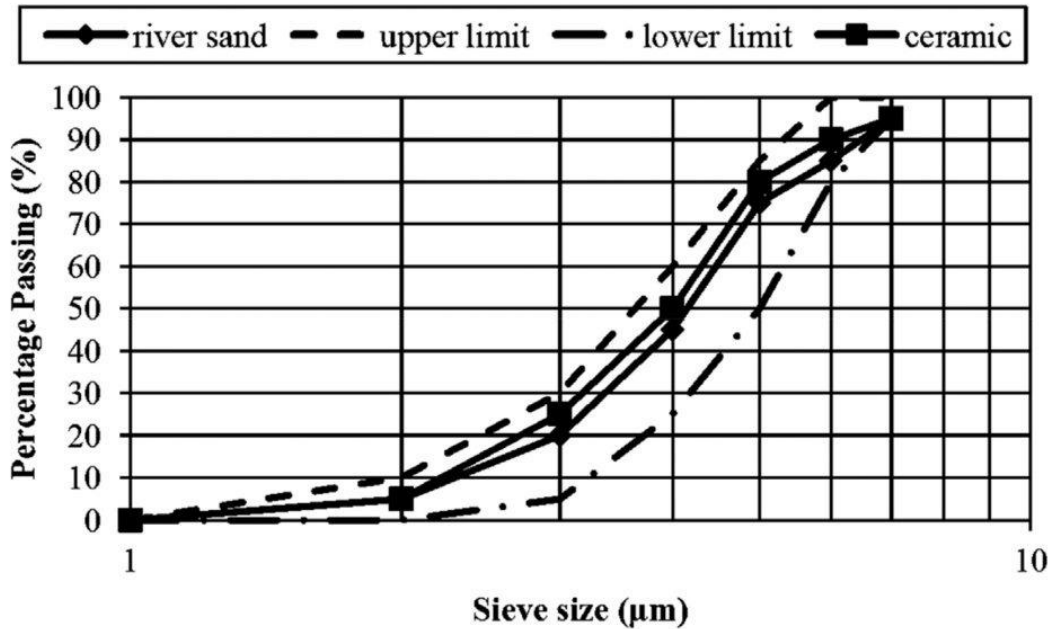


Figure 5. Sieve analysis of river sand and ceramic tile waste aggregates within the upper and lower limits of the ASTM C33 standard. (Altheeb, 2023.)

As shown in Figure 5, ceramic tile waste aggregate can be crushed and graded to be well within the ASTM C33 standards, which specify the quality and grading for the usage of both fine and coarse aggregate. Additionally it also is able to closely match that of river sand, a commonly used fine aggregate in mortars and concrete due to its well-rounded particle shape, consistent grading and chemical inertness, which all contribute to good workability, strong particle packing, and reliable mechanical performance. Its smooth surface texture reduces internal friction during mixing, allowing for easier placement and uniform distribution within the binder matrix.

Ceramic tile shares many similar properties to river sand as it is also hard, durable, and resistant to chemical, physical, and biological degradation, which supports good long-term durability in mortar systems.

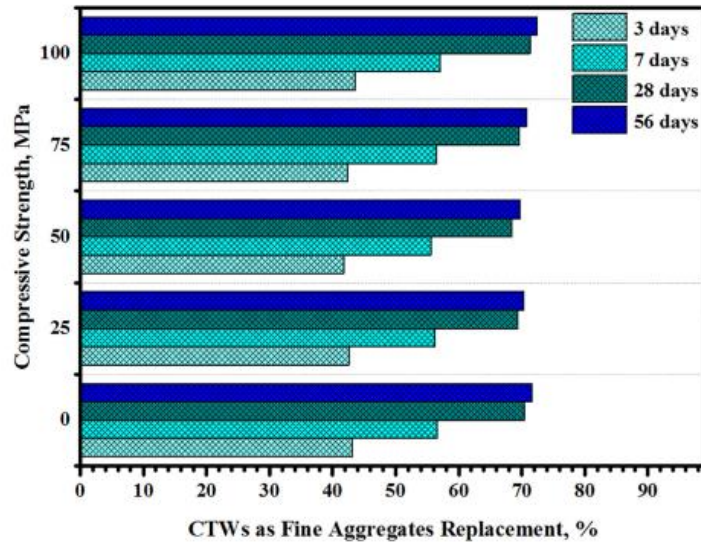


Figure 6. Ceramic tile waste aggregates' compressive strength over 3, 7, 28, & 56 days.

(Altheeb, 2023.)

Experimental results indicate that ceramic tile waste can replace natural river sand at replacement levels up to 100% without adversely affecting compressive strength (Figure 6). Mortars containing full ceramic tile waste replacement achieved strength values comparable to, and in some cases slightly higher than, those of control specimens made with natural aggregates. These findings demonstrate that properly processed ceramic tile waste can function effectively as a structural fine aggregate in alkali-activated mortar systems. The reuse of ceramic tile waste in alkali-activated mortars offers significant environmental and durability benefits. These include

reduced landfill disposal of ceramic waste, conservation of natural aggregate resources, and lower carbon emissions due to the elimination of Portland cement. In addition, mortars containing ceramic tile waste exhibited reduced water absorption and improved abrasion resistance when river sand was fully replaced, indicating favorable long-term durability performance.

Based on the study, ceramic tile waste can be effectively used as a full replacement for natural sand in alkali-activated mortars without significantly compromising compressive strength; however, several limitations must be considered. The performance of ceramic tile waste-containing mortars is strongly influenced by the binder composition, particularly the proportion of fly ash used. While ceramic tile waste itself exhibited comparable or slightly improved strength and abrasion resistance relative to natural sand, these benefits diminished when high levels of fly ash were incorporated. In such cases, the mortars showed increased porosity, reduced early-age strength, higher water absorption, and lower abrasion resistance due to slower geopolymerization and weaker bonding between the ceramic tile waste particles and the alkali-activated paste. These findings indicate that although ceramic tile waste is a viable and sustainable fine aggregate replacement, its successful application depends on careful optimization of the binder system to avoid durability and early-strength limitations. Under NYSDEC code 360.12, ceramic tiles would need to be approved for further use. The necessary addition of fly ash could help the approval of the application of ceramic tiles in mortars, as fly ash is one of the preapproved beneficial uses under code 360.13 (New York State Department of Environmental Conservation, n.d.).

New York City is composed of many brick and mortar establishments. Having an environmentally friendlier mortar can help the reduction of ceramic tile waste. With depleting

sources of river sand that can be used as fine aggregates, ceramic tile waste is an alternative that NYC can incorporate into more construction sites.

### **Ceramic Tiles in Sound Barriers:**

Due to ceramic tiles' porous nature, ceramic waste can be recycled as concrete aggregate for sound barriers. Sound barriers are typically porous concrete, using coarse aggregate to create many voids. These voids absorb energy through internal friction (Nelson, 1995). Noise barriers have conventionally been made with other waste materials such as rubber, metal shavings, plastic, and textiles. Using ceramics in noise barriers can prevent them from filling our landfills and to repurpose them. Ceramic waste was first sieved, then crushed to desired sizes. The ceramics were then mixed into Portland cement type II 32.5N, dried and cured for 28 days. 3 sizes of ceramic aggregates were used: fine, medium, and coarse aggregates. Using EN ISO 10534-2, the sound absorption coefficient ( $\alpha$ ) was determined for each sample. The compressive strength of each sample was also tested using ASTM-C39 standards.

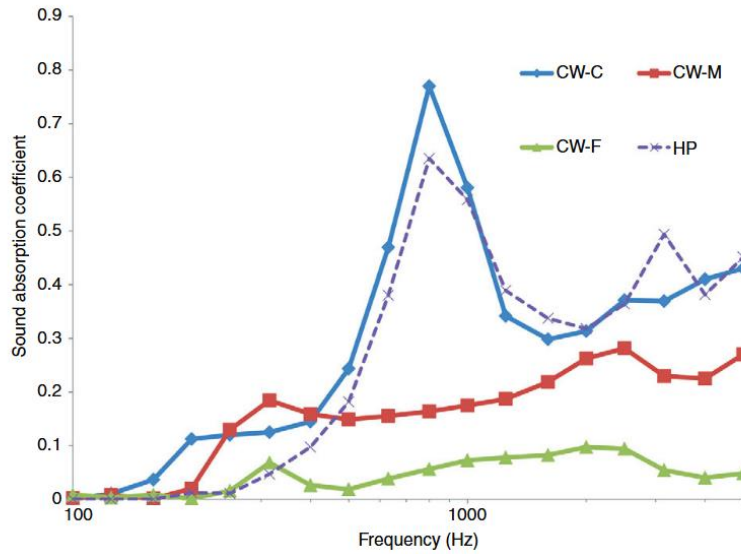


Figure 7. Sound absorption coefficients for each sample. (CW-C, coarse aggregate; CW-M, medium aggregate; CW-F, fine aggregate; and HP, control porous concrete)

(Arenas et al., 2016.)

Higher porosity, more void spaces, created the best results for sound absorption. In Figure 7, CW-C (coarse aggregate) had the highest sound absorption coefficient and outperformed the control sample. The CW-C sample had the highest absorption coefficient at approximately 800 Hz (Arenas et al., 2016.).

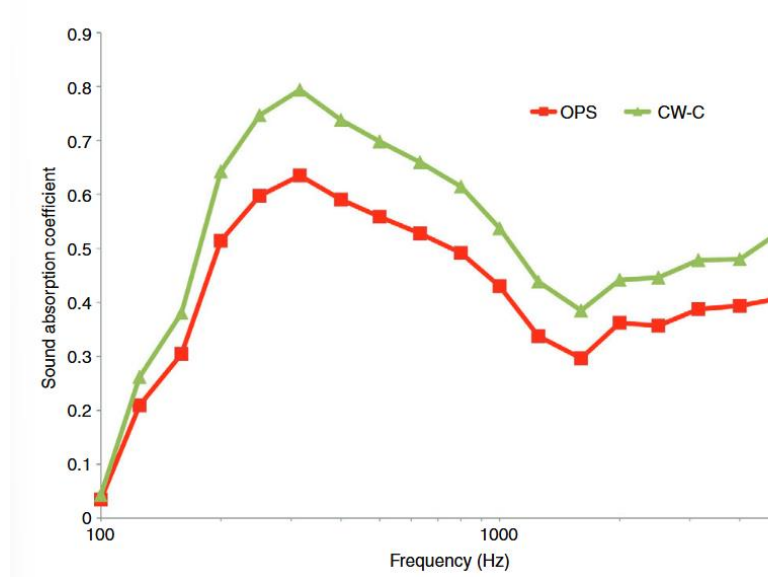


Figure 8. Sound absorption coefficient for CW-C (coarse aggregate) and OCS (optimal composite sample) (Arenas et al., 2016.)

The optimal composite sample is composed of all three sizes of aggregates, and performed poorer all across all frequencies. The OCS reduced the amount of void spaces from the aggregates and the cement, preventing it from being the best for sound absorption (Figure 8).

Overall, the CW-C sample was the most effective at absorbing sounds, specifically at sounds under 800 Hz. Most noise pollution is under 1000 Hz, which is the most difficult to eliminate (Arenas et al., 2016.). The recycling of the ceramic waste can prevent it from sitting in landfills being utilized. However, only one type of ceramic was used for testing. With many different compositions of ceramics, more testing must be done to test the usage of ceramics as aggregates in noise barriers. Under NYSDEC 360.12, ceramic waste is a predetermined additive into concrete (New York State Department of Environmental Conservation, n.d.).

With New York City being a large city, it means it comes with a significant amount of noise pollution. New York City is the second noisiest city globally. Noise pollution causes significant health issues to the city's residents. The implementation of these noise barriers along highways can reduce the amount of noise pollution around residential areas. With ceramic waste being approved as a concrete additive, it makes these sound barriers easier to implement throughout the city.

### **Ceramic Tiles in Soil Matrices:**

Soil stabilization is the process of increasing soil strength and durability for building purposes. Expansive soils are soils that have significant changes in volume with different water content. These can cause cracking in structures if structures are built on expansive soils.

In a study by *Onakunle et al. (2019)*, ceramics were collected from industrial and construction sites. It is then cleaned and crushed to a powder. The ceramic dust is then mixed into the soil with different percentages incorporated. It is then tested according to ASTM D1557 code to test its strength.

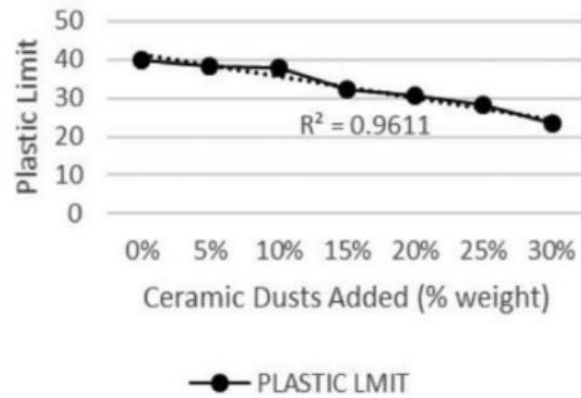


Figure 9. Plastic limit with ceramic dust added. (Onakunle et al., 2019)

The addition of ceramic waste reduced the plastic limit and liquid limit values. These contribute to the stability of the soil with the addition of ceramic dust. These soils are less likely to be affected by moisture differences and allow for more load to be carried.

Overall, up to 30 percent of ceramic dust can be used for soil stabilization in expansive soils. In areas where expansive soils are prevalent, this can be a viable addition to construction. This not only reduces ceramic waste, but also can make structures safer. However, the study by *Onakunle et al. (2019)* was only conducted on lateritic soil. Further testing would have to be required to determine its effectiveness in other places. These ceramics were taken from a construction site, and should go through a decontamination process. Because of this necessary step, under code 360.12, ceramic dust may not be used as a beneficial use option in soil matrices (New York State Department of Environmental Conservation, n.d.).

New York City is built on expansive soils. Regions such as the Bronx, Queens, and Brooklyn are subject to the effects of swelling every time it rains (Zavza Seal, 2025). The

incorporation of ceramic dust into foundations of homes and businesses can help reduce the amount of foundation damage that can occur from moisture.

### **NYC Context**

Ceramics, while not taking up a large proportion of New York City construction and demolition waste, are commonly used and flow through the city's waste stream. The Department of Sanitation estimates that, of C&D waste, 60% of fill materials and 40% of non-fill materials are currently being redirected for recycling.

While ceramic waste for reuse as aggregate is predetermined for beneficial use, reuse in alkali activated mortars is not specifically stated in subdivision 360.12. As a result, the latter is a candidate for case-specific BUD. Under current regulations, ceramic waste reuse in soil matrices and infrastructure improvement are not applicable for BUD. The table below expands upon the feedstock requirements and BUD status of each beneficial use option.

Beneficial Use Options	Feedstock Requirements	Part 360/BUD status (predetermined/case-specific /N.A./unclear)	BUD Sources
Concrete Coarse Aggregate	Ceramic Waste Must be: <ul style="list-style-type: none"> <li>• Unglazed</li> <li>• Greater than 4.75 mm in size (coarse aggregate specific)</li> </ul> (Senthamarai & Manoharan, 2005) (Bommisetty et al., 2019)	Ceramic waste is <i>predetermined</i> for incorporation into a concrete product under beneficial use.	360.12(c)(3)(xi)
Infrastructure Improvement	For Tile, Ceramic Waste Must be: <ul style="list-style-type: none"> <li>• Cut and sized for installation</li> <li>• Cleaned of contaminants</li> <li>• Compliant with ASTM E84 surface flame spread characteristics</li> <li>• Compliant with ASTM E136 verification of non-combustibility</li> </ul> For Structural Ceramic Brick: <ul style="list-style-type: none"> <li>• composition of 35 percent clay and 65 percent foam concrete</li> </ul> (Naser & Thavarajah, 2021) (Maslennikova et al., 2020)	Tile: Under current regulations, tiles sourced from ceramic waste are <i>Not Applicable</i> for BUD. Waste requiring decontamination and processing at the point of use may not be a candidate for case-specific BUD.  Structural Brick: The study Effective Building Ceramics for Transport Infrastructure done by Maslennikova et al.(2020) does not directly use ceramic waste to create structural ceramic brick. Thus, it is <i>unclear</i> whether the type of waste necessary to recreate this material would be a candidate for beneficial use.	360.12(d)(3)(iv).
Alkali Activated Mortars	Ceramic Waste Must be: <ul style="list-style-type: none"> <li>• Passing on 4.75 mm sieve and retained on 75 µm sieve</li> <li>• Consistent with conventional mortar mix designs in specific gravity and water absorption</li> </ul>	Reuse of ceramic waste in mortars is not directly identified in subdivision 360.12(c). However, it is possible to petition for a <i>case-specific</i> BUD under subdivision 360.12(d).	360.12(d)

	(Altheeb, 2023.)		
Sound Barriers	<p>Ceramic Waste Must be:</p> <ul style="list-style-type: none"> <li>Crushed into fine, medium, or coarse aggregate size (coarse aggregate found as optimal for sound absorption)</li> </ul> <p>(Arenas et al., 2016)</p>	Ceramic waste is <i>predetermined</i> for incorporation into concrete, under beneficial use.	360.12(c)(3)(xi)
Soil Matrices	<p>Ceramic Waste Must be:</p> <ul style="list-style-type: none"> <li>Pulverized for passability through sieve No. 200 (dust consistency)</li> <li>Cleaned of contaminants</li> </ul> <p>(Onakunle et al., 2019)</p>	Under current regulations, ceramic waste in soil matrices is <i>Not Applicable</i> for BUD. Waste that requires decontamination at the point of beneficial use may not be a candidate for case-specific BUD.	360.12(d)(3)(iv)

Table 3. Feedstock requirements and beneficial use determination status for reuse options.

As previously stated, NYCRR sections 360.12 and 360.13 declare that ceramic waste concrete may be used for pavements, embankments, subgrade and under foundations, or on sites where contamination is higher than that of the waste. Organizations such as the Hugo Neu Corporation and Sims Municipal Recycling Facility located in New York are committed to construction and demolition recycling and redirection for better use.

Ceramic construction and demolition waste that was not separated from other waste prior to processing is occasionally ground and used as alternative daily cover for landfills. However, it is debated whether this practice is considered recycling. There is no formal designation within New York for this practice to be considered recycling.

Unlike demolition, the practice of deconstruction focuses on meticulously dismantling structures and preserving materials so they can be reused with minimal damage. Organizations within New York City such as Rebuilding Together and Habitat for Humanity redistribute recycled building materials for housing. Examples of reconstruction within New York City include the New York City Fire Department preceded their partial demolition of a firehouse with the removal of sinks for resale.

Factors that discourage the implementation of widespread waste recycling include financial and physical limitations. An important component to C&D waste recycling, waste separation, is often difficult due to lack of physical space or lack of incentive to coordinate. As a result, most waste is generally collected as mixed material, which has limited use compared to separated materials.

Additionally, due to Wick's Law, which requires multiple independent contractors to work on construction projects that total \$500,000 or more, it can be difficult to coordinate reuse. On top of that, wage rates in New York City are typically higher than in most other areas, disincentivizing contractors from practicing labor intensive waste recovery due to its higher cost.

Factors that encourage processors and contractors to be waste recycling friendly include the possibility of waste being an untapped financial source. Due to an abundance of waste, an improvement in the rate of recycling will likely increase as processing sites improve their ability to advertise the waste. Additionally, as the burden on neighboring states to sustain New York City's waste grows, the incentive to recycle grows. As dumping grounds move further away, the cost of transportation increases, and receiving municipalities become increasingly displeased with receiving waste from far away (Gruzen Samton LLP with City Green Inc., 2003).

<b>Reuse Options</b>	<b>Benefits</b>	<b>Limitations</b>	<b>NYC Feasibility</b>
Concrete Coarse Aggregate	<ul style="list-style-type: none"> <li>- Increase in compressive, flexural, and splitting tensile strength with a 20% substitution of ceramic tile waste</li> <li>- Predetermined BUD in concrete</li> </ul>	<ul style="list-style-type: none"> <li>- Preprocessing is required: removal of debris; requiring more time</li> <li>- Increasing substitution of natural aggregates can decrease the strength of the concrete</li> </ul>	<ul style="list-style-type: none"> <li>- Can be widely used in buildings, roads, and foundations</li> <li>- Can be implemented in a short amount of time</li> </ul>
Infrastructure Improvement	<ul style="list-style-type: none"> <li>- Resist fire better than spray-applied fire-resistive materials and synthetic organic polymers</li> <li>- Does not melt under high temperatures</li> </ul>	<ul style="list-style-type: none"> <li>- Higher thermal conductivity; less effective insulators</li> <li>- Lack of standardization of testing fire resistant infrastructure</li> <li>- May not be a candidate for BUD as decontamination is required for use</li> </ul>	<ul style="list-style-type: none"> <li>- Could be difficult to implement into existing buildings; would require tearing up the walls</li> </ul>
Alkali Activated Mortars	<ul style="list-style-type: none"> <li>- Similar to river sand as fine aggregate</li> <li>- Reduces the amount of river sand used; preserving the limited quantity</li> </ul>	<ul style="list-style-type: none"> <li>- Only tested with the usage of fly ash; may not be viable without fly ash</li> <li>- Too much fly ash can negatively affect the mortars' properties</li> <li>- Needs a case-specific BUD</li> </ul>	<ul style="list-style-type: none"> <li>- Can only be implemented with the use of fly ash within the mortars</li> <li>- Can be widely used in roads or homes</li> </ul>
Sound Barriers	<ul style="list-style-type: none"> <li>- Can absorb sounds under 800 Hz; noise pollution under 1000 Hz being the most difficult to remove</li> <li>- Predetermined BUD in concrete</li> </ul>	<ul style="list-style-type: none"> <li>- Only one type of ceramic was used for testing; further testing is required</li> </ul>	<ul style="list-style-type: none"> <li>- Can be implemented in a short amount of time</li> <li>- Can eliminate noise pollution along highways more effectively</li> </ul>
Soil Matrices	<ul style="list-style-type: none"> <li>- Can reduce swelling in expansive soils; preventing cracking in structures</li> </ul>	<ul style="list-style-type: none"> <li>- Only tested on lateritic soil; further testing is required</li> <li>- May not be a candidate for BUD as decontamination is required for use</li> </ul>	<ul style="list-style-type: none"> <li>- Can benefit the areas that are prone to flooding</li> </ul>

Table 4. Benefits and limitations of reuse options.

## Conclusions

In this literature review, a number of reuse and repurposing methods have been introduced and could possibly be implemented within New York City after further testing. While traditional methods for recycling are difficult due to ceramics' material properties, New York City can use ceramic waste as concrete aggregates, soil stabilizers, infrastructure improvements, and for mortars.

The greatest limitations that hinder the implementation of ceramic waste beneficial use options include difficulties with contamination, potential adverse health effects in processing and implementation, and a financial burden on contractors and processing sites.

Due to their typical use in tiling, ceramic waste tends to contain secondary adhesive constituents. These impurities are difficult to remove, and may raise water demand in concrete and mortar mixes (Li et al., 2023). Additionally, ceramic waste reused as concrete aggregate benefits from deglazing prior to incorporation, which is difficult to perform on a large scale. The crushed aggregate itself often exhibits variability in surface area due to its brittle nature, which may contribute to inconsistent performance. (Akshahwany et al., 2024)

During the crushing or grinding process of ceramic waste for reuse purposes, heavy metals such as lead, cadmium, chromium, and nickel may be exposed to the surrounding environment. This increases the potential for soil and groundwater contamination. (Nyiramigisha et al., 2021).

On a financial level, implementing large-scale beneficial use options for ceramic waste requires a massive transition for both contractors and processing sites. This would likely disrupt

preexisting processing systems, and would thrust a large financial burden on all parties involved. Such a large change may not occur until greater financial incentives for ceramic waste reuse are implemented.

The most viable reuse options of ceramic tiles that could be effectively implemented in New York City would be in coarse concrete aggregates and in sound barriers. Both of these reuse options have the benefit of being a predetermined BUD, meaning it is easier to implement throughout the city as the NYSDEC has already preapproved its use within concrete. The sources of natural concrete aggregates are depleting and it is not renewable. These reuse options can decrease the overall amount of aggregates needed for the abundance of concrete used throughout New York City. With ceramic tile substitution producing even stronger concrete than natural aggregates alone, this is the most versatile option that can be implemented into construction. It is not limited to any specific use either. Despite the use of ceramic tiles in sound barriers being more limited, it still is a strong reuse option that the city could implement. With the increasing noise pollution throughout the city, more options should be available to help combat this growing problem.

In a dense urban environment such as New York City, we have a large construction industry with an abundance of waste. With our limited landfill space, New York City can reduce the environmental impact of ceramics using these new reuse methods and contribute to a more sustainable city.

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