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Glass waste as an alternative aggregate or binder in the production of cement artifacts

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ABSTRACT
This article aims to provide an overview of the current state of utilizing glass in the production of artifacts for civil construction. Specifically focusing on glass waste, existing literature presents numerous studies indicating the technical feasibility of incorporating glass into products used in the civil construction field, as discussed in the development of this material. This study conducted a comprehensive literature review to report the latest advancements in the post-use glass chain, primarily emphasizing reuse and integration into civil construction artifacts while discussing the advantages and disadvantages of this process. The reviewed works were sourced from databases such as Scielo, Science Direct, Periódicos Capes, etc. The utilization of glass waste in the production of civil construction artifacts holds great promise, as it allows for the substitution of a portion of both fine and coarse aggregates. Therefore, the incorporation of glass contributes to various aspects, particularly in addressing environmental concerns. The main observed factors that influence the physical and chemical characteristics include the particle size distribution of the glass, the quantity of glass used, and the moisture content of the mixture. The utilization of glass waste in different particle sizes demonstrates an increase in pozzolanic activity as the particle size decreases, with the physical properties of the resulting products being more significantly affected by particle size rather than the quantity of waste used in concrete or mortar.

KEYWORDS. Glass. Reuse. Cement artifacts.

1. INTRODUCTION

According to the European Federation of Glass Packaging Manufacturers (FEVE, in the Portuguese acronym), glass is not only a recyclable material but can also be reused without any loss of quality. For instance, returnable bottles can be used for up to 50 cycles before being melted and recycled into new refillable containers (FEVE, 2022). In Brazil, the Brazilian Association of Public Cleaning and Special Waste Companies (ABELPRE) reported that approximately 104,204 tons of glass were collected in 2019, with 52,000 tons being recycled and recovered in the country (ABELPRE, 2021).

According to Ferdous et al. (2021), global waste glass production is estimated to reach about 130 million tons annually. Recycling rates are estimated to be around 20%, indicating that the majority of glass ends up in landfills or other disposal sites (EPA, 2020; Ferdous et al., 2021; Lui et al., 2022). Fundação Verde states that glass has one of the longest decomposition times, estimated at around 5,000 years (FUNVERDE, 2022). However, glass also offers the potential for indefinite and 100% recycling (Ferdous et al., 2021).

Given these characteristics alone, the mere disposal of glass should be avoided. Glass possesses unique properties such as transparency, hardness, and thermal properties (Berneschi, Righini, Pelli, 2021), making it a special material that should be integrated into the circular economy. The incorporation of post-use glass into the production chain of new products, through reuse or recycling, contributes to various aspects, including the reduction of environmental impact, energy savings, and decreased reliance on raw material extraction (Lui et al., 2022; OgunDairo et al., 2019; Vettorato et al., 2021).

The utilization of solid waste in the chain of artifacts for civil construction shows promise, as it can replace a portion of the aggregates (Phutthimethakul, Kumpueng, Supakata, 2020; Júnior, Silva, Ribeiro, 2018).

2. DEVELOPMENT

2.1 Glass

Glass is a solid material primarily composed of silica or silicon dioxide, obtained through the cooling of molten inorganic substances like sand (silica), ash (sodium carbonate), limestone (calcium carbonate), and metallic oxides (iron, cobalt, manganese, nickel, aluminum, chromium, arsenic, barium, and others). It is an inorganic, homogeneous, amorphous substance that is inert and biologically inactive. Glass exhibits essential characteristics such as transparency, hardness, resistance, as well as thermal, optical, and acoustic properties. These qualities make glass a versatile material widely utilized in various industries and applications (ABRIVIDRO, 2019; Vettorato et al., 2021; Carrareto et al., 2011).

Glass is employed in different forms, including packaging (bottles, jars, flasks), flat glass (used for windows, cars, stoves, refrigerators), household glassware (glasses, plates, bowls), glass fibers (applied to insulation and reinforcement), and other applications such as lamps, medicine packaging, and ophthalmic glasses (Berneschi, Righini, Pelli, 2021; Carrareto et al., 2011).

Besides its common uses, glass finds applications in various fields such as health, communication, optics, and energy, thanks to its enduring physical and chemical properties (Berneschi, Righini, Pelli, 2021).

In addition to its versatility, glass can be recycled or reused. In the case of glass recycling, it can reenter the production chain to create new glass products, reducing the consumption of raw materials and energy, especially within the glass industry (Qi et al., 2019). Reuse can involve intact packages without being returned to the manufacturer (Coelho et al., 2020), or it can entail returning the package to the manufacturer for refilling the same type of product, such as soft drinks and beers (Boutros, Saba, Manneh, 2021). Glass can also be reused for the production of other products, with broken or crushed glass being incorporated, either replacing or supplementing other materials (Zhan et al., 2022; Souza-Dal Bó, Dal-Bó, Bernardin, 2021; Shishkin et al., 2021).

The global production volume of glass bottles and containers reached nearly 690 billion units in 2020, and it is projected to further increase by 2026, reaching 922 billion units. In 2018, glass containers accounted for approximately 45% of the total global glass production (Garside, 2022).

Japan, the United States, China, Germany, France, Italy, Spain, Belgium, and Portugal are among the largest glass producers worldwide. China, in particular, has experienced significant growth in this market due to high demand in the automotive sector and civil construction (Portal Virtuhab, 2022). In Brazil, the daily production of glass in 2021 was 7,530 tons, with 59% consisting of tempered glass, 23.7% mirror glass, 12.9% laminated glass, 3.8% top glass, and 0.5% insulated glass (Abrividro, 2022). According to the National Association of Collectors (ANCAT), approximately 55 thousand tons of glass were recycled in the same year, representing approximately 17% of the total generated glass (ANCAT, 2021).

2.2 Glass waste

Approximately 130 million tons of glass waste are generated worldwide each year, with only 21% being recycled, indicating a relatively low recycling rate despite glass being 100%

recyclable (Ferdous et al., 2021). Proper separation is crucial for effective recycling (PS Vidros, 2022).

The challenge of low glass waste recycling rates is not limited to underdeveloped countries. In the United States, over ten million tons of glass waste are produced annually, with around 60% ending up in landfills and less than 20% being recycled (Liu et al., 2022; EPA, 2020). The significant amount of glass waste disposed of in landfills and dumps emphasizes the urgent need for environmentally friendly and sustainable solutions (Cordeiro & Montel, 2015).

The production of goods stored in glass packaging (such as juices, extracts, etc.) or products containing glass components (such as electronic equipment, lamps, etc.) contributes to the substantial generation of glass waste. Since glass is non-biodegradable, improper disposal in landfills or the environment leads to environmental pollution (Liu et al., 2022). Increasing recycling rates would help reduce the improper disposal of glass waste and lessen the reliance on extracting new resources from nature (Ogundairo et al., 2019).

Furthermore, exploring the reuse potential of glass is crucial. Local reuse, as opposed to recycling, offers logistical benefits and cost reductions by facilitating reuse without the need for transportation to specific processing facilities. However, effective management of glass waste faces challenges such as proper segregation at the source and separate collection methods. Contaminated glass containing toxic elements requires special handling and treatment, adding to the costs of recycling and reuse. Despite these challenges, extensive research on glass reuse has demonstrated promising results (Brusatin et al., 2005; Chen et al., 2009; Mingfei et al., 2016; Calabrese et al., 2020; Idir et al., 2020).

In Hong Kong, glass waste has become a significant component of municipal solid waste. Although the majority is still discarded, approximately 10% of glass waste is reused as aggregates in civil construction (Lu & Poon, 2019). Limited collection points and low material prices are mentioned as reasons for the lack of further reuse.

As mentioned earlier, exploring new perspectives on recycling waste glass for sustainable civil infrastructure introduces the concept of reusing this waste. Studies have shown that the particle size and percentage of glass replacement have a significant impact on the compressive strength of concrete. Glass is being used to partially replace cement, and research indicates that incorporating glass waste can enhance compressive strength. Similarly, studies replacing fine or coarse aggregates with glass waste show varying effects on compressive strength, often linked to the size of the glass particles and the percentage of replacement (Guo Meng, Nassifi, 2020).

2.3 Reuse in New Products

The pursuit of environmentally friendly practices highlights the increasing demand for materials considered sustainable and high-performing in the construction industry (Oluwarotimi et al., 2019). As a result, numerous waste materials have been studied as raw materials, and glass is one of these wastes utilized in the production of various artifacts for construction purposes.

Studies on the incorporation of glass in ceramic formulations, for instance, aim to reduce firing temperatures while maintaining or enhancing the properties of the final product. According to Gol et al. (2021), the utilization of glass waste in the manufacturing of ceramic glazes led to a decrease in water absorption values for both transparent and matte glazes, along with an increase in heat resistance when incorporating 3% and 5% of glass waste in the mixture.

Furthermore, Souza-Dal Bó et al. (2021) observed positive effects in the preparation of a fused ceramic compound called ceramic frits, and in various ceramic glaze mixtures. These effects included increased resistance to chemical attack and the preservation of the ceramic glaze surface when in contact with sodium hypochlorite and hydrochloric acid, achieved through the use of 8-15% by mass of laminated glass waste.

In the production of synthetic clay aggregate, Oliveira et al. (2019) employed crushed glass (with a diameter smaller than 0.044 mm) as a reusable material, constituting 20% of the total mass. The authors found that this approach resulted in increased mechanical strength and bulk density, as well as a reduction in water absorption (2.8%) up to a temperature of 1,000 ºC (1,832 °F). However, at temperatures exceeding 1,000 ºC, water absorption increased (4.8%) due to the filling of voids caused by gas expansion during higher heating.

Trentin et al. (2020) conducted a study on the utilization of glass waste in mortar, partially replacing the fine aggregate at various percentages (10%, 15%, 25%, and 50%) at different curing times (7, 28, 63, and 91 days). The replacement of 50% of the fine aggregate with ground glass resulted in a notable 27.38% increase in compressive strength compared to the reference mixture. However, all glass-containing mortars exhibited high water absorption coefficients, leading the authors to discourage the use of these mortars for coatings.

In the work by Maier and Durham (2012), the incorporation of recycled cement aggregate and ground glass as substitutes for coarse and fine aggregates, respectively, yielded positive outcomes. The use of these materials, up to a 50% replacement ratio, showcased benefits in terms of strength and durability compared to conventional concrete made from virgin materials. Nevertheless, the authors noted drawbacks such as decreased workability, permeability, and strength of concrete when glass was added above the 50% threshold.

According to Letelier et al. (2019), the combined utilization of concrete and glass waste as a replacement for traditional Portland cement in mortar resulted in slower pozzolanic activity, indicating a delayed cement hardening process. However, the pozzolanic activity increased as the particle size of the glass waste decreased. In the case of glass powder with a maximum size of 38 µm, replacing 10% and 20% of the cement with glass powder maintained the compressive strength compared to traditional concrete. The authors further emphasized that the physical properties are more influenced by the particle size rather than the amount of waste material.

The utilization of crushed waste glass from fluorescent lamps as a substitute for fine aggregate in cement mortar yielded significant outcomes. The replacement of sand at various percentages (10%, 20%, 30%, and 40% in relation to the fine aggregate mass) improved workability, reduced drying shrinkage, and achieved a water absorption rate close to zero. However, the flexural and compressive strengths decreased as the content of glass residue increased in the mortar mixtures. Nonetheless, the overall findings of the study demonstrate the feasibility of replacing glass residue in cement mortar (LING; POON; 2017).

A study on the replacement of sand by glass shards as aggregates in 3D printing construction techniques (TIC3D) investigated substitution rates of 25%, 50%, 75%, and 100%. The results showed that the mixture of recycled glass shards with concrete is suitable for TIC3D applications, although the mix with 100% replacement of sand exhibited a 24.6% reduction in compressive strength compared to the original mix. The authors attribute this strength decrease to the lack of adhesion between the recycled glass particles and the binding matrix, caused by the higher water content added to the cement paste (TING; TAY; TAN; 2021).

Glass waste can be effectively reused in combination with other materials, such as red mud from bauxite refining and cement, to produce an eco-friendly geopolymer. This geopolymer can serve as a substitute for cement mortars, specific mineral products used in coatings, and fire- and heat-resistant adhesives, among others. Notably, the glass residue had a fine granulometry, with 90% of its grains being smaller than 21 µm, and a red mud/glass residue ratio of 1.5 (SILVEIRA et al., 2022).

In the production of concrete with recycled aggregate (CRA) with the inclusion of construction and demolition waste, Zhan et al. (2022) incorporated residual glass powder (RGP) and steel slag powder (SSP) in partial replacement of cement. The authors observed improvement in concrete due to the inclusion of RGP and SSP, with the results indicating that these two residues have a significant synergistic effect on improving performance in concrete. Moreover, CRA with the inclusion of 10% RGP and 20% SSP showed an increase in compressive strength at 28 and 120 days, 28.3% and 22.8%, respectively, in relation to conventional concrete. The granulometry of the RGP and SSP particles used in this research paper were smaller than that of cement.

Lee et al. (2018) conducted a performance evaluation of concrete incorporating glass powder and a finer-grade residue known as glass sludge, as a partial replacement for cement. The study revealed improvements in mechanical properties, microstructural characteristics, and durability of the concrete. When waste materials with fine granulometry were used as a partial replacement for cement in concrete production, it was observed that the concrete's strength at early ages was lower compared to traditional concrete. However, after 90 days, the strength of the waste-incorporated concrete surpassed that of conventional concrete. The authors emphasize that these findings contribute to sustainable development by utilizing waste materials and reducing production costs.

According to Costa, Almeida, and Moreira (2020), reusing glass from long neck bottles as a substitute for fine sand aggregate in concrete and mortar production yielded positive outcomes. The researchers investigated the incorporation of glass in 10%, 20%, and 30% of the fine aggregate mass. Compressive strength tests were conducted on specimens at 3, 7, and 28 days. The results demonstrated satisfactory strength improvements when a portion of the sand was replaced with ground glass. However, the presence of glass influenced the reduction of air content, making the compaction of concrete challenging. Furthermore, increased replacement of sand with ground glass reduced fluidity, hindering the workability of both concrete and mortar.

Oliveira et al. (2021) conducted an evaluation on the replacement of crushed stone with tempered glass in the production of concrete. The study involved replacing crushed stone with glass in varying proportions (0%, 10%, 20%, 50%, 70%, and 100%). The specific mass of the tempered glass was 2.5 kg/cm³, similar to that of crushed stone (2.7 kg/cm³), and the characteristic granulometry matched that of crushed stone. The findings showed that the replacement of crushed stone with glass resulted in reduced water retention and improved workability of the concrete compared to conventional concrete. The specific mass of the wet concrete and the compressive strength of the specimens did not exhibit significant variations across the different replacement percentages. Thus, the utilization of tempered glass waste as an aggregate replacement in concrete manufacturing yielded positive economic and ecological benefits, irrespective of the replacement percentage. However, the authors cautioned against its use for structural purposes.

In a separate study, Pazl and Santos (2019) explored the use of ground glass derived from crushed cachaça (known by the brand name "51") bottles and crushed long neck beer bottles as replacements for fine aggregate in concrete. The proportions of glass replacement were 5%, 15%, 25%, and 35%. The crushed glass exhibited a granulometry range similar to that of the fine aggregate, passing through a 4.8mm sieve and retained on a 0.075mm sieve. The results indicated that the concrete achieved a strength of 32.37 MPa, surpassing the minimum requirement set by standards (25 MPa) when the glass waste was replaced by up to 35%.

2.4 Glass in Concrete Blocks

The utilization of glass waste in the composition of concrete blocks can lead to various outcomes, including improvements in characteristics or indications of potential damage to the blocks. The following studies examine the variability of results associated with factors such as the type of aggregates replaced, replacement percentages, glass type and granulometry, age of block evaluation, and other relevant factors.

Carvalho (2021) demonstrated positive results in the production of concrete blocks by partially replacing sand with glass powder derived from waste long neck bottles. The replacement was performed at proportions of 0%, 10%, 20%, and 30%. The findings revealed an increase in compressive strength and a reduction in water absorption compared to the standard mix.

In a separate study, Grdic et al. (2021) incorporated discarded cathode ray tube glass (TV tubes) in the manufacturing process of concrete blocks. Glass was used as a replacement for sand, with replacement percentages reaching up to 50%. The glass particles were ground to a granulometry of 0.25 to 1.00 mm, matching the granulometry of the sand. The investigation indicated that the use of glass did not alter the apparent density, nor compromise the durability of the blocks against weathering. Furthermore, there was no increase in water absorption, nor any reduction in the strength of the concrete blocks.

In the study examining the combined utilization of sewage sludge ash (SSA) and recycled glass shards (GS) in the production of concrete blocks, it was observed that incorporating these residues into the concrete allowed for the replacement of up to 20% of cement while still achieving the recommended compressive strength at 28 days. Despite the increased water content in the mixture for cement hydration, the optimal content for the combined residues was determined as 20% SSA as a substitute for binder and 50% GS in the aggregates, both possessing granulometry smaller than 5 mm. Consequently, it becomes feasible to manufacture concrete blocks with a substantial GS content as aggregates and SSA serving as a complementary cement material, enabling the combined residues to account for approximately 39% of the block's weight compared to conventional materials. Hence, the combined utilization of SSA and GS yields durable mechanical properties in paving concrete blocks while contributing to the recycling of both types of solid waste (Chen, Li, & Poon, 2018).

As evident from previous studies, recycled glass can be effectively incorporated into dry and wet mix mortars for concrete block production. It allows for partial replacement of up to 30% of the cement mass with glass powder, featuring a granulometry of 48.3 µm. This research demonstrated positive outcomes concerning the control of alkali-silica-ASR reaction.

Additionally, glass can substitute sand in proportions of 0%, 50%, and 100%. The findings of this study indicated that the inclusion of glass powder as an additional material effectively mitigates the formation of gel caused by the silica-alkaline reaction in dry-mixed mortars. Moreover, higher replacements of cement and sand with glass powder resulted in reduced expansion due to the silica-alkaline-ASR reaction (Yang, Lu, & Poon, 2020).

Souza et al. (2017) conducted research on concrete blocks with added glass waste for paving applications. The study revealed positive outcomes in terms of compressive strength and water absorption when 25% of the sand was replaced in comparison to the standard mix. The blocks exhibited an average compressive strength of 35.28 MPa and water absorption of 5.11%, both complying with the limits set by the NBR 9781 standard.

Costa and Arruda (2017) emphasized the satisfactory compressive strength results achieved in concrete blocks for sealing and paving components. These blocks were produced using glass waste and recycled civil construction waste (RCC) as aggregates, completely replacing sand. The compressive strength reached 3.7 MPa, meeting the recommendations of Brazilian standards NBR 6136:2016 and NBR 12118:2014 (ABNT, 2014; ABNT, 2010). However, the water absorption test indicated that the blocks did not meet the maximum value specified by the aforementioned standards, with an increase in water absorption as the amount of glass powder replacement increased.

In a study investigating the addition of vitreous residues as fines in interlocking concrete blocks, Gonzaga et al. (2019) obtained satisfactory results. By replacing 5%, 10%, and 20% of the cement with ground glass powder, they achieved varied interlocking blocks with compressive strengths equal to or greater than 35 MPa. The authors noted that incorporating up to 20% of glass powder produced blocks that closely approached the ideal in terms of resistance and water absorption, with values ranging from 4.61% to 5.32%, meeting the standards specified in the regulations.

2.5 Materials and Their Reactions

The chemical composition of waste glass, as indicated by studies, consists of various components within specific percentage ranges. These include silicon dioxide (SiO_2) at 70 to 75%, calcium oxide (CaO) at 8 to 10%, aluminum oxide (Al_2O_3) at 1 to 3%, magnesium oxide (MgO) at 1.5 to 3%, sodium superoxide (NaO_2) at 0 to 15%, and iron oxide (Fe_2O_3) at 0.5 to 1%. The presence of SiO_2 in glass waste, which lacks a regular and crystallized shape, plays a significant role in its reaction with lime, resulting in the formation of calcium silicates. This reaction contributes to the agglomeration effect in cement, leading to improved performance of concrete, particularly in terms of hydration and strength development (Dhir, Dyer, & Tang, 2009; Rahma, El Naber, & Issa Ismail, 2017; Arabi et al., 2019).

The chemical composition of different glass wastes reveals significant amounts of silicon, calcium, and an amorphous structure. Glass has the potential to act as a pozzolanic or even cement material. Initial studies indicate that glass can be used as a raw material in cement production without any detrimental effects on its physical and chemical properties (Omran & Tagnit-Hamou, 2016; Jiang et al., 2022).

The mechanical performance and durability of materials obtained by replacing cement with glass waste are mainly dependent on particle size and the percentage of replacement. Studies suggest that fine particles of glass residue contribute to enhanced mechanical performance and durability. For achieving high strength, it is recommended to use glass particles smaller than 100 µm, as a decrease in mechanical performance has been observed with larger particle sizes (Jani & Hogland, 2014; Ahmad et al., 2022).

During the production of mortar or concrete, various reactions occur between the materials used, including the hydration reaction of cement with aggregates. However, depending on the mineralogical composition of the materials, other reactions may take place, which can have either positive or negative effects on the final product. One example is the alkali-aggregate reaction (AAR), encompassing alkali-silicate, alkali-carbonate, and alkali-silica reactions. Among them, the alkali-silica reaction (ASR) involves the reaction of alkaline ions (Na+ and K+) present in the concrete solution with silica in certain aggregates. ASR is considered a significant cause of concrete deterioration, leading to the formation of an expandable gel that induces internal stress and cracking (Andrade, 1997; Gillott, 1975; Hobbs, 1988; Xi et al., 2019).

According to Tinoco and Junior (2018), ASR occurs when aggregates, whether coarse or fine, possess a higher degree of reactivity and come into contact with alkali ions released by the cement, such as sodium oxide (Na2O) or potassium oxide (K2O). When the mineralogical constituents of the aggregates interact with alkalis, a hygroscopic gel is formed, which expands in the presence of moisture. This expansion has negative effects, including cracking, fragmentation, and other forms of deterioration, compromising the load-bearing capacity of the concrete (Islam & Ghafoori, 2013).

ASR is recognized as the most prevalent reaction in Brazil and one of the most harmful mechanisms affecting concrete durability. These reactions occur rapidly due to the involvement of reactive mineral forms (Souza, Zolett, & Carrazedo, 2016; Langaro et al., 2021).

Considering the nature of glass, its incorporation into cement-based materials has been associated with potential pathologies resulting from unwanted chemical reactions during cement hydration, such as the alkali-silica reaction mentioned earlier (Pazl & Santos, 2019). As a result, the alkali-silica reaction may limit the practical applications of recycled glass aggregates in concrete. However, it has been discovered that the expansion caused by the alkali-silica reaction of glass aggregates in mortars can be reduced by working with wetter mortar mixes (Yang, Lu, & Poon, 2020).

Moreover, Tinoco and Júnior (2018) suggested that the occurrence of ASR can be mitigated by correcting the concrete mixture during its preparation using neutralizing materials such as blast furnace slag containing pozzolanic materials and silica fume, among others. Certain types of cement, such as CP II E, CP II Z, CP III, and CP IV, which incorporate pozzolans and silica fume, also yield safe results with reduced chances of AAR occurrence. Various authors have demonstrated the effectiveness of controlling ASR through the use of appropriate materials, including the partial replacement of cement with pozzolans like fly ash, slag, and others (Souza, Zolett, & Carrazedo, 2016; Langaro et al., 2021).

According to Frias (2021), glass waste derived from bottles, windshields, and fluorescent lamps can exhibit long-term mechanical resistance equal to or greater than that of a reference matrix with 0% glass waste when replacing cement up to 20%. However, in the short term, glass waste with high sodium content (Na2O) ranging from 9% to 15% may induce AAR (Shao et al., 2000; Elaqra & Rustom, 2018; Liu, Florea, & Brouwers, 2018). To combat the effects of AAR, glass with a very fine particle size, smaller than 300 µm, is employed as a partial replacement for cement to ensure that the gel formed due to ASR is non-expansive (Matos, Sousa-Coutinho, 2012; Zheng, 2016; Cai, Xuan, & Poon, 2019).

Therefore, by making the necessary adjustments, it is feasible to utilize glass waste in the production of cement-based products, thereby avoiding or reducing its simple disposal and promoting local or regional collection and reuse networks. Table 1 provides an overview of several studies focusing on the use of glass waste in mortar and concrete applications.

While there is a substantial body of research on the utilization of glass waste in cementitious materials, there are relatively few studies specifically focusing on the production of dry concrete blocks. The presented studies, however, demonstrate the technical feasibility of incorporating glass as a replacement for aggregates or even cement, highlighting its potential from a circular economy perspective. Concrete is widely produced in many cities, and the local reuse of glass presents a realistic opportunity with lower logistics costs.

Source	Artifact type	Feature of the glass	Substituted fraction and granulometry	Percentage	Main results	Assumptions
Ortega et al., 2018	Mortar	Municipal recycling containers	Cement by glass powder at 10 nm to 0.1 mm	0, 10 and 20%	Compressive strength increased from 28 to 200 days in the studied mortars.	The increase in compressive strength may be related to the continuous decrease of voids in mortars.
Rahman; Uddin, 2018	Concrete	Discarded glass bottles	Cement by glass powder smaller than 0.075 mm	0, 10, 20 and 30%	Feasibility in replacement of only 20%, having a lower resistance to initial compression in relation to the standard mix, but reaching 2.03 MPa at 28 days, while the standard mix reached 1.96 MPa.	This increase in compressive strength when replacing 20% of cement with glass powder with this granulometry may be associated with the pozzolanic effect, also contributing to the reduction of alkali-silica reactions.
Natarajan et al., 2020	Concrete	Glass bottles discarded in landfills.	Sand per glass powder at 0.075 to 2 mm.	0, 10, 20 and 30%	Greater compressive strength in the glass tests than the standard mix at 28 days.	The replacement of fines by up to 30% may have contributed to the functionality of the concrete, which increased proportionally with the increase in the glass dust content.
Abdulazeez et al., 2020	Concrete	Glass from different beverage bottles	Cement by glass powder at 75 µm	0, 5, 7.5, 10, 12.5, 15 and 20%	The compressive strength increased, with up to 10% of replacement of glass powder, reaching the minimum value predicted in the standards, but decreasing workability and water absorption.	Due to its pozzolanic characteristics, glass powder in the replacement of 10%, made it possible to produce a very resistant concrete.
Tamanna and Tuladhar, 2020	Concrete	Mixed color glasses	Cement by glass powder at 45 µm	0, 10, 20 and 30%	Research has shown that the use of glass powder as a cement substitute is feasible for substitution levels of up to 10%.	With the replacement of glass powder, the concrete did not show resistance gains at initial ages due to the delay in the pozzolanic reaction, but later reached the characteristic resistance of 32 MPa at 28 days, with less water absorption.
Arivalagan and Sethuraman, 2021	Concrete	Mixed glass waste	Sand per glass powder at 0.15 to 2.36 mm	0, 10, 20 and 30%	Compressive strength within standards, with replacements of	The particle size distribution of fine aggregate of glass waste powder contributed to strength, however,

					up to 20%.	decreasing the workability of the concrete.
Zanwar and Partil, 2021	Concrete	Grouping of glass, beverage bottles	Cement by glass powder at 75 µm	0, 10, 20 and 30%	In up to 20% of glass waste inclusion, there was an increase of 12.5% in compressive strength compared to standard concrete, however, the workability and water absorption of the concrete decreased.	The incorporation of glass powder in cement paste reduces the presence of pores, thereby influencing the overall properties of the concrete. However, it should be noted that the finer nature of glass powder compared to cement leads to a decrease in workability. This is primarily due to its larger surface area, resulting in a reduced water demand as the pores close more rapidly. Additionally, the inclusion of glass powder contributes to lower water absorption in the concrete.
Zeybek et al., 2022	Concrete	Various types of soda bottles.	Cement per glass at 0.1 to 0.2 mm. Fine aggregate per glass from 1.7 to 4 mm. Coarse aggregate from 5 to 12 mm.	Cement per glass: 10, 20, 30, 40 and 50%. Fine and coarse aggregates: 10, 20 and 30%.	The replacement of up to 20% of the cement by glass powder and 30% of fine and coarse aggregate by glass waste was considered positive, within the standard standards.	It was concluded that when glass waste was used in partial replacement of cement, fine and coarse aggregate, there were significant increases in strength, but above 30% there was a decrease in workability in concrete and in strength.
Jiang et al., 2022	Concrete	Common glass containers	Cement by glass powder at 18.21 µm	0, 10, 20 and 30%	There was a decrease in compressive strength in the percentages replaced at room temperature and an increase in compressive strength at temperatures from 800 ºC to 1,000 ºC (1472 to 1832 °F).	This increase may be linked to the unreacted glass powder particles that melted after exposure to temperatures of 800 °C (1472 °F) and filled the pores of the cement paste matrix, making the matrix denser and more homogeneous, increasing resistance.
Malbila et al., 2022	Concrete	Glass from various beverage bottles	Cement by glass powder at 80 µm	0, 10, 20%	Compressive strength increased with up to 20% replacement of glass powder, reaching the norm but decreasing workability and water absorption.	Glass powder plays a significant role in shaping the physical and mechanical properties of concrete. It gradually attains the desired compressive strength within 28 days, thanks to the pozzolanic nature of the glass powder.

						However, it is worth noting that when the glass powder is used to replace more than 20% of the conventional ingredients, it tends to reduce the workability of the concrete and increases its water absorption capacity.

On the other hand, there is a need for improvements in the crushing and handling of glass. The process of obtaining ground or crushed glass requires a significant amount of energy, specialized equipment, and careful consideration for environmental and occupational health and safety.

Therefore, it is evident that further studies and advancements in equipment and techniques are necessary to achieve the required granulometry of glass efficiently in order to maximize the utilization of waste glass in the post-use glass chain.

3. CONCLUSION

The use of glass waste as a replacement for cement, coarse aggregates, fine aggregates, or other materials is not only possible but also technically feasible in the production of civil construction artifacts, with a primary focus on compressive strength and water absorption.

Several key factors were identified as influencing the physical and chemical characteristics of the resulting materials. These factors include the granulometry of the glass, the quantity of glass utilized, and the moisture content of the mixture. It was observed that the pozzolanic activity increases as the particle size of the glass decreases. Additionally, the physical properties of the final products are more affected by the particle size rather than the quantity of waste used in the concrete or mortar. It is worth noting that larger particle sizes of the glass residue negatively impact the workability of concrete and, consequently, its overall strength.

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