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Review

An overview on the hazards and handling methods of construction and demolition wastes: Special focus on recycled concrete aggregates

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ABSTRACT

With the demand increased in construction activities within the last century, several scientific research studies have been focusing on different aspects of construction and demolishing wastes, while considering the severity of environmental problems that they cause. This work presents the results of out an extensive literature survey in order to provide an overview on the hazards and handling methods of construction and demolishing wastes. Results of this literature review indicate that landfilling has been the most commonly used method, even though the recycling of the construction and demolishing wastes was found out to be the most environmentally-friendly solution. It was observed that groundwater and soil may be heavily affected by the leaching constituents of landfilled construction wastes. On the other hand, using these wastes in the form of recycled concrete aggregates was observed to eliminate these hazards. The results of literature survey pointed out that the use of demolished concrete wastes as recycled concrete aggregates could be widely adopted by construction sector only if the resulting concrete is of satisfactory quality. Hence, information on different quality aspects of concrete made of recycled concrete aggregates are presented systematically as a clear guide in this work, to verify its feasibility as an environment-friendly waste elimination method.

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1. Introduction

The change in the life of modern society yielded various types of wastes that affect the nature in different scales if not managed adequately. Several studies in the previous literature had investigated the effects of varying wastes on the nature in general as well as on ground water specifically (Özkarova et al. 2019; Ahmed et al. 2019; Rezende et al. 2019). Besides numerous waste types and sources, construction and demolishing wastes have also observed to be increased as a direct result of the significant increase of population worldwide from 1.5 billion up to 7.5 billion within this century (Xiao 2018). The increase of world population leads to higher demand of certain types of structures made up with varying construction materials. This increase in the construction activities also lead to an increase in demolition processes; hence generation of higher quantities of construction and demolition (C&D) wastes has been inevitable. With its continuously increasing quantities, C&D wastes and their consequent environmental hazards has become a significant problem worldwide (Alakara et al. 2022).

In certain developing countries, C&D wastes can unfortunately be disposed even directly on the ground in a totally unregulated and uncontrolled manner. Fig. 1 illustrates such an inappropriate disposal of construction and demolition wastes that was done in a developing country, possibly in an illegal way; avoiding the control of local authorities.

Figs. 1(a-b) provide a common example and a visual evidence of the possible variety and the mixed nature of construction and demolishing wastes. This fact makes environmental problem caused by C&D wastes a complex one; requiring a thorough understanding of its components, and their individual effects on nature before concluding on the optimum way the manage them.

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Fig. 1. Uncontrolled disposal of varying types of construction and demolition wastes in nature: (a) Plastics and tiles; (b) Asphalt and concrete.

1.1. Factors affecting C&D waste generation

Construction materials vary according to the countries that they are produced and to the construction traditions that they may have. In the USA, timber is a very conventional construction material; while in the UK for example, brick is used very widely. All construction materials have life cycle; first their raw materials are quarried from natural sources to in order to manufacture the exact construction material with the desired qualities to be used in the construction industry.

It is a matter of time until the structures made up of these produced construction materials have to be removed due to various reasons. Reaching the end of their designed lifetimes, any premature performance failure, or sometimes the demands to construct more modern structures could be the reasons for demolishing these structures and hence, construction and demolishing wastes are generated.

A noteworthy study published in 2023 presented the data on the estimated construction and demolishing wastes quantities worldwide and reported that EU generates more than 820 million of tons of annually (Soto-Paz et al., 2023). Among EU countries, France and Germany are observed to generate the highest C&D wastes quantities with the reported estimated values of 246 and 200 million of tons annually. Other significant waste quantities are reported for United States and China, being as 534 and 1130 million tons annually, respectively (Soto-Paz et al., 2023).

Additionally, numerous studies have been carried out previously in order to determine the type and the quantities produced by different countries. The results of these studies are for sure critical for the process of determining the optimum waste disposal and management methods, taking in to consideration of both environmental and economic aspects, that would cover the needs of the countries of concern (Martinez et al. 2010; Li et al. 2019).

In their study, Pellegrino and Faleschini (2016) have reported the annual construction and demolition waste quantities produced in various European countries with a remark on the year of their inclusion to European Union (EU). Their data indicated that the countries that have been included to EU at earlier ages are generating higher quantities of construction and demolishing wastes, when they are compared to other countries which have been included to EU more recently.

This finding could be due to the economic growth reached by elder European countries that might have reflected to their construction activities as well. However, it should be considered that the population of each country and hence, the total demand for construction activities, also are expected to play a great role on the exact quantity of the annual construction and demolition waste generation resulted.

Hence, each country may need to study the problem to a different extent; considering the type of waste generated and the total generated quantities of waste in order to determine the magnitude of the threat posed to their local environment, as well as the protective measurements and waste handling strategies.

1.2. C&D wastes as a source of hazardous materials

Previous studies focusing on the hazardous materials coming from construction and demolition wastes were observed to report leachate information mainly for a variety of mixed waste types such as; a mixture of concrete, asphalt, wood, plastic, glass, paintings, sealing agents etc. Hence, it is typical to see a list of concentration of these aforementioned elements together for a given waste case.

Previous studies report that construction and demolition wastes cause contamination by releasing hazardous materials such as heavy metals like Arsenic (As), Lead (Pb), Cadmium (Cd), Chromium (Cr), Copper (Cu), Mercury (Hg), Nickel (Ni), Zinc (Zn), Calcium (Ca), Magnesium (Mg), And Antimony (Sb); Also, Chloride (Cl), Fluoride (F), Sulphate (SO4), and phenol (Galvin et al. 2012; Butera et al. 2014).

The related literature also reports regulations that specify the allowed concentration limits of these mentioned potentially hazardous materials in the landfill leachates (EU Council 2003). Exceeding these limits in such a case of waste disposal is regarded as a potential threat to environmental balances in general.

In general, a lack of detailed information on the individual leachate results for each type of wastes; that would serve to identify the exact impact of that type of waste only to environment. On the other hand, concrete which is a very popular construction material is observed to be studied with an additional focus in the related literature, unlike many other construction materials that may end up being wastes. In these specific studies, concrete leachate is reported to lead to release of various materials like chloride, sulphate, and mainly calcium hydroxide in the soil. The effects of calcium hydroxide and other concrete leachates on nature will be discussed in further detail in the following sections.

2. C&D Wastes Handling and Management Methods

Numerous studies have been carried out in order to determine the optimum C&D wastes management method within three commonly used C&D waste management methods. The commonly used methods for managing construction and demolishing wastes are known as landfilling, incineration, and recycling. The efficiency of the waste management methods was discussed in these studies based on criteria such as cost reduction for both transportation and raw materials, and reducing the impact of the construction and demolition wastes on the environment. Fundamental information about these three C&D waste handling methods are presented in the below subsections.

2.1. Landfilling as a handling method for C&D wastes and consequent hazards

This method could be considered as the simplest, but not necessarily the most efficient, method among others. Landfilling is a waste disposal method where wastes are buried within the ground. As the wastes seemingly disappear, this method became popular and widely used especially in certain countries.

Landfilling is done by initially excavating destination location and in the bottom of the cavity formed at that location leachate collecting mechanism installed, and then filling with waste and cover the cavity with installation of gas vent It is known that by landfilling method of waste management, the adverse impacts of waste leachate on environment cannot be avoided fully. Landfills are expected to be designed to not to have a negative impact on the surrounding environment; yet, they still do, as reported in studies (Malek and Shaaban 2018). Landfilling activities are known to cause negative effects especially on the quality of soil and groundwater. This impact is caused mainly by leaching of hazardous materials from landfilled materials such as concrete, asphalt, wood, gypsum drywalls that are common C&D wastes, yielding a source of heavy metals and other chemicals permeate to soil (Plaza et al. 2017; Saxe et al. 2007).

After construction and demolition wastes are disposed into landfills, they will be exposed to the certain surrounding environmental factors. Water presence and percolation mainly causes leachate of the waste compositions. When it rains the rainfall permeate through the cover layer of the landfill, reaching the debris beneath. Rainfall water will react with materials of the debris causing these materials to leach into soil and then carrying them to groundwater. Hence, groundwater, which is a vital source for human activities, would also be contaminated eventually with these hazardous materials. Evidently this would cause negative effects on drinking water sources, as well as on agricultural activities and on the obtained crop qualities (Di Palma and Mecozzi 2010; Powel et al. 2015).

In their work, Powel et al. (2015) studied the effect of leachate minerals from construction and demolition waste landfills from 91 landfilling sites in Florida, USA, which contained wood, concrete and gypsum drywalls, on the quality of up-gradient and downgradient groundwater. Results obtained from the analysis of samples collected semi-annually for 10 years from these landfill sites showed that various materials like dissolved solids of sulphate, chloride, iron, ammonia-nitrogen and aluminum exceeded allowed concentration limits in groundwater and therefore, posed a threat on the surrounding nature and human activities around.

A study in Algeria took place in order to assess the impact of demolition debris buried 5 years ago on the quality of groundwater. The soil beneath the landfilling site was Marly-Calcareous with permeability of (10^{-2} m sec^{-1} to around 10^{-6} m sec^{-1}). Analysis of leachate results from the landfill site showed high Chemical Oxygen Demand “COD” (1136 mg/L O^2) and Biological Oxygen Demand “BOD5” (200 mg/L O_2). COD is a parameter indicating the measure of pollutants in water and deleterious wastes in aqueous form (Hu and Grasso 2005). Higher quantities of COD detected in water is reported to lead further negative environmental impacts (Hach 2023). Being another importer water quality parameter, BOD is known to facilitate the assessment of the effect of discharged waste water on the environment exposed to the wastes (Real Tech 2017); hence, higher BOD implies increased effects on the environment. Furthermore, leachate in this mentioned study showed pH value of 7.65 with heavy metals concentrations beyond national limits except for Zinc (Zn). For groundwater, three wells in the parameter of the landfill were considered as piezometers. Analyzing of the quality of water in these piezometers showed a pH value of 6.88; while for heavy metals concentrations were acceptable except for Zinc (Zn) with (0.779 mg/L). Also, a bacterial contamination was found in the groundwater by total coliforms (1100/100 mL) (Benmenni and Bemrachedi 2010).

Construction and demolition wastes debris can also cause emission of hydrogen sulide H_2S sourced from gypsum drywalls debris. H_2S has a serious effect on public health including eyes problems as well as cases coma if one is exposed to high concentrations (Lim et al. 2016). When debris is exposed to water such as rain from environment surrounding landfill, calcium and sulphate are released. With no presence of free oxygen, sulphate-reducing bacteria produces hydrogen sulphide H_2S that is released into the surrounding atmosphere causing harmful effect on the surrounding environment and residents (Lim et al. 2016).

Buildings wastes occupy 20–40% of cities' waste, and carbon dioxide emissions produced were 7% of the total CO_2 emissions which has a major role in global warming (Xiao 2018).

Debris leachate causes mobilization of various metals such as iron, manganese, nickel, and arsenic could lead to change of characterizations of soil due to alteration of the equilibrium within. Furthermore, metals could mobilize from soil to groundwater in the surrounding environment of a construction and demolition waste landfill. Metal mobilization is toxic and causes soil to be unsuitable for agricultural activities.

Also, when groundwater shows high concentrations of hazardous metals, this causes serious problems to public health and agricultural activities depending on such water sources (Di Palma and Mecozzi 2010; Wang et al. 2012; Hartwich and Vollpracht 2017).

A six-months study on C&D wastes landfills was made by Weber et al. (Weber et al.2002), which reported concentrations of soluble ions in the leachate like calcium and sulphate were predominant ions. Also, for heavy metals, it was showed that metals like arsenic, aluminum, copper, manganese, and iron were found. Arsenic concentrations exceeded the primary water quality limits. The greater impact in the secondary standards was recorded by manganese followed by iron, concluding that the problem is that generally C&D wastes landfills are unlined, unlike Municipal Solid Waste "MSW" landfills.

Moreover, when construction and demolition waste debris containing masonry and partially carbonated concrete, it was reported to have leaching of sulphate and chlorides, which have an effect on pH level of the soil and groundwater in the surrounding environment. This variation of pH level also leads to deplete agricultural properties of soil and properties of groundwater since plant roots cannot live in high or low pH levels and groundwater will not be drinkable by surrounding settlements residents depending on such water source (Galvin et al. 2012; Butera 2014). Furthermore, uranium could naturally occur in the environment and with presence of certain ions from leachate of construction and demolition wastes depending on the source materials like type of aggregates used such as granite. Uranium can mobilize into groundwater in elevated concentrations that leads to harmful health effects compared to other leachate material elevated concentration (Letman 2018).

A study prepared by Minnesota Pollution Control Agency showed a high concentration for both human and environmental standards of heavy metals like Arsenic, Boron, and Manganese. These three metals come mainly from concrete, steel reinforcement, and Chromated Copper Arsenate "CCA" treated wood (Chiles 2019).

Zhang et al. (2017) studied arsenic leaching tendency and effects in construction and demolishing debris landfills and the relation it has with the content of gypsum drywall within the wastes. This study reported that with the increase of sulfides up to a certain threshold value, the arsenic concentrations detected were decreasing and after that threshold value, even though the sulfides kept increasing the previously decreasing arsenic concentration started to exhibit an increasing trend (Zhang et al. 2017).

On the contrary, a study about landfilling of arsenic treated wood wastes in various C&D wastes unlined landfills and its impact on groundwater quality in Florida, USA. Results of the study showed that there is no evidence of hazardous mobilizing of arsenic into groundwater. This study suggested that the limited mobilization of arsenic could be due to the soil characteristics. Also, insolubility of wood as they are usually dumped in large pieces that makes the exposed surface for leachate is lower (Saxe 2007).

Another study stated the effect of diversion of wastes from construction and demolition activities on the surrounding environment including groundwater quality. Also showing that by applying C&D wastes diversion techniques, the impact on the surrounding environment and contaminating of groundwater will be reduced. Furthermore, applying C&D wastes diversion techniques has an economical effect by reducing the costs of handling and transportation, as well as avoiding regulatory issues, creating markets, with preservation of non-renewable virgin materials (Smith and Bishop 2005).

Undoubtedly demolished concrete is one of the most commonly found source of C&D wastes too. Previous studies point out calcium hydroxide as one of the major leachates of waste concrete affecting ground water and soil negatively. Calcium hydroxide yields in high alkalinity; hence more calcium hydroxide concentration in landfill surrounding soil will lead to higher pH value; which has negative effect on the vegetation existence and hence the animal existence. Furthermore, calcium hydroxide leachate can reach the groundwater which will also leads to increase the pH level that will affect the quality of groundwater (Hartwich and Vollpract 2017).

The information gathered from the previous studies clearly indicate that leachate from construction and demolition waste landfills leads to mobilization of heavy metals and other hazardous materials into soil and eventually into both surface and groundwater. Mobilization of these hazardous materials will negatively affect the vegetation cover hence the animals depending on these plants to survive. Furthermore, agricultural activities will also be negatively affected since they depend on water sources that will be contaminated with hazardous materials from nearby landfills that will eventually has an effect on public health and food supplies in agricultural communities.

Additionally, a recent study points out the increasing problem due to the scarcity of urban lands that could be for being used for landfilling (Chen et al. 2021). In this study, elimination of C&D wastes through sea filling has been defined as an emerging treatment method for wastes. However, the same study also states that there is lack of knowledge on the consequences of sea filling and therefore more research should be done on the environmental impacts of using sea filling treatment method for the elimination of C&D wastes (Chen et al. 2021).

2.2. Incineration as a handling method for C&D wastes

This method mainly consists of the action of burning wastes in facilities called "Combustors". It consists of two stages: the first stage is carried out with the initial burning "Chamber" (700°C) and then secondary burning "Grate" (980-1090°C) is employed in the second stage. This method has high application and opportunity costs with toxic pollutants emissions and high waste of energy and it is also applied to combustible wastes only. On the other hand, this method leads to reduce volume of wastes by 95% and mass by more than 85%, and in the case of being equipped properly, they can work as energy generators. Also, this method is known to require less space than it is required by landfills and it is reported that soil and groundwater contamination can be prevented in this way (Kumar and Ankaram 2019).

However, it should be noted that the applicability of this handling method for construction and demolishing wastes remains limited. Only some types of C&D wastes could be eliminated by incineration. Timber and certain types of plastics could be counted in incinerable category, where demolished concrete as well as bricks and tiles could not be eliminated directly with this technique (Rhyner 1998; Küçükvar et al. 2014)

2.3. Recycling as a handling method for C&D wastes: Special focus on recycled concrete aggregates application

A common way of recycling method used for construction and demolishing wastes is through reusing them as "recycled concrete aggregates" in the manufacture of new concrete elements. This method is known to reduce the cost and unlike landfilling and incineration, recycling has no harmful impact on the environment

Results obtained in the surveyed previous research studies have shown that recycling method for managing the construction and demolition wastes is the optimum method in cases of cost reduction, reducing environmental impact, and preserving raw materials (Ortiz et al. 2010; Marzouk and Azab 2014; Ulubeyli et al. 2017; Galvez-Martos et al. 2018; Shafiqul Islam et al. 2018; Abdeltawab-Abuellella and Elmalky 2023).

Wastes from demolished concrete buildings can be re-used in the form of recycled concrete aggregates (RCA). For this purpose, the demolished concrete elements are crushed into smaller fractions, separated from other undesired contaminations and added in to new concrete mixtures as a replacement to natural aggregates. In this way, the use of natural (i.e. quarried) aggregates can me decreased, supporting the protection of natural resources as well.

Fig. 2 illustrates summarized information about the life cycle of concrete as a construction material and regaining construction and demolishing wastes as recycled concrete aggregates. C&D waste treatment plants can be fixed or mobile, depending on the required services. Both types of treatment plants can receive and process all types of construction and demolition wastes.

Fixed treatment plants can process higher amounts of debris than mobile plants. However, they have some disadvantages such as their need to be installed in authorized closed areas; hence, debris transportation costs might become an issue since the fixed plants could be located far from the demolition site.

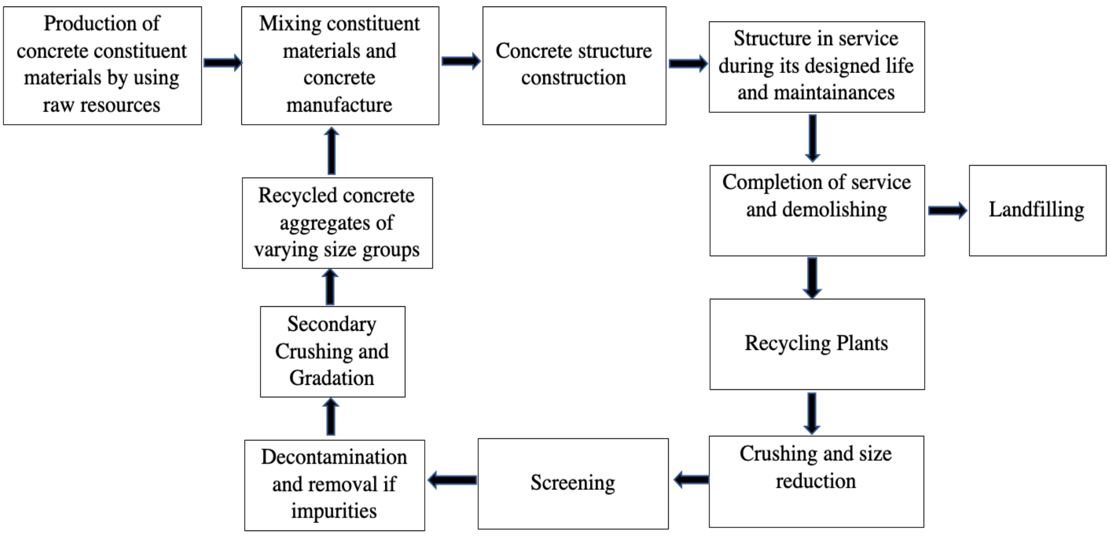

Fig. 2. Concrete life cycle and recycling.

Mobile treatment plants have the advantage of relocation ability; that can process debris directly onsite without needing extra transportation cost of debris.

On the other hand, they have lower rate of debris processing, since they are usually smaller than fixed treatment plants and they need extra labor for reinstalling on each desired site. In any case, general steps followed by both types of plants are very similar (Pellegrino and Faleschini 2016) and are as listed below:

- Crushing
- Separation of ferrous elements
- Screening
- Decontamination and removal of impurities (e.g. soil, glass, plastic, etc.)

Countries investing in recycling are mostly developed countries and the quantities of concrete recycling vary from one country to another (Tam et al. 2018).

A crushed old concrete fraction that is going to be used as RCA, involves the old and damaged mortar from the old concrete attached to old natural aggregates. The porous and damaged character of the old adhered mortar within RCA is reported to be likely to yield some adverse effects on the performance of the new concrete to be manufactured (Juan and Gutierrez. The extent of the negative effects of adhered mortar within recycled concrete aggregates, determines the success of RCA use in new concrete and the general feasibility of its application as a sustainable environmentally friendly waste elimination method.

3. Viability of RCA Use for New Concrete Manufacture as an Environmentally-Friendly Waste Elimination Method

Elimination of C&D wastes in an environmentally friendly way by converting them into a concrete constituent material only could be widely accepted and sustainable if new concrete mixes containing RCA can meet the performance criteria required for engineering applications. In general, concrete's mechanical properties and quality is known to depend greatly on the type and quantity of cementitious materials water and aggregates that are used (Akpinar and Khashman 2017; Khashman and Akpinar 2017; Al-Gburi et al. 2022). Hence, if the quality of the RCA and the performance of the new concrete containing it are monitored in detail, then the potential performance problems are suggested to be overcome by taking necessary concrete mix design precautions (Paul 2017).

Properties of both fresh and hardened concrete mixes containing recycled concrete aggregates, and their durability characteristics have been investigated by numerous researchers in order to evaluate their performance in comparison with conventional concrete mixes. A summary of these investigated concrete characteristics and the regarding performance of RCA-containing concrete mixes are presented in Tables 1 and 2, by providing the references of the previous research works encountered in the related literature.

These previous works provide detailed information on the experimental procedures that they have used in order to provide insights on the concepts selected concrete characteristics that they have focused. The codes and standard procedures that they have followed for material and sample preparations, as well as the test methods used for each parameter of interest varied in certain cases; however, their main findings about the concrete characteristics mentioned in given Tables 1 and 2 were observed to be in harmony. Bar charts presented in Fig. 3 have been prepared based on the experimental data presented in the references mentioned in these tables.

Table 1. RCA-containing concrete properties in comparison with conventional concrete.

Concrete characteristics	Performance of RCA-containing concrete	References presenting supporting experimental evidence
Compressive strength	Lower compressive strength	(Wang et al. 2012; Duan and Poon 2014; Paul 2017; Abdel-Hay 2017; Bulatovic et al. 2017; Pedro et al. 2017; Dimitriu et al. 2018; Gonzalez-Fonteboa et al. 2018; Hao et al. 2018; Hayles et al. 2018; Rao et al. 2018; Sharkawi et al. 2018)
Splitting tensile strength	Lower split tensile strength	(Thomas et al. 2013; Duan and Poon 2014; Pedro et al. 2017; Gonzalez-Fonteboa et al. 2018; Hao et al. 2018; Thomas et al. 2018; Akhtar and Sarmah 2018; Dimitriu et al. 2018)
Elastic modulus	Lower elasticity	(Thomas et al. 2013; Qi et al. 2017; Gonzalez-Fonteboa et al. 2018; Hao et al. 2018; Thomas et al. 2018; Amorim Junior et al. 2018)
Workability	Lower workability	(Abdel-Hay 2017; Hayles et al. 2018; Thomas et al. 2018; Pedro et al. 2018; Bravo et al. 2018; Dimitriou et al. 2018)
Permeability	Higher permeability	(Thomas et al. 2013; Xuan et al. 2017; Gonzalez-Fonteboa et al. 2018; Thomas et al. 2018; Guo et al. 2018; Pedro et al. 2018)

Table 2. Response of RCA-containing concretes to durability problems in comparison with conventional.

Durability problem	Response of RCA-containing concrete	References presenting supporting experimental evidence
Freeze and thaw	Higher deteriorations Higher ice expansions	(Pedro et al. 2017; Gonzalez-Fonteboa et al. 2018; Hao et al. 2018; Amorim Junior et al. 2018; Guo et al. 2018)
Alkali aggregate reaction	Higher reactivity Higher expansions	(Johnson and Shehata 2016; Delobel et al. 2016; Gonzalez-Fonteboa et al. 2018; Beauchemin et al. 2018
Carbonation	Higher carbonation rate	(Thomas et al. 2013; Pedro et al. 2017; Gonzalez-Fonteboa et al. 2018; Bravo et al. 2018; Guo et al. 2018)
Chloride attack	Higher chloride penetration	(Duan and Poon 2014; Ismail et al. 2017; Xuan et al. 2017; Pedro et al. 2018; Gonzalez-Fonteboa et al. 2018; Hao et al. 2018; Thomas et al. 2018; Akhtar and Sarmah 2018; Qi et al. 2017)
Sulphate attack	Higher expansions	(Pedro et al. 2017; Xuan et al. 2017; Bravo et al. 2018; Guo et al. 2018)
	Higher deterioration	(Gonzalez-Fonteboa et al. 2018; Rao et al. 2018)
Abrasion resistance	Similar to conventional concrete up to 50% replacement	(Pedro et al. 2017; Gonzalez-Fonteboa et al. 2018)

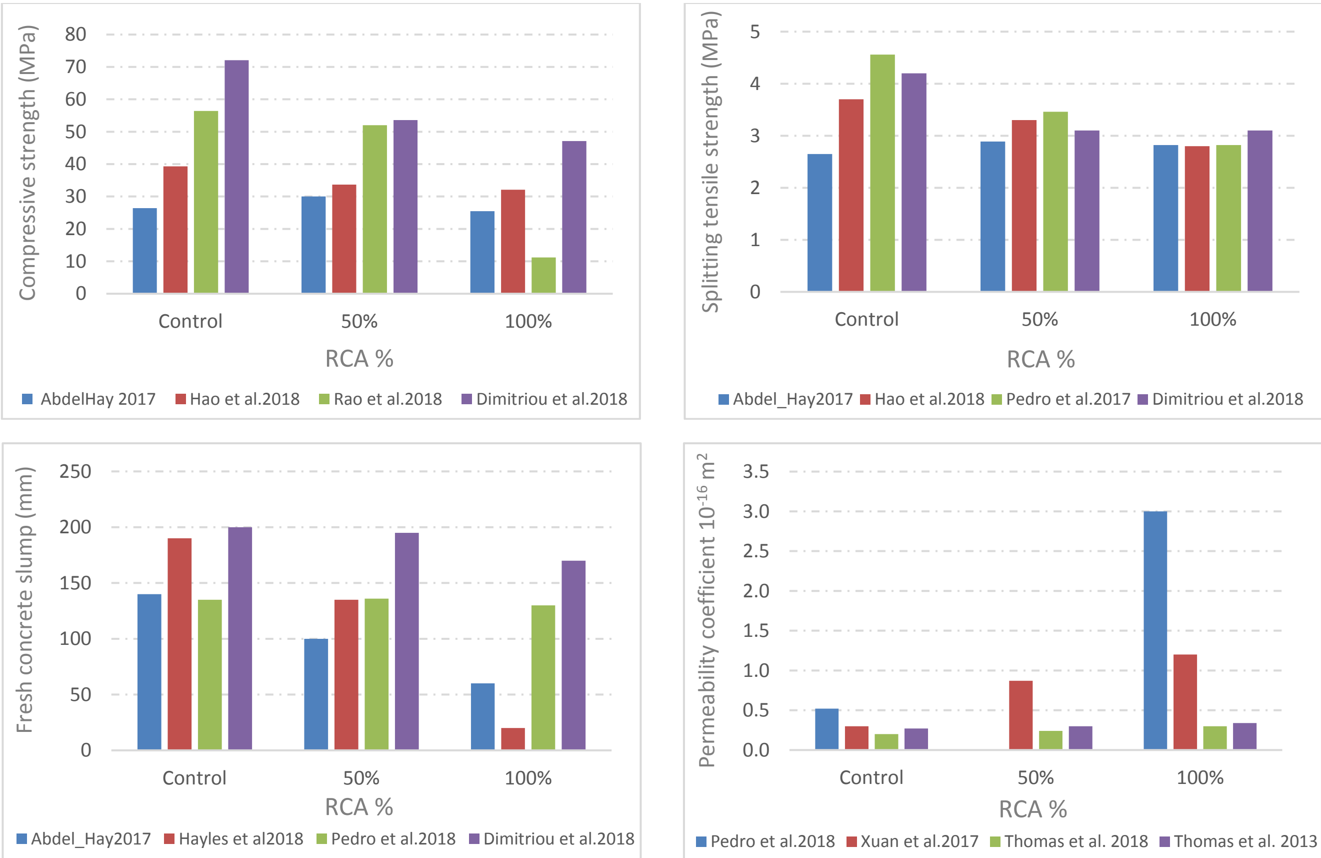

Fig. 3. Effect of % RCA inclusion on concrete properties:
(a) Effects on compressive strength; (b) Effects on splitting tensile strength;
(c) Effects on slump; (d) Effects on permeability coefficient.

Figs. 3(a) ad (3b) demonstrate the effect of %RCA inclusion on compressive and split tensile strength development (28-days) of concrete mixtures. Bars of each color represents concrete mixture results at a particular research study. Reported 50% and 100% RCA inclusions in comparison with the control mixtures in corresponding studies are demonstrated in each bar chart. When bars of each mix (of each study) is compared with respect to increasing percentage of RCA inclusion, it is observed that increased RCA contents yielded lower strength values. One should keep in mind that comparing strength values of the same RCA% from different studies could be complex, since each study had used different mix design parameters including w/c, cement contents, aggregate contents and so on, in addition to employing different cement types selected for their own studies. Fig. 3(c) demonstrates that the increase in the RCA inclusion yielded decreasing tendencies in the observed slump values. Part indicates that the increase in RCA content of the concrete mixtures yielded higher permeability coefficient of the samples.

RCA particles are produced from old and damaged and hence demolished building wastes. Each RCA particle includes traces of old aggregates as well as old mortar adhering it, both coming from the old and demolished concrete. Hence, these particles are known to be deteriorated as well; they might have defects and micro-cracks (especially within the old mortar within RCA) due to aging. Hence, they are known to possess lower quality compared to natural aggregates. All these drawbacks of RCA particles' quality affect the strength performance of the new concrete mixture that they are used within as well. RCA particles are also known to possess lower density, higher porosity and higher absorption in general. These would yield more water demand and reduced slump (if water content in the mix is constant). These qualities of RCA particles also are known to yield higher permeability tendencies in concrete mixtures if additional measures, such as increasing the cement and mineral additive content in the mix, are not taken (Derki 2019; Tayeh et al. 2020; Akpinar and Al-Attar 2021; Wang et al. 2021; Wang et al. 2023). All these characteristics and tendencies reported in the related literature are in parallel with the demonstrated tendencies in Fig. 3. More detailed discussions on the exact mechanisms that yielded the observed behaviors that are presented in parts a, b, c and d of Figure 3 are presented in the corresponding references cited in Table 1 and Fig. 3, considering the test set ups and specific materials and mix designs employed in each case of RCA use in concrete mixtures.

At a first glance, information presented in Tables 1 and 2, as well as in Fig. 3, might imply that RCA-containing concrete happens to possess definitively a lower quality when mechanical characteristics and its durability performance are compared to conventional concrete made only with natural aggregates. However, the continuing advancements in construction sector and the availability of various possibilities regarding the concrete additives and admixtures that can be included to concrete mixtures supplementary through a careful concrete mixture design process, enable the engineers to manufacture RCA-containing concretes with improved properties that are suitable for structural purposes (Xuan et al. 2017; Wang et al. 2017; Dimitriu at al. 2018; Akpinar and Al-Attar 2021).

Addition of pozzolanic materials such as silica fume, fly ash and blast-furnace slag, as cement additives, as well as using concrete admixtures such as superplasticizers have been reported to increase concrete density, compressive and flexural strength behaviour of RCA-containing concretes (Xuan et al. 2017; Guo et al. 2018 Thomas et al. 2018; Gonzalez-Fonteboa et al. 2018). Using such additives and admixtures were also reported to enhance impermeability of concrete and hence the durability characteristics of the concrete buildings in the cases where RCA was used (Chahal 2013; Pedro et al. 2018; Muhammedemin 2018; Derki 2019). In this way, the use of RCA in concrete manufacture can still be considered as a potentially effective method of elimination of C&D wastes, besides being an environmentally-friendly solution, minimizing the hazardous effects of these wastes on nature.

4. Conclusions

Conclusive remarks attained as the result of literature review carried out on more than sixty studies on the construction and demolishing wastes' characteristics, their impacts on groundwater and environmental, as well as their handling methods are presented below:

- The total quantity and the type of the construction and demolishing wastes generated by each country are determined by factors such as; their level of economic growth, population, total demand in construction activities and on the type of conventional construction materials that they use.
- Landfilling is reviewed as a widely used waste management method; however, leachate of hazardous materials from the landfilled wastes cannot be eliminated or kept under control fully.
- When landfilled, mixed types of construction and demolishing wastes have reported to cause leachate of potentially hazardous materials including heavy metals like arsenic, lead, cadmium, chromium, copper, mercury, nickel, zinc, calcium, magnesium, antimony, chloride, fluoride, sulphate and phenol that directly affects both soil and groundwater. International associations have been observed to make positive attempts to provide guiding information on the allowable concentration limits of these reported potentially hazardous materials.
- The listed leachates were observed to exceed the defined healthy limits in numerous studies. As a result, bacterial contaminations, highly toxic effects and severe pH changes in groundwater were reported. Consequently, these highly hazardous effects on groundwater were reported to be reflected on soil, agricultural activities, vegetation and animal life, besides its direct implications on potable water that is vital for human life.
- A lack of systematic information was observed on the surveyed literature regarding on the exact type of hazardous material likely to leach from each individual type of construction and demolition waste, since majority of the studies handled always mixed types of wastes.
- Being one of the most commonly used construction materials, concrete wastes effects on nature have been observed to be reported more insightfully within the surveyed previous studies. Results of these studies reported that leachate of calcium hydroxide from concrete and cement mortars mainly affects the pH level of soil and ground water and this causes negative effects on the natural vegetation, agricultural soil's quality and the on the quality of the groundwater resources.
- Recycling is reviewed as the most environmental-friendly waste management solution by the majority of the surveyed studies.
- Re-using demolished concrete wastes in the form of recycled concrete aggregates to be used in manufacture of new concretes is regarded as an effective solution for the problem of construction and demolishing wastes' elimination from nature.

Author Contributions

All of the authors made substantial contributions to conception and design, or acquisition of data, or analysis and interpretation of data; were involved in drafting the manuscript or revising it critically for important intellectual content; and gave final approval of the version to be published.

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Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this manuscript.

Data Availability

The datasets created and/or analyzed during the current study are not publicly available, but are available from the corresponding author upon reasonable request.

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