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Use of Coal Mining Wastes in the Construction Industry to Promote a Circular Economy: A Systematic Literature Review

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Abstract: The coal mining process generates wastes such as overburden and tailings, the disposal of which is a significant environmental challenge. The circular economy model of eliminating waste and regenerating the economy and ecosystems can minimise the impact of coal mining wastes. Another resource-intensive industry is the construction industry, which is responsible for significant resource consumption, waste generation, and emissions. Reusing and recycling coal mining wastes as secondary or value-added building materials in the construction industry per circular economy principles will help minimise the impact and have environmental and economic benefits. Several studies have demonstrated the use and reuse of coal mining wastes in the construction industry. This article conducts a systematic literature review to understand the state-of-the-art utilisation of coal mining waste in the construction industry. After a series of refinements using the PRISMA approach, 54 articles were included in the review. The articles were further divided based on using coal mining wastes in the construction industry as end products/application areas. The review results show that coal mining waste has been successfully used to make bricks and aggregates (fine and coarse), replace cement, and develop geopolymers, concrete, roads, and embankments. The studies suggest the utilisation of coal mining waste primarily in non-structural components, with very few studies suggesting using coal mining waste in structural applications. The systematic literature review helped in understanding the knowledge development related to the possible application of coal mine wastes in the construction industry, identifying the gap in the field, and suggesting future research directions.

Keywords: coal mine overburden; coal mine wastes; construction industry; R principles; circular economy

1. Introduction

The fossil fuel industry is one of the primary pollution sources across the globe. Among fossil fuels, coal is the prime source of electricity generation [1]. As per the increasing population and people living in cities, the demand for energy and resources is increasing tremendously, which stresses the existing coal mining countries to increase production to meet the demand. By 2035, coal mines are expected to account for almost 27% of global energy [2]. The international scientific community has recognized the importance of resource optimization in meeting the growing demand for a sustainable future [3].

Considering the significant contribution of the coal mining industry to meet the demand, increased production results in large amounts of waste in different forms. Natural resource consumption and waste generation are global economic and environmental problems, and the coal mining industry is a significant contributor [4]. Coal extraction, processing, and utilisation from open-cast or underground mines generate different forms of waste ranging from overburden, tailings, fly ash, bottom ash, coal dust, etc [2,5,6]. Coal waste accounts for nearly 46% of the total annual waste from leading coal-producing countries, i.e., the USA, India, China, and Australia [7].

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Globally, 5.5 billion tonnes of coal are produced annually, and almost half are disposed of as waste [8,9]. One of the significant wastes from the coal mines is the coal mine overburden. In most cases, the stripping ratio of coal is above 2, as in India, a leading coal-producing country, in 2022-23, it was 2.88 [10]. The amount of overburden is very high, and it lies on the coal mine site in the external pit boundary in the overburden dump yard, causing environmental, economic, and social problems [11]. Further, raw coal is processed in the washery, resulting in rejects (tailings) that account for an average of 30% of the total raw coal [12]. Finally, with the utilisation of coal at thermal power plants, coal gangue, fly ash, and bottom ash are produced in the form of waste [2]. These wastes are stored at the site and disposed of at some economic cost, resulting in serious environmental issues like pollution, fire hazards, ground deformation, slope failure, groundwater contamination, loss of biodiversity, etc. [13–16].

The possible solution to the problem is recycling and reusing the coal mine wastes in some valuable form, which prevents their disposal and has environmental and economic benefits. The best waste management practices lie in using the waste in different industries [17]. Several authors have explored the use of coal mining wastes in the construction industry. The coal mine overburden, which consists of rocks such as shale, sandstone, and clay, has mainly been used as backfilling material [14]. Other than backfilling, it has the potential to be recycled and reused as bricks [18] and as sand and aggregates in concrete [11]. [19] explored the recycling of different forms of coal mining waste in China, ranging from gangue piles into parks, fly ash used in building materials, recycling and reusing of coal mining water, coal bed methane for power generation, etc. The wastes from the coal mining activity are generated at different levels and through various activities, and the same may be utilised as valuable products like bricks, aggregates, and sand in the construction industry, thus contributing towards zero waste through material circularity and responsible resource utilisation [17]. [20] explored coal mining waste's physical and chemical properties. They concluded that it has the potential to be reused and recycled as valuable secondary raw material in the construction industry. In a study conducted by [13] through a comprehensive literature review of the structural, geotechnical, and geochemical properties of coal mining waste, it was found that coal mining waste can be reused and recycled as aggregates and binders in concrete and cementitious composites. Using industry rejects in the construction industry can suffice the need for 40% of the virgin raw materials required and reduce cost by 30% compared to natural raw materials [21,22].

With the coal mining industry as one of the significant contributors to global environmental problems, the other resource-intensive industry is the construction industry, which is responsible for significant resource consumption, greenhouse gas emissions, energy consumption, and waste generation [23,24]. This study aims to present the understanding of utilising wastes from the coal industry in the construction industry and thus contribute towards the objective of a circular economy. The circular economy is a model that has received significant global attention and aims to eliminate waste from the system and regenerate the natural ecosystems and economy [25]. The widely promoted 10R principles of the circular economy are "refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover" [26,27]. Of all the R principles of the circular economy, the most widely discussed are reduce, recycle, reuse, repair, repurpose, and recover. The advent of circular economy principles will help achieve the objective of responsible resource consumption and utilisation in both the construction and coal mining industries. Several studies have presented the use and reuse of wastes in the construction industry to promote circular construction [28–30]. The literature suggests that the global scientific community has paid significant attention to circular economy integration in the construction and coal mining industry. [31] explored the possibility of integrating the principles of circular economy in the coal mining industry to achieve the goal of zero waste by reusing all the possible resources, such as power plant waste, into building blocks, road construction, etc.

We conduct a systematic literature review to identify state-of-the-art methods of using coal mining waste in the construction industry. We analysed the global literature on using coal mining waste in the construction industry. We identified the possible application of the waste by integrating the R principles by dividing them based on application areas/end-products:

The study answers the following research question:

What are the different end products/application areas in the construction industry developed from coal mining waste that will help achieve a circular economy in the coal mining and construction industry?

The article is further divided into five sections. Section 2 presents the methodology adopted for the study; Section 3 presents the results/findings of the systematic literature review as descriptive analysis and content analysis; Section 4 discusses the results; and Section 5 highlights the conclusion drawn from the study.

2. Methodology

The methodology adopted is a systematic literature review to present the state-of-the-art utilising coal mine waste in the construction industry. The systematic literature review helps identify the need for research and development of a protocol to replicate and update the literature in the field [32,33]. The study adopted the systematic literature review method, including eight stages described by [34], which are systematic, transparent, and can be replicated.

The authors used the PRISMA approach to review the literature conducted in the field (see Figure 1) in the last two decades. The systematic literature review started with understanding the "Application of coal mining waste in the construction industry integrating circular economy principles." This was followed by identifying the studies that could be included in the systematic literature review, which created a network of studies focusing on utilising coal mining waste in the construction industry. In the second step, relevant research articles were identified in the two databases (Scopus and Web of Science) using the combination of: "Coal Mine Waste" AND "Construction Industry" AND "Circular Economy" AND "Sustainability" ("Coalmine Overburden" OR "Coal Mine Tailings" in Scopus and Web of Science electronic databases. This search found 54 articles in the Web of Science database and 82 in Scopus. After removing the repetitions from both databases, 83 were selected further for analysis.

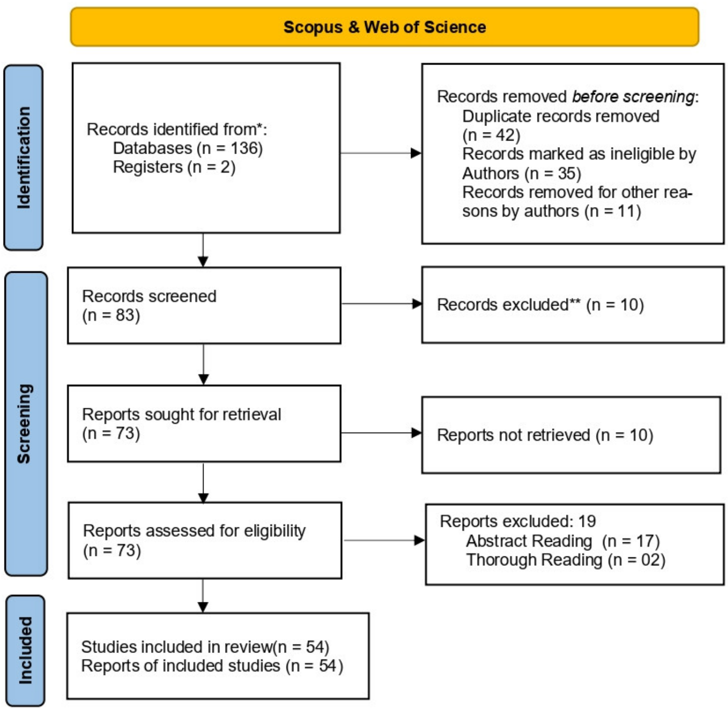

Figure 1. Steps of Systematic Literature Review (Source: The authors, *http://www.prisma-statement.org/*).

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Further, the authors filtered the articles based on Title, resulting in 73 articles. After the content analysis of the abstracts, 56 articles were selected (see Figure 1) to be included in the review, including two conference papers related to the subject area. In the last step, all the selected articles were read thoroughly, and two articles were removed as they were not directly related to the application of coal mine waste in the construction industry. Finally, 54 articles were selected to be included in the review.

3. Results

In the study, the systematic literature review is presented in two ways. One, growth in literature on the use of coal mining wastes in the construction industry is discussed through descriptive analysis based on the number of publications, geographical region, and journal type. Second, we discuss the state of understanding concerning the existing literature through content analysis. For this, the papers were divided based on the end-product/application areas: a) Bricks, b) Aggregates (Fine and Coarse) and Sand, c) Cement, d) Concrete, e) Geo-polymers, f) Roads, Embankments, and Backfill, and g) Others. The end products are the use of coal mining wastes in the construction industry, resulting in a new product, and the application areas are the use of coal mining waste as a substitute for an existing natural material in construction composites.

3.1. Descriptive Analysis

Firstly, the analysis of the selected articles was based on the number of publications per year, as shown in Figure 2 in the research domain. With the increase in the number of publications year by year, the research area of utilisation of coal mining wastes, thus achieving the aim of a circular economy both in the construction and coal mining industry, has gained the attention of the global scientific community.

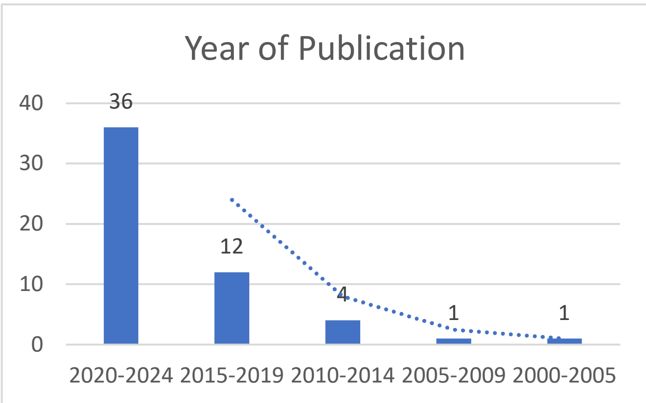

Figure 2. Number of Publication per year (Source: The Authors).

Further, analysis was based on the location of the research and the journals of the selected research articles. The maximum publication in the research area was from the “Construction and Building Materials” and “Journal of Cleaner Production” (see Figure 3). The journals are “Q1” in the “Scimago Journal and country rank”, which indicates the presence of research areas in important research sources across the globe.

As per Figure 4, the maximum number of publications is from leading coal-producing nations India, China, and Europe. Concerning leading coal-producing countries globally, it is evident that the research area has found its significance. One of the other highlights is from the Asian and African sub-continent, respectively, where the research area has found its importance.

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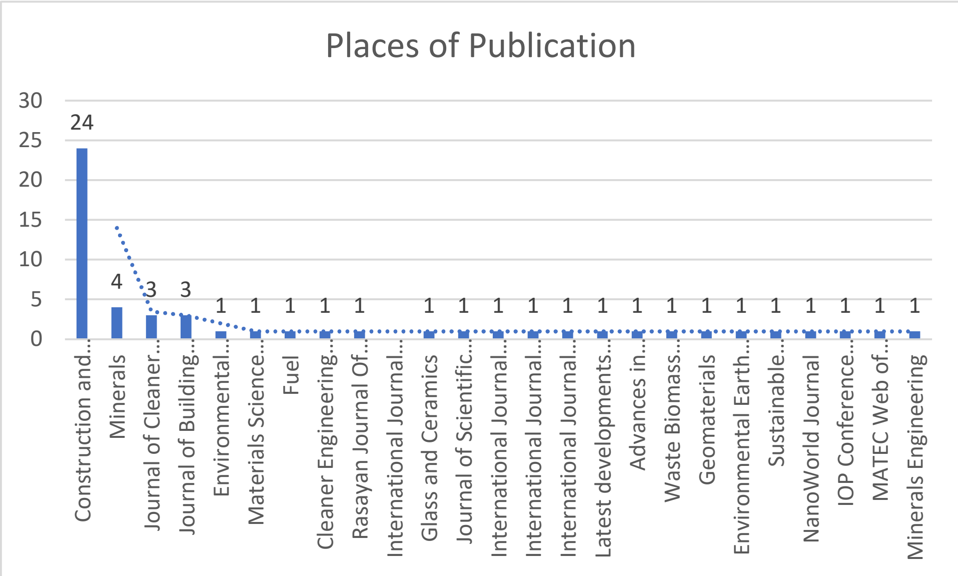

Figure 3. Places of Publications (Source: The Authors).

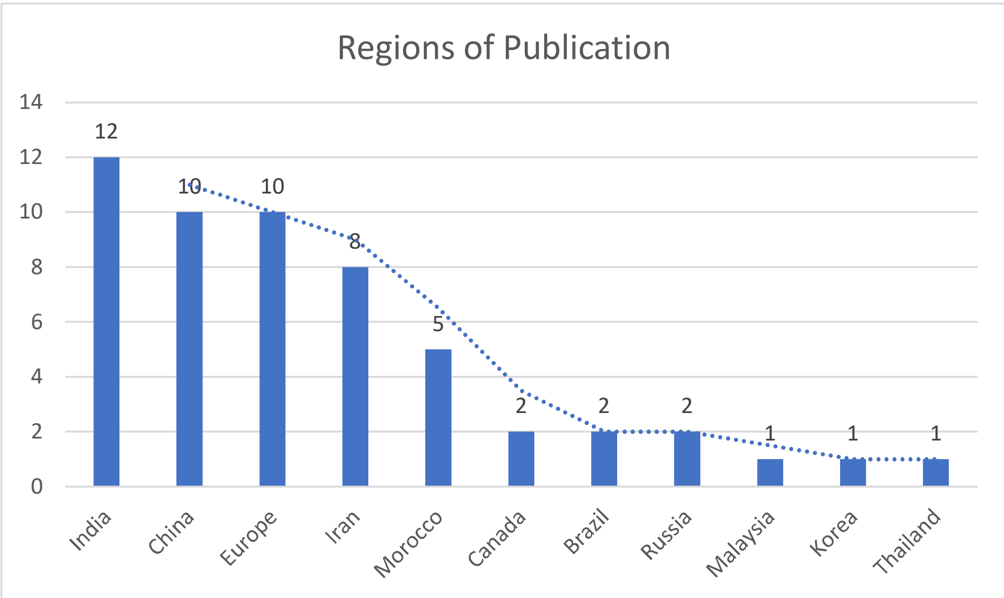

Figure 4. Countries of Publication (Source: The Authors).

3.2. Content Analysis

The content analysis of the selected article presents state-of-the-art information about the utilisation of coalmine overburden/wastes in the construction industry, integrating R principles of circular economy. To simplify the results, the articles are divided based on using coal mining wastes as end-product/ application areas in the construction industry. The end-product/application areas of the coal mine wastes in the construction industry are discussed under the following heads with the number of articles mentioned: Bricks (07), Aggregates (Fine and Coarse) and Sand (10), Cement (16), Geopolymers (06), Concrete (04), Road, Embankments, and Backfill (08), Others (03).

3.2.1. Bricks

This group of seven (07) articles presents the use of coal mine waste as bricks in the construction industry (see Table 1). Brick is one of the significant components of construction, and several authors have explored the possibility of using coal mine waste in brick manufacturing [18,35,36]. The

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literature suggests varied forms of coal mining waste used in making bricks, such as overburdened clay [35], overburdened rocks [21,37], coal waste dust, coal gangue powder, and coal mine tailings [18,36,38].

The use of coal mine overburden clay in making different specimens of compressed stabilized earth brick using varying percentages of sand and clay is explored by [35]. It was found that the texture of coal mine overburden clay was poor, resulting in high water absorption, which was improved further by the addition of coal mine overburden sand by 57%. Thus, the compressive strengths of compressive stabilised earth blocks were improved. [39] made clay bricks of desired Korean standards using coal mining wastes in different percentages and found that with increasing coal waste, water absorption increased. Still, compressive strength decreased, and a 30% mix was suitable for standard Korean clay brick. In a study by [40], coal mine overburden was used to make bricks and pavement around the coal mine site. They found that the overburdened bricks were better than burnt clay bricks on all the parameters except specific gravity. Specific gravity being insignificant makes it suitable for use in low-cost housing and low-height structures around mining sites.

In another study by [36], sintered bricks were developed using iron-ore tailings, coal-gangue powder bonded with sewage sludge, and shale. The composite sintered bricks have the desired properties of a Chinese-bearing brick and thus contribute towards a circular economy, eliminating waste and having environmental and economic benefits. [38] prepared bricks using coal dust waste produced at thermal power stations in Korba, Chhattisgarh, and found that coal dust waste bricks were economical and suitable for replacing conventional clay bricks.

[21] explored the production of defect-free ceramic bricks for walls using overburden rocks and waste coals from coal mining sites in Siberia. They were found to be 1.5 times better than traditional brick. [18] recovered coal from coal mine waste rocks, and with further treatment of this coal, treated coal mine tailings were used in making fired bricks, which have better properties than traditional bricks. At the same time, the process helps reduce greenhouse gas emissions by 70%, thus contributing to a circular economy.

Table 1. Coal Mining Wastes in making "Bricks" for the Construction Industry as per SLR.

S. No.	Type of Coal-Mining Waste	Application in Construction	Region	"R principle" integration	References
01	Coal Mine Overburden Clay	Compressed Stabilized Earth Brick	India	Reduce, Reuse, & Replace	[35]
02	Coal Gangue Powder from tailings and Shale (overburden) replacing natural clay	Sintered Bricks	China	Recycle, Replace & Reuse	[36]
03	Coal Mine Overburden	Clay Bricks	Korea	Recycle & Reuse	[39]
04	Coal Mine Overburden Rocks and waste coals	Ceramic Bricks	Russia	Recycle & Reuse	[21]
05	Coal Dust Waste at thermal power plants	Bricks	India	Recycle & Reuse	[38]
06	Coal Mine Overburden Rocks	Bricks	India	Recycle & Reuse	[37]
07	Coal Mine Waste Rocks and Treated coal mine tailings	Fired Bricks	Canada Morocco	Recycle & Reuse	[18]
08	Coal Mine Overburden (Rocks and Clay)	Bricks and Pavement Material	India	Recycle & Reuse	[40]

3.2.2. Aggregates (Fine and Coarse) and Sand

This group of ten (10) articles highlights the use of coal mine wastes replacing sand and fine and coarse aggregates for different concrete-based composites (see Table 2). The literature suggests using coal mine waste as fine and coarse aggregates and sand, replacing conventional and virgin materials in different construction composites.

A study by [41] found that using coal mines overburden to replace natural sand with up to 60% in concrete will enhance its strength and durability. [11,42] demonstrated the use of coal mine overburden rocks (sandstone) in making fine aggregates for concrete with desired properties. In another study by [43], coal mining waste was used as fine aggregates and sand, replacing natural and conventional sand in making concrete paver blocks. In another study by [44], the environmental impacts of coal mine overburden sand and manufactured sand (crushed granite) were compared using life cycle assessment. They found that coal mine overburden sand has lesser impact and is an environment-friendly sustainable alternative to river sand in the construction industry.

[45] explored using coal mine overburden to replace natural aggregates in mortar and concrete. The author proposed a 100% replacement of natural aggregate with fine aggregate derived from coal mine overburden in a mortar and a 100% replacement of coarse and fine aggregates derived from coal mine overburden in concrete. The replacement was found to be suitable as per standards. Further, the mortar and concrete with replaced aggregates were tested for corrosion and were found to be comparable with river sand. [9] explored the use of untreated coal waste as aggregates in concrete. They found that 5% of the natural aggregates can be replaced by untreated coal waste, which resulted in increased physical and mechanical properties of the concrete.

In another study, [2] used a systematic literature review to understand the knowledge development based on the mechanical and durability properties of coal mining and processing waste as a secondary aggregate in the pavement sub-base and base layers. It was found that coal mining waste in the sub-base and base layers of pavement helps in waste utilisation and responsible resource consumption, thus contributing to the circular economy.

In a few other studies, the coal mine wastes have been used as aggregates in other construction composites such as [22] coal mine waste rocks were used as fine aggregates in a fly ash-based geopolymer, and the developed geocomposites were within the limit of non-hazardous waste. [8] explored using coal waste powder to replace natural aggregate fillers in a micro-surfacing mixture. The results showed that using coal waste powder enhanced the performance of the micro surfacing.

Table 2. Use of Coal Mining Wastes replacing "Aggregates and Sand" in the Construction Industry as per SLR.

S. No.	Type of Coal-Mining Waste	Application in Construction	Region	"R principle" integration	References
01	Coal Mine Overburden Rocks and Clay	Sand, Fine and Coarse Aggregates in Concrete	India (3)	Reduce, Reuse, & Replace	[11,42,45]
02	Coal Mine Overburden	Fine Aggregates and Sand	India (2), Brazil	Replace & Reuse	[41,43,44]
03	Coal Mine Overburden Rocks	Fine Aggregates in fly ash-based geopolymer	Italy	Replace & Reuse	[22]
04	Coal Mining and Processing Waste (Overburden, Tailing, Fly Ash, Bottom Ash)	Secondary aggregates in the base and sub-base layer of pavement	India	Recycle, Replace & Reuse	[2]
05	Coal Waste Powder (Coal Extraction and Washing Process)	Replacing natural aggregate filler	Iran	Recycle, Replace & Reuse	[8]

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06	Untreated Coal Waste (Raw Coal)	Aggregates in concrete	Iran	Replace & Reuse	[9]

3.2.3. Cement

The third category, wherein the maximum number of studies (sixteen articles) have been conducted, is coal mine waste, which was appropriate for construction based on its pozzolanic properties. The global literature highlights the use of coal mining waste in untreated and treated forms to replace cement in the construction industry (see Table 3).

Several studies have demonstrated using thermally activated coal mining waste to replace cement in the construction industry [46–48]. [47] used thermally activated coal mining waste to replace cement by almost 20% in making blended cement with chemical, physical, and mechanical requirements per European standards. In a study conducted by [48], partial cement replacement with activated coal waste replacement increases the mechanical performance of cement-based composites. [49] demonstrated using thermally activated coal mining waste as a cementitious material, replacing cement by up to 20% in a cement-based blended binder. [50] used thermally activated coal mining waste replacing cement from 10 to 50% and further assessed the chloride permeability of the blended cement. The results revealed better chloride diffusion, refinement of the capillary network through decreased pore size, and increased electrical resistivity. [46] explored the use of shale from coal mines in Poland in natural and thermally activated forms. After the analysis, the results suggest that the thermally activated shale can be used as a partial cementitious substitute up to 20%.

In the study conducted by [51,52] in Spain, the coal mine tailings have kaolinite content, which, on thermal activation, is converted to meta kaolinite having pozzolanic properties. [53] explored the possibility of replacing cement with activated coal mine waste by 20% in a mortar. They found it suitable per strength and durability standards through the freeze-thaw test. These tailings can replace traditional cement in the construction industry and thus contribute to the circular economy.

[54], explored the potential of coal-washing waste ash as a replacement for blended cement. Upon thermal activation, the produced coal-washing waste ash demonstrates cementitious properties. Further, using coal-washing waste ash, geo-polymer concrete was developed, which has higher compressive and mechanical strength, resistance to acidic conditions, and low water absorption capacity. [55] tested coal mine wastes from the washery. They found that the major components of the waste are silica, alumina, and iron oxide, which can be used in cement clinker production in Spain. [55] took six samples of coal mine wastes from different locations in Spain and further prepared cement clinker samples, demonstrating Class I cement's properties in Europe, making it a sustainable and economical alternative to cement.

In a study by [56], the properties of coal gangue as a raw material for sustainable alkali-activated binder alternatives were explored. [57] suggested that mineral waste, including coal-rich alumina, silica, iron oxide, and calcium oxide, can replace cement and alkali-activated binders.

[58] conducted a literature review to understand the utilization of coal bottom ash replacing cement based on their physical, chemical, and mechanical properties. The results suggest that coal bottom ash is a sustainable alternative to cement in mortar and concrete up to a specific ratio. [59] suggested using coal fly ash to make fly ash fibres for fibre-reinforced cement composites. [60] explored using coal waste powder, coal waste ash, and limestone powder to replace cement in roller-compacted concrete pavement partially. They found that 5% of cement replacement bears the same strength as desired per standards. [61] studied the use of red mud and coal industry by-products in manufacturing cementitious material per mechanical and durability ASTM (American Society for Testing and Materials) standards and met the EPA (Environmental Protection Agency) regulation.

[62] explored the use of coal mining waste to replace cement, which helps in soil stabilization. They concluded that up to 5% of coal mine waste (by weight of cement) can improve the mechanical properties of cement sand containing 6% cement (by dry weight of used sand).

Table 3. Use of Coal Mining Wastes replacing "Cement" in the Construction Industry as per SLR.

S. No.	Type of Coal-Mining Waste	Application in Construction	Region	"R principle" integration	References
01	Thermally activated coal mining waste	Replacing Cement	Czech Republic (2), Spain (4), Brazil	Recycle, Replace & Reuse	[46–51,53]
02	Coal Washing Waste Ash	Blended cement	Iran	Recycle, Replace & Reuse	[54]
03	Coal Mining Wastes from Washery	Cement Clinker Production	Spain	Recycle & Reuse	[55]
04	Coal Gangue	Alkali-activated binder alternatives	Morocco	Recycle & Reuse	[56]
05	Coal Bottom Ash	Replacing Cement	Malaysia	Recycle & Reuse	[58]
06	Coal Fly Ash	Fly ash fibers for fiber-reinforced cement composites	Thailand	Recycle & Reuse	[59]
07	Coal Waste Powder, Coal Waste Ash, Limestone Powder	Replacing cement in roller-compacted concrete pavement	Iran	Recycle, Replace & Reuse	[60]
08	Coal Industry by-products and red mud	Cementitious Material	China	Recycle & Reuse	[61]
09	Coal Mine Waste	Replacing Cement, which helps in soil stabilisation	Iran	Recycle & Reuse	[62]

3.2.4. Geopolymers

The global scientific community has witnessed a recent trend in research development related to using geopolymers in the construction industry to foster sustainability [63]. The research has established that coal mining waste is rich in alumina and silica, making it a good alternative for developing geopolymers and composites. This group of six (06) articles presents the use of coal mining wastes as geopolymers in the construction industry (see Table 4).

Different mine wastes have been used for making geopolymers, and several authors discuss their use in concrete, including coal mine gangue [64]. [14] demonstrated using coal mine overburden (Shale) and tailings to make two geopolymers. They found that the geopolymer developed using tailings was a promising material and could be used for lightweight structural and non-structural applications. [65] used aggregates from open-pit mines, ground granulated blast furnace slag, and coal fly ash to synthesise geopolymers used in constructing open-pit mine roads.

[54] demonstrated the use of coal-washing waste, a rich alumino-silicate source, as a replacement to cement by 15% in developing geopolymer concrete. Further, with the thermal activation of coal-washing waste ash, the properties of geo-polymer concrete were enhanced significantly. In a study by [66], the geo-polymeric materials derived from mining wastes, including coal, had better physical, mechanical, and durability properties than Portland cement. [67] developed a geopolymer-based grouting material using coal gangue, fly ash, bentonite, and other additives for repairing the cracks in the critical strata of aquiclude, which protects the aquifer during underground coal mining.

3.2.5. Concrete

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The wastes from coal mines are physically and chemically heterogeneous and have been utilized successfully in many structural applications (Haibin & Zhenling, 2010). The studies discussed above illustrate the use of coal mining wastes in developing value-added materials used in concrete directly or indirectly. This group of four (04) articles presents the use of coal mining waste in developing concrete compared to traditional concrete (see Table 4).

A study by [69] found that the concrete developed using coal gangue replacing 25% and 15% of gravel and fly ash replacing 10% and 15% of cement has better water permeability than standard concrete. The developed concrete has a high subsurface drainage modulus, making it suitable for farmland drainage in high groundwater-level areas. [70] developed foam concrete using coal mining waste in Poland. Further, they studied the developed concrete's early-age hydration behaviour through air and water curing. [71] explored the possibility of creating an optimal mix proportion of concrete mixtures using coal waste based on the independent variables of water-cement ratio, cement content, gravel volume, and coal waste responding to compressive strength and water absorption percentage. The results show that the optimal coal waste concrete mix is a step towards sustainability and is a circular approach. [72] developed a concrete using crushed non-activated coal gangue replacing natural aggregates, and it was found that as the percentage replacement of aggregates increased, the workability and tensile strength of the concrete decreased, and as the maximum size of coarse non-activated coal gangue aggregates increased, the compressive strength of the concrete increased.

Table 4. Use of Coal Mining Wastes in "Geopolymers" and "Concrete" in the Construction Industry as per SLR.

S. No.	Type of Coal-Mining Waste	Application in Construction	Region	"R principle" integration	References
01	Coal Mine Waste	Geopolymers in light-weight structural and non-structural applications	Poland	Recycle & Reuse	[14]
02	Aggregates from open-pit mines, GGBS, and coal fly ash	Geopolymers in road construction	China	Recycle & Reuse	[65]
03	Coal-washing Waste	Replacing cement in geopolymer concrete	Iran	Recycle, Replace & Reuse	[54]
04	Coal-mining waste	Geo-polymeric materials replacing cement	Morocco	Recycle, Replace & Reuse	[66]
05	Coal Gangue, Fly ash, Bentonite	Geo-polymer-based grouting material	China	Recycle & Reuse	[67]
06	Coal Gangue	Replacing Gravel in concrete for farmland drainage	China	Recycle & Reuse	[69]
07	Coal Mine Waste replacing natural sand	Foam Concrete	United Kingdom	Recycle, Replace & Reuse	[70]
08	Coal Mine Waste (Coal Washing Plant)	Concrete	Iran	Recycle & Reuse	[71]
09	Non-activated coal gangue aggregates	Replacing Natural aggregates in concrete	China	Recycle & Reuse	[72]

3.2.6. Road, Embankments and Backfill

The other important area where coal mine waste has been extensively used is road construction. This group of eight (08) articles highlights the use of coal mine waste in backfill, roads, and embankment construction (see Table 5). Several authors have demonstrated using coal mine waste as a filler material in road construction [73] and as aggregates for road embankment applications [74].

[75] explored the use of coal waste ash derived from washery after incineration. They were found suitable for filling hot mix asphalt in constructing roads and pavements, which had higher water resistance, toughness index, and flexibility than the reference mix. [76] explored the use of coal gangue wastes as fillers in asphalt binders, replacing limestone, which is economical and protects the environment.

In another study by [77], the chemical, mineralogical, geotechnical properties, and economic feasibility of coal mine waste rocks were explored. They concluded that coal mine waste rocks in weathered form can be used alone to construct embankments. Further, stabilising agents and hydraulic binders can be used to construct road sub-base layers of high-traffic pavements. Using coal mine waste rocks to construct embankments and roads is environmentally friendly and economically beneficial if used locally [77].

[78,79] studied the mechanical properties and damage evaluation of coal-based solid waste cemented backfill. The wastes from the coal industry, such as coal gangue, coal bottom ash, and fly ash, were stabilized with cement to use as pavement base materials [80]. [81] demonstrated using coalmine overburden as a sub-ballast in railway tracks, an environmentally sound solution for coal mine waste management.

3.2.7. Others

This group of three (03) articles explores a few other coal mining waste application areas (see Table 5). The other uses of coal mining waste include coal mining waste in making ceramic tiles for construction [82]. After a corresponding treatment, they found that coal mining waste is a promising ceramic material.

Another study explored the use of coal fly ash and plant fibres in developing lightweight gypsum composites for temperature and moisture control in the building [83]. It was suitable for passive thermal and humidity control, thus contributing to energy efficiency and sustainability.

Another application area is the use of coal mine waste in structural elements. [16] demonstrated the use of coal mine overburden (Shale) in making controlled low to medium-strength composites in the construction industry using Shale as the base material and fly ash and cement as cementitious material. The developed material was found to be an effective sustainable construction material.

Table 5. Use of Coal Mining Wastes in Roads, Embankments, Backfill, and Other Applications as per SLR.

S. No.	Type of Coal-Mining Waste	Application in Construction	Region	"R principle" integration	References
01	Coal Mining Waste	Aggregates for Road Embankment	Canada	Recycle & Reuse	[74]
02	Coal Waste Ash from Washery	As filler in hot mix asphalt used in road and pavement construction	Iran	Recycle & Reuse	[75]
03	Coal Gangue Waste	As fillers in asphalt replacing limestone	China	Recycle, Replace & Reuse	[76]
04	Coal Mine Waste Rocks (Weathered Form)	Construction of Embankments	Morocco	Recycle & Reuse	[84]

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05	Coal Mine Waste (Coal Thermal Power Plant), Coal Gangue	Cemented Backfill	China (2)	Recycle & Reuse	[78,79]
06	Coal Gangue, Coal Bottom Ash, Fly Ash	Stabilized with cement to use as pavement base materials	China	Recycle & Reuse	[80]
07	Coal Mine Overburden	Sub-ballast in railway tracks	India	Recycle & Reuse	[81]
08	Coal Mine Waste (Power Plants)	Ceramic Tiles	Russia	Recycle & Reuse	[82]
09	Coal Fly Ash	Light-weight Gypsum Composites	Morocco	Recycle & Reuse	[83]
10	Coal Mine Overburden (Soft Shale)	Medium-strength composites	India	Recycle & Reuse	[16]

4. Discussion and Conclusion

This article presents a systematic literature review of different uses of coal mine wastes, such as overburden, tailings, coal dust, coal ash, etc., in the construction industry. The studies and examples show that coal mining waste can be successfully used as a value-added building material in the construction industry, integrating the 'R' principles of circular economy. Several environmental issues are related to coal mine waste disposal globally. The circular economy concept impacts the construction and coal mining industries by having environmental and economic benefits through waste use, reuse, and regeneration.

The article presents an overview of the use of coal mining waste in the construction industry as end products/ application areas. The first end-product, as presented above, is bricks. The coal mine waste, which contains 40-45% of overburden, has clay as one of the constituents. This overburdened clay has been used in making bricks, integrating the "Reduce" principle of circular economy, which is in the upper hierarchy of the circular economy principle. Other forms, such as tailings, coal dust from thermal power plants, and overburdened rocks, are also used to make bricks of the desired standard for reuse, recycling, repurposing, and replacing per circular economy principles. Although studies exist on using coal wastes in the construction industry to make bricks, the certification and policy for using waste-derived bricks in the construction industry will help make a more significant impact and thus achieve the goal of the circular economy.

Further, the article presents coal mining waste replacing fine and coarse aggregates and sand in construction composites. The coal mining waste in its different forms, especially overburden, was suitable for replacing sand and fine aggregates in mortar and concrete. Replacing river sand with coal mining waste-derived sand has environmental benefits, as river sand mining has severe environmental implications [85]. However, there are limited studies on replacing coarse aggregates using coal mining waste, with only one study conducted by [45] highlighting the same.

The literature review suggests maximum studies conducted on coal mining waste replacing cement in the construction industry. As per the review, the presence of oxides of iron, silica, alumina, and calcium [57] in coal mining waste, such as tailings, overburden, coal gangue, etc., demonstrates pozzolanic properties. The study highlights coal mining waste replacing cement, cement clinker, cement-based blended binder, alkali-activated binders, and cement-based composites. Most of the studies highlight the use of coal mining wastes as cement upon thermal activation. The studies on using coal mining waste in its natural form to replace cement are limited, with only one study by [46] included in the review. This suggests future research in this direction as the activation process is under the "Recycle" and then "Replace" principle of circular economy, which is at a lower hierarchy as recycling is resource-consuming.

The study also highlights the use of coal mining waste in making geopolymers because it has alumina and silica as significant elements. These geopolymers are a sustainable alternative in the construction industry, which helps achieve the circular economy's aim. The study presents the use of coal mining waste in making geo-polymer concrete, aggregates, and grouting material. With extensive studies highlighting the use of coal mining wastes in the construction industry, the studies presenting the application in structural components are meagre, with only one, as explored by [14], using coal mine waste in developing geopolymers that can be used as a lightweight structural material.

The use of coal mining wastes in developing green concrete, foam concrete, concrete for pavement, etc., is also presented in the literature review findings. With a very limited understanding of the use of coal mining wastes in the structural components, [16] highlighted the use of coal mine overburden in low to medium-strength composites. The literature also highlighted the use of coal mining wastes in road and embankment construction and backfilling in and around the coal mining site, whether underground or open pit. In the last section, a few other application areas of coal-derived waste, such as ceramic tiles and lightweight gypsum composites for temperature and humidity control, are highlighted in the review.

The literature review presents the state of the art of using coal mine waste in the construction industry. As highlighted in the above section, several environmental issues are related to coal mining wastes. Also, the resource-intensive construction industry has severe environmental and economic impacts. Using waste will mitigate the impact and help achieve a circular economy in the coal mining and construction industry. The following gaps in the study exist:

- The studies related to using coal mining wastes in the construction industry in the untreated form are limited. Waste treatment through the "R principle" of recycling or recovery is at a lower hierarchy in the circular economy. Therefore, to achieve the aim of a circular economy of waste elimination and regenerating ecosystems, the study proposes further research into using coal mining wastes in construction in untreated form.
- With extensive studies in the area, implementing the same in the construction industry is challenging. This requires a ready digital database of the amount and properties of the coal mining waste, which can help the construction stakeholders use them in the industry as applicable.
- One of the prime concerns on the coal mining site (open cast and underground) is overburden disposal because of the high stripping ratio. Although the literature suggests the usage of coal mine overburden in construction, a large amount of the same lie on the site. Further, more studies can be conducted using coal mine overburden directly into the construction industry, aiming towards zero waste on the coal mining site.
- Coal mining waste in the end products/ application areas mainly focuses on non-structural components. The use of the same in high-performance concrete and structural concrete is where further studies can be conducted.
- Several studies above demonstrate coal mine waste's pozzolanic properties in its raw, heat-treated, or thermally activated form. This is mainly due to iron, silica, alumina, and calcium oxides. Therefore, further research can be conducted on elements of high performance and binding, such as nano silica from coal mine waste, which can be used in concrete with healing and high durability properties.
- While there is strong evidence of coal mine wastes replacing sand and fine aggregates in concrete and mortar, the evidence of using the same replacing coarse aggregates in concrete products is limited.
- Using the latest tools, such as life cycle analysis, material flow analysis, and material passport (details of the end-product), can help derive better results and a more significant impact in the construction and coal mining industry.
- Another gap highlighted by [2] is the method for decreasing the high-water absorption properties of coal mining waste to make it more suitable for the construction industry.

Despite the growing research on the reuse and recycling of coal mine wastes, the amount of waste is very high and still lies on the site for disposal [22]. The systematic literature review reveals the knowledge of the end products/application areas of varied coal mining wastes in the construction industry. While the literature review reveals that the global scientific community has paid due attention to coal mining waste reuse and recycling in the construction industry, the realisation and adaptation of the same face challenges, and there is resistance to their usage from the construction stakeholders [13]. Also, the study highlights the knowledge gap (presented above) in the field based on the construction industry's current state. This needs to be addressed through wide-scale promotion, policy-level interventions, regulatory framework, and financial support through institutions. The growing research area, in alignment with circular economy principles, will benefit the construction and coal mining industries.

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