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Original Article

Physico-chemical characterization of clay raw materials from the Thicky quarry (Senegal) for the manufacture of earth bricks

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Clay, clay bricks, laterite, physico-chemical characterization

ABSTRACT

This study focuses on the physico-chemical characterization of the clayey raw materials of the Thicky quarry. We made a geotechnical, mineralogical, chemical and microscopic study of the laterite and the Thicky clay. Mineralogical analysis by X-ray diffraction (XRD) reveals that our clay consists mainly of quartz (Q), kaolinite (K), illite (I) and calcite (C) while laterite consists of quartz (Q), kaolinite (K), hematite (H) and calcite (C). The results of the chemical composition show the presence of SiO_2, Al_2O_3 and Fe_2O_3 in large quantities and also K_2O, CaO, MgO, Na_2O, TiO_2 and P_2O_5 in small quantities in our materials. Infrared spectroscopy reveals the presence of relatively broad absorption bands located around 3500 cm^{-1} which are related to phyllosilicates such as kaolinite or illite. Microscopic observation of clay and laterite samples shows that the texture is relatively compact, formed of several superimposed planar sheets with turbostratic disorder. The results obtained show that these clayey raw materials are poor in organic matter and calcium carbonates so they can be used for the manufacture of earth bricks.

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1. INTRODUCTION

To understand a material, it is essential to characterize it, that is to say to determine its properties. The characterization of a material in a general way is the whole of the processes of identification which allow to evaluate the properties of the material.

The use of earth-based materials in the building industry requires a good knowledge of their physicochemical properties in order to best meet the severe constraints imposed in the construction sector.

Today, more than any other material, soil is the basis of human construction. Its popularity, availability, ease of extraction and processing, ensure its use as a building material for the future. The chemical nature, the physical form, the surface state of the different materials constituting this material give it particular properties that can be used in several industrial sectors. Thus, to properly use a material in construction, it is important to know its specific characteristics. Raw materials are valued according to their physical and chemical properties, in relation to the available industrial

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processes. Depending on the origin of the raw materials, a small variation in one of these characteristics can considerably limit the field of application [1]. In an industrial context, it is necessary to be interested in the size, shape, density, specific surface and structural characteristics while identifying the chemical and mineralogical compositions of the raw materials. The earth used in construction must meet the technological requirements in order to obtain good quality products. Thus the raw materials must be poor in organic matter and have a good plasticity to facilitate the manufacture of bricks which it ensures the cohesion in raw [2].

Numerous material characterization techniques exist and are essentially based on various basic physico-chemical principles.

These are characterizations:

- geotechnical (natural water content, organic matter content, Atterberg limits, methylene blue test) ;
- microscopic;
- chemical (Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES), X-ray fluorescence, atomic absorption spectroscopy);
- mineralogical (X-ray diffraction, infrared spectroscopy).

In our study, we are interested in clay and laterite which are materials used in Senegal in construction. The objective of this work is to determine the physico-chemical properties of clay and laterite from Thicky quarry (Senegal).

2. MATERIALS AND METHODS

2.1. Presentation of the Site

The soil of Senegal contains a large number of clay and laterite deposits [3, 4].

The study was conducted on clay soil and laterite collected from the Thicky quarry. Thicky is located in the Thies region, in western Senegal at 14°50' N, 17°06′ W. The geographical map is shown in Figure 1.

2.2. Geotechnical Identification Tests

a) Natural water content (W)

The water content of the various samples was determined by the method of drying in the oven, following the experimental standard [XP CEN ISO/TS 17892-1, 2005] [1]. This involves determining the mass of free water eliminated by drying in an oven at a temperature of 105°C. The determination of the natural water content is based on the following formula:

$$W(\%)=\frac{m_h-m_s}{m_s}x100 \quad (1)$$

with

mh: mass of the soil sample in its natural state;

ms: mass of this soil sample after being oven dried at 105°C for 24 hours;

mh - ms = mass of water [2].

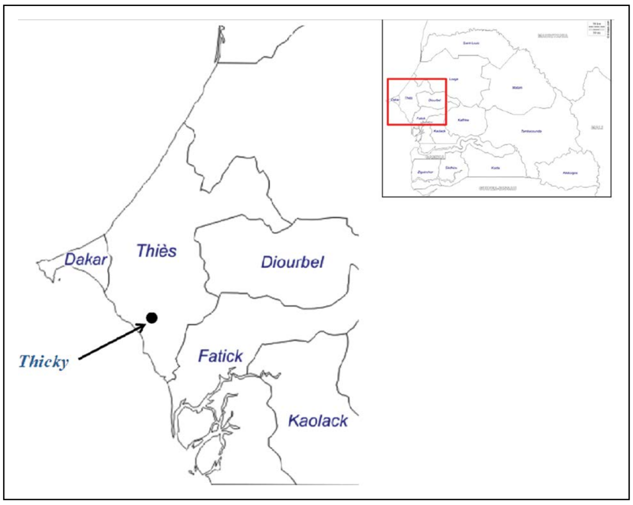

Figure 1. Position of Thicky in Thies region (Senegal).

b) Organic matter (MO) content

The organic matter (MO) content in the soil is equal to the ratio of the difference between the initial sample mass m and the sample mass after the reaction with hydrogen peroxide m' to the initial test mass m (100 grams) [2].

It was determined according to the french standard [NF P94-055, 1993] [5].

The organic matter (MO) content is calculated by the formula:

$$MO(\%)=\frac{m-m'}{m}x100 \quad (2)$$

c) Calcium carbonate ($CaCO_3$) content

The calcium carbonate ($CaCO_3$) content was determined according to the french standard [NFP94-048, 1996] [6], using the Bernard calcimeter.

The $CaCO_3$ content is calculated by the formula:

$$\%CaCO_3=\frac{m_t}{m}\frac{V_b}{V_t}\frac{(\theta_t+273)}{(\theta_b+273)}x100 \quad (3)$$

with

V_b: volume of carbon dioxide (CO_2)

V_t: volume of CO_2 after reaction with excess HCl

m: mass of soil sample

m_t: mass of pure $CaCO_3$

θ_b and θ_t: the test room temperatures, respectively, during the material test and during the pure calcium carbonate test, expressed in degrees Celsius.

d) Particle size analysis

Particle size analysis presents the percentage distribution of solid particles according to their dimensions.

For our raw materials, the particle size analysis was done according to two techniques: the coarser fraction (>80 µm) was analyzed by wet sieving, and the finer fraction (<80 µm) by sedimentometry according to the standard [NF P 94-057, 1992] [7].

e) Atterberg limits

Atterberg limits are tests that allow to define indicators qualifying the plasticity of a soil, and more precisely to predict the behavior of soils during earthwork operations, in particular under the action of water content variations. The purpose of these tests is to determine the liquidity limit W_L and the plasticity limit W_p of the raw materials. The difference between the liquidity and plasticity limits gives the plasticity index I_p.

The liquidity limit (W_L) was measured by the method of the dish of Casagrande and the plasticity limit (W_P) by the method of the roller. These measures were realized according to the french standard [NF P94-051, 1993] [8].

f) Methylene blue test

This is to determine the necessary amount of this dye to cover the internal and external surfaces of all the clay particles present in the sample. The test consists in measuring by dosage the quantity of methylene blue which can be adsorbed by the material suspended in water. The methylene blue value (MBV) was determined on the total sample according to [NF P94-068, 1998] [9].

The specific surface of particles can be determined by the amount of absorbed methylene blue (MB). Thus, the specific surface area (Ss) can be calculated from the following equation [10]:

$$S_S = \frac{m_{MB}}{m_S} \times \frac{A_v}{319.86} \times A_{MB} \qquad (m^2/g) \tag{4}$$

where

m_{MB} is the mass of the absorbed MB at the point of complete cation replacement, m_S is the mass of the soil specimen, A_v is Avogadro's number (6.02×10^{23} mol^{-1}) and A_{MB} is the area covered by one MB molecule (typically assumed to be 130 Å2).

g) Bulk density of raw materials

The bulk density of a material is the density of a cubic meter of the material taken in a heap, including both permeable and impermeable voids of the particle as well as the voids between particles. The sample to be tested is placed in a funnel closed by a metal plate. This plate is slid and the aggregates are collected in a cylinder of known volume (V). After removing the excess material, the mass (m) of the material is determined.

The bulk density is given by the following equation:

$$\rho_{app} = \frac{m}{V} \tag{5}$$

2.3. Mineralogical Analysis of Raw Materials

a) X-ray diffraction (XRD)

The mineralogical composition of the samples was determined by the X-ray diffraction technique. This technique allows the identification of the different crystallized mineral phases present in the sample. The general method consists in bombarding the sample with X-rays coming from a metal anode and which are first collimated by a divergence slit in order to produce a sub-parallel beam.

X-ray diffraction (XRD) analysis was carried out using a diffractometer model X'PERT Pro MPD PANALYTICAL. The equipment uses a copper anode tube (λ=1.789 Å), a standard resolution goniometer containing the geometry for performing measurements, symmetrical and asymmetrical configurations, a minimum step size of 0.002° and an X-ray proportional counter.

b) Infrared spectroscopy (IR)

Infrared spectrometry is one of the most widely used tools for the characterization and identification of organic molecules. It is used to determine the functional groups present in the material. The method of infrared spectroscopy requires the use of an infrared-transparent medium such as potassium bromide (KBr). The method involves grinding a few milligrams (0.5 to 1 mg) of the sample in the presence of dry KBr powder in an agate mortar. The mixture is then compressed in a hydraulic press.

The infrared spectra of our raw materials are obtained thanks to a Nicolet 6700 FT-IR apparatus on a recording interval included between 400 cm^{-1} and 4000 cm^{-1} medium infrared range.

2.4. Chemical Analysis of Raw Materials

The elemental chemical analysis consists in measuring in atomic form the different chemical elements that constitute the sample. The elemental chemical analysis of our raw materials was obtained by ICP-AES (Atomic Emission Spectrometry in an inductively coupled plasma). Nitric (HNO_3) (2 ml) and hydrofluoric (HF) acids (6 ml) were used for wet solution in a volume of 100 ml. The results were obtained under a pressure of 60 bar with a step of 0.8 bar/second, at the temperature of 240°C, with a power of 900 W, a ramp of 20 min and a step of 30 min.

2.5. Microscopic Observations by SEM

Scanning Electron Microscope (SEM) allows to observe the surface topography of a sample by scanning its surface with an electron beam and collecting the image formed. For our samples, clay powder was deposited on a carbonaceous pellet. This pellet is then metallized by covering it with a thin layer of metal by sputtering platinum to make it conductive. Once metallized, the sample is introduced into the SEM chamber for analysis.

3. RESULTS AND DISCUSSION

3.1. Geotechnical identification tests

a) Natural water content (W)

The results of the natural water content of our samples are presented in Table1.

Both samples have low natural water contents. However, the clay sample has a natural water content 4.78% higher than the laterite sample which has a water content of 1.50%.

Table 1. Natural water content of samples

Samples	Wet mass: m_h (g)	Dry mass: m_s (g)	Water content: W (%)
Clay	99.88	95.32	4.78
Laterite	100	98.52	1.50

Table 2. Organic matter content of samples

Samples	Initial test mass: m (g)	Mass after the reaction: m' (g)	Organic matter content MO (%)
Clay	100	95.09	4.91
Laterite	100	98.54	1.46

Table 3. Carbonate content and classification of the different samples

Samples	Carbonate content in %	Classification
Clay	5	Not marl
Laterite	1.25	Not marl

Variations in natural water content may be related to the amount of fine or clay elements contained in the analyzed samples.

b) Organic matter (MO) content

The results of the organic content of our samples are presented in Table 2.

The results show that Clay is weakly organic (OM = 4.91%) while Laterite is non-organic (OM = 1.46%) [11].

Therefore, their negative effect in the brick making process (stabilization or firing) is negligible.

c) Calcium carbonate ($CaCO_3$) content

The results of the calcium carbonate content of our samples are presented in Table 3.

Analysis of the results shows that both samples are classified as non-marl materials, since the calcium carbonate content does not exceed 10%.

d) Particle size analysis

Figure 2 show the results obtained. The results indicate that Thicky clay is composed mainly clay (45%), silt (47%) and sand (8%). Laterite is composed clay (8%), silt (20%) and sand (72%) [12].

e) Atterberg limits

The liquidity limit of the clay is 41.8% and that of the laterite is 38%.

Plasticity limit of the clay is 24.3% while the plasticity limit of the laterite is 21.9%. Plasticity indices of clay and laterite are 17.5% and 16.1% respectively [12]. These results show that the Thicky clay and laterite are moderately plastic [13].

f) Methylene blue test

The specific surface of the clay S_S (Clay) = 83.25 m^2/g shows that our clay contains illite [10]. The specific surface of laterite S_S (Laterite) = 22.76 m^2/g shows the presence of kaolinite [10].

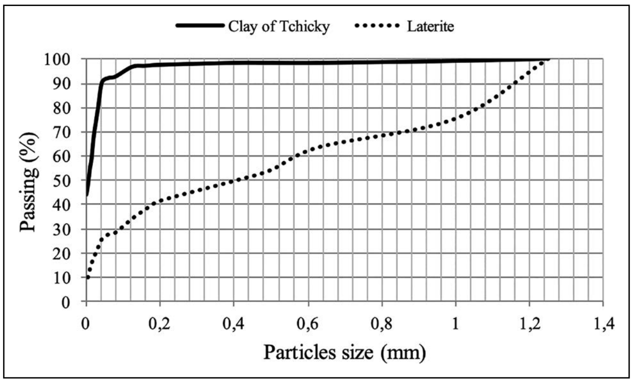

Figure 2. Particle size curves of raw materials (clay and laterite) [12].

The particle size results could also confirm these obtained values of specific surface area because Thicky clay contains more fine fraction (<2 µm) than laterite. The finer the clay the greater its specific surface area. Also, these specific surface area values suggest that both Thicky clay and laterite may contain clay minerals such as illite and kaolinite.

g) Bulk density of raw materials

The bulk density of clay is 1297 kg/m^3 and that of laterite is 1366 kg/m^3. Both materials have bulk densities of the same order of magnitude. But clay has a lower bulk density than laterite. So clay is less dense than laterite.

3.2. Mineralogical Analysis of Raw Materials

a) X-ray diffraction (XRD)

The diffractograms of the two raw samples are shown in Figure 3.

The results show that the Thicky clay (TR1) and laterite (TR2) are essentially composed of quartz and clay.

To differentiate the clays, it is therefore necessary to perform the clay slide test.

Thus, we performed various treatments to modify the inter-sheet space: heating, acidification, replacement of the interfoliar cation. Two of these treatments were successively applied, namely saturation by a polyalcohol (Ethylene-Glycol: E.G) and heating to 500°C on the oriented preparations already analyzed under natural conditions.

Saturation by a polyalcohol aims at swelling the clay mineral sheets by introducing, in the interfoliar space, ethylene glycol molecules of big size.

Heating allows the characterization of clay minerals particularly sensitive to heat such as kaolinite and other hydrated minerals.

We can therefore recognize the clay by looking at the evolution of the diffraction peaks at low angles according to the treatment. The XRD results of the oriented aggregate slides are shown in Figure 4.

The diffractograms of the oriented aggregate slides show that the Thicky clay (TR1) consists of kaolinite (7.13 Å) and illite (10 Å) while the laterite (TR2) consists of kaolinite (7.13 Å).

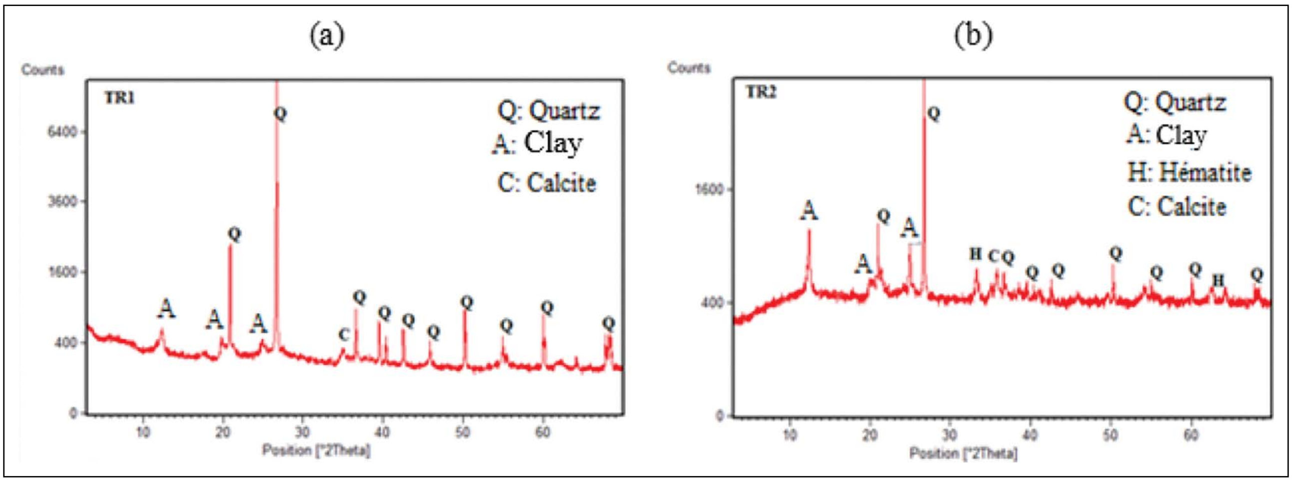

Figure 3. X-ray diffractograms of clay **(a)** and laterite **(b)** powders before using oriented aggregate slides.

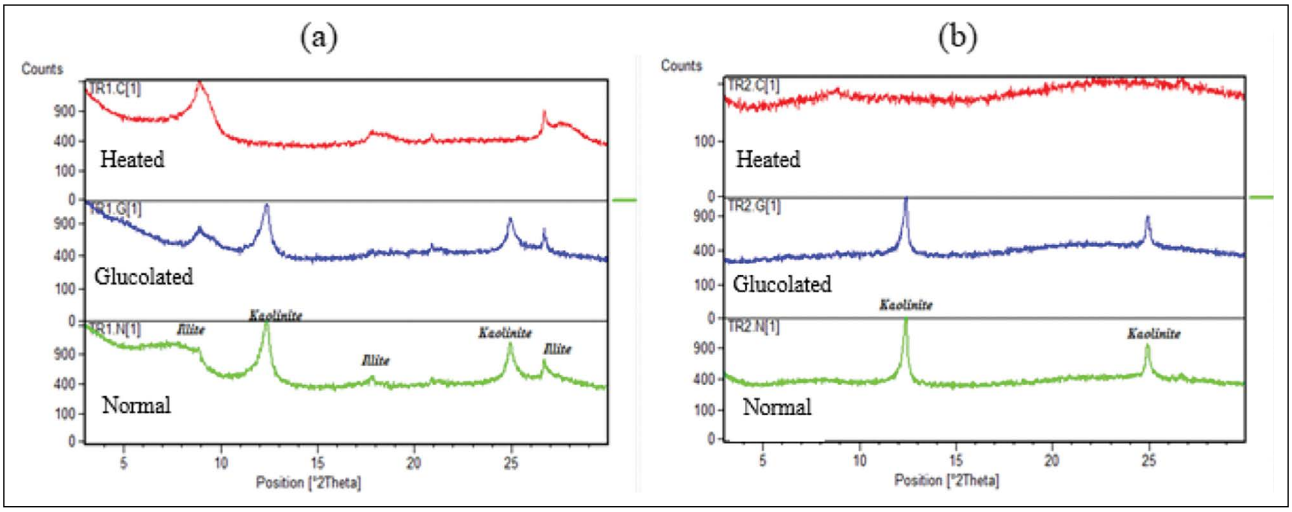

Figure 4. X-ray diffractograms of oriented aggregate slides of clay **(a)** and laterite **(b)**.

Table 4. Chemical composition of raw materials (wt %)

Sample	SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	PF
Laterite	23,00	22,77	33,67	<L.D.	0,13	0,16	0,03	0,11	1,32	1,63	16,14
Clay	74,04	12,16	4,12	<L.D.	0,69	0,19	0,16	1,24	1,04	0,10	7,05

Figure 5 shows the diffractograms of the two raw materials studied.

The XRD results show that the Thicky clay consists mainly of quartz (Q), kaolinite (K), illite (I) and calcite (C) while the laterite consists of quartz (Q), kaolinite (K), hematite (H) and calcite.

b) Infrared spectroscopy (IR)

Within the framework of our study, the infrared spectra of clay and laterite presented on Figure 6 are obtained thanks to an apparatus of type Nicolet 6700 FT-IR on an interval of recording ranging between 400 cm^{-1} and 4000 cm^{-1} medium infrared domain.

From these spectra, two essential groups stand out: the OH and H_2O groups (bands of 1640 cm^{-1} and 3456 cm^{-1}) characterizing respectively deformation and elongation vibrations; and the Si-O group (broad, intense band centered around 1027 cm^{-1}) corresponding to the bond valence vibration in clay minerals.

The relatively broad absorption bands located around 3500 cm^{-1} are related to phyllosilicates such as kaolinite or illite.

The absorption band around 1640 cm^{-1} may be due to the presence of interfoliar water.

Overall, the similar patterns of the IR spectra confirm the information provided by the X-ray diffraction. However, elemental chemical analysis will help to further this information by providing the amount in oxide of each chemical element.

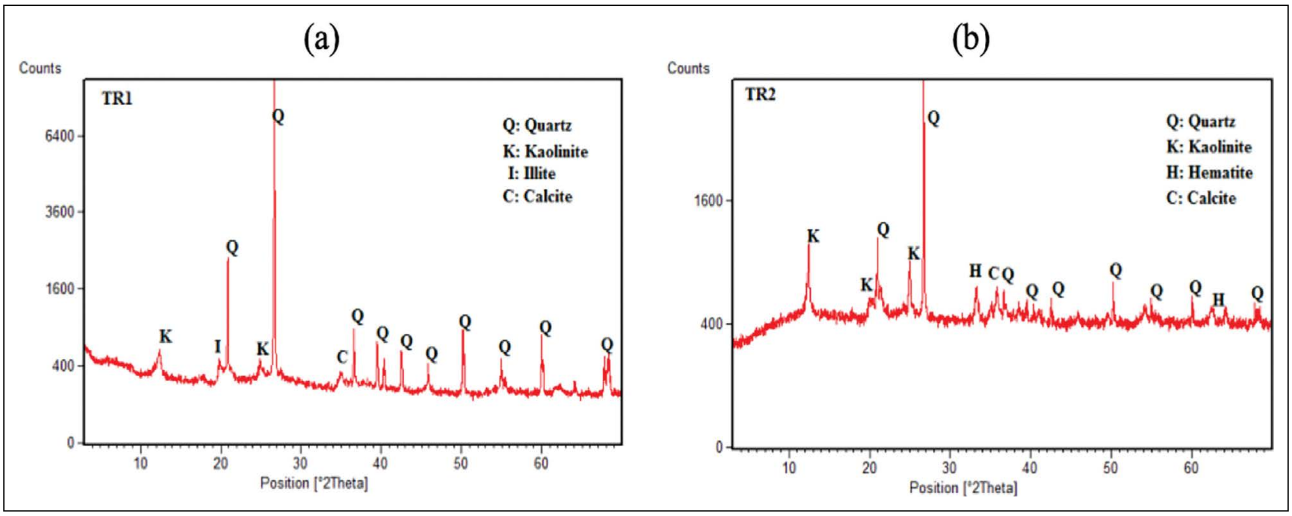

Figure 5. X-ray diffractograms of clay powders **(a)** and laterite **(b)**.

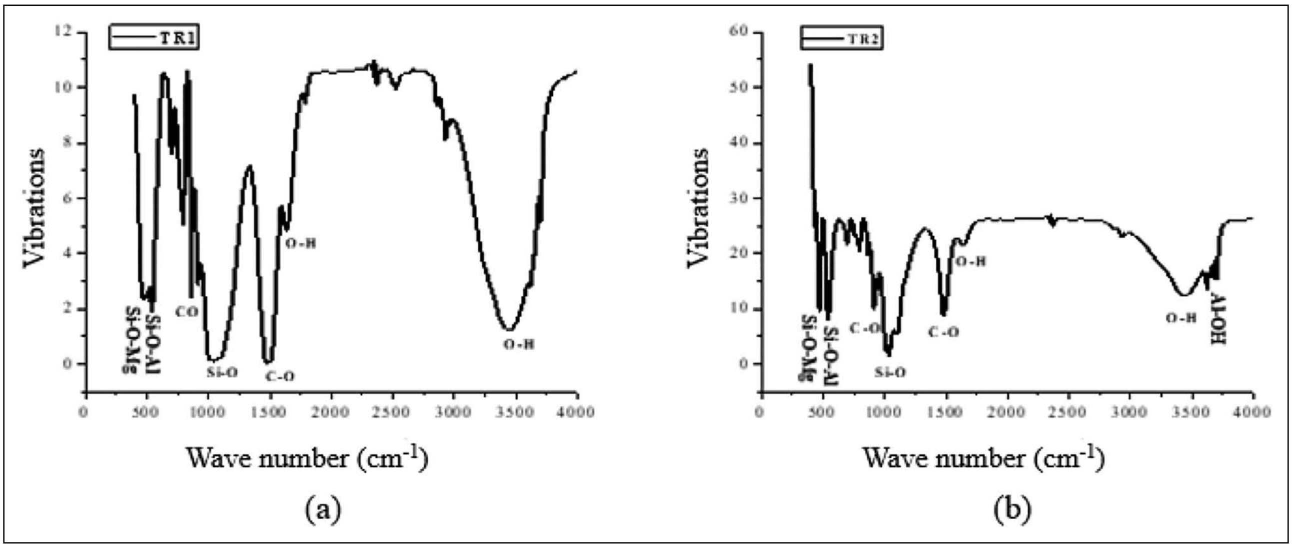

Figure 6. Infrared spectra IR of clay **(a)** and laterite **(b)**.

3.3. Chemical Analysis of Samples

Chemical composition of samples was determined by Bodian et al. [12].

The results of the chemical composition of the samples are presented in Table 4.

The results showed that SiO_2, Al_2O_3 and Fe_2O_3 are the most abundant oxides in both samples while K_2O, CaO, MgO, Na_2O, TiO_2 and P_2O_5 are present only in small amounts.

The SiO_2/Al_2O_3 ratio of the clay sample shows that there is a large amount of kaolinite in the material. The results also indicate a low illite content in the clay and the presence of a large amount of quartz in the clay than in the laterite.

3.4. SEM Microscopic Observations

The microstructure of the samples was observed and analyzed using a JSM-5400 scanning electron microscope (SEM).

Figure 7 and Figure 8 show the microscopic images of the different samples.

Microscopic observation of clay and laterite samples shows that the texture is relatively compact, formed of several superimposed planar sheets with a turbostratic disorder.

We observe the presence of quartz in both samples and that the matrix of the laterite sample is denser than that of the clay. We also note the presence of some pores and microcracks.

Both samples have an open texture with no preferential arrangement of the laminae. The random orientation reveals voids in the structure of the samples, and subsequently the appearance of a network of discontinuities.

4. CONCLUSION

In this paper, we have determined the physico-chemical characteristics of the clayey raw materials from Thicky quarry.

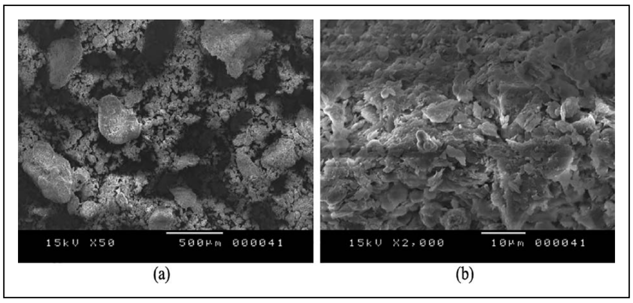

Figure 7. SEM images of clay.

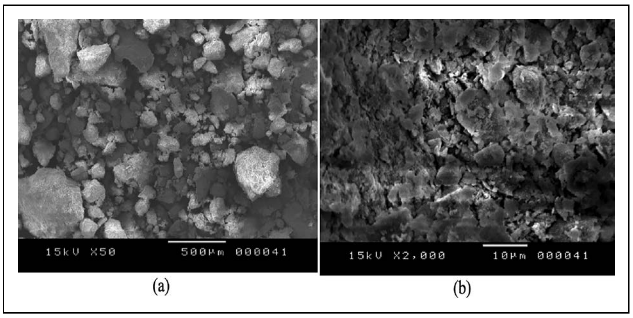

Figure 8. SEM images of laterite.

We determined the water content, organic content and calcium carbonate $CaCO_3$ content of the raw materials. The water content results show that both samples have low natural water contents.

The results of organic matter content show that the Clay is low organic while the Laterite is non-organic. Therefore, the negative effect of organic matter in the brick making process (stabilization or firing) is negligible.

The calcium carbonate content results show that both raw materials are classified as non-marl materials, since the calcium carbonate content does not exceed 10%. Both materials have bulk densities of the same order of magnitude.

Mineralogical analysis by X-ray diffraction (XRD) reveals that our clay consists mainly of quartz (Q), kaolinite (K), illite (I), and calcite (C) while laterite consists of quartz (Q), kaolinite (K), hematite (H), and calcite.

The results of the chemical composition show the presence of SiO_2, Al_2O_3 and Fe_2O_3 in large quantities and also K_2O, CaO, MgO, Na_2O, TiO_2 and P_2O_5 in small quantities in our materials.

Infrared results reveal the presence of relatively broad absorption bands located around 3500 cm^{-1} which are related to phyllosilicates such as kaolinite or illite.

Microscopic observation of clay and laterite samples shows that the texture is relatively compact, formed by several superimposed planar sheets with turbostratic disorder.

These results of the physico-chemical characterization show us that our two raw materials can be used in construction because they present the characteristics sought in the processes of manufacture of the earth bricks.

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DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declare that they have no conflict of interest.

FINANCIAL DISCLOSURE

The author declared that this study has received no financial support.

PEER-REVIEW

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Original Article

Investigation of İstanbul Kartal Example within the scope of urban transformation

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ABSTRACT

Due to the increasing migration from rural to urban areas in the world from past to present for various reasons, cities need to be renewed and transformed in future times with the irregular construction occurring in the cities. In this direction, States develop and implement urban transformation policies with various methods. In the study, the logic of urban transformation is discussed with definitions and the progress of urban transformation in history is mentioned with which aims and methods are carried out. In addition, the data obtained in the incident that occurred with the collapse of a building in Kartal district of Istanbul province in 2019 were mentioned and the construction in the area in question was discussed.

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1. INTRODUCTION

Cities around the world have seen dramatic and important changes since the second half of the 20th century. Urban transformation in Europe has been supported by varying levels of central government since the late 1960s [1]. With the industrialization since the 1980s, many countries have faced urban regression and collapse problems and have implemented urban regeneration strategies with the mentality of restructuring as a way out of this crisis situation [2].

Turkey's urban renewal policies currently applied in many cities. However, Istanbul, which has the feature of being the city with the largest population, is of great importance. The city, which is located in the earthquake zone, has survived many earthquakes in centuries and has great risk in terms of recurrence in the coming years. Accordingly, Istanbul, the city with the highest migration from the village to the city, is the capital of the country in the unhealthy and illegal construction. One of the most important examples is the migration of a house in the Kartal district. For many reasons, this unhealthy building has lost a large number of people.

2. CONCEPT OF URBAN TRANSFORMATION

Urban transformation; considering the urban problems and urban needs, it is the creation of a viable road map after examining the spatial, social and economic characteristics of a region. It is defined as the reorganization of plans, ownership and functions for the improvement of urban parts that have worn out, deteriorated, risk of earthquake or have become an economic, social and structural collapse area such as slum areas, illegal construction areas, old industrial sites [3].

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Figure 1. Istanbul's existing urban area.

Risky area in the Law No. 6306 on the Transformation of Areas Under Disaster Risk published in the Official Gazette dated 31.05.2012 and numbered 28309; It refers to the area determined by the President and at risk of causing loss of life and property due to the ground structure or construction on it. Reserve site; It refers to the areas determined by the Ministry or depending on the demand of TOKI or the Administration or to be used as a new settlement area in the applications to be carried out in accordance with the law numbered 6306. Risky structure; It refers to the structure within or outside the risky area, which has completed its economic life, or has been identified on the basis of scientific and technical data that it is at risk of collapse or severe damage [4].

2.1 History of Urban Transformation

City-related policies in the 1970s; It focuses on issues such as urban poverty, housing need, increased unemployment and long-term unemployment [5]. The adoption of a private sector-weighted urban transformation model in America by the governments in Europe in the 1980s started a new process [6]. With this process, the way for local governments to start making more partnerships with the private sector has been opened. In the 1990s, local people were integrated with the public-private sector, for the first time, multi-sector and multi-actor partnerships emerged. However, the emergence of this partnership has created a governance system that few people know at the local level and is becoming more and more complex [7]. In the 2000s, while concepts such as Urban Renaissance and Urban Power Association emerged, sustainability, diversity and local people parameters were effective in urban transformation [8].

A major problem with the proclamation of the Republic of Turkey the city, has been the reconstruction of cities ravaged during the war. This situation was also the main subject of the urban transformation actions of the period [9].

Another legal regulation made within the scope of combating illegal housing zones is the Slum Law No. 775, which came into force in 1966 and aims to transform slum areas into regular residential areas [10]. Within the boundaries of this law, 640 slum prevention areas were determined in 20,000 hectares of land and 30,672 houses were built for low-income families. In addition to this, within the scope of the aid to the self-builder, 40,000 houses were provided. Besides, 808 reclamation areas were defined in 16,000 hectares of land, and infrastructure services were provided for these areas, while 202 purging areas in 1,325 hectares of land were cleared of slums [11].

The latest legal development related to urban transformation is the Law on Transformation of Areas under Disaster Risk numbered 6306, dated 16.05.2012 [9]. The purpose of the law; In areas where there are risky structures other than these areas along with disaster risk areas, procedures for improvement, liquidation and renewal are defined to constitute their safe living environment.

2.2 Aims of Urban Transformation

Urban transformation, by its field of activity and nature, can affect the structure of the existing city and the physical, social and economic future of the people living there, and consequently to all the traditions of the city [12]. Urban transformation should be designed to serve five main purposes.

1. Urban transformation projects should investigate the causes of social disruption and make recommendations to prevent this deterioration.
2. Urban transformation projects should enable the city

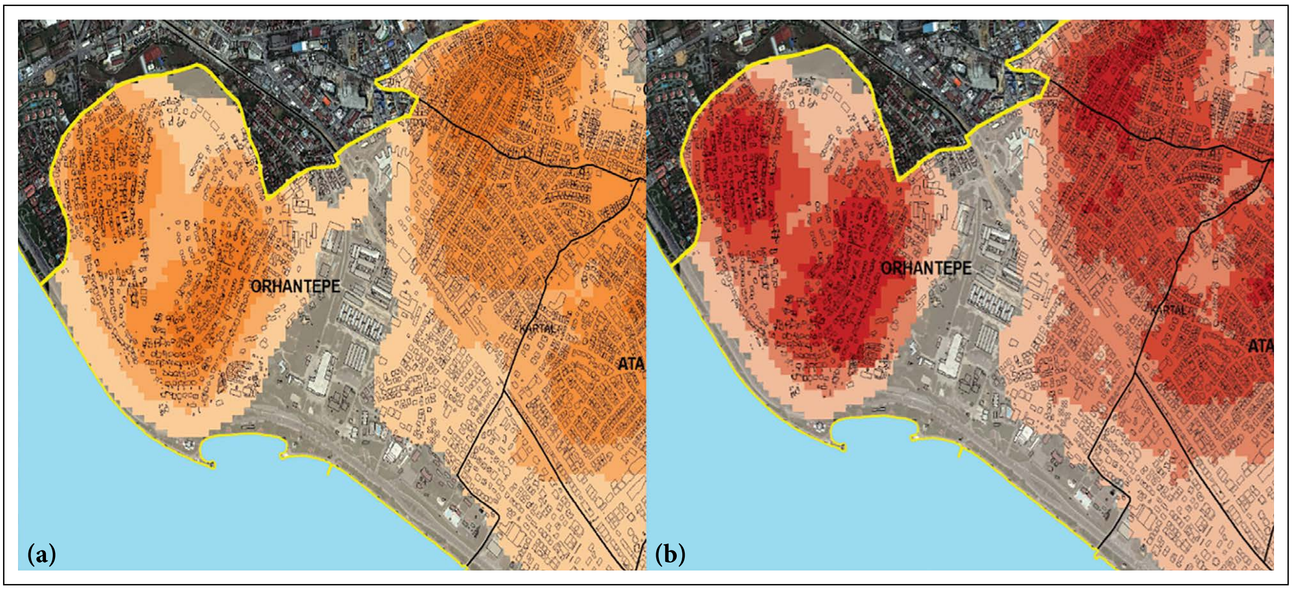

Figure 2. **(a)** Current structure stock risk distribution. **(b)** distrubiton of population at risk.

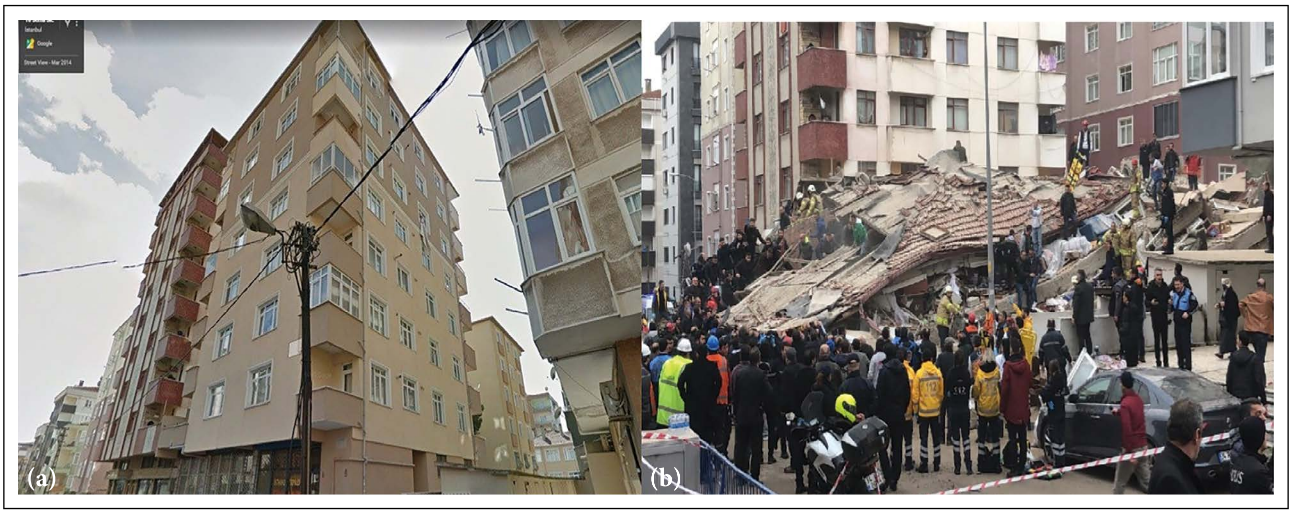

Figure 3. **(a)** Yeşilyurt Apartments before collapse. **(b)** Yeşilyurt Apartments after.

to be redeveloped according to the new physical, social, economic, environmental and infrastructure needs emerging in the rapidly growing, changing and deteriorating texture of the city.

3. The economic development model should be designed with the feature of enhancing urban welfare and quality of life.
4. Strategies that will bring economic vitality back into urban parts, which in urban areas that have become areas of physical and social collapse, should be developed and thus, it is aimed to increase the urban welfare and quality of life.
5. Strategies should be put forward for the most effective use of urban areas and to avoid unnecessary urban spread.

In Urban Transformation projects, one or more of these goals may come to the fore, depending on the characteristics of the region's problems and potentials [13].

3. İSTANBUL CITY KARTAL DISTRICT URBAN TRANSFORMATION EXAMPLE

The history of Istanbul dates back to 8,500 years ago and has been the capital of three universal empires, such as the Roman, Byzantine and Ottoman Empires. The area of Istanbul, which takes its name from the city and is located on the peninsula between Haliç and Marmara, is 5712 km^2. According to Turkish Statistical Institute data, the population of Istanbul is 15 million 519 thousand 267 people in 2020.

In Figure 2, the current general structure of Istanbul is shown, yellow areas show urban settlement areas, purple

Table 1. Observational report of the reserve building area

Apartment name	Constructional use	Structural system	Visual quality	Weak storey	Heavy cantilever	Short column effect
Ünal	House	Reinforced concrete frame	Medium	No	Yes	No
İhya	House	Reinforced concrete frame and concrete shear wall	Medium	No	Yes	No
Karalar	Mix	Reinforced concrete frame	Medium	No	Yes	No
Potur	House	Reinforced concrete frame	Medium	No	Yes	No
Uzunlar	Mix	Reinforced concrete frame	Medium	No	Yes	No
Nuri Bey	House	Reinforced concrete frame and concrete shear wall	Medium	No	Yes	No
Bahar	Mix	Reinforced concrete frame	Medium	No	Yes	No
Anadolu	Mix	Reinforced concrete frame	Medium	No	Yes	No
Uğur	House	Reinforced concrete frame	Medium	No	Yes	No
Çam	Mix	Reinforced concrete frame and concrete shear wall	Medium	No	Yes	No

Figure 4. The view after removal of the wreckage of Yeşilyurt Apartment.

regions show industrial areas and finally green areas indicate agriculture and green areas. Considering the current structure of Istanbul, the excess of green areas stands out, and the residential areas are predominantly concentrated in the coastal regions of the Bosporus overlooking the Marmara Sea.

Kartal; It is one of the important districts of Istanbul and approximately 3.12% of the total population of Istanbul live here. Its old name is called "Kartalimen" and its history dates back to the 6th century. The total number of buildings is 54.368 and the number of buildings declared as risky buildings within the scope of Law No. 6306 is 4.109. The district, which has a surface area of 278 km^2, consists of 20 neighbourhoods. Orhantepe neighbourhood, one of these neighbourhoods, constitutes 6% of the total population of Kartal district.

When Orhantepe District is analysed in general, it is observed that the building is not high-rise and is on the average of 5–6 floors. It was determined that the buildings were built between 1982–1994. Accordingly, when

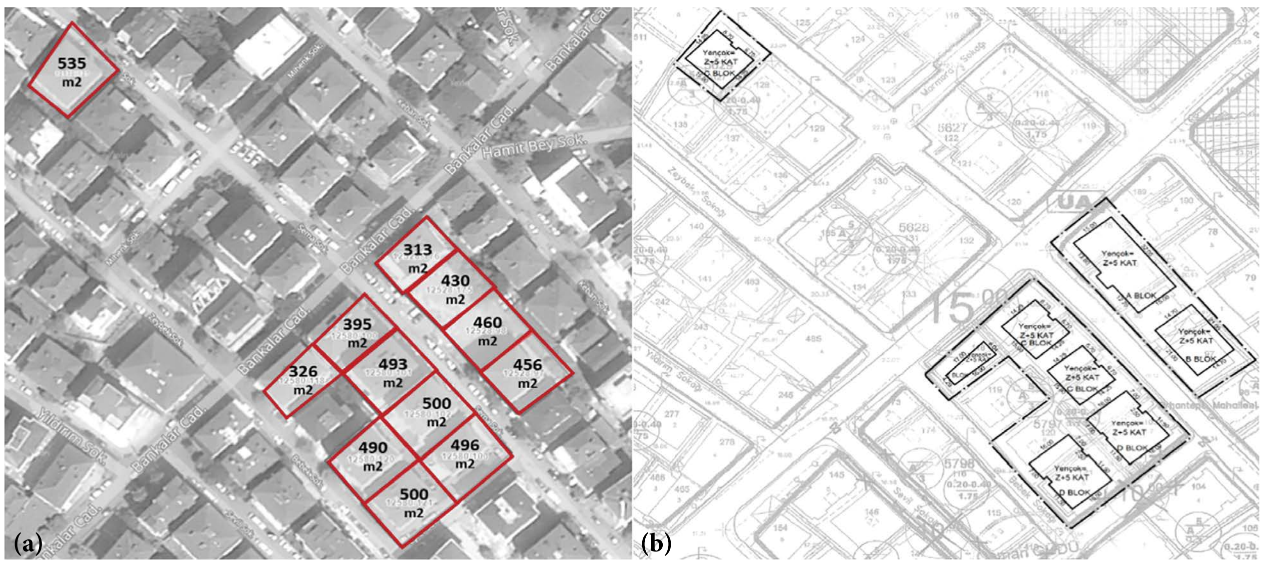

Figure 5. **(a)** The reserve building area. **(b)** The reserve building area plan.

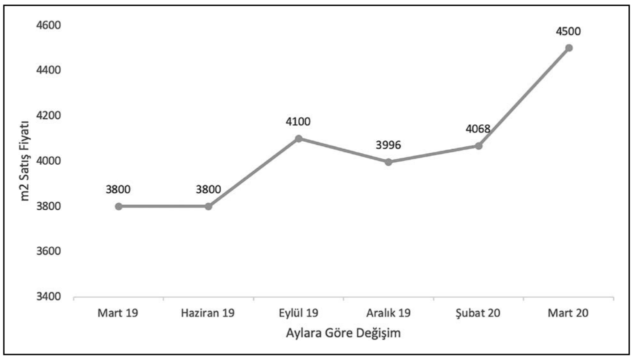

Figure 6. Orhantepe district real estate index.

the floor numbers and construction years of the buildings in the neighbourhood are taken into consideration and the ground coefficients are added to the results obtained from the core samples taken from risky structures, the map in Figure 6 appears. Areas with intensive risk generally show structures built before the 2007 earthquake regulation, structures built before 2000, when the ready-mixed concrete was widely used, and structures that did not receive engineering services under the building inspection law numbered 4708, which came into force in 2001. When these results are combined with the population, Figure 7 occurs. In this analysis, taking into account the settlement of the population, the condition of the distribution of the density by region is examined. When the two results are combined, on average, the data reveal that the same regions pose a risk. In any disaster, these regions will be heavily affected.

The building on the block number 12580 and 101 parcels located in Orhantepe District collapsed at an unexpected date on 06.02.2019 and 21 people died due to dent and 14 people were taken out from the dent. The mentioned structure was built in 1992 with a total of 9 floors, including basement + ground + 7 normal floors. In the license certificate of the building dated 20.10.1992, there is a 7-storey construction permit, including 1 basement floor + ground floor + 5 normal floors. The building was built as 2 floors more in violation of the license given by the relevant administration. Basement and ground floors are used for commercial purposes and other normal floors are used for residential purposes. Basement and ground floors are used for commercial purposes and other normal floors are used for residential purposes. The mentioned structure consists of 14 residences and 3 commercial units. The parcel area is 493 m^2 and the construction area is 1122 m^2 according to the current zoning plan. However, the current construction area of the building is 2209 m^2 with illegal floors.

As a result of observational determinations, it is understood that 5 buildings are residential + commercial and 5 buildings are housing. It is seen that the vast majority of buildings are built as reinforced concrete frames. Although the visual quality of the buildings is medium, the building order is separate. here is heavy cantilever in all buildings. The soft floor and short column effect were not observed.

After observational determinations from the mentioned structures, drilling core samples were taken within the scope of Law No. 6306 and necessary reinforcement stripping was done. As a result of the examination of the data obtained; It has been determined that the buildings are in a position to endanger the safety of life and property, and that there is intense deformation in the buildings, and accordingly, the buildings located in the mentioned parcels except İhya and Çam Apartments have been declared as “Risky Buildings” within the scope of Law No. 6306. The buildings identified as Risky Buildings were immediately evacuated by the authorities to avoid any danger and demolition of the buildings was carried out.

The Reserve Building Area was declared on 11.03.2019 within the scope of Law No. 6306, in order to prepare Yeşilyurt Apartments and the surrounding buildings for earthquake risk, and to provide a liveable area for the protection of life and property security. The 1/1000 scale Implementation Development Plan change and plan disclosure report for the mentioned Reserve Structure Area was approved on 14.03.2019.

The buildings within the borders of the Reserve Building Area consist of 129 residences and 29 workplaces. Following the announcement of the Reserve Building Area and the planning processes, the construction process of the construction in the area was started by TOKİ. Along with the mentioned project, 105 houses and 25 workplaces are produced. Approximately 11 months after the date of the incident, 06.02.2019, residences and workplaces were delivered to the beneficiaries on 23.01.2020.

After the delivery of the houses and workplaces, a significant change was observed when the real estate values statement around the area where the crash occurred. After the apartments were handed over to the beneficiaries in February, a significant increase was observed in March.

5. CONCLUSION

In the 19^{th} century, when the industrial revolution took place in Europe, all policies have changed and especially agricultural policy has entered into a great change and industry has been focused, and as a result, migration from rural to urban areas has increased. With the increase in immigration to the cities, unplanned urbanization started to occur. As a result, an unhealthy city has emerged for people, in this direction, the need for urban transformation in Europe has emerged and urban transformation practices have gained importance.

In our country, the first steps of urban transformation were taken in the 19^{th} century, the last century of the Ottoman State. The first steps were started to be taken in Aksaray in 1854 and it was tried to be extended by various laws with the 1960s. The first legal regulation issued with the expression of Urban Transformation is the Law on Transformation of Areas under Disaster Risk dated 16.05.2012 and numbered 6306. With this law, concepts such as Risk Area, Reserve Structure Area and Risky Structure have directed the transformation.

As a result of the collapse of a building in Kartal district of Istanbul province, 21 people died under the rubble. In this incident, two times more floors have been raised in violation of the license and its annexes given by the relevant administration, and the use of building materials that do not comply with the standards has created an environment for the dentist. Then, with the drilling core samples taken from the surrounding buildings, the buildings were declared as Reserve Building Area and the transformation was started, and new buildings were built within 11 months from the date of demolition and delivered to the beneficiaries.

In the studies carried out in the buildings where the collapse occurred and the 10 buildings around it, it was observed that almost all of the structures were used in unstructured and unwashed sea sand. In addition, considering the construction date of the buildings, it was observed that no ready-mixed concrete was used, no engineering services and no S420 ribbed iron was used, and these irons were exposed to great corrosion. It has been observed that similar techniques and materials were used in the buildings since it was built on similar dates in the mentioned settlement unit, and it is obvious that this will bring great destructions during a disaster.

Accordingly, this situation has revealed that urban transformation is too important to be ignored. There are many buildings like this and so on, and urban transformation needs to be accelerated before similar events occur. Otherwise, it is obvious that it will bring unavoidable material and moral results and it is of great importance that states change their main policies within this scope.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

FINANCIAL DISCLOSURE

The authors declared that this study has received no financial support.

PEER-REVIEW

Externally peer-reviewed.

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Review Article

The carbon footprint of construction industry: A review of direct and indirect emission

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ABSTRACT

The construction industry is considered to be among the major sectors that contribute significantly toward the emission of GHGs in our environment, which have a major effect on the climate change, and is approximately responsible for about 19 percent of the overall GHG emission globally, rendering it a pollution hotspot requiring urgent mitigation measures. Unfortunately, there are few studies on this subject to help construction companies meet their low-carbon targets. As a result, this paper reviewed the contributions of researchers across the globe towards carbon dioxide and other GHGs emissions from the industry. After a systematic review of some of these studies, it was found that the majority of researchers focused primarily on a specific feature of the construction industry, a case study of a particular country/city or region, using the Life Cycle Assessment approach. And, even those who have studied similar aspects such as cement or steel, have all used different methodologies, units, and techniques of reporting. As such, a comparison between the findings of the literature is unrealistic. Despite this, the scope of the emission from the construction industry is remarkably clear, and the carbon findings can be found throughout the literature.

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1. INTRODUCTION

The sudden growth in the greenhouse gas emissions within our environment was initiated from the industrial age till around the end of the eighteenth century [1]. Human activities are the primary contributors to all these emissions by the consumption of fossil fuels and desertification, which increases the amount of greenhouse gasses in the atmosphere at an immense rate [1, 2]. The increase in CO_2 has become the agreed level above which the consequences of climate change will become dangerous. The impact of these actions on humankind will be pervasive and lead to disruptive weather disasters, agricultural production instability, and public health challenges [3]. CO_2 is one of the dominant compound elements of the greenhouse gases and the principal causal factor of global warming [4]. It accounts for almost 82% of overall global warming, with the remainder coming from active greenhouse gases, meth-

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ane, and nitrous oxide [5]. The United States Energy Information and Administration estimated that by 2035, global carbon dioxide emissions would grow to around 7 percent higher than that in 2007 [6]. This suggests a potential rise in overall greenhouse gas emissions in many countries [6]. In his study, Wei Huang et al. [7] found a percentage rise in the annual average growth rate of the carbon footprint from buildings in the urban areas of Xiamen between 2005 and 2009. The carbon footprint growth between 2005 and 2007 was low, but it started to leap in 2008 [6]. In general, he found that there was an increase in the CO_2 emissions from the onsite construction activities, production of construction materials, building waste disposal, building use, and material transportation [7]. In addition to that, a November 2018 study from the United Nations World Meteorological Organization found that average global CO_2 concentration in 2017 exceeded 405.5 ppm, higher than that of 2015 and 2016, in which the concentration was 400.1 ppm and 403.3 ppm respectively [5]. The increment of these emissions in our atmosphere has caused the average global temperature to rise over the past 100 years by more than one degree Celsius [1, 8]. However, if left uncontrolled, the average temperatures of the earth may increase in the next coming 100 years by about 4.5 degrees Celsius or even more [1, 8]. Related research studies on economic, social, as well as other aspects were undertaken by various governments, organizations, and scholars, attempting to discover a low-carbon opportunity for sustainable development [9].

Global warming and several other environmental issues have stirred up strong international community concerns [9]. A series of international treaties have been signed, such as the "Bali Roadmap (2007), the UN Framework Convention on Climate Change (1992), the Copenhagen Agreement (2009), and the Kyoto Protocol (1997)", demonstrating the Government's commitment to respond to the global warming [9, 10]. Countries have made promises on pollution cuts and a plan of action according to the consensus has been finalized. Thus, the revolutionary ideas of the low-carbon life, low-carbon economy, carbon tax, low-carbon environment, and carbon trading, etc. have become the world's primary development strategy [9]. The 2015 to 2050 period can be considered as an era of transition phase toward net-zero emissions for both buildings as well as the physical environment reflecting the agreement reached by the numerous countries attending the Paris "COP 21" [11] in 2015 [4]. The conference saw a big milestone with various stakeholders from around the world agreeing that environmental change is a shared problem for humanity. They decided that steps and measures need to be implemented to keep the average temperature of the earth well below 2 degrees Celsius with attempts to restrict the warming around 1.5 degrees Celsius [1, 11]. Because of such agreements, Malaysia attempted to minimize about 40% per capita of its carbon and other GHG emissions by 2020 [12]. Also, the United Kingdom has set out big plans for the zero-carbon rating of all new household and commercial structures by 2016 and 2020 [13]. These are among the world's most advanced sustainable goals for the built environment [13]. The construction sector is making a rapid transition toward net-zero carbon and energy buildings infrastructure. Today, the NZE Buildings are more often affordable and widely available across many countries [14]. Unfortunately, there are fewer studies on this dimension to help companies meet their low-carbon targets. As such this paper focuses on examining the numerous contributions of researchers across the globe towards carbon emission from the construction industry. To this end, a systematic review of the carbon footprint studies of the construction industry were undertaken, highlighting the key results and gaps for future research.

2. METHODOLOGY

A total of 105 research papers were collected originally for the study focusing on the carbon footprint of the construction sector in general, of which only 61 were chosen for the study offering a more detailed overview of the construction industry from multiple perspectives [15]. Two steps were used to improve the quality and reliability of the literature review sources [13]. The first step was carried out using structured keywords in high-quality scientific repositories and journals, including Scopus, ScienceDirect, ResearchGate, Google Scholar, and the rest from other reputable journals such as Hindawi, Academic Journal of Science, American Journal of Engineering Research, Journal of Mechanical and Civil Engineering, Journal of Environment and Earth Science, etc. Most of these articles have been published or cited over the last ten years, to ensure reliability. Various keywords were used to obtain the materials, some of which include, carbon, carbon footprint, green building, sustainable construction, zero carbon, cleaner production, carbon assessment, sustainable building materials, rating system, etc. The search found that there were a small number of papers dealing specifically with the carbon footprint of the construction industry and very few major reviews in the field. The second step consisted of industry and university studies, governments and international agencies reports, internet and media publications, etc. most of which are frequently alluded to by numerous stakeholders in the construction industry when contemplating concepts related to carbon emission aspects. This study includes databases approved by well-established sources such as the IPCC report, the World Bank records, and UN studies and reports, etc. Majority of the review studies have some limitations [13], but, in this study, a strong emphasis was placed on discussing the general research results and content analysis by various authors on the carbon footprint of the construction sector, rather than targeting specific articles, writer, or a specific aspect of the industry. The process used in establishing this study is demonstrated in the Figure 1 [13].

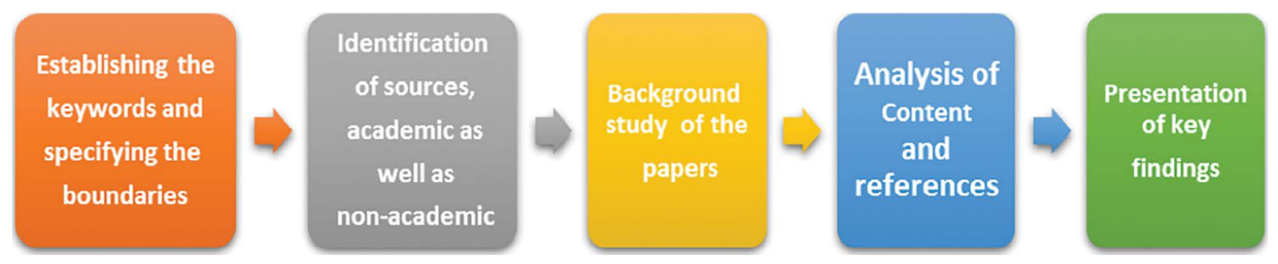

Figure 1. Literature review workflow (adopted from Zaid Alwan et al. 2015).

3. DEFINITION OF KEY TERMS

3.1 GHG

Greenhouse gas is a general name for a group of gases containing CH_4, CO_2, N_2O, SF_6, HFC, and PFC that usually trap heat from the sunlight in our atmosphere, and they are the essential causative factor for the persistent rise in the average temperature of the earth [16].

3.2 GWP

The potential of retaining sunlight heat by a particular GHG based on its absorption capacity in the atmosphere is called the global warming potential of that respective gas, which is determined over a given period. The primary objective of using GWPs is to transform a particular GHGs into CO_2e, which is the common method of global emission reporting [16].

3.3 CO_2e

CO_2 equivalent is a statistical scale that is used for the evaluation and measurement of different GHGs emissions on the basis of their GWP. The CO_2e of a particular gas can be obtained by the multiplication of its weight by its related global warming potential as described in equation 1. Below [16];
"$kgCO_2e$=(weight of the gas in kg)×(GWP of the gas)……… (1)"

3.4 CF

The carbon footprint is the cumulative quantity of GHG emissions generated by a person, firm, company, activities, or items, measured in CO_2e, and expressed in tons of carbon dioxide emissions per year [17].

3.5 LCA Approach

The Life cycle assessment aims to identify the environmental impact that any services or goods may have from its beginning (cradle) to its end (grave). The definition of cradle to grave concept implies that; the consequences from the extraction to final disposal of a product is properly considered over its entire life cycle, these, however, include all the activities in between such as production, transportation, packaging, processing, and other associated services [18–20].

4. CARBON FOOTPRINT OF CONSTRUCTION INDUSTRY

The construction industry is considered to be among the major sectors that contribute significantly toward the emission of GHGs in our environment through the mechanism of energy usage, various GHGs emissions associated with the energy production, and generation of waste, etc. And due to its significant contribution to higher GHGs emissions, Mahmure et al. [21] regarded the construction industry as one of the major drivers toward the persistent rise in temperature and global warming in general. Zaid Alwan et al. [13] added that construction has particularly impacted the environment through the production of waste, CO_2 emissions, change of land use, loss of biodiversity, and climate changes. However, these problems appeared more in developing countries, for example, 24% of the CO_2 generated in Malaysia comes from the construction sector [22], in India 130,477 Gg which is equivalent to 53.4% of national CO_2 [23], in Nigeria, the emission from the construction and manufacturing industries increased from 2557 to 23714 Gg of CO_2 equivalent between 2000 and 2015 reflecting approximately 827% increase as observed which is much above normal [24].

The "U.S. energy information and administration" reported that the CO_2 emission globally will increase, by the year 2035, to about 42.7% higher than that of 2007. Thus, showing an increment of greenhouse gases in many countries [6]. However, almost 40% of the total amount of these emissions are from the construction sector [10, 18, 19, 25], in which materials consume 10–20% out of the 40% from their production to demolition, including all the related emissions from their construction, transportation, and even renovation activities, etc. [19]. The "Sustainable Building and Construction Initiative (SCBI) of the United Nations Environment Program (UNEP)" reported that 30-40% of global energy demand is from the construction industry, which is expected to grow at an average of 1.5% to 3.4% rate in the next coming 20 years. In practical terms, the buildings contribute annually to the atmospheric emission with about 8.1 Gt of carbon dioxide [4, 26]. Tathagat D. et al. 2015 have recognized that buildings accounted for 33 percent or 7.85 Gt of all the global CO_2 emissions related to energy, and the emissions are forecasted to rise by 2030 to about 11 Gt or even much higher value of 15.6 Gt [10]. It can therefore be identified as a major contributing sector to carbon emissions that requires urgent mitigation for a sustainable future. Several studies on carbon emissions from the construction of various types of structures have been carried out by different researchers globally, some of which are presented in Table 1.

4.1 Direct and Indirect Emission

For a given construction project there are two major components of CO_2 emissions, Direct emission (operational CO_2) and Indirect emission (embodied CO_2) [49]. The operational (Direct) CO_2 emissions are usually generated from the consumption of energy at the site and during other various construction activities, while indirect carbon emissions are generated through the extraction of construction materials, production, transportation, demolition, and other non-building activities [9, 7]. The construction industry's carbon footprint is a concept that takes into accounts all the environmental impacts of CO_2 and other GHGs generated during various construction activities [25]. This includes all the emission impacts related to the materials used during the construction of the projects, as well as other emissions impacts related to the construction process itself, the service period of the structure, and even the various emissions associated with its demolition [27]. Shihui Cheng et al. 2020 [29] reported that direct energy use consists of only 9.8% of the construction process of his study with 358.8 kt CO_2, while the emissions from the material production constitute 90.2 percent, reaching 3310.2 kt. In his study, "Jingke Hong, et al. 2014" [27] indicated that the manufacturing of construction materials and the energy usage at the site were the major sources of CO_2 for both embodied and operational GHG emission, with 97 percent of the total emissions coming from indirect sources. He further identified numerous sources of GHG emissions from his research on GHG emissions during the construction process of a building in China, in which he categorized the emissions as direct and indirect, the summary of the categories is presented Table 2 [27].

Environmental impacts in construction projects arise from the extraction of raw material to its final disposal, this, however, includes all the related activities in between including manufacturing, installation, distribution, maintenance, and demolition, which are based on the LCA process [50]. Using a similar scenario, Wei Huang et al. 2017 [7] used five components to measure the CF of buildings; construction materials production, transportation, the construction process, direct energy usage, demolition, and waste disposal [7]. Apart from that, other studies follow a similar pattern while measuring, estimating, reporting, or developing tools related to the CF of the construction sector. Some of which include a study by J. Giesekam, et al. 2016 [52], Jennifer Monahan 2013 [3], Institute of Civil Engineers (ICE) [51], Fei fei Fu et al. 2014 [28] among others.

4.1.1 Extraction and Quarrying

It involves the extraction of precious minerals and other natural resources from the earth, typically from the ore, lode, vein, shale, reef, or deposit [53]. Mining is necessary to acquire any material that cannot be produced agriculturally or artificially in a laboratory or factory. Materials extracted by the mining process include gemstones, iron, potash, oil shale, coal rock, chalk, calcareous stone, clay, salt, and gravel, etc. [53], that are primarily used in the construction industry.

The mining sector produces an annual Greenhouse gas emission of between 1.9 and 5.1 gigatons of Carbon dioxide equivalents (CO_2e) [54]. Mineral resources are presently being drawn from the earth more frequently and often faster than in the last 4 to 5 decades [55]. The world consumes over 92b tons of metals, biomass materials, minerals, and fossil fuel every year, and this estimated value is increasing by about 3.2 percentage rate yearly [55]. Nonetheless, many countries are not having adequate mining industries, which means that they have to import fully or semi-processed products and base metal concentrates to meet their ultimate demand, however, as they import these materials and products, they also import and contribute to their related environmental impacts [56]. The mining activities including the extraction and processing of the minerals generate nearly 20 percent of the total air pollution health implications, and 26 percent of the total global carbon emissions [55]. Even with all those massive amounts of carbon emissions, the sector has just begun to set carbon mitigation targets [54]. Theoretically, extraction can be decarbonized completely (except for fugitive methane) [54].

4.1.2 Materials Production

As new buildings are becoming more energy-efficient, material-related emissions account for a higher percentage of their overall impact on environmental changes. Developers, builders, architects, and planners are becoming more mindful of the building material's impacts on climate change and are gradually incorporating considerations of environmental issues while selecting techniques and procurement of various construction materials [2]. Feifei Fu et al. (2014) [28], reported that; 97 percent of the overall carbon emission of his study is from embodied construction materials, with the remaining 3 percent coming from cradle to site transportation. He further found that the main contributors to these emissions were blocks, steel, and concrete used during the construction, which together contributed to more than 60 percent of the total emission [28]. A similar report by Jingke Hong et al. (2014) found the top 10 major construction materials that accounted for about 86.6% of all carbon emissions of his study, with steel and concrete as the best two [27].

The construction sector is society's largest energy user which consumes about 40% of all the generated energy through the production of building materials such as steel and cement [10, 57]. In particular, materials production needs more energy, generates more waste, and pollutes natural resources [58]. The fast expansion and rapid development of the manufacturing industry would inevitably lead to an increase in the overall CO_2 emissions globally [59].

Table 1. Reviewed studies on various type of civil engineering projects

Reference	Country	Referenced from	Type of structure	Main material	Floor area	Method	Quantity of CO_2
Jingke Hong et al. (2014) [27]	China		Residential complex	Reinforced concrete structure	11508 m^2	LCA Process	8707004 kg CO_2e
Feifei Fu et al. (2014) [28]	UK		Single story training center	Masonry wall Timber frame wall	180 m^2	LCA process	432 kg CO_2/m^2 363 kg CO_2/m^2
Shihui Cheng et al. (2020) [29]	China		High speed railway line	Concrete and steel	120 km	Hybrid I-O LCA	3669.0 Kt CO_2
Shashwath Sreedhar et al. (2016) [16]	India		Highway pavement construction	Bituminous concrete Portland cement concrete		Computer program took lit	3.09×107 $KgCO_2e$ 3.89×107 $KgCO_2e$
Rossi et al. (2012) [30]	Belgian	Jingke Hong et al. (2014) [27]	Residential building	Masonry Steel	192 m^2	Process LCA	189 kg CO_2e/m^2 164 kg CO_2e/m^2
Surahman and Kubota (2013) [31]	Indonesia	I. C. Ezema et al. (2016) [4]	Simple residential house Medium residential house Luxury residential house		57 m^2 127 m^2 300 m^2	Hybrid LCA analysis	575 kg CO_2/m^2 721 kg CO_2/m^2 942 kg CO_2/m^2
Konig and Cristofaro (2012) [32]	Germany	Jingke Hong et al. (2014) [27]	Residential building		970–7292 m^2	Process LCA	430 kg CO_2e/m^2 (average value)
Abanda et al. (2014) [33]	Cameroon	I. C. Ezema et al. (2016) [4]	Houses	Mud brick Cement blocks		ICE database	228 kg CO_2/m^2 397 kg CO_2/m^2
Brunklaus et al. (2010) [34]	Sweden	Jingke Hong et al. (2014) [27]	Residential building	Concrete, wood		Process LCA	400 kg CO_2e/m^2
I. C. Ezema et al. (2016) [4]	Nigeria		Residential block	Reinforced concrete frame	720 m^2	Survey and LCA methods	2395 kg/m^2
Blengini and Carlo (2010) [35]	Italy	Jingke Hong et al. (2014) [27]	Residential building	Reinforced steel concrete	250 m^2	LCA	"770 kg CO_2e/m^2"
"Nassen et al. (2007)" [36]		Jennifer Monahan (2013) [3]	Detached dwelling Multi-occupancy dwelling			LCA Cradle to occupation	264 kg CO_2/m^2 360 kg CO_2/m^2
Ortiz et al. (2010) [37]		Jingke Hong et al. (2014) [27]	Residential building	Bricks based Not mentioned	125 m^2 108 m^2	Process LCA	246 kg CO_2e/m^2 257 kg CO_2e/m^2
Hacker et al. (2008) [38]	UK	Jennifer Monahan (2013) [3]	Light weight timber frame Heavy weight concrete	Timber Concrete		LCA Cradle to occupation	492 kg CO_2/m^2 569 kg CO_2/m^2
Williams et al. (2012) [39]	UK	Jingke Hong et al. (2014) [27]	Construction of office complex	Reinforced steel concrete		LCA	467 kg CO_2e/m^2
Jennifer Monahan (2013) [3]	UK		Timber framed house with larch cladding	Larch and timber	83 m^2	LCA	405 kg CO_2/m^2

Table 1 (cont.). Reviewed studies on various type of civil engineering projects

Reference	Country	Referenced from	Type of structure	Main material	Floor area	Method	Quantity of CO_2
			Timber framed house with brick cladding	Brick and timber			535 kg CO_2/m^2
			Conventional house, made with masonry cavity wall	Masonry			612 kg CO_2/m^2
Wallhagen et al. (2011) [40]	Sweden	Jingke Hong et al. (2014) [27]	Office building	Reinforced concrete	3537 m^2	Process LCA	160 kg CO_2e/m^2
Atmaca and Atmaca (2015) [41]	Turkey	I. C. Ezema et al. (2016) [4]	High-rise 13 floor apartment Low-rise 3 floor residency	Reinforced concrete		LCA	5222 kg CO_2/m^2 6485 kg CO_2/m^2
Wu et al. (2012) [42]	China	Jingke Hong et al. (2014) [27]	Office building	Reinforced concrete	36,500 m^2	Process LCA	803 kg CO_2e/m^2
Li, et al. (2013) [43]	China	I. C. Ezema et al. (2016) [4]	Residential building		1460 m^2	LCA	1238 kg CO_2/m^2
"Van Ooteghem and Xu (2012)" [44]	"Canada"	Jingke Hong et al. (2014) [27]	Commercial building	Hot-rolled steel Structure made with a heavy "Pre-engineered steel" "Steel-PREDOM" "Timber-PREDOM"	586 m^2	LCA	549 kg CO_2e/m^2 517 kg CO_2e/m^2 355 kg CO_2e/m^2 522 kg CO_2e/m^2 451 kg CO_2e/m^2
"Kua and Wong (2012)" [45]	Singapore	Jingke Hong et al. (2014) [27]	Commercial building	Reinforced steel concrete	52,094 m^2	LCA	"121 kg CO_2e/m^2"
"Yan et al. (2010)" [46]	"Hong Kong"		Commercial building	Reinforced concrete	43,210 m^2	LCA	"525 kg CO_2e/m^2"
Alam and Ahmad (2013) [47]	Bangladesh	I. C. Ezema et al. (2016) [4]	Residential building	Stone Bricks	502 m^2	LCA	9941 kg/m^2 1274 kg/m^2
Filimonau et al. (2011) [48], (adjusted)	UK	Jingke Hong et al. (2014) [27]	Hotel		3300 m^2	Process LCA	761 kgCO_2e/m^2

Table 2. GHG sources

Direct emission	Indirect emission
1) Energy consumption of construction equipment such as; • Bulldozers • Excavator • Piling machine etc. 2) "Onsite transportation" 3) "Construction electricity use" 4) "Assembly and miscellaneous works" such as; • "Welding process" • "Chemical use" • "Waterproof paint" • "Reserve holes" • "Pipe binder etc." 5) "Onsite worker activities" such as; • "Cooking oil consumption" • "Fugitive discharge from septic" • "Water production and discharge"	1. Building materials productions and transportation 2. "Transportation of construction equipment" 3. "Offsite staff activities, including;" • "Offsite electricity use" • "Staff transportation" • "Fugitive discharge from septic" • "Water production and discharge"

Adopted from Jingke Hong et al. 2014 [27].

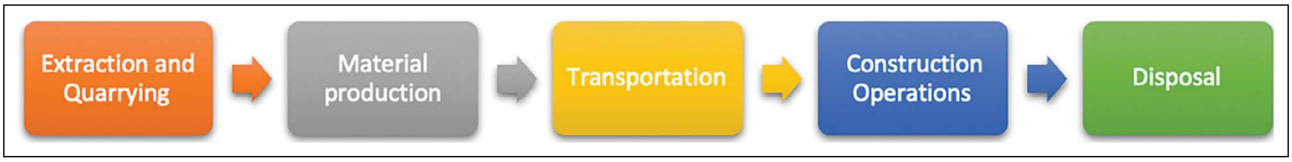

Figure 2. Process of carbon generation from construction industries [3, 7, 28, 51, 52].

Table 3. CO_2 emission coefficient and waste rate for the production of construction materials

Materials	Timber	Aluminium	Glass	Cement	Steel
CO_2 emission coefficient of the material	0.200	9.677	1.582	1.169	3.672
Rate of waste	5%	2.5%	5%	2.5%	5%

Source: [7, 62, 63].

Apart from that, the value-added of the manufacturing sector was found to be the most significant positive driver of the CO_2 emissions growth [60]. Jian Liu et al, 2019 [59] state that the carbon dioxide emissions from the manufacturing sector in china increased by around "220.77%" from 1995 to 2015 and contributed to about "58.27%" of the country's carbon dioxide emissions. Nigeria is reported as one of the highest emitters of CO_2 from the manufacturing and construction industries in Africa, with a total fuel combustion rate of about 12.2 percent in 2014 [61]. Another study by Wei Huang et al. (2017) revealed that the CO_2 emissions from the production of material for construction purposes are responsible for more than 45 percent of the overall footprint of the industry. while on the other hand, the emissions from the use of resources accounted for about 40 percent, and carbon emissions from the transportation of building materials were just about 1%.[7].

The carbon dioxide emissions from the production of materials including, iron, flat glass, aluminium, timber, steel, and cement are generated through the life cycle process of the production [7]. In which the manufacturing process of iron and steel produces the highest volume of the total carbon emissions from all these materials [56]. Chen W Q et al. [62], and Zhu Y et al. [63] conducted a research study on the cases of environmental emissions and LC energy use from the production of materials used in residential constructions, in which they found the CO_2 emission condition for the production of some of the major construction materials including timber, aluminium, glass, cement, and steel as described Table 3.

The embodied CO_2 of materials used in a particular building is determined by the amount and types of various materials used during the construction process. The choice of suitable construction materials therefore directly defines the type of the energy source as well as the quantity of CO_2 emission based on material type, material quality, and the emission factor of each of the materials [28]. Some of the reviewed studies related to the carbon footprints of various construction materials are tabulated Table 4.

In general, the production of construction materials contributes significantly to the overall CO_2 emissions of the industry, with 2/3 of the total emissions mainly coming from the production of concrete and steel. However, the emission from these two materials is connected to their manufacturing processes including cement production and steel processing, which are among the economic sectors that are heavily dependent upon fossil energy usage [27].

4.1.3 Transportation

Transportation is the movement of people and goods from a particular location to another. It includes the transportation of various construction personnel, machinery, and materials such as steel, reinforcement, fine and coarse aggregates from the original supply source to the project site [28]. Transportation and supply of various materials and equipment often affect our environment significantly by the mechanism of additional energy consumption while moving and conveying them from the production to the assembly points and finally to the project site [58]. Due to these environmental effects, this transportation activity has drawn considerable attention as it is among the primary contributors toward higher CO_2 emissions globally [66]. "The Intergovernmental Panel on Climate Change (IPCC)" reported that the transport industry generates about 13 percent of the overall global GHG emissions annually [IPCC Climate Change (2007)] [16]. In his study, Yi Yang, et al. (2019) reported that, the carbon footprint of some major megacities including New York, London, Tokyo, and others are mainly connected to building constructions, and transportation activities, with the manufacturing sector not having more than 10% proportions [67]. Also, according to the Asian Development Bank [68], transportation contributes to about 13% of the total GHGs globally and 23% of CO_2 emission related to energy usage [68], out of which 3/4 of all the transportation-related emissions is directly related to the road freight traffic [68]. Road freight in the UK accounts for about 22 percent of the transportation sector's emissions, or 6 percent of the country's total CO_2 emissions [66]. In the United States, freight transportation accounts for about 78 percent of the total emission from transportation activities, and the percentage of the overall transportation's GHG emissions rose from about 24.9 percent in 1900 to about 27.3 percent in 2005 [66]. Related figures were also reported in China, where the road freight activities generate about 30% of the total transportation sector's CO_2 emissions [66].

A study by Raymond J. Cole [69, 70] found that employee transportation to and from the construction site typically led to higher CO_2 emissions than either the on-site machinery used or the movement of materials and equipment to the job site [69, 70]. The research study finally revealed that, based on the assembly of the work, the movement of workers to and from the work site added between 5 to about 85 percent of the entire Greenhouse gas emission [69, 70]. In addition to these studies, other researchers have identified the emissions resulting from the transportation of different building materials with regard to either fuel consumption, loads, or distance, some of which include the following Table 5.

Transportation emissions are rising faster than in other energy-using industries and are forecasted to increase worldwide by 80% between 2007, and 2030 [66]. Many scientific consensuses exist on the need to drastically minimize our GHG emissions to prevent severe environmental changes such as global warming in the upcoming years [68].

4.1.4 Construction Operation

Throughout the stages of major construction projects such as foundation works, road construction, site preparation, and maintenance activities, etc., diesel-driven construction machinery contributes significantly towards air pollutions and GHGs in the environments [73]. Pollutants from equipment such as carbon monoxide (CO), PM 2.5, PM 10, and Nitrogen oxides endanger our environment and pose a potential risk to the health of the people and other living species [73]. Different construction activities and processes have different working requirements and conditions, which affect the equipment's working period under various engine status and load conditions [7]. For construction works such as hauling, digging, compaction, packing, lifting, and backfilling, etc. "off-road construction equipment" is usually deployed for the operation [73]. The off-road equipment's carbon emissions come from the fuel and energy usage during these activities [28]. Carbon dioxide is produced from the burning of fossil fuel through activities involving power generation, production of various materials such as concrete, and combustion of solid waste [20].

However, it is difficult to quantify and measure the actual emissions from the equipment as they fluctuate with many impacting factors [73]. Estimating the exact amount of emissions is a complex job due to the lack of monitoring data and measurement. The measurement of the emission nowadays can only be performed based on the time of operation, specified emission rates, deterioration of equipment, and load factors. The emission can also be calculated based on the amount of fuel consumed by the engines during a given time. Pollutants and CO_2 emissions from the gasoline-based construction vehicles are major risks to climate, industry, government, and the public in general [73] as they release a substantial volume of GHGs into the environment. Hence, the selection of suitable construction management techniques in the use of construction equipment, human activities, and transportation should be emphasized [27].

Table 4. Reviewed studies on the CO_2 emission of 18 construction materials

S/N	Material	Type of building	Reference	Country	CO_2 emission
1	Cement	Type of building	Jingke Hong et al. (2014) [27]		0.759 kg CO_2/kg
		Residential complex	Shashwath Sreedhar et al. (2016) [16]	India	0.8207 kg CO_2e/kg
		Highway construction	Hammond & jones (2008) [64]	UK	0.83 kg CO_2/kg
			Hammond & jones (2011) [45]		0.95 kg CO_2e/kg
			Mahmure Övül Arıoğlu Akan et al. (2017) [21]	Turkey	1.165 kg CO_2e/kg
2	Steel	Highway tunnel	Jingke Hong et al. (2014) [27]		1.45 kg CO_2/m^3
		Residential complex	Shashwath Sreedhar et al. (2016) [16]	India	4.67 kg CO_2e/kg
		Highway construction	Jennifer Monahan (2013) [3]	UK	3.81 kg CO_2/kg
		Timber frame house	Mahmure Övül Arıoğlu Akan et al. (2017) [21]	Turkey	0.43 kg CO_2e/kg
		Highway tunnel	Purnell (2013) [43]		0.43 kg CO_2e/kg
3	Timber	Residential complex	Jingke Hong et al. (2014) [27]		583 kg CO_2/m^3
4	Glass	Residential complex	Jingke Hong et al. (2014) [27]		1..09 kg CO_2/kg
5	Aluminium	Residential complex	Jingke Hong et al. (2014) [27]		5.9 kg CO_2/kg
		Timber frame house	Jennifer Monahan (2013) [3]	UK	8.231 kg CO_2/kg
6	Crushed sand	Highway tunnel	Mahmure Övül Arıoğlu Akan et al. (2017) [21]	Turkey	0.005 kg CO_2e/kg
7	Concrete	Timber frame house	Jennifer Monahan (2013) [3]	UK	0.1741 kg CO_2/kg
		Residential complex	Jingke Hong et al. (2014) [27]		261 kg CO_2/m^3
8	Bitumen	Highway construction	Shashwath Sreedhar et al. (2016) [16]	India	0.426 kg CO_2e/kg
9	Gypsum	Timber frame house	Jennifer Monahan (2013) [3]	UK	0.30615 kg CO_2/kg
10	Brick	Timber frame house	Jennifer Monahan (2013) [3]	UK	0.519 kg CO_2/kg
11	Ceramics tile	Conventional building	Judit Nyári (2015) [19]		0.6125 kg CO_2e/kg
12	Copper sheet (roof)	Conventional building	Judit Nyári (2015) [19]		0.9732 kg CO_2e/kg
13	Wooden door	Conventional building	Judit Nyári (2015) [19]		18.450 kg CO_2e/piece
14	Wooden window	Conventional building	Judit Nyári (2015) [19]		42.175 kg CO_2e/piece
15	Fly ash	Highway tunnel	Mahmure Övül Arıoğlu Akan et al. (2017) [21]	Turkey	0.01 kg CO_2e/kg
			Purnell (2013) [43]		0.01 kg CO_2e/ton
16	Super plasticizers	Highway tunnel	Mahmure Övül Arıoğlu Akan et al (2017) [21]	Turkey	0.01 kg CO_2e/kg
17	Lime	Highway construction	Shashwath Sreedhar et al. (2016) [16]	India	2.81 kg CO_2e/kg
18	Aggregates	Highway construction	Shashwath Sreedhar et al. (2016) [16]	India	0.0028 kg CO_2e/kg

Table 5. CO_2 emission from transportation activities

Reference	Country	Materials	Load	CO_2 emission
Ozen & Tuydes (2013) [71]	Turkey			2.66 kg CO_2/ litre
DEFRA (referenced from Mahmure Övül Arıoğlu Akan et al. 2017) [21]	UK		24 ton	0.918 kg CO_2/km
Thomas et al. (2019) [72]			30 ton	33.81g CO_2/ton per km
Wei Huang et al. (2017) [7]	China	Cement		28.57/100 m^2
Mahmure Övül Arıoğlu Akan et al. 2017) [21]	Turkey		24 ton/round	1.01 kg CO_2/km
Wei Huang et al. (2017) [7]	China	Steel		9.71/100 m^2
Mahmure Övül Arıoğlu Akan et al. 2017) [21]	Turkey		24 ton/round	0.95 kg CO_2/km
Wei Huang et al. (2017) [7]	China	Sand		57.9/100 m^2
Mahmure Övül Arıoğlu Akan et al. 2017) [21]	Turkey	Natural sand	27 ton/round	0.95 kg CO_2/km
	Turkey	Crushed sand	27 ton/round	1.01 kg CO_2/km
Wei Huang et al. (2017) [7]	China	Gravel		120.48/100 m^2
Wei Huang et al. (2017) [7]	China	Timber		1.3/100 m^2

Most of the data are adopted from [7].

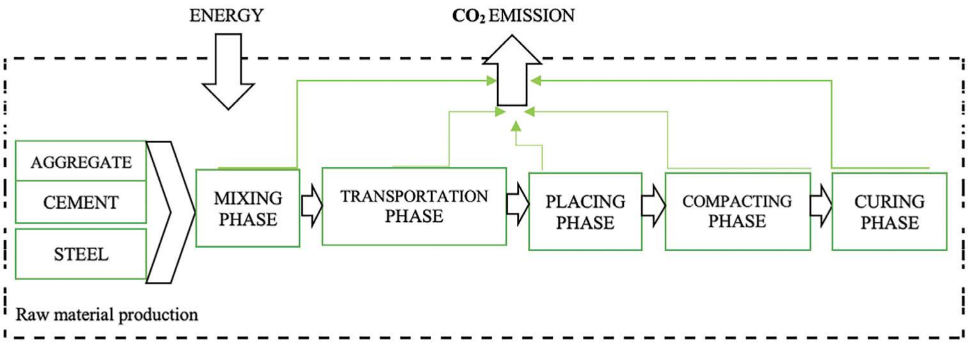

Figure 3. Emission from concrete production [74].

The Figure 3 describes some of the processes which emit carbon during the production of concrete at the site [74].

A large amount of CO_2 is released during these processes through the heavy construction equipment operations that add to the industry's overall carbon footprint from different activities, including mixing, transporting, placing, compacting, and curing [73]. As demonstrated in the above figure;

- The CO_2 emissions of the mixing phase are derived mainly from the consumption of energy by the mixing machines. Also, the mixing cylinder, sieving, control system, weighting components, and material transferring components are all electrically operated [74], which also contributes to the total CO_2 emissions through its generation.
- The emission of the transportation phase is attributed to the pollution emitted by vehicle engines, conveyor belts, and other transportation equipment [74].
- In the laying and placing process, the emission is derived from the consumption of energy by various equipment used for laying and fixing materials [74].
- The GHG emission of the compacting process comes from the rollers and vibrators' diesel/energy consumption [74].
- And lastly, the emission of the curing phase comes mainly from the consumption of fuel by the trucks and equipment used for curing the materials [74].

4.1.5 Demolition and Disposal

Building activities can generate a significant amount of waste materials that need to be disposed of, besides, it has to be deconstructed or demolished at the end of its useful life cycle, producing large quantities of waste [51]. The carbon emission from disposal activities is primarily derived from the initial embodied emissions of the recycled materials as well as the transfer of materials after the construction activities to other areas outside the project's site [28]. The construction industry uses 40 percent of the world's overall raw materials and it produces about "136Mt of waste" in the US alone per year [19]. In the United Kingdom, the industry generates approximately about 70 million tons of waste annually, out of which 13 million tons are disposed of [58]. Although there are alternatives for recycling and reusing materials for the amount of waste produced in the first place, there is still a significant amount of waste being disposed of in landfill [51]. Energy is consumed to demolish the construction, recycle certain materials and disposal of others by transporting debris and waste to landfill sites or incinerators [75]. Hence large quantities of CO_2 will be generated from activities that are carried out by heavy construction equipment which, in return, will make a significant contribution toward greenhouse gas emissions.

5. DISCUSSION

The discussed papers in this review are not an extensive list of all the research studies conducted in this field, but it is easy to see proof of so many challenges, for example, the limits of each case study are often different. Some studies use a lifecycle assessment in which they study the entire impact of the concerned project or structure. While others only consider the emission measurement during extraction, production, or transportation of a particular material in their study [1]. The literature review found that the quantification for the construction sector did not put much focus on capturing the sector's overall potential greenhouse emissions and reduction potential [15]. Nonetheless, many of the reviewed studies concentrated more on the indirect emissions and were mostly restricted owing to the inadequate comprehensive off-site and on-site process information due to limited system boundaries, especially the data related to various miscellaneous works and assembly as well as human activities associated with the construction. Apart from that other observation were made from the analysis of the literature as summarized below;

- The majority of the studies analysed the carbon footprint concerning a particular country, city, or region of developed countries and were mostly funded by the public authorities. While on the contrary, developing countries and Africa, in particular, has a very minor share of the studies [15]. Hence, there is a desperate exigency for a CF study of other numerous construction activities and the industry itself in developing countries where massive amount of CO_2 is generated every year, for example, 24% of CO_2 generated in Malaysia comes from the construction sector [22]. In India, the transportation sector generates around "161 MMT" of CO_2, making it 3rd in the world's annual CO_2 emissions, which is responsible for about 6 percent of the total emissions globally as reported in 2016 [53, 15]. Similarly, in Nigeria, the emission from the construction and manufacturing industries Increased from 2557 to 23714 Gg of CO_2 equivalent between 2000 and 2015 reflecting approximately 827% increase as observed which is much above normal [24].
- The literature review found that, more than 50 percent of the studies use the process-based LCA as their main methodological approach for quantifying the construction sector's CO_2 emission. Other approaches used include input-output analysis, Hybrid LCA, surveys, structural decomposition analysis, computer-programmed tools, and simulation [3, 1, 15]. And despite the fact that many of the research findings were based on the LCA techniques, most of these methodologies were often largely employed for buildings or regional CF analysis without focusing much on the consumption-based CF of various construction activities taking into account the unwavering importance of transportation and construction processes [15, 28]. However, even though some researchers have recognized the emission effect from the construction process, it should be noted that many other activities in the construction industries such as electrical fittings, waterproofing, thermal insulation, and painting, etc. that produce additional greenhouse gases were often omitted in such studies [27]. As such, there is a need for a thorough study on the greenhouse gas emission of a construction site using full system boundaries, including on-site assembly processes and human activities related to the construction, among many others.
- After analyzing each particular source of emissions and numerous studies in the literature, it can be seen that the activity with the greatest potential for GHG emission reduction were building material production. As such studies should be focused on addressing various sustainable construction material with a lower carbon footprint for use.
- Lastly, there are very few papers that discussed the estimation of the CO_2 emissions pertaining to infrastructural projects. And, apart from a paper by Jingke Hong, et al. 2014 [27], there is no other paper found in the reviewed studies presenting a systematic, open-access, and functional tool that would enable researchers across the globe to estimate the construction's CF comprehensively, and because of that, a comparison between these studies is not realistic owing to the wide variability in the reported figures and the different assumptions and presumption made by the authors [72]. This shows areas where steps can be taken to minimize the carbon emissions not just in the construction sector itself but also in many other interconnected sectors such as transportation, mining, manufacturing, among others [15].

6. CONCLUSION

Several researchers have studied the various contributions of the construction sector towards GHG emissions. However, from the systematic analysis of some of these studies, it has been found that the majority of researchers are primarily focused on a case study of a particular country, city, or region using life cycle assessment methods [3, 1]. In general, comparisons between the results of the reviewed papers are unreasonable as many of the findings were different, some of the authors examined only one particular aspect of the construction, some towns, some countries, etc. And even those who have studied similar aspect, such as cement or steel, have all used separate methodologies, different techniques of reporting, and even the units used were mostly different. Despite this, the scope of emission from the construction industry is remarkably clear, and the carbon findings can be found throughout the literature [3][9, 72]. Various ways to reduce the CF of the construction industry have been widely discussed, but most of the strategies are designs to mitigate the near future climate change impact without considering the impact in the longer future [18].

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declare that they have no conflict of interest.

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PEER-REVIEW

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Review Article

An overview of the impact of using glass powder on mechanical, durability properties in self-compacting concrete

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ABSTRACT

Color, texture, and shape alternatives of glass, chemical similarity, and close reactions with cement has made it preferred in the construction industry. Studies reveal that the use of glass in concrete after grinding to micron size provides improvements in strength and durability parameters by increasing pozzolanic reactivity. Besides, research studies have also shown that glass powder not only contributes positively to strength and durability properties but also reduces the amount of cement used, energy and cost losses. This paper presents current studies on waste glass powder, one of the by-products used in self-compacting concrete. Information was given about the physical and chemical properties of glass powder used in related studies. In addition, the effect of glass powder in self-compacting concrete on fresh, strength, and durability properties were investigated in detail. Inferences were made in line with the information in the literature and suggestions were made about what can be done in future studies.

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1. INTRODUCTION

Advances in the field of chemistry and the advancement of polymer technology have led to the discovery of highly impressive fluids. These plasticizers, which have high water-cutting properties, also increase the workability of concrete. With this effect provided by the fluids, the researchers demand that the concrete be placed without the need for any compression during the placement of the concrete. This situation has led to the emergence of a notice called Self-Compacting Concrete (SCC). SCC has very important advantages such as fast construction time, reduction in labor costs, facilitating surface smoothing, providing the opportunity to obtain a void-free and smooth surface, providing impermeability, flowing consistency, not requiring placement and compaction, and increasing the workability, preserving time-related loss of consistency. It is also used in mineral additives as well as chemical additives such as superplasticizers, viscosity-increasing, air-entraining additives in SCC production. These additives must have pozzolanic properties and comply with the relevant standards before use [1]. There are many studies on the usage of pozzolanic materials such as fly ash (FA), silica fume (SF), granulated blast furnace slag (GBFS) from mineral admixtures or by-products separately or in combination in SCC. In studies, both mechanical and durability performances of

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this type of additives were examined and their suitability in concrete was investigated and good results were obtained. In addition to these types of additives, the usability of waste glass aggregate or waste glass powder (WGP) in concrete has been discussed recently. Glass, which has similar properties to cement in terms of physical, chemical, and mechanical structure, can make a positive contribution to the environment as it can reduce cement consumption when used in concrete after grinding to micron size WGP. Using it in this form in concrete not only improves its mechanical and durability properties but also provides environmental and economic benefits [2–7].

The theme of sustainability has taken an important place in the concrete industry in recent years. It is aimed to ensure sustainability in the concrete sector with options such as reducing the amount of cement used, using recycled aggregate, and adding treated water to the concrete mixing water. The environmental impact assessment, which includes the social consequences of potential permanent or temporary effects on the environment and alternative solutions, needs to be analyzed. Environmental impacts related to the production of a product are evaluated, from the extraction of the raw material to its final disposal. This concept, which covers the entire life cycle assessment (LCA), is also called the cradle-to-grave approach. When concrete LCA studies are evaluated, it is known that it is negative in terms of production, transportation, placement, CO_2 emission, energy consumption, cost, and many other factors. The use of industrial wastes in concrete becomes a sustainable and smart solution to limit these effects and create a positive effect. At this point, the use of glass, one of the industrial wastes, protects the environment by reducing the consumption of natural materials, CO_2 emissions, and energy consumption. However, with the wide usage area of glass, the emergence of high amounts of waste glass is a serious problem. Every year, $2x10^{13}$ kg of solid waste is produced in the world and 7% of this waste is glass waste. Storage problems can be solved by creating new areas where waste glass can be used. By expanding the recycling possibilities of waste glass, which is a material currently used in recycling, the waste storage costs and the number of required facilities can decrease, and this can also be reflected in the production costs as a decrease.

In this review study, the effect of the utilization of WGP, which is one of the industrial wastes, on the mechanical and durability properties of SCC is discussed. In the studies carried out so far, many researches have been carried out on the integration of different industrial and agricultural wastes, especially into normal concrete. Since SCC is more difficult than normal concrete in terms of added materials, placement, flow, and different methods and meeting special project requirements, studies are limited. In this study, the main aim is to present the current studies on the inclusion of WGP in SCC, to give information about the methods used, to express the missing aspects of the studies, and to draw attention to the need for more studies to be added for the limited literature on this subject.

2. LITERATURE SURVEY ON THE USAGE OF WGP IN CONCRETE

Raju and Kumar [8] stated that there was a decrease in consistency and density with the increase in the use of WGP in concrete. The increase in surface area due to the fineness of WGP affected this result. In the studies conducted by Elaqra et al. [9] and Rahma et al. [10], the increase in the content of WGP, increases slump. The reason for this is that as the amount of hydrated cement decreases, less water is required for hydration which results in the increase in consistency. Another reason for this is that WGP is transparent, it has smooth surface texture, low water absorption, and a low specific surface compared to cement. Studies on the effects of hardened concrete have shown that there is a decrease in the compressive and flexural strengths at the initial gain, while an increase in the final strength. It has been determined that the interfacial transition zones (ITZ) intensifies with the acceleration of the pozzolanic reaction in later ages. When the strength at later ages were examined in the studies, it was observed that the use of WGP at 0–20% by volume or weight as cement or aggregate substitute resulted in positive results on the strength [10–14]. It has been understood from the studies that the increase in flexural strength improves the interface region and slows down the crack propagation rate thanks to the fineness of WGP. The contribution of WGP to mechanical properties is realized by showing better reactivity, being a finer-grained material, and having more surface area than cement [3, 15–21]. In addition, the WGP used in concrete also contributes to the durability parameter since the concrete has low porosity and moisture content, lower absorption rates (surface water retention), a decrease in alkali-silica reaction (ASR), and chloride depth decrease in drying shrinkage, increase in resistance to sulfate, electrical and corrosion, along with strength [3, 10, 14, 18, 22–24]. Corrosion is one of the most serious problems affecting reinforced concrete structures and it should be tried to inhibit damage or to keep it at a minimum even if the damage cannot be prevented. Resistance to corrosion in reinforced concrete is possible by increasing the pH values of WGP. The increment in pH value has been associated the color of glass as well as with the rise in the amount of WGP. It has been found that green glass is richer in calcium alumina than white glass, and silica does not dissolve easily in voids [25].

3. SELF-COMPACTING CONCRETE

SCC is a special type of concrete with a very fluid consistency, which can settle with its weight, even under harsh conditions (with dense reinforcement and deep sections), compressible without requiring any internal and external vibration, and maintains its cohesion without causing problems such as segregation and bleeding. Its differences from plain concrete is that it has all or some of the chemical additives, viscosity enhancing additives, and a very high amount of inert or pozzolanic mineral additives are used in this concrete. In addition, with SCC, high quality finishing is obtained in terms of architecture and aesthetics in reinforced concrete structures compared to conventional concrete. However, more knowledge and experience are required in determining the components and mixing ratios of SCC compared to conventional concrete. Although SCC is classified according to its workability properties, it must also meet certain mechanical performance criteria. The expected mechanical performance of SCC depends on the following conditions;

- Selection of material types and ratios suitable for the desired performance (mixture optimization),
- Minimization of the change in material types and ratios during the production phase (using homogeneous materials, reducing the problems that may arise from raw material variability),
- Considering the effect of ambient conditions on SCC, both in the design of the mixture and in the production phase.
- Continuously control of fresh concrete quality with selected tests during the production phase, immediate intervention in the mixture that does not provide the desired properties.

If the above criteria are met, it is possible to obtain the highest mechanical performance from SCC. This condition is also valid for normal concretes. However, the sensitivity to these criteria is higher in SCC and it is much more difficult to correct the mistakes to be made compared to normal concrete production [26–28].

3.1. History of SCC

Thanks to the development of the ready mixed concrete sector in the world, other sectors that provide raw materials to the sector have also developed. One of the most important of these is the additive sector. Concrete additives are mainly used to improve and develop the properties of concrete and especially in the production of concrete that is more resistant to environmental conditions. Before the use of chemical additives in concrete, a high water/cement (w/c) ratio was used in the concrete mix to increase the workability of the concrete. However, it reduces the quality of the concrete. In the early 1970s, plasticizers or superplasticizers were used to increase the workability of concrete at a low w/c ratio. In 1986, research on self-leveling and compacting concrete was started at the University of Tokyo, and thus the first steps of SCC design were taken. After the ACI Workshop in Bangkok in 1994, many researchers started to work on SCC. Usage of SCC in Swedish highway structures in 1990 is the first example in Europe. In 1996, with the publication of the papers on SCC at ACI Autumn Congress in New Orleans, SCC became more used in the United States and Canada. After 1997, European Union started studies aiming to increase the use of SCC. In 2005, European Precast Concrete Manufacturers Association (BIBM), European Cement Association (CEMBUREU), European Ready Mixed Concrete Association (ERMCO), European Concrete Admixture Manufacturers Federation (EFCA), European Federation of Special Construction Chemicals and Concrete Systems (EFNARC) have prepared a common specification by coming together [26–28].

4. SCC APPLICATIONS

- It can be used in all kinds of reinforced concrete productions, but due to its high cost, it is used in structures and prefabricated elements, panels, and floors where concrete settlement is difficult.
- It is used in reinforcement productions due to the problems experienced in the placement of concrete and facilitates the strengthening process.
- Unlike the geometrically frequently used molds, it can be used in unusual molds, in very densely reinforced structures, where it is not possible to use vibrators.

5. WASTE-GLASS

Glass is not affected by water and neutral liquids under normal conditions. The solubility rate of amorphous silica in water at 25ºC is 0.012%, but this rate increases as the temperature increases. As a result, non-ionized monomeric silica is formed. Although the resistance of glass to acids is generally high, hydrofluoric acid and phosphoric acid at high temperatures affect silica glass. This effect of hydrofluoric acid on glass is used in the glass industry for polishing glass and etching glass for various purposes. To produce glass resistance against water and humid environments, limestone (CaO) must be added to the glass. Limestone or limestone-added glass products are both resistant to humid environments, water and exhibit stable behavior without losing their qualities. The molecular structure of glass, which has an amorphous structure, is irregular and does not have a certain freezing and melting temperature. It softens as heat is given, melts at an uncertain temperature, and has no upper temperature limiting the melting process. The density of the glass varies between 2.20 g/cm^3 and 8.00 g/cm^3. When it is desired to increase this density, some oxides such as ZnO, BaO, and PbO can be added to the mixture. According to the Mohr hardness scale, the hardness of normal glass is between 5 and 6, that is, between apatite and feldspar. Since materials softer than this hardness cannot scratch the glass, the glass does not lose its transparency and brightness for many years. Abrasion resistance also depends on the raw materials in the glass. SiO_2 and B_2O_3 increase this resistance, while Na_2O, CaO, and PbO decrease it [29–34].

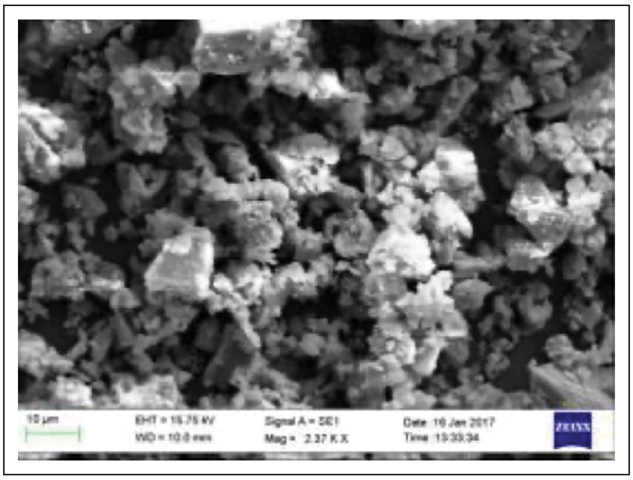

Figure 1. SEM image of WGP [40].

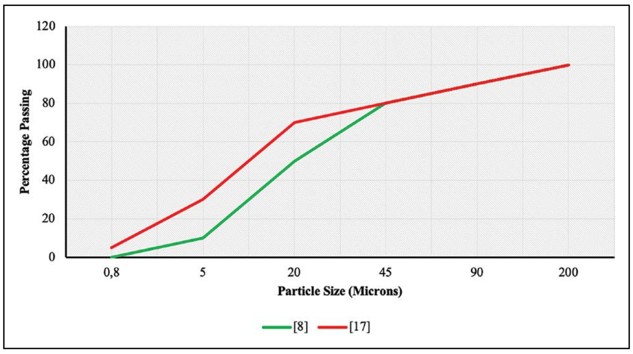

Figure 2. Sieve analysis of WGP.

5.1. Waste Glass Powder

WGP is a building material with an amorphous structure and a high degree of silica content, with a density of 2.6 g/cm^3, obtained by being brought to micron dimensions after certain processes such as after the collection, separation, and sieving of waste glasses, after certain processes. In addition to its low conductivity and moisture-absorbing properties, it also has high hardness. For this powder to show binding properties, the particle size must be less than 0.075 mm. The powder in these levels is sieved through the sieve and made ready for use and can be used as an alternative binder replacement of cement [35–37].

The physical properties of WGP, which has lower specific gravity and bulk density than cement, are given in Table 1, information on its chemical properties are given in Table 2, and SEM image is given in Figure 1.

The replacement of waste glass, which has a high SiO_2 content, with cement, also affects the pozzolanic reactivity index. As the waste glass reacts with calcium hydroxide and consumes cement hydrates, the pore structure is filled with calcium silicate hydrate gels and a denser matrix structure is formed. It was determined that grinding the glass into 45–75 µm glass powder and using it replacement of cement up to 30% increased the pozzolanic reactivity index as well as the strength index. It was observed that another parameter increasing the pozzolanic activity apart from the fineness was the curing temperature. As the curing temperature increased, the pozzolanic reactivity index increased [5, 10, 38, 39].

Table 1. Physical properties of WGP

Physical properties	**Ref.**				
	[8]	**[41]**	**[42]**	**[17]**	**[24]**
Specific gravity	2.58	2.43	2.22	2.53	2.68
Bulk density (kg/m^3)	2.58	2.53	–	–	–
Fineness (%)	–	3.4	–	–	–

Table 2. Chemical properties of WGP

Component	**Ref.**					
	[8]	**[12]**	**[43]**	**[24]**	**[17]**	**[44]**
SiO_2	72.5	72.61	70.22	70	72.08	71.4
Al_2O_3	0.4	1.38	1.64	1.2	2.19	2.54
Fe_2O_3	0.2		0.52	0.65	0.22	0.37
CaO	9.7	11.42	11.13	8.7	10.45	11.2
MgO	3.3	0.79	–	3.7	0.72	1.6
Na_2O	13.7	12.85	15.29	16	13.71	12.25
K_2O	0.1	0.43	–	0.35	0.16	0.36
SO_3	–	–	–	<0.05	–	0.16
CI	–	–	–	<0.005	–	0.04
TiO_2	–	–	–	–	–	0.1
Cr_2O_3	–	–	–	–	–	0.01
LOI	0.36	–	0.8	0.92	–	0.82

6. EFFECT OF WGP USE ON FRESH AND HARDENED CONCRETE PROPERTIES IN SCC

Prasetyo et al. [45] investigated the tensile strength and porosity of SCC to which WGP (5–30%) was incorporated in various proportions as replacement of cement. Good results were obtained in terms of tensile strength at the ratio of 5% WGP, and the optimum value was determined at the ratio of 5.5% WGP. For the porosity values, better results were obtained than the reference concrete at the ratio of WGP between 5–10%. A decrease in properties was observed for WGP percentages higher than these ratios.

Noorzyafiqi et al. [46] examined properties such as flow, specific gravity, and compressive strength in SCC with partial replacement of WGP for 14 days. In the study, the mixture was made using a 5–30% WGP, 0.35 w/c ratio, and 1% superplasticizer. The research results showed that the flow, specific gravity, and compressive strength increased with the addition of 5–20% WGP in SCC, while the properties decreased at 25% and 30% WGP ratios.

In the study conducted by Khudair et al. [47], in which WGP was added to SCC and its effects on rheological properties and compressive, splitting tensile and flexural strengths were analyzed, WGP was used at the ratio of 0–40% replacement of cement, and five different mixtures were designed. In the experimental study, compressive strengths were realized on the 7th, 28th, and 56th days, and splitting tensile and bending strength were performed only on the 28th day. The research was not only limited to this but also included the evaluation of CO_2 emission and production cost in terms of sustainability with the statistical optimization model. The results demonstrated that the rheological properties (Slump flow, T500, L-box, and Segregation test) and compressive, splitting tensile and flexural strength increased by 30% with the usage of WGP, the maximum compressive and splitting tensile strength were increased by 10% with the use of WGP and the highest bending strength was attained by using 20% WGP.

Yücel [40] constituted SCC by using WGP replacement of FA and assessed the fresh, mechanical, and durability effects of WGP on SCC. In the study, SCC's were produced with 550 kg/m^3 binder content, 0.32 water/binder (w/b) ratio, and a constant slump diameter of 700±10 mm. The reference mixture was designed by using 20% of the total binder amount of FA, while the other mixtures were prepared by using 5–20% WGP replacement of FA. The results showed that increasing WGP amount decreased slump diameter, height ratio in L-box, while T500 (mm) slump flow time and discharge time in V-funnel increased compared to reference mixtures. In addition, with the increase in the amount of WGP used replacement of FA, compressive, flexural, and splitting strength results on the 28th and 56th days increased, and these strengths increased as the curing time increased. The best results regarding mechanical properties were found in mixtures designed using 20% WGP replacement of FA. Capillary water permeability and rapid chloride permeability decreased with increasing WGP and curing time. From here, it can be seen that the durability properties improve with the increase in the amount of WGP as replacement of FA.

Rehman et al. [48] analyzed the effect of WGP and granulated steel slag (GSS) as replacement of cement and fine aggregate on the fresh and hardened properties of SCC. In the study, 20%, 30%, and 40% WGP were added as replacement of cement, and 40%, 60%, and 80% GSS was added as replacement of fine aggregate. The effects of fresh concrete properties on workability, density, and air content, and hardened concrete properties on compressive strength, splitting tensile strength, bending strength, and modulus of elasticity were researched. Although the results showed that workability decreased with the usage of GSS, workability increased with the WGP additive. However, compressive, splitting tensile, flexural strength, and modulus of elasticity decreased due to the increase in WGP content and stability of steel slag aggregates. The best results of the study regarding compressive, splitting tensile and flexural strengths were found with the use of 20% WGP and 80% GSS.

Tariq et al. [49] surveyed the effect of WGP additive on durability properties in SCC. In the work, the mixtures were prepared with 20%, 30%, and 40% WGP additive and 0.4 w/b ratio replacement of cement. Oxygen permeability, electrical resistivity, porosity, and chloride diffusion from the durability properties were measured at curing period of 3 to 545 days. The results of the study indicated that the usage of FA and WGP together increased the compressive strength, as well as decreased the porosity, oxygen and chloride permeability, and drying shrinkage (up to 180 days). Mechanical and durability properties of SCC evidenced the best values at 20–30% WGP replacement level. Thanks to the small size glass particles, the microstructure is denser and results in improved particle packaging, which creates lower particles. In addition, the service life in terms of corrosion initiation time was tried to be determined by using the Life 365 software in the study. A threshold concentration of chlorides of 0.05% and 0.1% by mass of the concrete was used to be realistic for mixes at different ratios. Regardless of the ratios, a significant advantage was observed in the mixtures containing WGP in terms of time to the onset of corrosion compared to mixtures containing only FA, an increase of about 2 to 3.5 times in service life is determined.

7. CONCLUSIONS AND RECOMMENDATIONS

Literature information on the usage of WGP as cement or fine aggregate replacement in SCC was evaluated. The results showed that up to 30% usage of WGP increased slump flow, J-ring flow, L-box, T500, V-funnel values, and reduced segregation in SCC. It can be stated that this is due to the decrease in the amount of hydrated cement and the increase in WGP, and as a result, the need for more water and the increase in consistency. However, it was emphasized that a high amount of WGP adversely affected the slump results and reduced the consistency. This is expressed by the decrease in the Ca(OH)2 content with the increase of the fineness and surface area of the WGP, thus limiting the area through which the water passes. Additionally, it was stated that the addition of WGP to SCC increases compressive, flexural, and tensile strengths, decreases permeability, oxygen, and chloride penetration, and increases electrical and sulfate resistance. It was also pointed out that WGP, one of the different by-products used in SCC, has great potential for sustainable development [50–54].

Concrete pouring, placing and compaction is a difficult task for ready mixed concrete producers and consumers. Quality workmanship and strict control are required to ensure adequate compaction and homogeneity of the poured concrete to ensure the section is filled correctly. For the advantages of SCC to be seen clearly, its design must be done correctly and it must comply with the specified standards. Since SCC has a very fluid consistency, the formwork systems to be used should be carefully selected and the formwork supports should be smooth and sufficient. The utilization of SCC is increasing day by day in the world, and it is rapidly taking the place of traditional concrete in many application areas. It has advantages such as reducing labor costs as a result of ease of placement. It can provide great convenience especially in complex molds, narrow and tightly reinforced sections, high shear walls where placement and compression are difficult, in the production of large-surface floors, and the applications in the prefabricated sectors [26].

The number of studies on the durability properties of WGP added to SCC can be increased. In particular, the number of studies on the effect of corrosion is limited and experimental studies have not been found much. The effect of WGP added to SCC on reinforcement corrosion and mechanical properties in reinforced concrete structural systems can be examined experimentally and compared with numerical analyses. In addition, by including different industrial and agricultural wastes in the SCC mixtures to be made, it may be possible to compare the results, determine the most appropriate waste type and rate, and compare the pros and cons. Another shortcoming of the studies is the deprivation of LCA, focusing only on the effect of WGP added to SCC on its mechanical and endurance properties. Studies on LCA's should be appreciated more, as the gain in the service life of the structure to be strengthened with different industrial and agricultural wastes which can benefit both the country's economy and help in the reduction of energy losses.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declare that they have no conflict of interest.

FINANCIAL DISCLOSURE

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