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Research Article

Properties of glass-ceramics foam based on granite dust-clay-maize cob composite as a sustainable building material

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ABSTRACT

In this study, samples of glass-ceramics foam were obtained from granite dust-clay-maize cob composite and chemical additives at low temperature. Effects of the addition of maize cob as the pore-forming agent as well as the chemical additives on the performance properties of the samples of the glass-ceramics foam were investigated. The result of the prepared glass-ceramics foam showed water absorption, apparent porosity, bulk density, compressive strength and thermal conductivity of 25.6–46.7%, 43.5–75%, 1.45–1.9 g/cm^3, 0.7–9.7 MPa and 0.11–0.53 W/m.K. respectively. The mechanical and thermo-physical properties as well as microstructural properties of the glass-ceramics foam synthesized in this study provide a feasible indicator that the material can be used in promoting green and sustainable buildings.

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1. INTRODUCTION

Glass-ceramics foam is a class of materials that possesses interesting properties including low density, good moisture absorption, low thermal insulation and high chemical resistance among others [1, 2]. Important applications of glass-ceramics foam as a sustainable material for promoting green buildings cannot be overemphasized. World over, there is an escalating need for energy-efficient building design through the use of climate responsive materials or passive cooling devices for wall insulation [3]. Glass-ceramics foam is advantageous over polymeric foams (such as polystyrene and polyurethane) for use in building/construction due to its non-flammability, flame resistance, chemically inertness and non-toxicity [4, 5]. Glass-ceramics foam can be obtained through different processing methods including: replica template, direct foaming method, partial sintering, sacrificial template, additive manufacturing [6] and freeze-drying method [7] among others. The simplest processing technique by far is by sacrificial template method which involves powder sintering with the incorporation of foaming agents [8]. Another interesting thing about this method lies in the fact that cellulosic wastes such as saw dust, banana leaves, walnut and Yaba mate among others have found useful application as pore-forming agent in the production of glass-ceramics foam rather than culminating into environmental pollution [9–12].

Several researches on fabrication of glass-ceramics foam are commonly based on the use of by-products of high tem-

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perature industrial activities including metallurgical slag, fly ash and waste glass among others [13–26]. However, in view of the limited resources of these pyrotechnical industrial wastes for mass production of value-added products, the raw material base route for production of glass-ceramics foam is relevant [27, 28]. Hence, using natural raw materials such as granite dust which are available in abundance and are suitable for the production of glass-ceramics foam is necessary [29]. Single-step sintering of glass-ceramics foam based on aluminosilicate rocks provides an energy-saving route that eliminates preliminary glass melting by making it possible to combine the formation of a glassy phase and its cellular structure in a single technological process [30]. In this respect, glass-ceramics foam have been prepared based on: siliceous rocks and thermonatrite ($Na_2CO_3{\cdot}H_2O$) [31], waste quartz sand and coal gangue [32], tripoli with the addition of microsilica (10–50 wt.%) and 45% NaOH [27], and diatomite and 40% NaOH [33] among others. Based on the foregoing, it is noteworthy that processing glass-ceramics foam from industrial and agricultural wastes does not only promote environmental sustainability but also provides a route for mass-production of value-added building materials at low cost.

[34, 35] observed that thermal insulation in buildings have not been massively adopted in developing countries such as Nigeria mostly due to cost issues among others. In order to channel a feasible path for the development of cost-effective thermal insulation materials in Nigeria, [36] has investigated into the possibility of developing porous ceramics from wastes using single-step sintering. This study makes an attempt to experiment on the possibility of obtaining glass-ceramics foam from cheap natural resources such as granite dust and ball clay using maize cob as pore-forming agent. Ball clay is richly available in millions of tonnes across each states within the six geopolitical spreads of the country [37]. According to National Bureau of Statistics, Nigeria produced 9.62 million tonnes of granite, 2.12 million tonnes of granite aggregates, 28, 420 tonnes of granite block and 3.39 million tonnes of granite dust in the 2018 fiscal year [38]. Annual maize production in Nigeria as at 2018 was over 10 million metric tonnes [39]. Based on these statistics, it is evident that granite dust and maize cob are available in abundance in the country. However, these wastes have not been fully utilized in Nigeria as at the time this research was conducted. While maize cob (or corn cob) has been employed as a pore-forming agent in the production of porous ceramics in previous studies [40, 41], this research is novel in that it synthesized glass-ceramics foam from granite dust-clay-maize cob composite with a mixture of NaOH and Na_2SiO_3, a combination of starting materials which have not been used in the production of glass-ceramics foam based on extant literature reviewed. Given that building contributes enormously to carbon emission and energy consumption, thermal insulation is a green building strategy that leads to energy efficiency, low cost and low maintenance [42, 43]. Green-building problem has been identified as a one of the major problems among the numerous difficulties the housing sector has suffered from the COVID-19 pandemic [44]. Therefore, this research investigated into the performance properties of glass-ceramics foam developed using locally sourced raw materials as well as easy ceramic fabrication technique with a view to providing additional documented procedures of synthesizing materials that promote green and energy efficient environment in developing countries.

2. MATERIALS AND METHODS

2.1 Raw Materials and Chemical reagents

The study used granite dust sourced from Dotmond Quarry, Ita-Ogbolu, Ondo State, Nigeria as the base raw material, ball clay obtained from Ire-Ekiti, Ekiti State, Nigeria as the binder, maize cob powder obtained from the Seed Department, Agricultural Development and Processing, Akure, Nigeria as the pore-forming agent and mixture of NaOH and Na_2SiO_3 as the sintering aid. The NaOH and Na_2SiO_3 used was supplied by Qualikems Fine Chemicals Pvt. Ltd. And May & Baker Ltd., Dagenham, England respectively. The NaOH pellets used has minimum assay of 98.9% and the Na_2SiO_3 used contains about 12% Na_2O, 30% SiO_2 and 58% water.

2.2 Preparation of Samples

The raw materials including granite dust, ball clay and maize cob were sun dried, oven dried, grinded and sieved. Granite dust, ball clay and maize cob were sieved through 300 μm, 300 μm and 425 μm British Standard sieve respectively. 10 M NaOH solution was prepared. Mixture of 10 M NaOH and Na_2SiO_3 was prepared in ratio 1:1. Formulation of samples involved the mixture of varying percentage by weight of granite dust, ball clay and maize cob up to 100 g with constant percentage by weight of the mixture of NaOH and Na_2SiO_3 in three different groupings as shown in Table 1. After this each of the formulated samples was thoroughly mixed, the homogenized compositions was poured into the mould of dimension 50 mm x 50 mm x 50 mm and was uniaxially pressed at 10 MPa. The pressed samples were dried in the electric oven at 110 ^oC for 6 hours and sintered in the gas kiln up to 850 ^oC for 3 hours and soaked for 2 hours.

2.3 Characterization

To obtain the chemical composition of the raw materials used in this study, X-ray Fluorescence (XRF) analysis was conducted using Skyray Instrument, Model: EDX3600B and Nikon SMZ745T Stereomicroscope was used to investigate the microstructural properties of the developed glass-ceramics foam sintered at 850 ^oC.

Table 1. Formulation of glass-ceramics foam samples

Samples grouping	Sample designation	Granite dust (g)	Ball clay (g)	Maize cob (g)	NaOH (cm^3)	Na_2SiO_3 (cm^3)
1	C_1	63	32	5	7.5	7.5
	C_2	60	30	10	7.5	7.5
	C_3	57	28	15	7.5	7.5
2	R_1	63	32	5	10	10
	R_2	60	30	10	10	10
	R_3	57	28	15	10	10
3	N_1	63	32	5	12.5	12.5
	N_2	60	30	10	12.5	12.5
	N_3	57	28	15	12.5	12.5

2.3.1 Water Absorption, Apparent Porosity and Bulk Density

The values of water absorption, apparent porosity and bulk density of the samples were measured using the Archimedes method according to ASTM C20-00 [45] and were calculated using equations (1), (2) and (3) respectively.

$$Water\ Absorption = W_2 - W_1 / W_1 \times 100\% \quad (1)$$

$$Apparent\ Porosity = W_2 - W_1 / W_2 - W_3 \quad (2)$$

$$Bulk\ density = W_1 / W_2 - W_3 \quad (3)$$

Where W_1, W_2 and W_3 are the sintered weight of sample, the soaked weight of the sample after boiling at 100 °C for 2 hours and the suspended weight of samples in water respectively.

2.3.2 Compressive Strength

A digital Instron Series 3369 compressive strength testing machine at a fixed crosshead speed of 10 mm min−1was used to measure the compressive strength of the produced glass-ceramics foam samples in accordance to ASTM C240-97 [46].

2.3.3 Thermal Conductivity

Thermal Conductivity test was carried out on the samples using a self-constructed Lee's Disc apparatus according to [47]. Thermal conductivity (k) was calculated using equation (4).

$$k = 2.303\ MC\delta\ [log\ (\theta_1 = Ts - T_1 / \theta_2 = Ts - T_2)] / A.\ \tau \quad (4)$$

where, k, M, C, δ, θ_1, θ_2, Ts, T_1, T_2, A and τ are thermal conductivity of the specimen, (W/m˚C), mass of water in conical flask (kg), specific heat capacity of water in conical flask (4200 J/kg˚C), thickness of sample (m), temperature of steam (˚C), initial temperature of water in the conical flask (˚C), final temperature of water in the conical flask (˚C), Area of sample (m^2) and time (s) respectively.

3. RESULTS AND DISCUSSION

3.1 Chemical Properties of the Starting Raw Materials

The result of XRF analysis as shown in Table 2 revealed that the granite dust used mainly contained silicon oxide (SiO_2), aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3) representing 59.72%, 12.82% and 11.29% respectively. Hence, granite dust is a suitable raw material for glassy phase as required for the production of glass-ceramics foam since it contains a considerable amount of SiO_2 which is generally known as glass former and Al_2O_3 which always serves as stabilizer in glass formation. Potassium oxide (K_2O) and calcium oxide (CaO) representing 5.74% and 5.67% of the granite dust sample respectively are other significant oxides suitable for glass production. K_2O serves as fluxing agent in glass production and CaO contributes to the crystallinity of a glass-based material. The ball clay used mainly contained SiO_2, Al_2O_3 and Fe_2O_3 representing 58.15%, 21.60% and 12.40% respectively. The ball clay shows a good quality of aluminosilicate material with iron oxide as the major impurity which is mostly responsible for the brown colouration in ball clay. The essence of using ball clay in this study is due to its plasticity so as to provide the required binding aid to granite dust (a non-plastic material) which is the main raw material for this study. However the presence of high amount of SiO_2 in the ball clay could have served as an additional aid in providing glassy base material for the study. The maize cob used mainly contained SiO_2, Al_2O_3,

Table 2. Chemical compositions of the raw materials used in this study (wt %)

Oxide	Granite dust	Ball clay	Maize cob
Al_2O_3	12.82	21.60	13.79
SiO_2	59.72	58.15	27.75
P_2O_5	0.44	0.21	1.42
SO_3	0.82	0.71	6.37
K_2O	5.74	2.30	9.28
CaO	5.67	0.15	7.19
TiO_2	0.35	0.81	–
Fe_2O_3	11.29	12.40	10.88
SnO_2	–	–	4.66
Sb_2O_3	–	–	4.74
LOI	3.15	3.67	13.92

Table 3. Chemical properties of some main raw materials used in previous studies compared to granite dust used in this study

Main raw material	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	Na_2O	MgO	P_2O_5	SO_3
Coal Fly Ash [14]	35.42	39.40	2.63	10.04	0.40	–	–	0.217	4.62
TTP Slag [48]	57.5	23.0	10.8	1.9	3.6	–	–	–	–
Glass Cullet [49]	66.0	3.0	0.3	11.2	3.3	12.2	3.7	–	–
Granite Dust*	59.72	12.82	11.29	5.67	5.74	–	–	0.44	0.82

*: Present study.

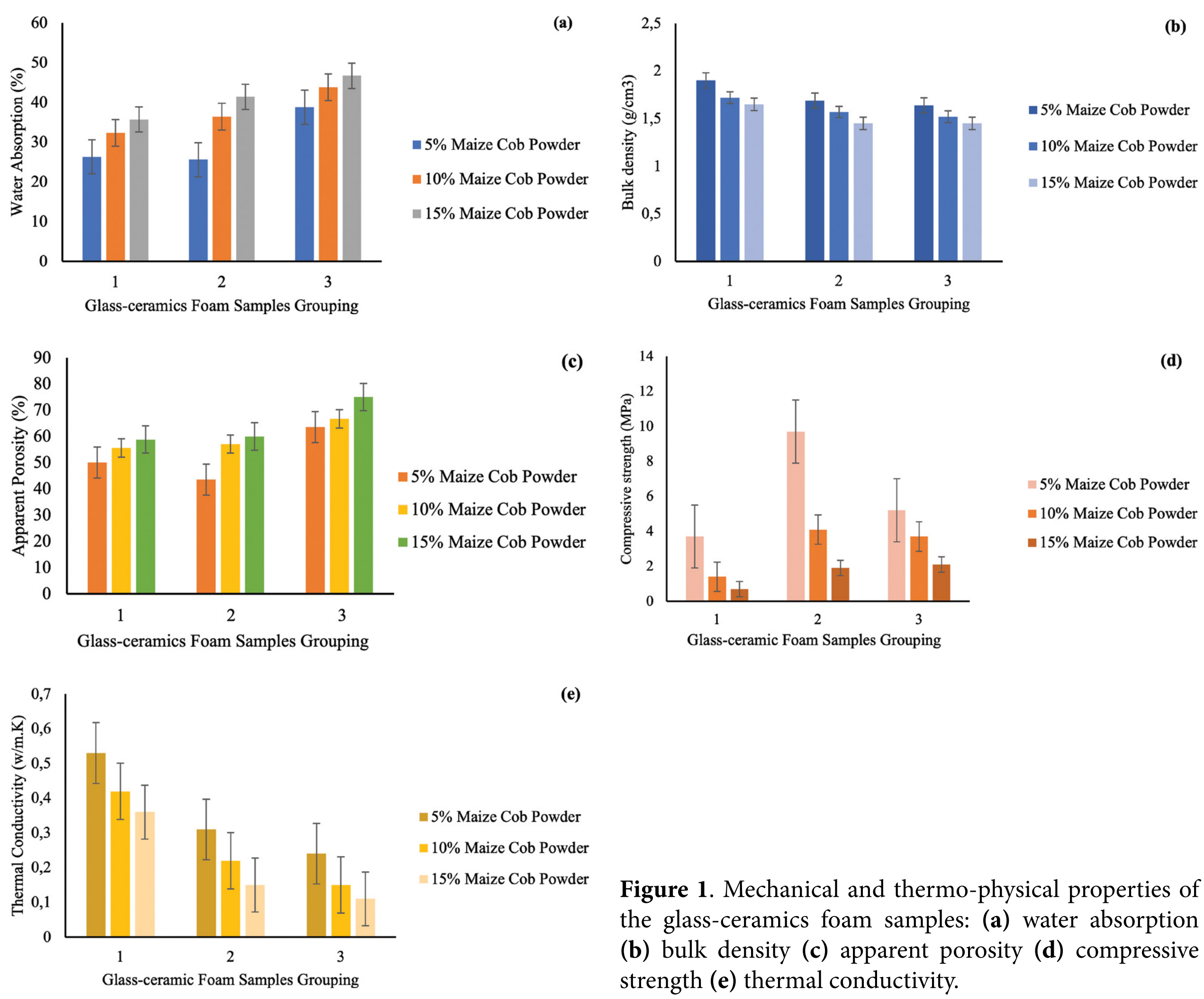

Figure 1. Mechanical and thermo-physical properties of the glass-ceramics foam samples: **(a)** water absorption **(b)** bulk density **(c)** apparent porosity **(d)** compressive strength **(e)** thermal conductivity.

Fe_2O_3, K_2O and CaO representing 27.75%, 13.79% and 10.88%, 9.28% and 7.19% respectively and these are important oxides in glass and ceramic production.

The comparative analysis of chemical properties of some main raw materials used in previous studies to granite dust used in this study are as shown in Table 3. While Coal fly ash, TTP slag and glass cullet are industrial wastes of high temperature processes, granite dust is an industrial waste of the quarry industry which has not been subjected to any initial heat treatment; however, it can be observed from Table 3 that the chemical composition of granite dust used in this study matches favourably with some of the wastes that have undergone heat treatment used in previous studies for the synthesis of glass-ceramics foam. This reveals its suitability for the fabrication of glass-ceramics foam via single-step sintering route which was achieved in this study by using chemical additives (NaOH and Na_2SiO_3) as sintering aid.

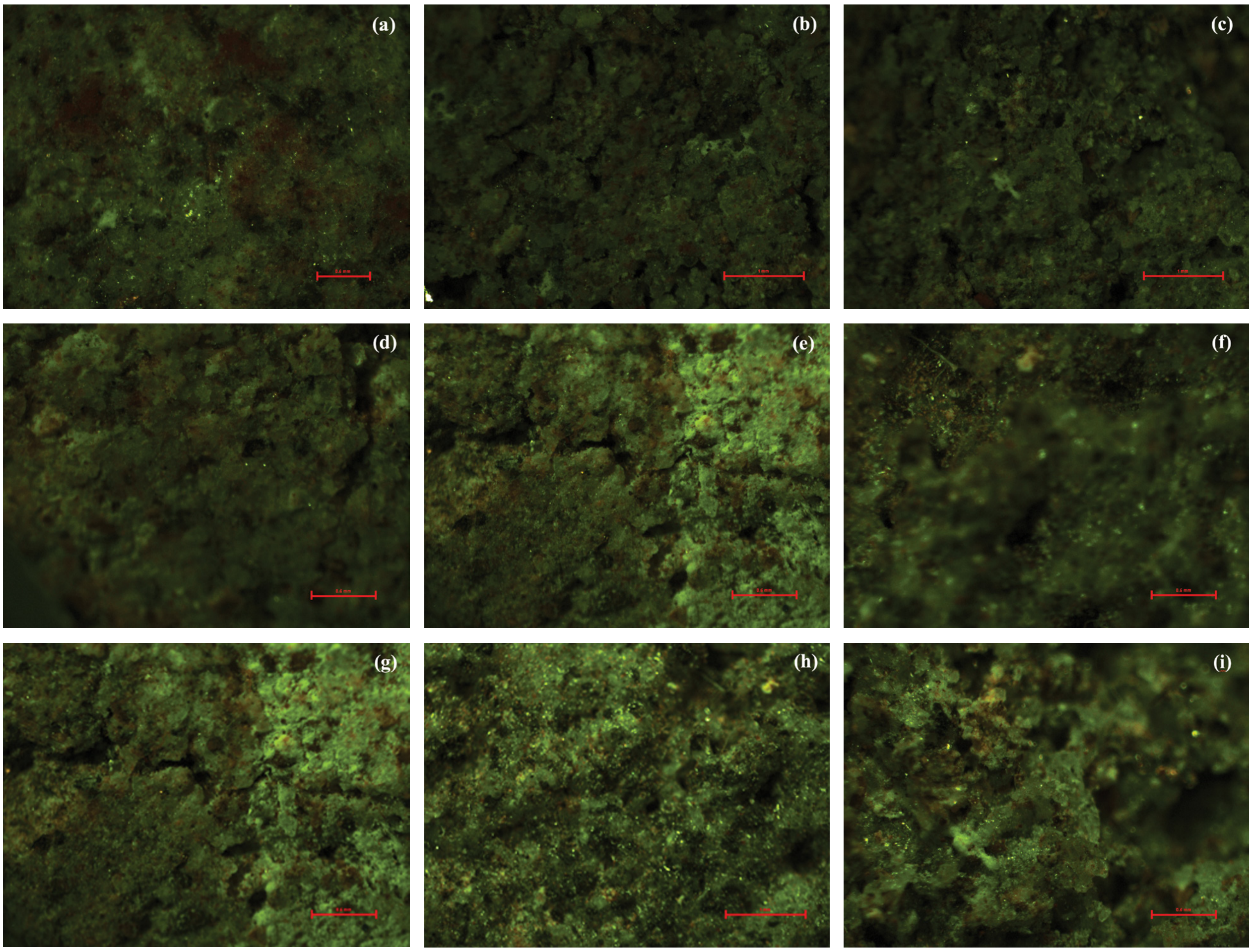

Figure 2. Stereomicroscope images of the porous glass-ceramic samples: **(a)** C_1 **(b)** C_2 **(c)** C_3 **(d)** R_1 **(e)** R_2 **(f)** R_3 **(g)** N_1 **(h)** N_2 **(i)** N_3.

3.2 Mechanical and Thermo-Physical Properties

The trend in the mechanical and thermo-physical properties of the glass-ceramics foam synthesized in this study are presented. Figure 1a–c show the result of water absorption, bulk density and apparent porosity of the glass-ceramic foam samples at varying addition of pore-forming agent and chemical additives. It is observed that the samples sintered at 850 °C, water absorption increased gradually from C_1-C_3, R_1-R_3 and N_1-N_3 respectively; apparent porosity increased gradually from C_1-C_3, R_1-R_3 and N_1-N_3 respectively while the values of bulk density decreased gradually from C_1-C_3, R_1-R_3 and N_1-N_3 respectively with the increasing amount of maize cob powder and the chemical additives used.

Figure 1d showed that the compressive strength of the samples decrease linearly from C_1-C_3, R_1-R_3 and N_1-N_3 respectively with the increasing amount of maize cob powder and chemical additives used. Figure 1e showed that the thermal conductivity values of the samples decrease from C_1-C_3, R_1-R_3 and N_1-N_3 respectively with the increasing amount of maize cob powder and chemical additives used. These trends of properties of the glass-ceramics foam samples with respect to increase in pore-forming agent are in agreement with [50] and also justifies the use of alkali-based chemical additives to activate an enhanced sintering process [4, 51].

3.3 Microstructure

The microstructural properties of the developed porous glass-ceramic samples sintered at 850 °C are as shown in Figures 2a–i. The micrographs show different morphological structures of various degrees of agglomeration and porosity. The porosity is observed to increase with the increase in percentage of the alkali-based chemical additives and maize cob powder added, leading to decrease in compressive strength, increase in water absorption as well as increase in coefficient of thermal conductivity in each of the sample groupings 1–3, that is, from C_1-C_3, R_1-R_3 and N_1-N_3 respectively of the samples is observable. The pore size distribution is heterogeneous. The developed glass-ceramics foam exhibit open-celled morphology which is advantageous to its effectiveness not only in thermal insulation but also in acoustic insulation in the sense it provides an absorbent surface as large as possible that favours sound absorption [52].

4. CONCLUSION

The results obtained in this study in compliance with ASTM standards revealed that one-step sintering method can be used to develop glass-ceramics foam with the addition of appropriate chemical reagents at a temperature as low as 850 °C. The use of waste resources in this research encourages wastes remediation which is an important means of promoting environmental sustainability. The different degrees of agglomeration and porosity of the samples as revealed by the micrographs confirm the results of their varying physical, mechanical and thermal properties. The properties of the material synthesized in this study indicate that it can be suitably used in promoting green and sustainable buildings. While this research focused on evaluating the effect of varying the amount of the mixtures of NaOH and Na_2SiO_3 on the properties of glass-ceramic foams sintered at a constant temperature, further research should explore the effect of different sintering temperature ranges and other types of chemical reagents than the ones used in this study on the properties of glass-ceramic foams obtained from granite dust-clay-maize cob composite.

DATA AVAILABILITY STATEMENT

The author 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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Research Article

Evaluation of the modern architectural buildings in terms of sustainability: A case of Çorlu municipality building

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ABSTRACT

Çorlu municipality building was built in 1984, by famous architects Maruf Önal and Hakkı Önel through modern architecture signs in Turkey. It was designed with a modest and rational approach, with meticulous construction, although it is a public building in line with a modern style. In terms of location, the municipality building was built in front of today's Cumhuriyet square, between the Kumyol Street and Omurtak Street, in the period when Salih Omurtak Street was just opened, during the years when the construction in Çorlu was not concentrated yet. In the project area, it was decided to demolish the Sücaettin primary school building built in 1936 and the old reinforced concrete baths and cisterns belonging to the Çorlu municipality and replace them with the municipal structure, and they were placed in this area with the square in front of the municipality building. Around the building; the Military Hospital, the Officer's Club and the 5th Corps Command buildings were located which were built in the 1930s. The aim of the study is to preserve the building and to sustain its life longer by questioning constructional building systems. Therefore the target is to preserve the function of the building with the original architectural language and concept. To design a structural system that will increase the strength and similar characteristics of the existing structure to the previous level. Creating the level determined analytical and experimental means within the framework of current regulations and to ensure that the performance of the building is at a level that will prevent wholesale collapse in an earthquake. Therefore the structural systems of buildings are to be rearranged according to new earthquake regulations.

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1. INTRODUCTION

Especially in the 80s, the structures that pioneered the change of state are public structures that come up with new spatial arrangements. The most striking of these public buildings are the municipal buildings, which deal with a new spatial arrangement together with the art and theatre stages in their surroundings and interior arrangements. In this article, the architectural features and structural system of the municipality building, which was built in Çorlu in the 80s, is discussed.

The city of Çorlu, located in the Thrace Region, has a more crowded population than many provinces and districts with a population of 273.000 today. It is a frequent destination for many people due to its location on the way to Europe and its proximity to Istanbul. The expansion of the industry, the increasing socio-cultural, economic and technological developments also affected the architectural environment and it was decided to build a new municipal building for the city. During the mayor Seyfettin Meriç term, "Yıldız University Revolving Fund" proposed projects for the municipality and the projects were completed in February 1984. In the project working group, Prof. Maruf Önal, Assoc. Hakkı Önel, Assoc. Ali Duzgun and lecturer Radi Birol have been present. The design of the projects of the building took 4 years and was completed in 1984, 2 years after the completion of the design, the construction of the building officially started in 1986 [1].

As a location, it was built in front of today's Republic Square. In the project area, the old reinforced concrete baths and cisterns belonging to the Çorlu municipality and the Sücaettin primary school building were demolished and the municipality palace was decided to be built instead, and the square in front of the municipality building was placed in this area. The Military Hospital, which was built in the 1930s, is located around the 5th. Corps Command and Army House buildings are located. The south side of the building is designed as a street and the north side as a large square.

The municipality building shows its modernity not only in terms of exterior but also in terms of plan and interior design, by considering all kinds of architectural details. The most striking feature of the building is that there is a large atrium in both blocks on the ground floor. These atriums have increased the interior visually of the building incredibly. These spaces are shown as a social interaction section exemplified by the architects.

The mass of the municipial building is formed by the juxtaposition of two square prisms, which are basically a prime geometric form. In this building plan, it consists of a linear combination of offices placed symmetrically around the atrium, which is simple and widely used. Simplicity and simplicity are at the forefront both in the smooth and static mass of the building, as well as in the facades and plans.

2. MATERIALS AND METHODS

In this study, through the examination of municipality structure in the city of Çorlu, on-site observations were made across the building and its surroundings, detailed photographs were taken, and documents were created about the interior and exterior architecture of the building. Old photos taken during the construction period of the building have been obtained to have a strong idea of buildings' production survey. Moreover the building structural system is modelled in the structural analysis program.

3. STRUCTURAL SYSTEM OF MUNICIPALITY BUILDING

Çorlu Municipality Building is a nine-storey building with a high entrance, two and a half floors below ground level, and six floors above ground floor including the attic. This building, which is located on a sloping area, was made with reinforced concrete construction technique and is a public building with a regular geometric shape. There is a large square on the front of the building, that is, on the north side, and a clock tower in the middle of the square. The height of the building is 24 meters and the width is 42 meters [1].

The building has two and a half floors of basement. On the basement floor, there is a theatre, artist rooms and archive-storage sections. Besides them, there is a sitting area, a theatre stage and a seminar room. On the ground floor, there are shops, entrance hall and cashiers. 1st floor is presidential floor, 2nd floor is science-calculation floor, 3rd floor is water-bus, 4th floor is legal affairs floor and there is an attic at the top.

In our country, which is located on an active seismic belt, devastating earthquakes have occurred in short time intervals. With the development of new technologies, changes were made in the regulations after these earthquakes. In the period when Çorlu municipality building was built, the 1975 earthquake regulation was active in our country.

According to this map, our country; First degree, Second degree, Third degree, Fourth degree earthquake zone and Safe zone divided into five regions (Fig. 1). In this regulation (1975 Earthquake Regulation), the effect of the ground is considered in more detail in the earthquake calculation. The acceleration spectrum coefficients were determined, and it was requested to take them into account while calculating the earthquake forces. However, the current regulation is more detailed [2, 3].

The risk status for Çorlu/Tekirdağ according to Turkey Earthquake Zones Maps 1972 is the third-degree earthquake zone (Fig. 2). 2018 Turkish Earthquake Code has been officially enforced as of January 1, 2019.

Four different earthquake ground motion levels are specified in Turkey Building Earthquake Code 2018. DD-2: 10% probability of exceeding in 50 years, corresponding to a return period of 475 years. This earthquake ground motion is also called standard design earthquake ground motion [4].

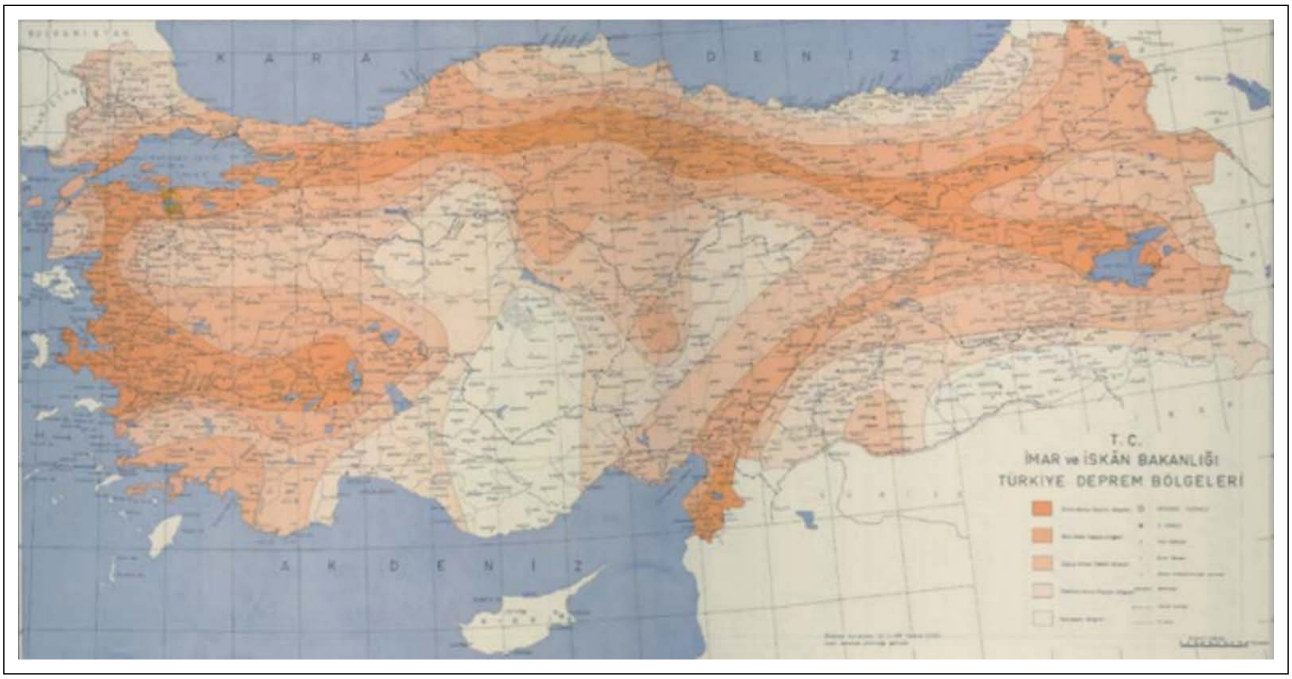


Figure 1. Turkey earthquake zones map of 1972.

Figure 2. Çorlu municipality building area.

For the coordinates where Çorlu Municipality Building is located, the maximum ground acceleration (PGA) for ZD soil type (Tight layers of sand, gravel, or very solid clay) was determined as 0.332g from the AFAD Turkey Earthquake Hazard Maps Interactive Web Application [5]. The maximum ground speed (PGV) is 20.397 cm/sec.

3.1. Structural System Properties of the Building

Geometric Information about floor levels of Çorlu municipality building

Number of floors: 8

Effective number of floors: 8

Number of rigid basement floors: 3

- RC Frame system was used in the plan design of Çorlu Municipality Building.
- The structural system of the building is Reinforced Concrete with Frame System.
- Cartesian grids were used on the facade of the building

The building importance coefficient is I=1.5 for municipal administration buildings according to TBDY2018. The building use categories coefficient is BKS=1. The building use categories is determined according to the building importance coefficient. Buildings that need to be used after an earthquake, buildings where people stay for a long time and intensely, buildings where valuable goods are stored and buildings containing dangerous substances are within the scope of BKS=1.

The concrete class used in the building is C30 according to the current project. Detailed information could not be obtained for foundations and other structural elements. According to its current project, the steel class is B225.

According to the Turkish Building Earthquake Code 2018, vertical and horizontal irregularities are defined in the buildings. However, such irregularities were not found in the Çorlu municipality building.

According to the Turkish Building Earthquake Code 2018, the structural system behaviour coefficient has been determined as R=4 and Overstrength Factors as D=2.5 for buildings where all the earthquake effects are covered by reinforced concrete frames with limited moment-transmitting ductility level.

Unfortunately, devastating earthquakes have occurred in our country, especially in the last century. Building earthquake codes were updated after these earthquakes. Until the 1949 Earthquake Regulations, did not fully mention reinforced concrete buildings in the regulations. Due to the fact that reinforced concrete buildings are not widely used, there are no studies on earthquake calculation in these regulations. Although the first earthquake calcula-

Figure 3. Turkey earthquake zones map of 2018.

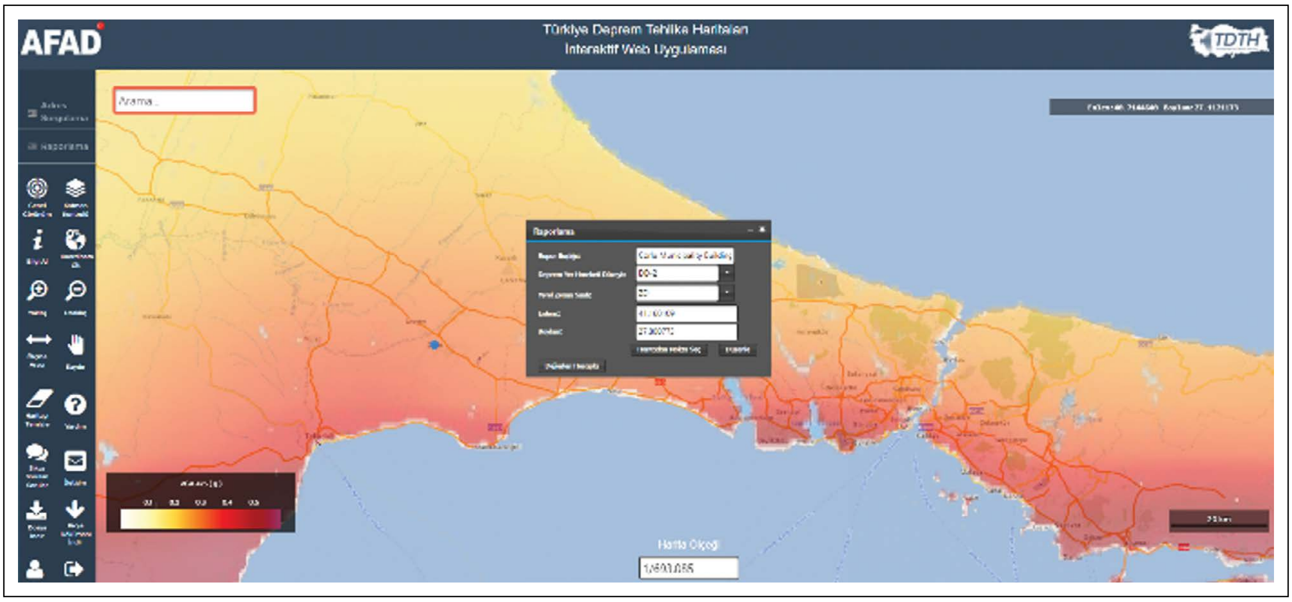


Figure 4. AFAD Turkey earthquake maps interactive web application.

tion is very simple, it is available in the 1949 Earthquake Code. In later regulations, earthquake calculations became more and more detailed. Also in Turkey Earthquake Code 2007, methods for the evaluation and retrofitting of existing structures was introduced. Push-over & capacity spectrum method was introduced (Fig. 3, 4).

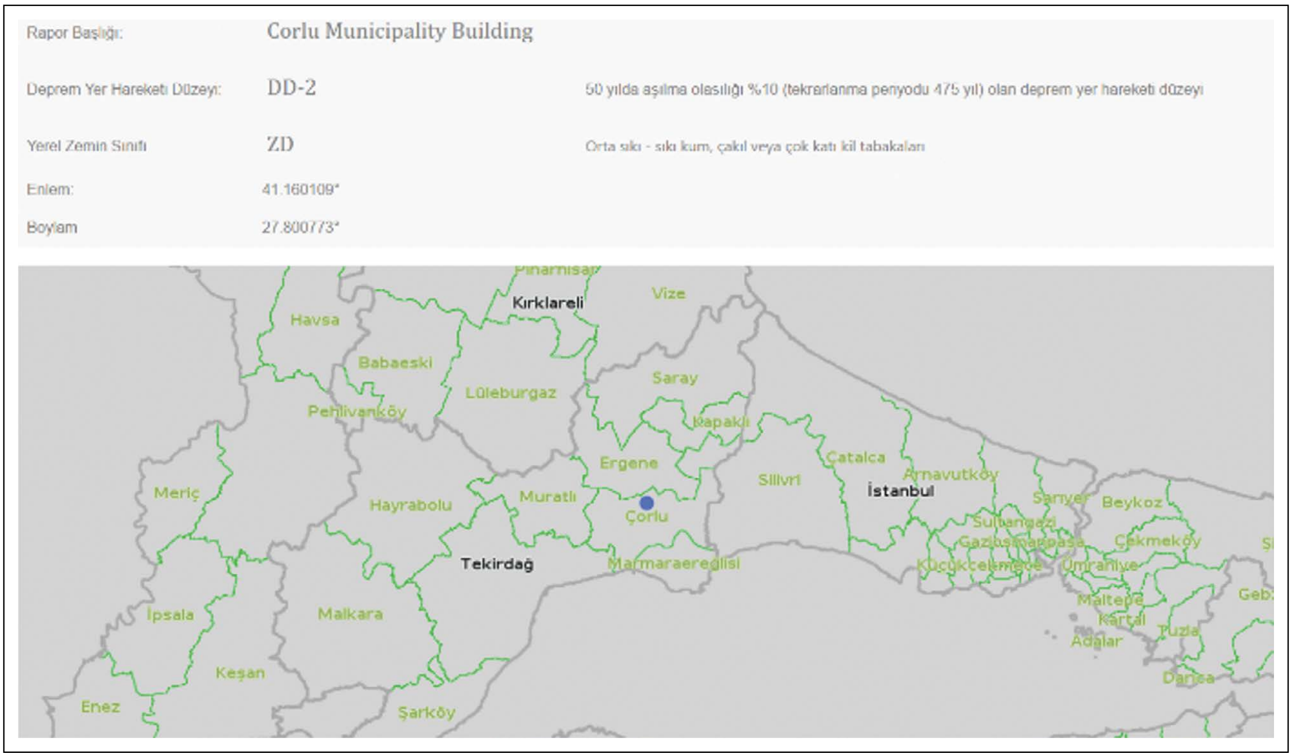


Figure 5. AFAD Turkey earthquake maps interactive web application - Corlu municipality building.

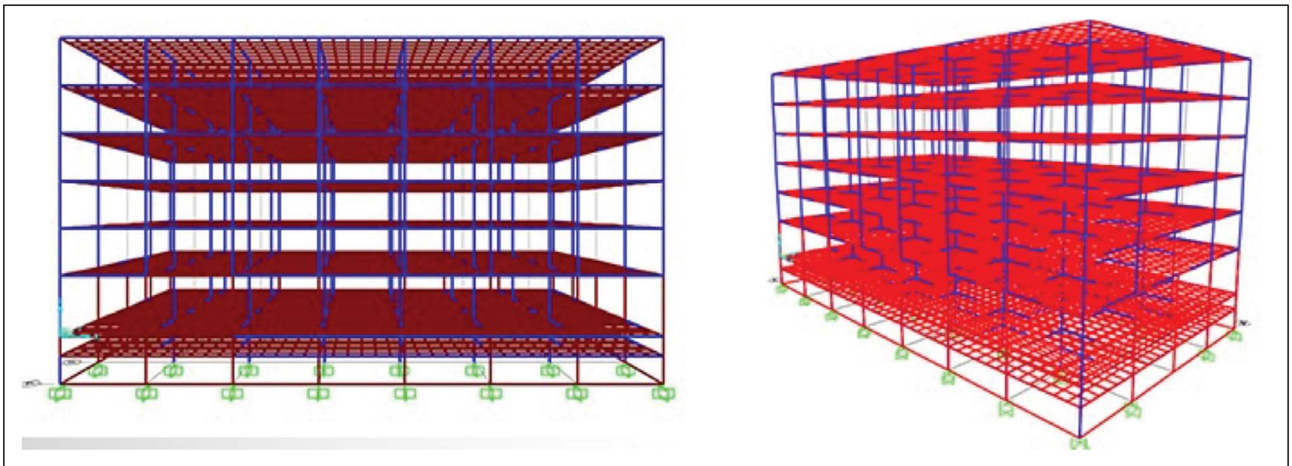


Figure 6. Structural system of the building with two dimensions.

Earthquake hazard maps also show that the earthquake risk prepared for the same region in those years is quite low compared to the Turkey Building Earthquake Code 2018 (Fig. 5).

Çorlu Municipality Building is reinforced concrete buildings with frame system as in most of the building stock in our country (Fig. 6, 7). When we look at the years of construction, it is estimated that the buildings was built in accordance with the Turkey Earthquake Code 1975 (Table 1). Due to the fact that earthquake regulations have become more detailed, earthquake safety of existing building should be checked and retrofitted according to new regulations.

It is known that in earthquakes, structures reach the collapse zone due to the formation of some or all of the three main elements: Insufficient lateral stiffness, insufficient ductility and insufficient strength. Retrofitting: is the study carried out to bring the rigidity and ductility of a structure to its pre-damage state or to increase it above the current state [6].

These traditional retrofitting methods cannot create optimum solutions due to both the long application and construction periods and the high cost level. In addition, these methods create situations that prevent the building from fulfilling its architectural functions [7, 8].

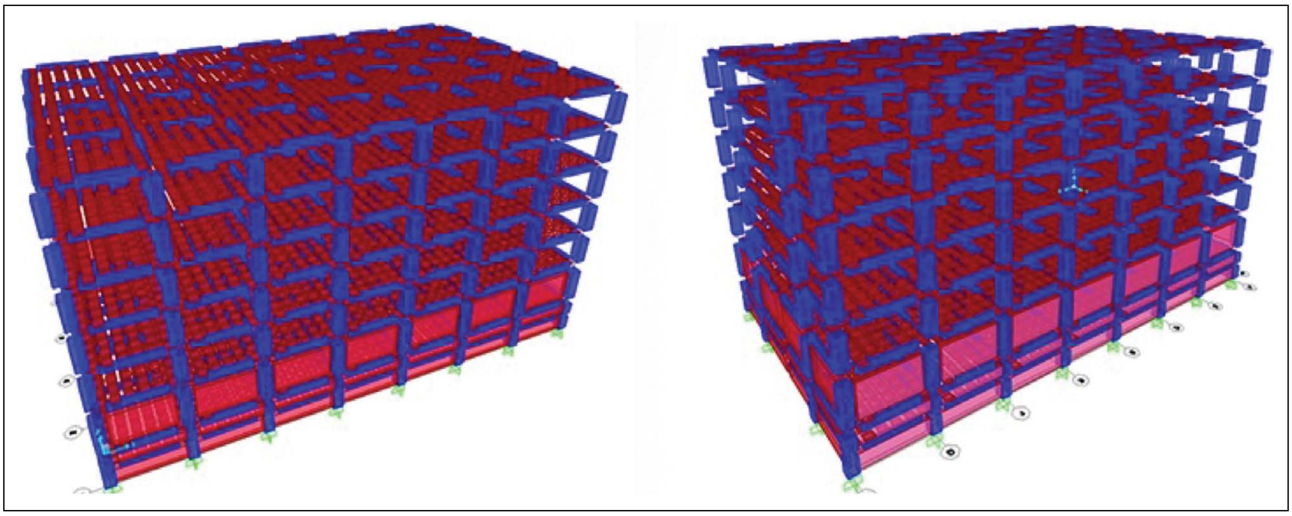


Figure 7. Structural system of the building with three dimensions.

Table 1. General structural information about Çorlu municipality building

Municipality building	Data
The place of hotel	Corlu/Tekirdag (1984)
The usadge of the building	Municipality Building
Altitude	173 mt
Building importance coefficient	1.5
Ground type	ZD
Ground safety tension	30 KN/m^2
Foundation depth	Front part 5,60 mt- back part 10,60 mt
Material	Reinforced concrete
Steel class	B225
Earthquake motion level	DD2 (TBDY 2018 2.2.2. article)
Height of the building	41,43 mt
PGA 475	0,332 g
PGV	20,397 cm/sn

Table 2. Iinformation about FRP type [9]

FRP type	Modulus of elasticity (kN/mm^2)	Tensile strength (N/mm^2)
Carbon	230-640	2500-4000
Aramid	120-130	2900
Glass	70-90	2000
Steel St37	210	370

Retrofitting technique with fibrous polymer, one of the new generation methods; is a system that increases the strength, ductility and rigidity capacities of the structure, obtained by bonding high-strength fibers such as carbon, glass, aramid with resins to the surfaces of building elements with different methods and shapes (Fig. 8, 9) [9].

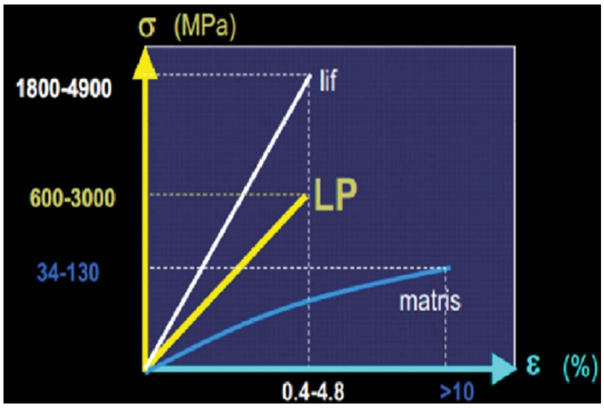


Figure 8. FRP composite properties.

Figure 9. FRP composite.

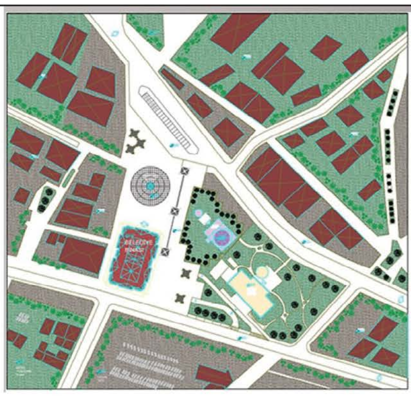
The fibers are the load-bearing component with a high modulus of elasticity. It can be based on glass, aramid and carbon (Table 2). The fibers are attached to the reinforced concrete surface with epoxy etc. bonds with a matrix and

Table 3. Architectural Information of the building

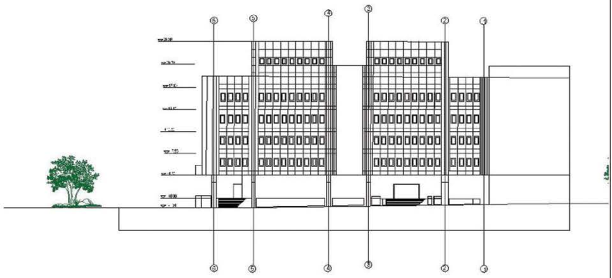
Corlu municipality building

General information about architectural drawings and photos of the building

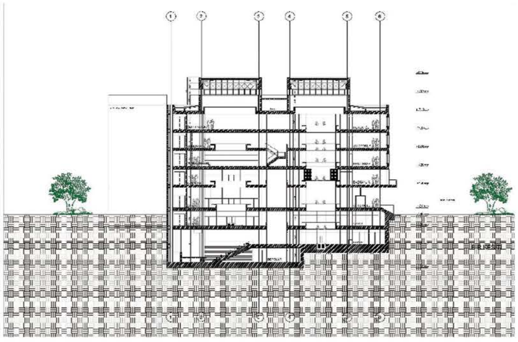
Location: Çorlu, Tekirdağ, Turkey date of construction: 1984 architect: Maruf ÖNAL



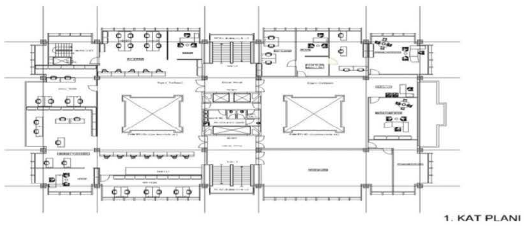
Site plan



Elevation of the building

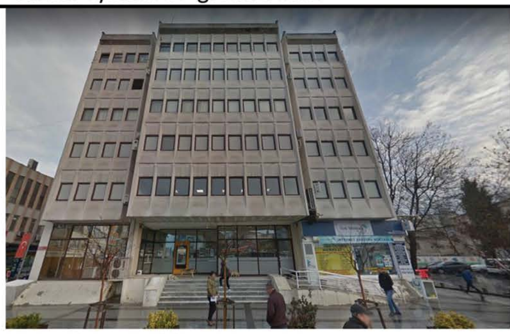


Section of the building



Carrier system of ground floor

Views from Building



Views from Building

Views from Building

Views from Building

creates a composite section behaviour. Fiber reinforced polymers increase the strength and ductility of the building elements and increase the ductility of the structure under the effect of earthquakes.

Tensile strength of FRP components is ten times that of St37 steel. Strength and ductility values of the structure to be retrofitted should be improved on an element basis. For this purpose, after determining the demands of the building under the effect of earthquake and vertical loads, the increase in the element capacities of these demands can achieved with the FRP application.

4. CONCLUSION

Çorlu Municipality Building shows that the modern language in architecture has been shown on the facades and architecture of the building. We can see modern architecture signs on the building. In particular, the window edges on all facades are deepened with deep joint gaps, and their deletions and geometries are continued on four floors, eliminating the floor levels as an interesting detail in the plastic of the building. This dominant plastic pursuit ends with a clean flat surface on the last floor. Moreover, the interpretation of the multi-storey, grid-fronted monoblock architecture of single modern buildings draws attention in this building. While both rationalism and functionalism principles come to the fore in the spatial setup of the building, there is also a harmonious composition of geometric volumes seen as in nationalist architectural period Turkey (Table 3) [10].

Earthquake is the heaviest loading situation encountered by the structures during their lifetime. It is known that due to insufficient ductility, insufficient strength and insufficient rigidity in reinforced concrete structures, damages occur under the influence of earthquakes and even the structures reach the point of collapse. In order to restore the building safety and to continue the existing architectural functions of the building, the entire load-bearing system and damaged elements must be repaired and retrofitted.

There are different retrofitting alternatives, especially in reinforced concrete structures that constitute the majority of the building stock in our country. New generation retrofitting methods are behavior controlled techniques (active and passive dampers etc.) and fiber reinforced polymers. Retrofitting technique with fiber reinforced polymer, one of the new generation methods; ıt is a system that system that increases the strength, ductility and rigidity capacities of the structure with epoxy etc. of high strength fibers such as carbon, glass, aramid.

Retroffing of reinforce concrete frame type structure with fiber polymers is a very effective method due to both rapid application and not changing the architectural functions. In buildings that is important in terms of architectural heritage, such as the Çorlu Municipality Building examined, this application can be used to ensure earthquake safety.

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

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Research Article

Effect of nanosilica addition on the mechanical properties of cement mortars with basalt fibers with or without silica fume

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ABSTRACT

Fiber reinforced concrete is widely used throughout the world however to reveal its full potential, optimization with different additives should be asserted. In this study, effect of the three different parameters were diagnosed by means of compressive strength, flexural strength and fracture. Ordinary Portland cement mortars were studied with three different basalt fiber contents (0, 0.5, 1%), three different nanosilica addition (0, 1, 2% by wt. of cement) and also silica fume incorporation (0, 5% by wt. of cement). The results showed that adding basalt fiber significantly improved the flexural strength and toughness properties and also with the addition of nanosilica the increase in flexural strength boosted up to 23% level of increase at the presence of silica fume. This synergy effect was found to be significant when incorporating basalt fibers. When nonfibrous specimens were inspected, it is seen that addition of nanosilica was not significantly efficient increasing neither the flexural strength nor fracture properties.

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1. INTRODUCTION

Concrete is the most widely used material constructional material owing to its remarkable features such as easy molding abilities and ease of supply of the ingredients, high strength and low cost. Nanotechnology is an evolving area of research in material science. Application of ultra-fine additives such as nanosilica is to enhance several properties of the composite. Micro and nano-scaled silica particles exhibit ultra-fine filler effect stimulating the internal cement matrix structure by filling voids with minimal sizes [1].

Nanosilica is the most popular nanomaterial used in the cementitious materials due to its pozzolanic reactivity along with the void-filling abilities. Nanosilica incorporation into concrete results in denser and compact microstructure due to refinement of the pore structure and accordingly permeability is also decreased with the help of nanofilling and pozzolanic characteristics [2, 3]. Nanosilica also serves as a siliceous precursor and acts as a nucleation site to promote further hydration [4]. Another important issue to deal with the proper implementation of nanosilica particles into the cement matrix when mixing since due to its large specific surface area, risk of agglomeration arises [5–7].

Basalt fiber is a new type of inorganic fiber which is being produced from the basalt rock [8]. This type of fibers have several superiorities with respect to others considering

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the environmental issues construction sector has been facing in the last decades. Manufacturing process is although similar to others like glass fibers, production of basalt fibers consume less energy and no additives are needed [9, 10].

Mechanical performance and chemical endurance properties are also more than adequate to facilitate in structural concrete. Besides high tensile strength and good chemical resistance, basalt fibers provide resistance to high temperature, increase in strain capacity, high modulus of elasticity [11]. Production process of basalt fibers is also simple, inexpensive and environmentally friendly creating a perfect sustainable perspective [12].

However, provided that research on these fibers are still limited, in order to increase the use in standard construction facilities, additional studies should be conducted to investigate on the dual or ternary usage of these fibers with different additives. These studies may both optimize the use of basalt fibers and also increase the performance of reinforcing activity by enhancing the cement matrix adhering the fiber structure.

2. MATERIALS AND METHODS

2.1 Materials

CEM I 42.R ordinary portland cement and silica fume were used as binders whereas 0–2 mm river sand was adopted as fine aggregates for mortar specimens. Nanosilica was purchased from Nanografi. Basalt fibers were also used as fiber reinforcements. Properties of materials used are given in Tables 1 and 2.

2.2 Mortar Specimen Preparation

Mortar specimens were prepared conforming to the specifications given in TS EN 196-1 [13]. 18 different mortar specimens were prepared incorporating two different silica fume content (0, 0.5%) and three different nanosilica content (0, 1%, 2%) and three different basalt fiber content (0, 0.5, 1%). For each series, 3 prism specimens for 3, 7 and 28 day flexural and compressive tests were produced whereas 2 more specimens were also produced for 28-day flexural toughness measurements. Mixtures were constructed with constant binder:sand:water ratio as 2:2:1 and mixture proportions were given in Table 1. A total of 187 specimens were cast into 40 x 40 x 160 mm steel molds.

Nanoparticles were mixed with a part of mixture water for uniform dispersion. Firstly, binder and sand were blended for 60 seconds in a Hobart mixer and then the aqueous nano-additive suspension was added to the mixture for 60 seconds and basalt fibers were added in a duration of 60 seconds and final mixture was further mixed for 120 seconds more to achieve the proper homogeneity for all mixtures. All specimens were kept in the molds for 24 h in a moist room at a temperature of (23±2) °C and relative humidity of 95%. After demolding specimens were placed in water tanks at 20 ˚C until the age of testing (Table 3).

Table 1. Properties of basalt fibers

Diameter (μm)	Length (mm)	Tensile strength (MPa)	Elasticity (GPa)	Density (kg/m³)
9–23	12	4840	89	2700

2.3 Flowability of Mortar Specimens

Flowability of fresh mortars were conducted according to ASTM C1437-15 [14]. Flow mold with a 50 mm height was placed on the jumping table and filled as two layers of mortar by tamping 20 times for each layer before lifting the mold. After lifting the mold, 25 strokes were applied to the fresh mortar in 15 seconds using the jumping table. Average diameter of the spread mortar mixture was measured in two perpendicular directions of the spread mix to determine the flowability of the mortar mixtures.

2.4 Mechanical Testing of Specimens

The flexural and compressive strengths were measured at the ages of 3, 7 and 28 days according to TS EN 196-1 [13]. Mortar specimens were loaded until crushing under three-point flexural loading with a displacement rate of 0.5 mm/min by a servo-hydraulic closed loop-controlled flexural loading machine with 100 kN maximum force capacity. The span length for flexural loading was used as 120 mm. The load-displacement curves were obtained by the 2 LVDTs that were attached to two sides of the prism specimen and the vertical deflection was taken as the average of these 2 recordings. Three-point loading test results were used to assess the flexural stress values by Equation 1:

$$\sigma = \frac{3PL}{2bd^2} \quad (1)$$

where σ is the flexural stress; P is the maximum load; d, b and L are the depth, width and span length, respectively. The compressive strength tests were carried out at a loading rate of 0.5 MPa/sec on the half prisms that were formed after the three-point bending test.

Fracture toughness is a significant parameter to monitior the toughness capacity of cementitious materials. Toughness of the mortar matrix was examined by applying the specifications given in ASTM C1609 [15]. Tough-

Table 2. Properties and compositions of cement and silica fume

Composition (%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	LOI	Density (kg/m³)
Cement	19.81	5.58	3.42	63.70	1.22	3.34	0.24	0.66	1.85	3110
Silica fume	96.31	0.91	0.42	0.78	0.43	–	–	–	1.20	2350

Table 3. Mix proportions of cement mortar specimens

Mixture	Cement (g)	Silica fume (g)	Sand (g)	Water (g)	Nanosilica(g)	Basalt fiber (g)
Control	1000	0	1000	500	0	0
SF0NS0BF0.5	1000	0	1000	500	0	12.5
SF0NS0BF1	1000	0	1000	500	0	25
SF0NS1	990	0	1000	500	10	0
SF0NS1BF0.50	990	0	1000	500	10	12.5
SF0NS1BF1	990	0	1000	500	10	25
SF0NS2	980	0	1000	500	20	0
SF0NS2BF0.5	980	0	1000	500	20	12.5
SF0NS2BF1	980	0	1000	500	20	25
SF5	950	50	1000	500	0	0
SF5NS0BF0.5	950	50	1000	500	0	12.5
SF5NS0BF1	950	50	1000	500	0	25
SF5NS1	940	50	1000	500	10	0
SF5NS1BF0.5	940	50	1000	500	10	12.5
SF5NS1BF1	940	50	1000	500	10	25
SF5NS2	930	50	1000	500	20	0
SF5NS2BF0.5	930	50	1000	500	20	12.5
SF5NS2BF1	930	50	1000	500	20	25

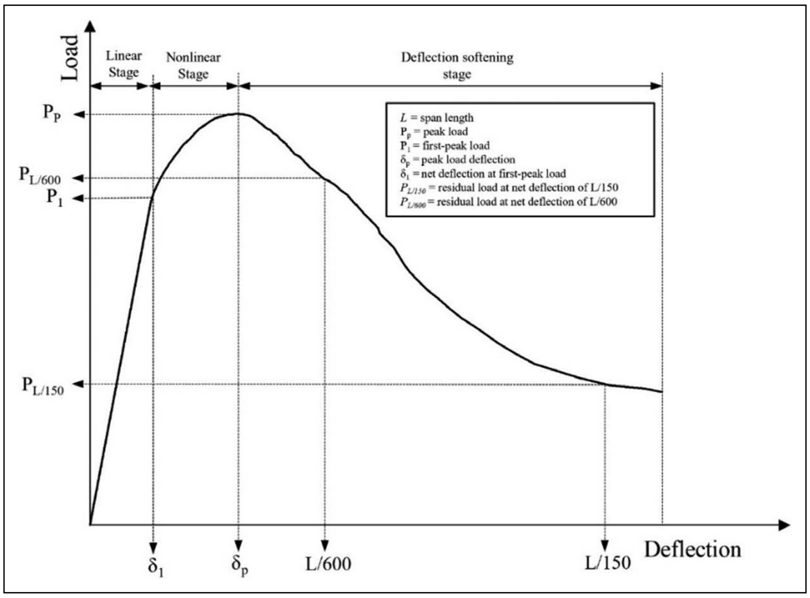

Figure 1. The load-deflection response curve.

ness values were calculated as the net area under load-displacement curves between the zero deflection and net deflection points. Net deflection points were selected as L/150 and L/600 according to ASTM C1609. Load ($P_{L/600}$ and $P_{L/150}$) and energy absorption ($T_{L/600}$ and $T_{L/150}$) values were also obtained.

Toughness results were obtained by the load-deflection curves as given in Figure 1. As depicted in Figure 1, flexural behaviour is inspected in 3 different stages. First stage is the linear elastic region also known as pre-crack stage, second stage is the non-linear stage whereas the third stage is the deflection softening stage also called post crack stage. In the first stage, flexural capacity of the cement matrix is of importance and when the loading exceeds the first crack load, cement matrix in the tensile zone is cracked thus triggering the nonlinear propagation upto the peak load. After the peak load, deflection softening stage occurs with the decreasing amount of loading.

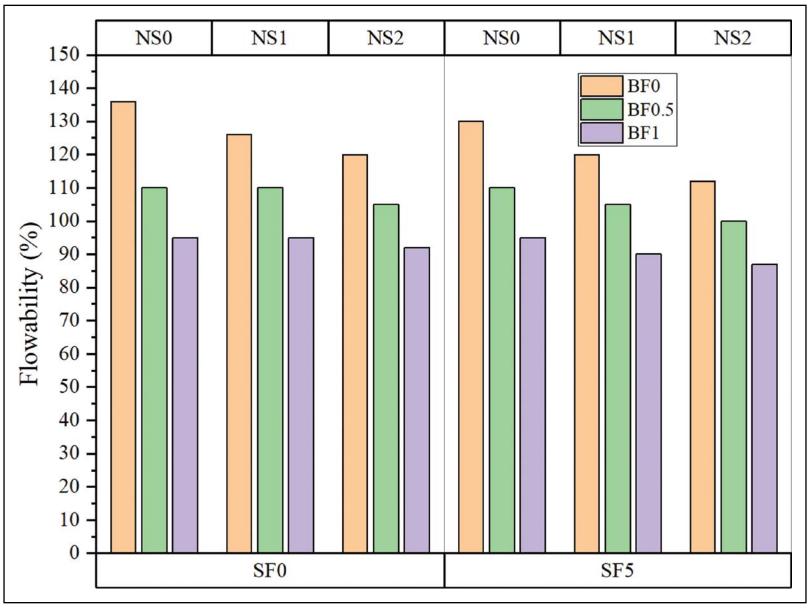

Figure 2. Flowability test results of mixtures.

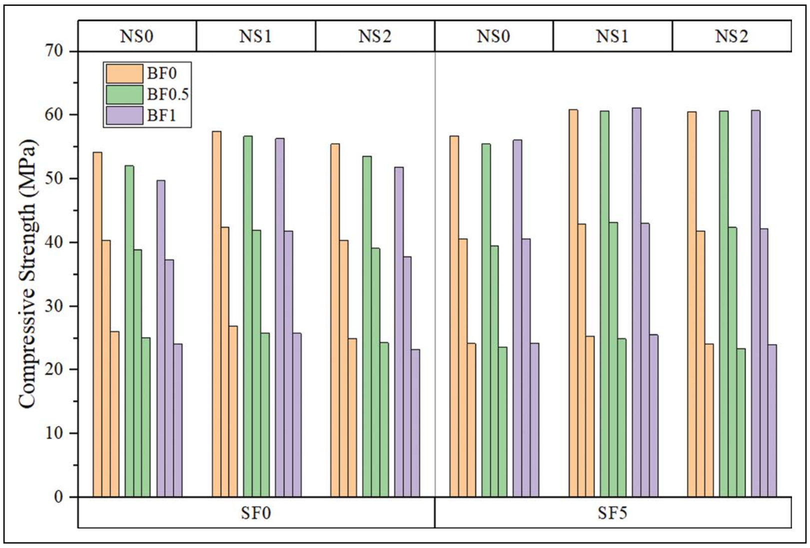

Figure 3. 3, 7 and 28-day compressive strength results.

3. RESULTS AND DISCUSSION

3.1 Workability

Flowability measurements were taken for 18 different mixtures and the results were illustrated in Figure 2. All mixtures were found to be in good workability to produce enough compaction in the steel molds. When all results are compared, it is seen with the increase of all three parameters flowability was influenced adversely. Most significant effect was noticed with the inclusion of the fibers and silica fume addition was the second whereas addition of nanosilica was third. This may be related to the addition of nanoparticles in relatively very small amounts. These results were all found to be relevant since both additions of fibers and addition of micro and nano sized particles affect the workability in earlier studies in literature.

3.2. Compressive and Flexural Strength Results

3, 7 and 28-day average compressive strength results of 6 tests for each mixture type are given in Figure 3.

Compressive strength test results reveal significant findings on the effect of the parameters used in the study. When 28-day results are compared, as anticipated compressive strength of the specimens were found to be increased with the addition of silica fume for all specimen series. Addition of basalt fibers caused a decrease in overall compressive strength values which may also be related to defi-

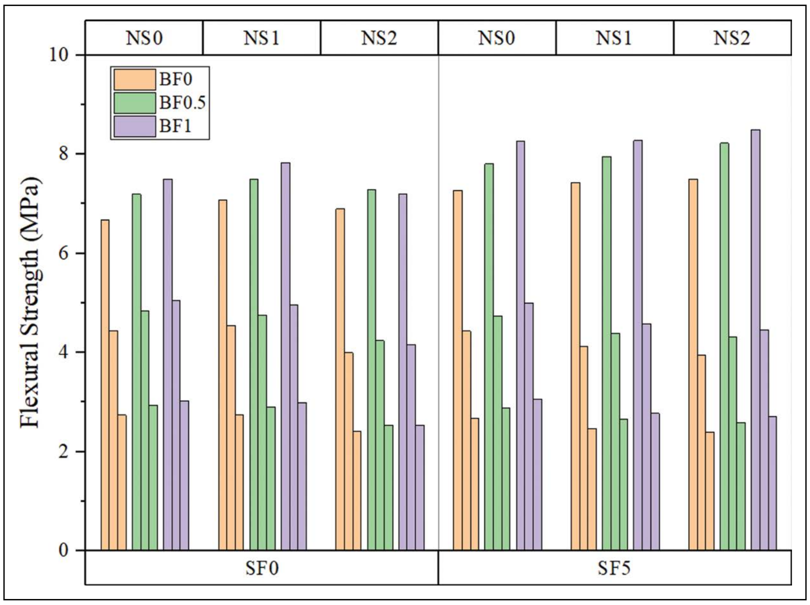

Figure 4. 7 and 28-day flexural strength results of specimens with different additive ratios.

ciencies in the overall matrix integrity due to presence of fibers. With the increase in the fiber content, decrease in the compressive strength was observed to be more critical. Dias and Thaumaturgo reported 3.9% decrease in compressive strength with the fiber content of 0.5% [16]. Nanosilica particles were also found to be efficient enhancing the compressive strength, however with higher amount of nanoparticles were found to be problematic when there is no silica fume in the mixture. Thus, combined effect of these parameters exhibited significant effect on the results. When silica fume is present in the mixture, addition of higher amount of nanosilica was similar to lower amount of nanosilica added specimens. Li et al. [17] investigated the synergy of using nanosilica and silica fume together and reported significant improvement in durability. Brescia-Norambuena et al. [18] also investigated combined use of nanosilica and silica fume and reported important improvements in the mechanical properties.

When 7 day results are examined, similar results were found with respect to 28 day results. However, overall findings were noticed to be closer to each other. Effect of extra nanosilica adversely affected the strength when used without silica fume. When 3 day results are examined, it is seen that mixtures with silica fume were found to have lesser strength which may be explained by the pozzolanic reactions. Also addition of nanosilica was not effective which may also be explained by the puzzolanic activity appearing later.

28-day flexural strength results reveal that inclusion of basalt fibers were significantly effective increasing the ultimate flexural strength (Fig. 4). Control specimens exhibited 7 and 12% increase with the addition of basalt fibers respectively without any other additive. For specimens with

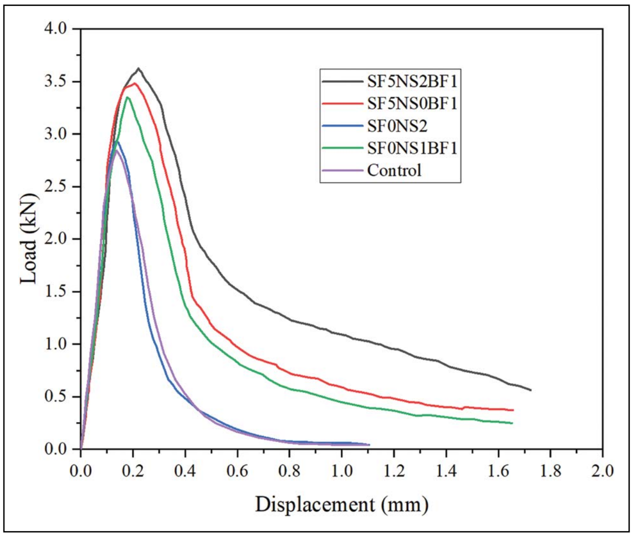

Figure 5. Load-deflection curves.

lower nanosilica addition, basalt fibers were also found to be effective with increases of 12 and 17% although no silica fume was added. However, when there is no silica fume addition, higher NS levels were monitored to have lesser progress. This may be related to possible negative effect of high NS level on the structural integrity of the cement matrix. When specimens with SF are considered, this effect was found to be diminished. Higher NS level was also found to be more effective than all other specimen series. Thus, highest increase in the flexural strength was obtained for SF5NS2BF1 series. It should be clearly said that presence of SF contributes to effectiveness of NS particles in the cement matrix thus promoting their effect on the overall microstructure [18].

Table 4. Results for the flexural toughness

Specimens	P_p (N)	δ_p (mm)	$P_{L/600}$ (N)	$P_{L/150}$ (N)	$T_{L/600}$ (N.mm)	$T_{L/150}$ (N.mm)
Control	2.85	0.137	2.33	0.063	718	411
SF0NS0BF0.5	3.07	0.157	2.57	0.499	1078	424
SF0NS0BF1	3.20	0.177	2.85	0.574	1219	436
SF0NS1	3.02	0.135	2.30	0.065	731	416
SF0NS1BF0.50	3.20	0.155	2.69	0.547	1110	438
SF0NS1BF1	3.34	0.178	3.20	0.569	1265	438
SF0NS2	2.94	0.137	2.24	0.072	692	402
SF0NS2BF0.5	3.11	0.148	2.42	0.626	1010	426
SF0NS2BF1	3.07	0.169	2.80	0.687	1139	418
SF5	3.10	0.147	2.46	0.071	790	445
SF5NS0BF0.5	3.33	0.177	2.97	0.716	1289	436
SF5NS0BF1	3.53	0.206	3.48	0.721	1424	469
SF5NS1	3.17	0.149	2.49	0.067	782	466
SF5NS1BF0.5	3.39	0.189	3.19	0.757	1437	456
SF5NS1BF1	3.53	0.212	3.48	1.188	1785	453
SF5NS2	3.20	0.144	2.40	0.072	799	456
SF5NS2BF0.5	3.51	0.197	3.49	0.785	1476	442
SF5NS2BF1	3.62	0.220	3.56	1.227	1731	454

When 7-day flexural strength values are investigated, similar adverse effect of higher NS level specimens without SF were also noted. Also, it should be clarified that due to pozzolanic activity improvements in the flexural strength were limited with respect to 28-day results. In 3-day results, similar conditions were noticed and especially for this curing period, effect of basalt fibers were also diminished since earlier reactions were limited which affect the interface between the cement matrix and the fibers.

3.3. Fracture Toughness

The load versus deflection graph under flexural loading is given in Figure 5. Each curve resembles the average values of the load-deflection curves for each specimen set which are obtained accurately by using the procedure described in a previous study [19].

Fracture findings exhibited consistent results with the flexural strength results generally (Table 4). Fibrous specimens showed promising results in terms of energy absorption resisting higher loading levels after cracking [20]. Also, peak load values were also higher than specimens without fibers. Contribution of silica fume was also significant for fracture results which may be related to better transition zone between the fibers and the cement matrix. Higher specific surface area of silica fume has acted as microfiller on the bondage of the fibers to the cement matrix increasing the adherence. Also, NS addition was effective especially for mixtures with silica fume, inclusion of NS increased the peak load and also the energy absorption capacity. However, when nonfibrous specimens were compared, similar findings were noted.

4. CONCLUSION

As a result of this study, considerable insight has been gained about the use of basalt fibers in presence of silica fume and nanosilica and the findings on the mechanical properties are summarized as follows:

Addition of basalt fibers adversely affected the compressive strength results between 4%–9%. However, with the presence of silica fume this adverse effect diminished. Flexural strength values were improved with the increasing amount of basalt fibes up to a value of 27%. However, this increase was limited with only 12% without any other addition.

Addition of silica fume into all mixtures were found to be effective for both compressive and flexural strength values. 8% increase was detected for SF addition alone. Also it should be reported that presence of SF increased the effeciency of NS particles increasing the overall contribution by dual usage in cement matrix.

Nanosilica addition was found to be effective for both fibrous and unfibrous specimens and these improvements were found to be the highest when used ternary. Highest increase in compressive strength was noted as 12% for NS2SF5BF1.

Investigating the effect of the synergy of the three important additives into the cement matrix presented promising results that may give contribution to the growing body of literature on the use of micro and nanoscale pozzolanic additives in cementitious composites.

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DATA AVAILABILITY STATEMENT

The author 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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Research Article

Implementation of shear wave velocity and standard penetration test correlation for Edirne district, Turkey

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ABSTRACT

It is critical to determine the shear wave velocity (V_s) for earthquake resistant construction design and ground improvement methods. V_s is used in geotechnical earthquake engineering and microzonation studies to calculate the stresses and strong motion characteristics that an earthquake will generate in the soil layers. Characterization of soil and rock small-strain shear modulus and shear wave velocity is an essential component of different seismic analyses such as ground classification, hazard analysis, site-response analysis, and soil-structure interaction. Due to the high expense of seismic testing in comparison to other field tests, these tests are often favored in more significant projects. In circumstances when field seismic testing cannot or only in a limited number of cases be undertaken, the need for correlations between shear wave velocity and other experimental data leads to calculation of V_s. In circumstances when undisturbed soil samples, such as gravel, sand, and silt, cannot be acquired, the Standard Penetration Test (SPT) has been effectively implemented, and numerous researchers have investigated the relationships between the obtained values and the shear wave velocity. It was discovered that the parameters influencing SPT-N number also influence shear wave velocity. Because the relationships presented in the literature are empirical formulae, they may not offer consistent findings for all soil conditions and soil types. The goal of this study is to determine the closest empirical relationships given in the literature by comparing derived SPT values to average shear-wave velocity to 30-m depth (Vs30) values obtained from Multichannel Analysis of Surface Waves (MASW) for the same sites in the Edirne area. Among the investigated relationships, the ones with the lowest error were recommended for estimate of V_s data in the locations with missing V_s data.

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1. INTRODUCTION

The characteristics of earthquake motion in an area are significantly affected by the presence of soil deposits. Ground motion features can be made from either a simplified field classification method or a site-specific ground response analysis. For all these methods, shear wave velocity (V_s) is the most important parameter representing the hardness of the soil. It is useful in evaluating shear wave velocity, foundation stiffness, seismic site response, lique-

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faction potential, soil density, soil classification, soil stratigraphy, and foundation settlements [1–5]. The maximum shear modulus (G_{max}) can be measured in the laboratory using a resonance column device or bending elements. While void ratio and stress conditions can be reproduced in a disturbed sample, other factors such as soil texture and cementation cannot [1]. Laboratory testing requires very high quality, undisturbed samples. High quality sampling and testing is very expensive and often not possible for incompatible soils. Table 1 summarizes the effect of increasing various parameters for V_S.

Unlike laboratory experiments, geophysical tests do not require undisturbed sampling, maintain in situ tension during the experiment, and measure the response of large amounts of soil. Kramer (1996) discusses various geophysical methods for measuring shear wave. Shear wave velocities of soil profiles are determined using in situ seismic measurements. Because in situ measurements involve very low stress levels, the measured shear wave velocity can be used to obtain G_{max} at a given depth in a soil slump. However, G_{max} can also be estimated by empirical correlation to the results of in situ tests such as SPT [1].

The shear wave velocity profile at a site is usually obtained by performing wave propagation tests. However, the impact number (N) from the standard penetration test (SPT) is readily available for many geotechnical investigations. A number of studies have been carried out to determine empirical shear wave velocities for different soils [6–19]. Some of the empirical relationships use uncorrected SPT pulse counts, while others are based on energy corrected SPT pulse counts. Such relationships have been proposed for many different soils. Table 2 provides a summary of 20 empirical correlations based on SPT-N and V_s. These correlations are valid for all soils.

Table 1. The effect of increasing various factors on G_{max} and V_S [3]

Parameter	Effect of G_{max} on V_S
Confining stress	Increases as σ'_{v0} increase
Void ratio	A decrease occurs with an increase in the void ratio
Over consolidation ratio (OCR)	Increases
Cementation	Increases

Table 2. Summary of empirical correlations based on SPT-N and V_s [20]

Researcher	V_s correlations
Kanai (1966)	$V_s=19N^{0.6}$
Ohba and Toriumi (1970)	$V_s=84N^{0.31}$
Fujiwara (1972)	$V_s=92.1N^{0.337}$
Ohsaki and Iwasaki (1973)	$V_s=81.4N^{0.39}$
Imai et al. (1975)	$V_s=89.9N^{0.341}$
Imai (1977)	$V_s=91N^{0.337}$
Ohta and Goto (1978)	$V_s=85.35N^{0.348}$
Imai and Tonouchi (1982)	$V_s=97N^{0.314}$
Jinan (1987)	$V_s=116.1(N+0.3185)^{0.202}$
Kalteziotis et al. (1992)	$V_s=76.2N^{0.24}$
Athanasopoulos (1995)	$V_s=107.6N^{0.36}$
Sisman (1995)	$V_s=32.8N^{0.51}$
Jafari et al. (1997)	$V_s=22N^{0.85}$
Kiku et al. (2001)	$V_s=68.3N^{0.292}$
Hasançebi and Ulusay (2007)	$V_s=90N^{0.309}$
Hanumantharao and Ramana (2008)	$V_s=82.6N^{0.43}$
Dikmen (2009)	$V_s=58N^{0.39}$
Uma Maheswari et al. (2010)	$V_s=95.64N^{0.301}$

2. GEOLOGY AND TECTONICS

The mentioned study area was carried out in Edirne, Merkez, Havsa and Enez districts. Edirne is located in the Thrace part of the Marmara Region in the northwest of Turkey. Edirne Province, with an area of 6,276 km^2, is located between 40°30' and 42°00' north latitudes and 26°00' and 27°00' east longitudes. According to the data obtained after the observations and drillings in the study area, units belonging to the Ergene Formation (Mie) and Çanakkale Formation (Miç), which are the dominant formations of the region, were observed under the current fill layer at the top. Çanakkale Formation Holmes (1966)'s Ergene formation; Ünal (1967)'s Ergene Group, Büyük Anafarlalar formation; Kellog (1973)'s Anafartalar and Kilitbahir formation; The Eceabat formation of Önem (1974); Saltik (1974)'s Gelibolu formation is the equivalent of Gazhanedere, Kirazlı and Alçıtepe formations. This contrast shows that only a single formation feature is dominant in the study area. To define the units geologically, yellowish-white or brownish-yellow, cross-layered sandstone and locally clayey sandstone, reddish, greenish colored claystone and slightly attached pebble-pebble lenses are observed [21–25]. Figure 1 shows the generalized geological map of the study area and Figure 2 shows the generalized stratigraphic section of the study area.

There is no significant active fault within the borders of Edirne province, but the Ganos fault, which passes just south of the province and has a high earthquake potential, forms the westernmost segment of the northern branch of the North Anatolian Fault and extends to the Saros Gulf.

Regional tectonically, in the North of the Thrace Region, normal fault systems determine the structure of the massif in general [26]. The first and most effective of these fault systems extending perpendicular to each other are the NW - SE trending normal faults, starting from the Bulgarian border and extending from the Çatalca vicinity to the Marmara Sea. The second system is the NE - SW fault which developed perpendicular to these faults, cutting and offsetting them.

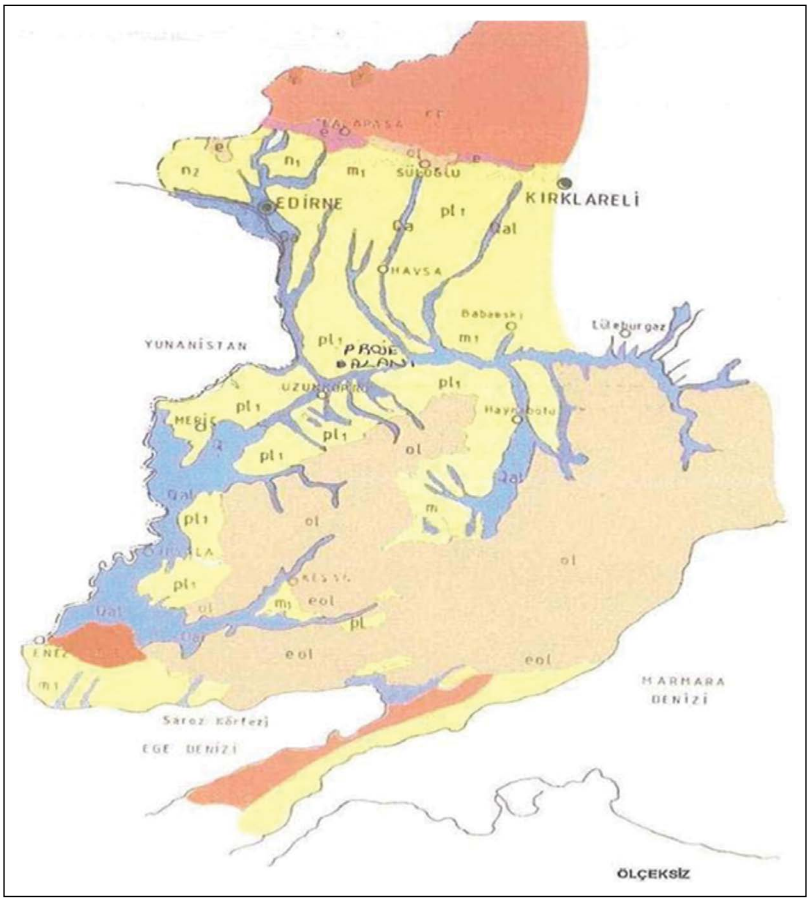

Figure 1. Generalized geological map of the study area (DSI, XI. Regional Directorate. 1996).

NW - SE normal faults; Starting from the Bulgarian border and traversing the massif from the border to Çatalca, the step has caused the fragmentation of the Paleozoic basement and the deepening of the sea towards the north-northeast, in the form of a fault bundle with five parallel extensions. The strike components of these faults could not be determined by the researchers in the field. However, in terms of kinematics, it is expected that the NE-SW strike-slip faults, which are the second fault system, will be offset as a natural result of their movement and the dextral strike components will develop. The most important NW - SE trending normal fault is the Sergen fault. The fault, which starts within the borders of Bulgaria and enters into the borders of Turkey around Malkoçlar village, loses its trace in the north of Kocayazı village, is traced in small pieces from place to place, and reappears around Kapaklı. Around Kömürköy, it disappears under Tertiary units. 66.6 km from the border to Kömürköy. This fault is normal fault and strike component could not be determined by the researchers. Approximately 8 km from the Sergen fault. In the southwest, a second fault bundle runs parallel to the Sergen fault between Devletliağaç and Koruköy. The fault beam, which is cut and offset in places, acquires a high-angle thrust character between Erikler and Koruköy. Figure 2 shows the locations of the faults within the provincial borders of Edirne on the digital map.

Table 3. V_s and SPT N values for boreholes in Edirne province

Borehole no	N_{av}	V_s30 (m/s)
2	27	345
8–1	40.5	407
8–2	30.66	407
11	29.11	387
15	17.55	323
24	35.285	395
26	11.17	337
27	13.22	251
28	22.33	357
37	34.33	346
57	10.44	269
64	25.142	365
79	24.55	325
81	18.88	273
90	43.125	377

Figure 2. Locations of faults on the digital map within the borders of Edirne province (Düzce University Journal of Science and Technology, 2017).

3. VS- SPT-N CORRELATION

In this study, SPT-N and V_s values obtained from 15 boreholes were used in the analysis. Average shear wave velocity (Vs30) and uncorrected mean SPT-N (N_{av}) values obtained from geophysical experiments are given in Table 3. In the literature, the effect of correcting N values on the proposed relationships was examined and it was found that the unadjusted N value provided better correlations [26]. Therefore, uncorrected N values were used in this study. For these data, 20 correlations shown in Table 2 were applied and compared with the V_s values obtained from MASW. Relationships that give the best result and the lowest error for the selected region are determined. The results of the comparisons are given in Table 4 for each borehole. In addition, for boreholes mentioned in Table 5, Athanasopoulos [14], Jafari et al. [15], Hanumantharao, and Ramana [18] correlations are compared with each other.

In the relationships shown in Table 5, the mean relative error is below 12% and the relationship suggested by Athanasopoulos (1995) gives the lowest error.

Table 4. Estimation of the best V_s - SPT N correlation for boreholes in Edirne province

Borehole no	Correlation	Relative error (%)
2	Hanumantharao and Ramana (2008)	1.22
8–1	Athanasopoulos (1995)	0.21
8–2	Jafari et al. (1997)	0.82
11	Jafari et al. (1997)	0.82
15	Jafari et al. (1997)	0.82
24	Athanasopoulos (1995)	1.75
26	Athanasopoulos (1995)	22.58
27	Hanumantharao and Ramana (2008)	0.13
28	Athanasopoulos (1995)	7.80
37	Jafari et al. (1997)	0.82
57	Jafari et al. (1997)	0.82
64	Athanasopoulos (1995)	5.88
79	Hanumantharao and Ramana (2008)	0.65
81	Jafari et al. (1997)	2.08
90	Hanumantharao and Ramana (2008)	10.55

Table 5. Correlation comparison for boreholes in Edirne province

Borehole no	Athanasopoulos (1995) Relative error (%)	Jafari et al. (1997) Relative error (%)	Hanumantharao and Ramana (2008) Relative error (%)
2	2.16	5.02	1.22
8–1	0.21	25.65	0.32
8–2	9.35	0.82	11.57
11	9.35	0.82	11.57
15	9.35	0.82	11.57
24	1.75	15.15	3.20
26	22.58	47.14	29.39
27	3.21	8.59	0.13
28	7.80	13.64	12.03
37	9.35	0.82	11.57
57	9.35	0.82	11.57
64	5.88	6.57	9.46
79	4.80	2.82	0.65
81	13.50	2.08	7.02
90	10.65	43.08	10.55
Mean relative error (%)	7.95	11.59	8.78

4. DISCUSSION AND CONCLUSIONS

In previous research, equations based on uncorrected SPT-N values have shown a slightly better fit than equations based on energy-corrected SPT-N values. Therefore, it is recommended for practical purposes to use an equation developed for all soil groups based on uncorrected impact counts in this study. In the study, field tests (SPT and MASW) were carried out to measure shear wave velocity V_s and standard penetration resistance N in selected regions in Edirne. Based on these field experiments, the relationship between V_s and N was investigated. Among the 20 investigated correlations, 3 correlations with the lowest error were selected and compared with each other. In addition, the mean of the relative errors was calculated for the selected correlations. All three correlations applied show good estimates for different regions, and as indicated in Table 5, Athanasopoulos (1995) correlation gives a lower error than the other 19 relationships and there is an 8% difference between the estimated V_s values and the actual values.

DATA AVAILABILITY STATEMENT

The author 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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Review Article

Sustainability in the civil engineering and construction industry: A review

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ABSTRACT

The negative consequences of construction may be minimized by using environmentally friendly construction techniques. There are many ways construction work impacts the environment. The purchasing and use of building materials and the chopping down of trees are only some of the various processes involved in construction. However, the bulk of traditional building methods have the most significant harmful impact on the environment. For future generations, sustainable construction techniques and practices must prioritize all principles of sustainability. This study examines the idea and substance of sustainable development, sustainable development's triple bottom line, the significance of the triple bottom line to the construction industry, corporate sustainability and knowledge transfer. Sustainability in construction works, how construction works affect the environment, environmental benefits of construction, barriers to sustainability in the construction industry, and recommends steps to sustainability in construction. The study also points out research gaps to be filled. In the methodology reputable academic sources were found were found on Google Scholar, SCOPUS, the Web of Science, IEEE, Xplore, and Science Direct. As part of their study, the authors trimmed down the papers to those that best answered their research questions. After examining these sources, the authors restricted their attention to 55 sources that had a strong link to their study. Recommendations and conclusions were derived from a review of the available research as presented in this study. The study found that a project's social sustainability success depends on meeting the requirements of a wide range of stakeholders, also that sustainable construction creates a more equitable working environment, reduces costs, boosts productivity, and better health. It also provides economic advantages, more efficient use of resources, promotes the environment's protection, and increases the overall quality of life.

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1. INTRODUCTION

The construction industry has a significant effect on the global GDP. However, construction accounts for 36% of world energy use and 39% of CO_2 emissions whereas manufacturing accounts for just 3% of global CO_2 emissions [1]. Sustainability in the construction industry is a topic interest for policymakers, industry professionals, and academics. When it comes to sustainable building, it is not enough to focus just on ecological or environmental issues; it also has

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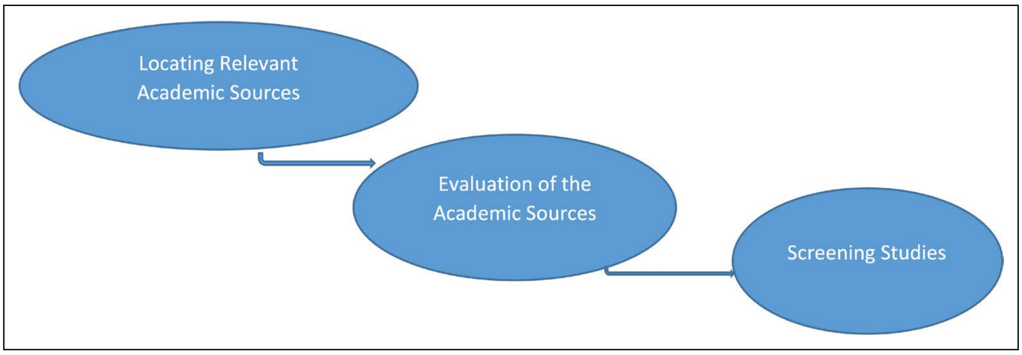

Figure 1. Pictorial representation of the research method for the research (source; authors, 2022).

Table 1. Sources of academic works cited in this article

S/No	Type of academic article	Number used	Percentage
1	Academic journals	38	69%
2	Books	10	18%
3	Government publications	4	7%
4	Webpages	3	6%

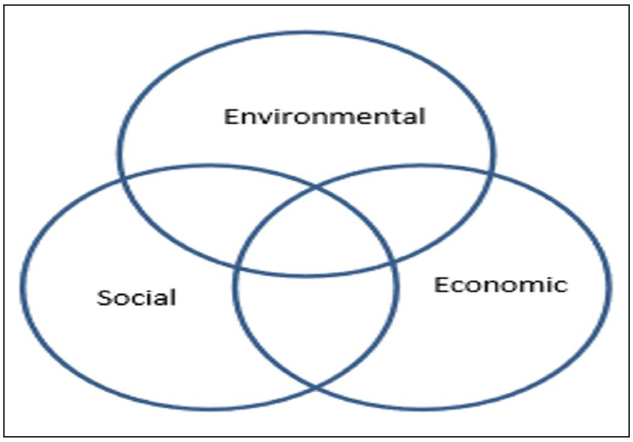

Figure 2. Triple bottom line concept of sustainability [24].

to include economic (e.g., construction prices, construction time) and social and technical aspects [2]. The pillar, "technical sustainability," concerns issues such as a building's capacity to function, quality, and lifespan [3]. Mechanisms for assessing the sustainability of building projects are also needed [4]. Construction firms are increasingly turning to sustainable construction methods as a means of mitigating the industry's harmful effects on the environment, such as global warming, environmental degradation, and the depletion of natural resources. A responsible built environment may be achieved using sustainable construction principles and methods to generate high-performance green buildings, or simply, "green buildings" [5]. The study of sustainability in the construction sector has yielded a wide range of new research topics and hypotheses. Even while some research has concentrated solely or partially on a single component of sustainability, others have attempted to cover all three areas. Projects or programs are implicit in the conversation about sustainability in the construction sector. Many studies have been conducted on the topic of building sustainability, from value management in construction to evaluating construction projects' performance on sustainability fronts including work on social sustainability in construction project development phases and policy implications for infrastructure projects [6].When evaluating social sustainability in the construction industry, ideas of social network analysis, sustainability, and equality are often used [7]. Information and communications technology (ICT) may also help achieve sustainability in building projects through process optimization, media substitution, and external control [8]. There are dangers in focusing just on one aspect of sustainability while overlooking others [9]. In attempts to address other elements of sustainability, we risk creating suboptimal or even harmful "solutions" if we sacrifice certain aspects of sustainability. Is it possible that the widespread usage of natural material has led to the displacement of indigenous communities, resulting in a loss of cultural resources. As a result, students, academics, and industry experts in the engineering and construction professions should be acquiring the capacity to address the social component [10]. In the case of construction projects, the government plays a more prominent role as a facilitator of sustainability, and society plays a more active role as impacted stakeholders. Therefore, all these stakeholders in the construction industry should be made to take this seriously.

2. METHODOLOGY FOR CONDUCTING THE LITERATURE REVIEW

As a result of the study's goals, the authors devised two research questions: "What are the future research avenues for sustainable building projects?" and " What have been the most significant research areas in construction project sustainability? Academic sources were obtained from various sites, including Google Scholar, SCOPUS, the Web of Science, IEEE Xplore, and Science Direct. As part of this research, the authors narrowed down the publications to those that best answered their research questions. After evaluating these sources, the authors narrowed their attention to 55 sources that had a significant connection to their research. The diagram Figure 1 illustrates the steps of this research method while Table 1 indicates the sources of academic materials used in the work.

3. STATISTICS OF ACADEMIC SOURCES FOR THE REVIEW

3.1. The Idea and Substance of Sustainable Development

As a concept, sustainable development has never been more widely discussed and interpreted throughout the globe, with a wide variety of different definitions and meanings. Sustainable development theory and practice have their roots in human knowledge that has evolved through time in a specific set of social, economic, cultural, and ecological contexts [11]. Initially used for forests and fisheries, the term "sustainably developed" comes from the field of ecology and refers to a resource management plan that focuses on extracting just a good portion of total resources while ensuring that existing resources are not depleted [11]. In the later part of this article, three significant dimensions of sustainability: economic, social, and environmental will be well considered in context of construction. Any assessment methodology for project sustainability should therefore contain these three critical characteristics [12].

3.2. Sustainable Development's Triple Bottom Line

An overarching objective of a sustainable business plan is to profit shareholders while simultaneously positively influencing the environment or society [13]. Sustainable business models are becoming much more critical to corporate leaders as they seek to tackle the most pressing global concerns while assuring long-term profitability [14, 15]. Understanding what it means to be sustainable and devising a strategy for achieving it are essential to success [15]. The concept is known as the "triple bottom line" and may be used to analyze a company's sustainability initiatives [15].

"Beyond greening lies an enormous challenge—and an enormous opportunity," Stuart Hart observed in 1997, when industrialized nations began to concentrate on sustainability. Developing a global economy that the earth can support eternally is a problematic issue [16]. After that, Hart highlighted that removing pollution is not the only answer to the issue of sustainability and that the world needs to look at it from a broader perspective. Even if all emissions were eliminated by the year 2000, the globe would still face resource shortages, making it impossible to satisfy the demands of future generations [17]. We are dealing with a complex problem that touches on economics, the environment, politics and society [18]. To achieve sustainability, all of these components must be seen through the same lens. It was decided to include economic and social bottom lines when determining sustainability [18]. The Figure 2 shows a pictorial representation of the triple bottom line concept.

3.3. Construction Industry Significance of Triple Bottom Line

For a net-zero carbon construction industry to be achieved by 2050, direct building. Environmental costs must have been cut in half by 2030 from their current levels. In the opinion of the World Bank, reduced facilities should be given top priority in economic stimulus packages, and updated climate commitments must be made [19]. People spend a great hours of 24 hours of their waking hours surrounded by structures, and as a result, the built environment has a significant impact on their well-being and productivity at work. The construction industry contributes significantly to the global economy and is continually expanding around the globe [19, 20]. The relevance of triple bottom line (TBL) can only be recognized if all of these factors are dealt with sustainably. It is becoming more and more common for designers and contractors to include sustainable approaches into their designs to remain competitive in the global building sector. All the major construction firms use TBL to assess the environmental implications associated with their work [21]. TBL has used social and economic factors to broaden building industry methods. Organizations have been able to measure their performance quantitatively and qualitatively, producing excellent outcomes in terms of long-term sustainability. According to TBL principles, there has been a greater emphasis on the management of the building industry, which uses a significant amount of natural resources [22]. There has been a growing emphasis on environmental and social factors and customer and stakeholder service [22]. TBL has helped raise awareness of the need to return part of the natural resources that we have stolen from the earth, which is a result of their efforts. However, when we consider social and environmental factors and look at the sustainability outcomes, our financial performance may seem less optimistic [23, 24]. To summarize, TBL has altered the building industry's practice, and applying it to a sector that uses a large share of natural resources will help us progress toward more environmentally friendly development.

Environment Consideration: The TBL building strategy emphasizes resource efficiency, which means less wastage and more effective use of water, energy, and materials. Passive design strategies reduce energy consumption, emphasize reusing materials, and water consumption and waste are avoided during construction. To determine a building's environmental friendliness, various green rating systems are used, such as the Green Star rating system in Australia and the LEED rating system in the United States [25, 26].

Social Consideration: The focus is on the people who will be using the buildings, and considerations such as accessibility, safety, and security are taken into account. Designing a sustainable building considers the community's requirements and ensures that the building interacts with and contributes to the community as a whole, rather than functioning in isolation [27]. It is therefore ensured that the most cost-effective building techniques are used at all times. There are methods to reduce the amount of time it takes to build a structure. The materials used are selected for their affordability and long-term usefulness. In order to reduce costs, local materials, labor, and suppliers are prioritized, which also helps reduce transit time and logistics expenses. Designers are instructed to employ less expensive materials to save costs. Summarily, this approach to sustainable building considers both the environment and the social and economic aspects of a project.

Economic Considerations- also known as "profit," the company's or society's economic worth, which is also known as "economic benefit, "Profit, cost reductions, economic progress, and research are all addressed here [28].

3.4. Corporate Sustainability and Knowledge Transfer

The management of a single firm or organization must change its governance and policy thinking in order to implement the notion of sustainability. Financial, human, environmental, and social capital challenges must be addressed together [29]. As a business-related interpretation of sustainability, it means looking at sustainability from the standpoint of the company's stakeholders rather than only the viewpoint of the company's shareholders.

Myers [30] discovered that only the most significant construction businesses had a positive attitude toward corporate sustainability, and even then, they had only just started to understand the importance of sustainability. The vast majority of construction enterprises have fewer than ten workers, and even fewer have a track record of long-term viability. According to Myers [30], a similar pattern may be seen at the European Union level.

There is little indication of greater participation or efficiency in construction than in other industries, although more and more enterprises accept the sustainability goal. The absence of proof suggests the opposite. The construction industry, particularly in Europe, is highly fragmented and complicated, making a swift shift to participation difficult, if not impossible [30].

It is argued by Robinson et al. [29] that organizational, consumer, and human aspects are all considered when determining the economic worth of intellectual capital. After workers have gone home for the day, the company's hardware, software, and supply lines become structural capital. Finally, the term "customer capital" refers to the goods, as well as the knowledge of customers, society, and other stakeholders, that a company has amassed. For the future standard ISO 26000, ISO is developing a framework for corporate sustainability that includes social responsibility components of corporations.

Figure 3. Concerns about the long-term sustainability of construction companies (adapted from Robinson et al, 2006) [29].

3.5. The Construction Industry in View

According to Du Plessis [10], the most often used definition, "construction," is best described as a "narrowly defined" process. It restricts its usage to a single phase of the construction life cycle by defining construction as solely site-level activities that lead to the building of construction facilities [31], similarly holds this position, referring to the "construction industry" as a collective term for all businesses directly engaged in the planning and construction of buildings and other structures. It is difficult to see how this notion of "construction" works [32]. This eliminates other essential players, such as those that produce and supply materials and those that operate the facilities. The term "sustainable construction," which is the focus of this article, takes a far more extensive view of the construction sector, necessitating the inclusion of the factors listed above. Consequently, it can be said that the construction sector is concerned with the development of the built environment as well as its planning, design, manufacturing, change, maintenance, and destruction.

3.6. Sustainability in Construction Works

After focusing on environmental concerns alone for the previous decade, the construction industry's research community has begun considering sustainability holistically, including the triple bottom line. Furthermore, the building industry has been heavily focused on environmental factors exclusively, according to Lützkendorf and Lorenz [33]. According to [34] buildings are intertwined with regional culture and sustainability since the current building stock is a crucial aspect of the region's cultural and geographic variety. The charming character of the value-laden world of sustainability causes people to interpret the term differently based on their image of society and how others accept this view. Among the terminology often heard in construction while discussing sustainability are "green" and "sustainable" building. The stakeholders in a construction project often perceive this in various ways based on their education, age, cultural background, etc. [35]. However, international building sustainability research cannot link effectively with local situations because of additional barriers.

3.7. How Construction Works Affects the Environment

"Everyone acts like nothing will change, yet everything changes" is a common phrase. When it comes to building, this could not be more accurate. While some deny that the climate is changing and that their operations influence the environment, others attempt to behave as if this is not a problem [36].

3.7.1. Natural Resources

Non-renewable materials are a significant source of waste in the building industry. According to the World Watch Institute, the industry absorbs 40 percent of raw stone, gravel, and sand consumption worldwide and 25 percent of the world's virgin wood usage annually [37]. When it comes to natural resources, we may be able to pretend that they do not exist, but we will run out sooner or later. Some firms are gradually using new technology, such as 3D printers and biodegradable fabrics, to minimize the amount of resources they need. On the other hand, construction is one of the least digitalized businesses; therefore, the shift may be too late.

3.7.2. Biodiversity

Biodiversity is the second most crucial factor. Consider the effect that buildings have on animals. Images of nighttime building sites or noisy equipment likely flashed through your head right off the bat. When it comes to animals, the disruption of the normal circadian rhythm that bats, badgers, and birds are used to is particularly devastating. As a result, it is merely a tiny component of a much larger issue. In the long run, wildlife is also impacted by construction and development [38]. To name a few, here are a few examples: pollution of the air and water, hydrologic effects, -isolation, and when people become more dispersed, as a result of these changes, animals are forced to adapt to a new way of life and reduce their numbers [39]. Consequences such as these are sometimes overlooked by decision-makers since the difficulties may only become apparent over a lengthy period (usually long after the project has finished) [40].

3.7.3. Atmospheric Conditions

Everyone's actions directly impact air pollution since the creation of carbon dioxide emissions is a significant contributor to global warming. Up to 39% of all energy and process-related CO_2 emissions come from the building industry [41]. Construction-related activities, transportation, and the production of building materials all contribute significantly to this high figure. Dust from building sites is also a significant contributor to air pollution. PM10 is made of concrete, wood, or stone, and may be spotted with a simple magnifying glass. This dust may create significant health issues for both people and animals if it is carried for lengthy periods of time [42].

3.7.4. Waste

Waste may be found just about everywhere. Consider that the construction industry accounts for 59% of the total wastes. Because of this, it is hard to overlook the enormity of the problem. Much waste is generated in the construction industry since it depends on short-term, low-cost solutions that must be changed often. Many good resources go to waste because building sites do not require recycling. Mahayuddin et al. [43] studied unlawful disposal sites in Malaysia. It was found that aggregate and concrete make up the vast majority of the waste in construction (see Fig. 3). Concrete waste and other potentially helpful demolition materials were found to be dumped straight into landfills, indicating that waste generation is outpacing resource use. Recycled aggregate may be used to solve the issue of waste disposal while also substituting for natural aggregates due to the abundance of waste available for recycling.

3.7.5. Environmental Benefits of Construction (How Construction Can Benefit the Environment?)

At the beginning of every building project, the [44] standards state that environmental considerations should take precedence over other considerations. As a result, one must ensure that all subcontractors doing construction work are aware of these requirements and that the company takes environmental protection seriously. Any or all of the above guidelines might be used to help new contractors get up to speed. Take a look at the Code of Regulations, which has a plethora of information that may ultimately beneficial when included in everyday conversations, meetings, and training sessions.

3.7.6. Measures to Prevent Pollution

Many of the chemicals used in construction might be hazardous to the contractors' health and the environment if they are not appropriately handled [45]. In order to guarantee that pollutants are released appropriately and safely with minimal impact on the environment, the EPA recommends creating "effective pollution prevention measures" throughout a project. On the other hand, the EPA standards state that this need is not essential if there is no danger of pollutants contaminating nearby waterways or the atmosphere around a building site [46]. Figure 4 illustrates the common composition of illegally dumped wastes.

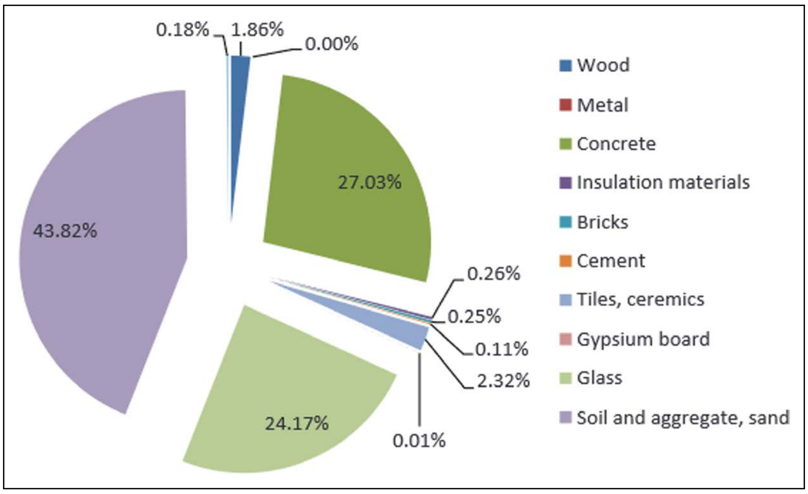

Figure 4. Analyses of the composition of illegally dumped construction waste [43].

3.7.7. Restrictions on Discharges

One must adhere to EPA regulations, which ban specific releases to safeguard employees and the environment. The following are some of their guidelines. When concrete is washed away, much water needs to be "managed." Painting, oil release, curing chemicals, and "other construction materials"-related wastewater discharges "Other pollutants" are released during vehicle and equipment operation or maintenance. Many of these guidelines can help reduce the environmental footprint. However, in recent years, a growing number of construction companies have been incorporating green buildings into their design and construction processes.

4. SUSTAINABILITY BARRIERS IN THE CONSTRUCTION INDUSTRY

According to available literature, the following are considered barriers to sustainability in the construction industry.

4.1. Inattention from Clients and Stakeholders

According to the reviewed literature, clients often lacked the knowledge they required to decide whether development alternatives would be more or less sustainable [47]. Contractors, end-users, and funding organizations all have poor levels of sustainability knowledge and comprehension, according to [48]. They also cited employees in public-client organizations as having low sustainability awareness and understanding levels. Many institutions and professional organizations lack training in sustainability concerns, and the nature of related norms of conduct is advisory rather than mandated, which may be a contributing factor. Inadequate sustainability knowledge and skills:Uncertainty over how and when to utilize evaluation tools and indicators and who should use them is causing practitioners to become overwhelmed and unable to focus on their day jobs. Developing simple but versatile instruments and methodologies for evaluating sustainability is required. A considerable and ongoing investment in education and training, together with enhanced publicity, will be required to address these issues [49].

Resistance to change: The phrase "sustainability" necessitates new ways of thinking, doing things, and shifting perspectives. As a result, it needs revision. Because of this reluctance, new initiatives might be challenging for long-standing businesses to adopt. Problems emerge in client organizations due to a lack of leadership, budget restrictions, and advice [50].

4.2. Fragmentation

Because of the industry's scale and fragmentation, it is challenging to encourage sustainable building. On the bright side, it has given us the ability to handle a wide range of workloads. Stated that partnership and framework agreements might be utilized as instruments to set goals and promote sustainable building to combat fragmentation and increase performance [50]. Sustainability in construction is more than just a matter of continuing to expand as a company; to achieve sustainable development, it may be necessary to curtail or alter corporate expansion in certain circumstances [51]. To put it another way, in the context of the construction industry, sustainability refers to attaining a win-win situation in which construction firms profit economically while also improving the environment [52].

4.3. Finances

Cost is a significant concern for implementing sustainable building practices in the construction industry. One of the biggest deterrents to owners of sustainable buildings is the higher initial investment costs [52]. A sustainable building costs 2 to 7% more than a conventional building, and only a small percentage of such projects can recoup their net expenditures over time.Although the cost of environmentally friendly construction and development is higher

Table 2. Advantages of sustainable construction

[1]	Sustainable construction offers a more fair working environment.
[2]	Sustainable construction helps to save costs.
[3]	Sustainable construction increases productivity.
[4]	Sustainable construction is better for your health.
[5]	The use of sustainable building provides economic advantages.
[6]	Waste reduction is improved by sustainable building.
[7]	Sustainable building provides a more efficient use of resources.
[8]	Sustainable construction promotes protection of the environment.
[9]	Noise pollution is reduced as a result of sustainable building.
[10]	Sustainable constructions enhance the reputation of the organization.
[11]	The use of sustainable building increases the overall quality of life.
[12]	Emerging markets benefit from Sustainable constructions.
[13]	Organizations' environmental sustainability is improved as a result of sustainable building.
[14]	Sustainable construction is a business strategy.

than ordinary projects, most customers are unsure whether there is a market for such structures [53]. As a result of the current financial crisis and the worldwide recession, building prices have fallen somewhat. Financial and working capital issues for contractors are significant problems. Contractors often find it challenging to keep up with their cash flow and expand their working capital resources. Changing stakeholders' perspectives from one of cost to one of value and from the short term to the long term may help overcome these roadblocks.

4.4. Lack of Government Regulation

The policies, laws, incentives, and dedication of leadership may not be sufficient to advance sustainable development. A value-added tax (VAT) was implemented in the United Kingdom for building renovations but not for new construction, according to Sourani and Sohail [48]. By underlining that renovation was a more environmentally friendly choice. Although the government has implemented several laws and policies to address sustainability concerns, it was suggested that these measures might be inadequate. Consequently, an essential role is therefore required to deal with sustainability effectively.

4.5. Sustainable Building: Cost-Benefit Analysis

Sustainable construction has perceived higher costs, which, when combined with the low perceived value of social quality, have kept most people from taking action thus far [54]. As a result, green construction and sustainable design are becoming more popular with customers, who realize that they may save money by constructing environmentally friendly structures [55]. Research shows that greener buildings may attract tenants and investors and fetch higher rents or sell prices from across the globe [56]. Contrary to popular belief, designing to ecologically friendly standards do not inevitably increase capital costs.

According to the findings of this research, several of the writers provided various benefits of sustainable building, some of which are shown in the Table 2.

5. RECOMMENDED STEPS TO SUSTAINABILITY IN CONSTRUCTION

It is not enough to design sustainable structures. The following must also be taken into account by construction companies.

Ensuring the long-term viability of a Project. One of the utmost thought-provoking components of this profession is sustainability. Natural resources are used in the construction of buildings. When such materials have served their purpose, they are usually discarded. To make room for the needed alterations, renovating a structure may necessitate removing installed elements initially. This technique can quickly deplete natural resources, resulting in a significant environmental effect. Using sustainable building materials does not have to be an all-or-nothing proposition. The construction itself may have a substantial environmental effect. It takes a lot of energy to construct construction sites, equipment, and machines. The total energy used includes energy utilized to heat the building or crew quarters. Emissions may be significantly affected by how this energy is utilized and where it originates from. The use of fossil fuel-powered heavy gear in construction further adds to the project's environmental impact. Another option to minimize the adverse effects on the environment is to use lean production methods in carefully monitored facilities. Indoor factories, where waste may be minimized and resources recycled instead of being thrown away, can manufacture products under controlled conditions. Afterwards, the building's components are transported to the site and erected, resulting in a lower environmental impact.

5.1. Designing Structures for Reuse

Today's engineer is faced with the difficulty of constructing a structure that can be modified to fit changing demands rather than a single purpose. Reusing rather than demolishing buildings allows us to minimize the quantity of garbage we send to landfills and the amount of raw resources we utilize. Sustainable building solutions are being produced all the time, which is a good thing. In a circular design approach, "design, build, use, and dispose of" is replaced with a more ecologically responsible pattern. A more sustainable approach to building is to design waste, keep goods and resources in use, and regenerate natural systems to keep up with demand while minimizing environmental effects. In order to create new structures, builders devised construction systems that could be dismantled and rebuilt. Ninety per cent of the materials must be re-usable without deterioration in quality.

5.2. Taking into Account the Materials

When it comes to recycling and reuse, there is a lack of efficiency in the design of construction materials. Furthermore, these buildings are made from raw materials, making this much more of a concern. It is damaging to the environment both locally and globally because of the mining and processing of these raw materials. Reusing and recycling materials is a significant consideration when building new structures or remodeling existing ones. The circular economy relies heavily on recycling, and it is time for building to follow suit. Buildings designed with the circular economy in mind also need a high level of durability and endurance from the materials utilized. Investing in long-lasting, multipurpose construction materials saves money in the long run by reducing the frequency and expense of future renovations.

5.3. Researchgap and Recommendations

There are, a number of areas in which more study might make a substantial contribution to the understanding of the concept of sustainability in the construction industry: It is thus recommended that; further research is also needed on the topic of sustainable building project management due to the fact that academics and practitioners have divergent views on the subject. The interrelationships between the many components that contribute to project success have to be looked into. The establishment of a single method for evaluating sustainability in projects is thus necessary, as this study shows there is currently none, by this, it is meant that there are varying methods of determining sustainability in the construction industry, the varying stakeholders in the construction industry should adopt a single or standard way by which each variable in the construction industry can be measured. Investigating the relationship between construction industry sustainability and factors necessary for construction success, and lastly, the need for a comparative study on sustainable construction and processes in both developed and developing countries still expresses significant paucity.

6. CONCLUSIONS AND RECOMMENDATIONS

In order to present a sustainable framework for managing construction projects, the assessment was able to identify the sustainable characteristics of projects. Many questions have been raised as a result of this investigation. There should be more research done on the following; Project success is evaluated by looking at how various sustainability elements interact. Finding a variety of strategies and methods that have a high success rate in increasing the long-term viability of a project, a single or dominant method for evaluating the sustainability of projects is being developed. What can be done to make sustainability assessments as prevalent as risk assessment and mitigation in projects? Investigating the relationship between construction industry sustainability and benefits management. Sustainability in building projects in industrialized and developing nations is compared and contrasted. Clients are increasingly demanding sustainability in both their businesses' construction and day-to-day operations. Sustainable construction projects currently lack standard regulations and strategies. As a result, many additional studies are needed to help the project delivery team better understand how to apply sustainable principles to the building process. It is important to remember that every building activity affects the environment. All of our actions, from the resources we consume to the technology we use to develop building sites, contribute to global warming. We cannot halt our enterprises or the economy as a whole, but we can minimize our negative influence on the environment by taking reasonable measures. The growing importance of sustainable construction project managers may be analyzed in various ways. To keep the economy going, building projects may be small or large in scale, depending on the final product or resources used in the construction process. These initiatives typically lead to smaller-scale government-supported construction projects. The project manager is at the heart of sustainability decisions in government and commercial construction projects. This imposes an additional constraint on time, money, quality, and scope. These problems are not sufficiently addressed by the project management frameworks presently in use. It was discovered in this research that the complex linkages in sustainable construction project management might also be complicated interactions or both challenging and tough at the same time.

DATA AVAILABILITY STATEMENT

The author 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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