

AN ASSESSMENT OF THE EXTENT OF APPLICATION OF GEOSYNTHETICS TO CIVIL INFRASTRUCTURE PROJECTS IN GHANA

ABSTRACT

This study was informed by the lack of literature that gave a **country-specific** holistic account of the extent of the **application** of geosynthetics **to civil infrastructure projects**. Thus, this **current** study determined the extent that geosynthetics had been applied **to civil infrastructure projects** in Ghana and, established the relative level of application of geosynthetics **to civil infrastructure projects** in Ghana. Structured questionnaire aided in data collection. Data were analysed using **frequency, percentage**, mean, standard deviation, and one sample t-test. The study revealed that there was a **low level of application** of geosynthetics **to civil infrastructure projects** in Ghana. However, Ghana's case was of great concern as geosynthetics had been applied to only **7 out of the 28 civil infrastructure projects identified in previous studies**. Pipe projects had the most application of geosynthetics whereas geosynthetics were least applied to retaining structures. Moreover, the study further revealed that **only 6 out of the 9** types of geosynthetics had been applied **to civil infrastructure projects** in Ghana namely: geopipes, geomembranes, geotextiles, geogrids, geonets, and geocells. Relatively, geopipes were the most applied geosynthetics whereas geocells were the least applied geosynthetics **to civil infrastructure projects** in Ghana. This study serves as reference material on the extent of application of geosynthetics **to civil infrastructure projects** in Ghana which hitherto was lacking in the construction industry in Ghana. It also serves as the basis for future studies on the application of geosynthetics as it contributes to the existing body of literature on the subject.

Keywords: Civil Engineering, Civil Infrastructure, Construction, Geosynthetics, and Ghana.

INTRODUCTION

Civil infrastructure **projects** are the basic systems and facilities that help society to function and also maintain the environment [1, 2]. They include roads, railways, buildings, tunnels, canals, dams, ponds, manholes, pipes, earth retaining structures, wastewater treatment systems, landfill projects, water supply systems, breakwaters, airfields, and utilities, among others [1]. The quest to deliver civil infrastructure **projects** within time, within budget and in compliance with quality and sustainable measures has necessitated the application of several technologies to infrastructure delivery with an example being **geosynthetics** technology [3, 4, 5]. Geosynthetics technology is the application of geosynthetics **to** man-made structures, projects, or systems [3, 6]. The application of geosynthetics **to civil infrastructure projects** contributes to reducing the use of natural materials [7, 8]. Thus, minimizing the depletion of natural resources within the environment. It also offers a comparative cost advantage and time efficiency in the delivery of civil infrastructure **projects** [5, 7, 9, 10, 11]. Additionally, the application of geosynthetics generally improves the conditions of soil, rock or earth as an integral part of civil infrastructure **projects** [12, 13]. Experimental evidence and field tests have in previous studies concluded that the application of geosynthetics to civil infrastructure projects enhances the bearing capacity of soil more than calculated and that deformations are much lower than expected in such soil [5, 15].

On the other hand, geosynthetics are planar products produced from polymeric materials and used with rock, soil, earth, or other geotechnical engineering-related materials as an integral part of man-made structures, projects, or systems [2, 6]. Geosynthetics are of nine major types [2, 16]. They are geonets, geocomposites, geogrids, geomembranes, geosynthetic clay liners, geofoams, geopipes, geotextiles and geocells [2,16].

Whereas the application of some types of geosynthetics to civil infrastructure projects such as roads, buildings, landfills, wastewater treatment systems, and harbour infrastructure is known [3, 10, 14, 15]; little is known, if any, of country-specific studies that give a holistic account of the extent of application of geosynthetics to civil infrastructure projects. This account will form the basis for deriving and deploring country-specific measures towards promoting the application of geosynthetics, owing to its numerous benefits to construction industry stakeholders. Studies on geosynthetics applications are usually country-specific as it is influenced by a multiplicity of factors such as the macro and micro economic conditions, the culture within the construction industry, and the education level of construction practitioners, among others [3, 7, 17]. Thus, this current study, in part, contributes to addressing this gap in the literature as it seeks to determine the extent that geosynthetics have been applied to civil infrastructure projects in Ghana and, establishes the relative level of application of geosynthetics to civil infrastructure projects in Ghana.

The specific objectives that governed the study were:

- to determine the extent that geosynthetics have been applied to civil infrastructure projects in Ghana;
- to establish the relative level of application of geosynthetics to civil infrastructure projects in Ghana.

In this study, construction practitioners encapsulate practising civil engineers, construction engineers, construction technologists, building technologists, and consultants who are responsible for the design, construction and/or management of civil infrastructure projects.

A SURVEY OF THE APPLICATIONS AND TYPES OF GEOSYNTHETICS FOR CIVIL INFRASTRUCTURE PROJECTS IN PREVIOUS STUDIES

The extent of application of geosynthetics to civil infrastructure projects varies across nations. This is attributable to factors such as the level of knowledge among construction practitioners and clients, and the availability of geosynthetic products in the country's market, among others [18]. According to [5] and [19], geosynthetics are applicable to road infrastructure projects. Moreso, [20] found geosynthetics applications to include road and harbour infrastructure projects. Whereas [14] argued that geosynthetics are applicable to retaining structures and building structures. Accordingly, [2] and [21] gave a wide range of applications of geosynthetics including landfill projects, pipe projects, duct and irrigation systems, water reservoirs, and drainage projects.

There are nine main types of geosynthetics [2, 4, 5, 6, 25]; with geotextiles and geogrids being the most applied geosynthetics to civil infrastructure projects [5]. According to [2] and [16], the types of geosynthetics include geotextiles, geonets, geogrids, geomembranes, geosynthetic clay liners, geofoams, geopipes, geocomposites, and geocells. Primarily, the functions of geosynthetics include separation, protection, filtration, drainage and sealing [15, 18].

Geotextiles

Geotextiles are permeable geosynthetic textile materials or fabrics used as an integral part of civil infrastructure projects and are in contact with the soil, rock, earth, or any other geotechnical substance [6,10, 22, 23]. The functions of geotextiles include reinforcement, filtration, separation, and drainage [6,10, 22, 23]. There is a wide application of geotextiles. This includes walls, roads, railroads, embankments, airfields, retaining structures, canals, pipelines, reservoirs, dams, bank protection, harbour projects, and landfill projects [16, 22]. Geotextiles have also been applied to civil infrastructure projects such as landfills, roads, harbours, and drainage structures [21]. Unpaved and paved roads in airport runways, sidewalks and sand drainage layers, landfills and stone base courses, parking lots and curb areas, green areas and recreational facilities, duct banks and pipe trenches, and retaining wall structures were civil infrastructure projects that had geosynthetics as an integral part [24]. Geotextiles have also been applied to roads and harbours infrastructure projects [20].

Geogrids

Geogrid is a polymeric structure that is unidirectional or bidirectional, and comes in the form of a manufactured surface, consisting of a normal network of integrally connected elements that can be linked by extrusion, bonding, and whose openings are larger than the constituents and are used as an integral part of civil infrastructure projects [2, 10]. Geogrids are manufactured primarily as a reinforcement or stabilizer material in addition to providing separation between soil and aggregate layers [10]. They are able to redistribute load over a wider area, have high holding capacity, and high tensile strength, and are eco-friendly in nature [2, 10, 14]. Applications of geogrids include reinforcement of soil for steep slopes, walls, roadway and railway bases, and foundation soil, among others [14]. Existing literature informs that geogrids have been applied as to civil infrastructure such as roadways, railways, retaining walls, and buildings with shallow foundations [2, 25].

Geomembranes

Geomembranes are low-permeability or impermeable geosynthetic materials, used as an integral part of civil infrastructure projects to reduce or prevent the flow of fluid through the soil [10]. Thus, this is a type of geosynthetics with an inherent impermeable membrane [25]. Geomembranes are in the form of a sheet. They are commonly applied as cut-offs and liners [10]. Geomembranes are also applied as hydraulic barriers (an example is when used as canal lining), field seaming, and minimization of installation damage [10, 25]. Applications of geomembranes include ponds, landfill lining, tunnels, canal lining, environmental projects, transportation projects, oil and gas containments, and general civil infrastructure projects [25, 26].

Geonets

Geonets are polymeric structures formed by a set of continuous parallel polymeric ribs at acute angles to one another, forming a net-like pattern [10, 25]. They are used for in-plane drainage of gases or liquids (especially leachates from landfill and mining projects) and filtration of sediments contained within these fluids [25]. Geonets are frequently laminated with geotextiles on one or both surfaces and are then referred to as drainage geocomposites [6, 12]. Generally, geonets are used for drainage behind retaining structures, plaza decks, or green roofs [27].

Applications of geonets also include road projects, road widening, asphalt work, building construction and foundations, dams, artificial ponds, and water reservoirs, among others [25].

Geofoams

Geofoam is a closed-cell, super-lightweight, rigid, plastic foam [9]. Geofoam is used to reduce settlement below embankments, provide sound and vibration damping, reduce lateral pressure on sub-structures, and reduce stresses on rigid buried conduits and related applications [9]. Primarily, geofoam provides a lightweight fill below a highway, bridge approach, bridge abutment, flood control levees, basement insulations, railways, embankment, and parking lot [9, 14]. It also serves as new fills around culverts and pipelines to reduce the load over the base structure [9, 14]. It is also applicable in stadium seating, building foundations, and retaining structures [9, 14]. Using geofoam for retaining structures reduces lateral pressure, prevents settlement, and slope stabilization and improves waterproofing [9, 14].

Geocells

Geocells are three-dimensional geosynthetic cellular structures made with novel polymeric alloy (NPA) or ultrasonically welded high-density polyethylene (HDPE) strips [12, 28]. Applications of geocells include channel protection, erosion control, road construction, landfill projects, landscaping, mining operations, and structural reinforcement for load support and earth retention, green infrastructure projects, protective linings for channels and hydraulic structures [12, 29]. Geocells provide support for static and dynamic loads on weak subgrade soils [12, 29]. Geocells provide both a transfer of load through the cellular structures and physical containment of a depth of soil [29]. Geocells are also applicable to foundations, waste containment, embankments, and road and railway structures [30].

Geosynthetic clay liners

Geosynthetic clay liners consist of thin layers of bentonite clay sandwiched between two layers of geotextiles and bonded to a geomembrane [25, 31]. The two layers of geotextiles are stitched together by a sewing process (needle-punched non-woven) thereby creating a perfectly balanced mat which has an internal shear resistance [25, 31]. Anytime geosynthetic clay liners come into contact with water, the bentonite in the mat puffs up thereby creating a waterproof mineral layer [25]. Application of geosynthetic clay liners includes canals, stormwater impoundments and wetlands, highway construction, secondary containment, landfill liners and landfill caps, mines and general civil infrastructure projects [25, 31].

Geopipes

Geopipes are solid-wall or perforated polymeric pipes for the drainage of fluid (gases and liquids) [25]. They are primarily used for leachate collection and in instances of high compressive loads [25]. Geopipes are preferred for landfill use as a means for the collection and quick drainage of the leachate to a sump, and removal system [25]. Further applications of geopipes include subdrainage for buildings and roads, oil and gas production, sewer and wastewater transportation, and duct and irrigation systems [25].

Geocomposites

Geocomposites are geosynthetics formed by a mixture of two or more geosynthetics such as geomembrane-geonet, geonet-geotextile, and geogrid-geotextile, among others [14]. The primary functions of geocomposites include separation, reinforcement, drainage, filtration, stabilization,

containment, and erosion control [27]. The application of geocomposites is prevalent in road construction, drainage segment, pavement base course or edge drains, rooftops, trench drains, tunnels in railways and roads, retaining walls and bridge abutments, among others [25].

SUMMARY OF APPLICATIONS AND TYPES OF GEOSYNTHETICS IN FOR CIVIL INFRASTRUCTURE PROJECTS IN PREVIOUS STUDIES

Thus, from the review of existing literature, it was revealed that nine (9) types of geosynthetics have been applied to civil infrastructure projects. The civil infrastructure projects were twenty-eight (28) in number, namely: highways, railroads, embankments, duct and irrigation systems, oil and gas transportation, airfields, retaining structures, canals, pipe projects, water reservoirs, harbours, dams, landfills, green areas and recreational facilities, stormwater impoundment, wetlands, sidewalks, parking lots and curb areas, stadia, bridges, levees, buildings, tunnels, plaza decks, culverts, ponds, channels and drainage projects.

Civil infrastructure	Geotextiles	Geogrids	Geomembranes	Geonets	Geofoams	Geosynthetic clay liners	Geopipes	Geocells	Geocomposites
Highways	X	X		x	X	X	x	X	
Railroads	X				X		x	x	
Embankments	X				X				
Duct and irrigation systems							x		
Oil and gas transportation							x		
Airfields	X								
Retaining structures	X			x	X				
Canals	X	X	X		X				x
Pipe projects	X								
Water reservoirs	X			x					
Harbours	X								
Dams	X			x					
Landfills	X				X	X		x	x
Green areas and recreational facilities	X				X			x	
Stormwater impoundment						X			
Wetlands						X			
Sidewalks	X								x
Parking lots and curb areas	X				X				
Stadia	X				X				
Bridges					X				
Levees					X				
Buildings		X		x	X	X			
Tunnels			X						
Plaza decks				x					
Culverts					X				
Ponds			X						
Channels					X				
Drainage									x

Table 1: A matrix of the extent of application of geosynthetics to civil infrastructure projects from previous studies

METHODOLOGY

This study followed a cross-sectional research design. The data collected was a snapshot of what prevailed within the period of data collection. Firstly, literature was reviewed which aided in identifying the applications and types of geosynthetics to civil infrastructure projects. The second stage was the use of a structured questionnaire to solicit the views of construction practitioners on the extent that geosynthetics have been applied to civil infrastructure projects in Ghana and, the relative level of application of geosynthetics to civil infrastructure projects in Ghana, based on their knowledge and/or experience. Experience means having had the opportunity of applying or supervising the application of geosynthetics to civil infrastructure projects over a period of at least five (5) years. Knowledge means being cognisant of the application of geosynthetics to civil infrastructure projects in Ghana. The respondents included construction practitioners from 257 construction firms who belonged to the Association of Building and Civil Engineering Contractors of Ghana (ABCECG). This sample size of construction firms was determined based on the principle that, for a population of size around 1500, 20% of the population should be sampled [32, 33]. Thus, 20% of the population of 1282 construction firms registered with ABCECG was equivalent to 257 construction firms. The population size was obtained from the ABCECG secretariate and was affirmed by [34]. ABCECG was chosen as the study population because it was the association for building and civil engineering contractors (construction firms) in Ghana with members in all regions of Ghana. In each firm, information was solicited from construction practitioners within the field of civil engineering, construction engineering, construction technology, or building technology who have the knowledge and/or experience in the applications and types of geosynthetics. In addition, the views of five (5) construction industry consultants were purposively sought. Within each consulting firm, information was sought from practitioners within the field of civil engineering, construction engineering, construction technology, or building technology who had the knowledge and/or experience regarding the applications and types of geosynthetics. Thus, the views of 262 construction practitioners were sought regarding the application of geosynthetics to civil infrastructure projects and the relative application of geosynthetics to civil infrastructure projects based on a 5-point scale, where (1) represented strongly disagree, (2) was disagree, (3) was neutral, (4) was agree, and (5) denoted strongly agree. The questionnaire was self-administered with the help of twenty (20) field workers from March 2022 to July 2022 and a 100% response rate was recorded. Respondents spent at most 8 minutes on the survey, and further clarification was given when requested. Data were analysed using the standard deviation, mean and one sample t-test. Accordingly, a hypothesized mean was set at 3.5 [2]. The significance level was also set at 95% in accordance with predictable risk levels [2]. Any significant (1-tailed) value (p-value) not exceeding 0.05 was considered statistically significant [2]. In this study, construction practitioners embodied construction practitioners with both consultants and contractors (construction firms).

RESULTS AND DISCUSSIONS

Table 2. Respondents' demographic characteristics

Main variables	Specific variables	Frequency(N)	Percentage (%)
Job role of respondents	Civil engineer	112	42.75

	Construction Technologist	35	13.36
	Building Technologist	85	32.44
	Construction Engineer	25	9.54
	Consultant	5	1.91
	Total	262	100
Working experience in Ghana	5 years	40	15.27
	6 to 10 years	43	16.41
	11 to 15 years	42	16.03
	16 to 20 years	79	30.15
	Above 20 years	58	22.14
	Total	262	100
Gender	Male	247	94.27
	Female	15	5.73
	Total	262	100

The demographic characteristics of the respondents from Table 2 suggested a great level of work experience. This was an indication that the research respondents were informed and experience was brought to bear in response to the questions on the questionnaire. The percentage of male and female respondents reflected that the construction industry in Ghana was a male-dominated sector and there was the need to cautiously bridge the male-female ratio in construction programmes.

Table 3. The extent of application of geosynthetics to civil infrastructure projects in Ghana

Civil infrastructure projects	Mean	Mean score ranking	Standard deviation	Sig(1-tailed)	Statistical significance
Pipe projects	2.46	1 st	0.72	0.00	Yes
Duct and irrigation systems	2.32	2 nd	0.59	0.00	Yes
Building structures	2.30	3 rd	0.57	0.00	Yes
Water reservoirs	2.28	4 th	0.57	0.00	Yes
Landfill infrastructure	2.11	5 th	0.72	0.00	Yes
Highway infrastructure	1.96	6 th	0.86	0.00	Yes
Retaining structures	1.71	7 th	0.73	0.00	Yes

From Table 3, standard deviation values were all below one (1.0). This was an indication that there was consensus in the views respondents expressed and variability in responses was insignificant. Hence, the collected data were accurate and reliable. Moreover, all the p-values for the one-tailed test from Table 3, indicated a strong statistical significance of the data collected. All, the t-test p-values were 0.000.

In relation to determining the extent that geosynthetics have been applied to civil infrastructure projects in Ghana, the results revealed that geosynthetics had been applied to only seven (7) civil

infrastructure projects in Ghana out of the twenty-eight (28) civil infrastructure projects identified from previous studies. The seven civil infrastructure projects were pipe projects, duct and irrigation systems, building structures, water reservoirs, landfill infrastructure, highway infrastructure, and retaining structures. This implied that the application of geosynthetics to civil infrastructure projects was low in Ghana. This could be attributed to the inadequate education on geosynthetics among construction practitioners in Ghana. According to [7], [14] and [18], a low level of education among construction practitioners correlates with the extent of application of geosynthetics to civil infrastructure projects. But that notwithstanding, relatively, pipe projects were the civil infrastructure project that had the most application of geosynthetics in Ghana. It recorded a mean score of 2.46 and ranked 1st. This was consistent with the study by [25], which among others revealed the application of geosynthetics to civil infrastructure projects such as pipe projects and duct and irrigation systems. Specifically, [24] identified the application of geotextiles to pipe projects whereas [9] and [14] identified the application of geofoams as a fill material around pipe projects. The 2nd ranked civil infrastructure project to which geosynthetics had been applied in Ghana was duct and irrigation systems with a mean score of 2.32. This was followed by building structures with a mean score of 2.30. According to [14], geosynthetics were applicable to retaining structures and building structures. However, in the case of Ghana retaining structures ranked 7th with a mean score of 1.71. Moreso, water reservoirs with a mean score of 2.28 ranked 4th. It was followed by landfill infrastructure with a mean score of 2.11 ranking 5th, and highway infrastructure with a mean score of 1.96 ranking 6th. According to [16] and [22], geosynthetics were applicable to civil infrastructure projects including reservoirs, landfill and highway infrastructure projects. In relation to landfill infrastructure, geosynthetics such as geomembranes were found to have been applied according to [26]; whereas [21] identified geotextiles being applied to landfill infrastructure. Specifically, [14] found the application of geogrids to highway infrastructure projects whereas [24] found the application of geotextiles to highway infrastructure projects. Also, [30] identified the application of geocells to highway infrastructure to improve the soil conditions at the base course.

Table 4: Mean score ranking of the relative application of geosynthetics to civil infrastructure projects in Ghana

Geosynthetic(s)	Mean score	Ranking
Geopipes	4.12	1 st
Geomembranes	3.11	2 nd
Geotextiles	2.24	3 rd
Geogrids	0.71	4 th
Geonets	0.67	5 th
Geocells	0.20	6 th
Overall mean score	1.84	

In relation to establishing the relative level of application of geosynthetics to civil infrastructure projects in Ghana, it was revealed that there was generally a low level of application of geosynthetics to civil infrastructure projects in Ghana. An overall mean score of 1.84 was recorded which was less than the hypothesised/population mean of 3.5. This was attributable to inadequate knowledge of geosynthetics among construction practitioners and the possible non-

availability of certain types of geosynthetics in the construction industry in Ghana. Inadequate knowledge among construction practitioners by [3, 9, 16, 17], and non-availability of certain types of geosynthetics in the market [18], were found to have saddled the application of geosynthetics to civil infrastructure projects in some national contexts. Furthermore, [17] argued that the low level of application of geosynthetics was attributable to inadequate geosynthetic content in the curriculum of civil engineering and related programmes at the bachelor's level.

Specifically, only six (6) out of the nine (9) geosynthetics had been applied to civil infrastructure projects in Ghana. Apart from geopipes which recorded a mean score of 4.12, all the other types of geosynthetics recorded mean scores that were lower than the population/hypothesised mean of 3.5. This was an indication that there was generally a low application of geosynthetics to civil infrastructure projects in Ghana. This was consistent with the findings by [16] that the application of geosynthetics to civil infrastructure projects was low globally. This was attributable to the general lack of education on geosynthetics among construction practitioners as observed by [3, 9, 16, 17]. Additionally, this study unravelled that relatively, the geopipes were the most applied geosynthetics as an integral part of civil infrastructure projects in Ghana. It ranked 1st with a mean score of 4.12. Whereas the least ranked was geocells with a mean score of 0.20, ranking 9th. This contrasted with the argument that geotextile and geogrids were the most applied geosynthetics to civil infrastructure [5].

CONCLUSIONS

This current study determines the extent that geosynthetics have been applied to civil infrastructure projects in Ghana and, establishes the relative level of application of geosynthetics to civil infrastructure projects in Ghana. The study concludes that the extent of application of geosynthetics to civil infrastructure projects is low in Ghana as pertains globally. However, Ghana's case is of great concern as geosynthetics have been applied to only seven (7) out of twenty-eight (28) civil infrastructure projects revealed in previous studies namely: pipe projects, duct and irrigation systems, building structures, water reservoirs, landfill infrastructure, highway infrastructure, and retaining structures. Pipe projects were the civil infrastructure projects that received the most application of geosynthetics whereas geosynthetics were least applied to retaining structures. Moreover, this study concludes that only six (6) out of the nine (9) geosynthetics have been applied to civil infrastructure projects in Ghana namely: geopipes, geomembranes, geotextiles, geogrids, geonets, and geocells. Relatively geopipes were the most applied geosynthetics to civil infrastructure projects whereas geocells were the least applied geosynthetics to civil infrastructure projects in Ghana. This contrasts with the argument that geotextile and geogrids were the most applied geosynthetics to civil infrastructure.

Thus comparing the outcome of this Ghana study with existing literature, it was evidenced that the extent of application of geosynthetics to civil infrastructure projects and the relative application of geosynthetics to civil infrastructure projects were country-dependent and thus, it would be inaccurate to generalize the findings to be the same across the nations. Hence, the findings of this study are limited to Ghana only though they may provide fruitful lessons for countries like Nigeria, Angola, and Togo whose construction industry shares close characteristics with Ghana. This study serves as reference material on the extent of application of geosynthetics to civil infrastructure projects in Ghana which hitherto was not in existence. This is of enormous benefit to construction practitioners such as civil engineers, construction technologists, building

technologists, and other stakeholders within the construction industry in Ghana. It also has the tendency of informing policies aimed at enhancing the application of geosynthetics to civil infrastructure projects in Ghana. It will serve as the basis for future studies on geosynthetics applications as it contributes to the existing body of literature on the subject. Practically it has demonstrated that geosynthetics applications in Ghana have been limited to pipe projects, duct and irrigation systems, building structures, water reservoirs, landfill infrastructure, highway infrastructure, and retaining structures; whereas geopipes, geomembranes, geotextiles, geogrids, geonets, and geocells were the geosynthetics which applications to civil infrastructure projects in Ghana were known.

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