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Towards Enhancing Awareness on Sustainable Development: A Survey of the Types, Functional Uses and Project-Level Applications of Geosynthetics

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ABSTRACT

Although geosynthetics are sustainable materials for developing sustainable civil infrastructures, there is a low level of awareness among key stakeholders in the construction industry. Hence, the low project-level applications of geosynthetics globally. This desk study enhances the awareness level of geosynthetics among industry stakeholders as it seeks to give a more comprehensive literature account of geosynthetics highlighting the main types, functional uses, and project-level applications of geosynthetics in the development of sustainable civil infrastructures. The study employed the narrative literature review approach. The outcome revealed applications of twelve (12) main types of geosynthetics in the development of thirty-one (31) sustainable civil infrastructures. Project-level applications of geosynthetics included highways, ponds, airfields, and retaining structures. The main types of geosynthetics included geotextile and geomembrane. Primarily, the functional uses of the geosynthetics included soil reinforcement, stabilization, and filtration. This study informs stakeholders in the construction industry of the available geosynthetics that could be employed in the development of sustainable civil infrastructures. Also, it provides a more comprehensive basis for future country-specific studies that seek to evaluate project-level applications of geosynthetics in the development of sustainable civil infrastructures.

Keywords: Geosynthetics, Infrastructures, Sustainable development, Sustainability

INTRODUCTION

Sustainable Development Goal (SDG) (12), target (8), seeks to ensure that by 2030 people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature (UNDP, 2024). Thus, this current study sheds light on geosynthetics in the development of sustainable civil infrastructures. Sustainable civil infrastructure refers to systems or projects that meet the needs of the present generation without compromising the ability of future generations to meet their own needs (Mansell et al., 2020; Rimoldi et al., 2021). The development of sustainable civil infrastructures meets the requirements of society, the environment, and the economy. Thus, such projects do not impact negatively on the environment, society, and the economy (Rimoldi et al., 2021). Geosynthetics offer a more sustainable approach to the development of civil infrastructures (Rimoldi et al., 2021). Geosynthetics are polymeric materials or products for improving or stabilizing soil, rock, earth, or any geotechnical substance (ASTM, 1994; Ziegler, 2017; Khan & Singh, 2020). Geosynthetics could be applied to improve ground conditions, and/or as an integral part of the civil infrastructures to serve several purposes including barrier, drainage, and separation (Rimoldi et al., 2021).

Users of geosynthetics leverage the product's comparative cost advantage, mechanical properties advantage, physical properties advantage, hydraulic properties advantage, the life span of the product, and sustainability when compared with other alternative traditional materials/products or construction. These comparative advantages have been established in previous studies (see GMA, 2002; Morgan and Rickson, 2011; Nicholson, 2015; Boyle et al., 2015; Jeon, 2016; Ziegler, 2017; Khan and Singh, 2020; Bayraktar, 2020; Qamhia and Tutumluer, 2021; Ait, 2021; Oginni and Dada, 2021; Christoforidou et al., 2021), among others. For instance, the cost advantage in geosynthetics applications encapsulates, but is not exhaustive, cost savings in extra material, reduction in the amount of waste material, and reduction in the cost of transportation (Raja, 2011; Bayraktar, 2020). Thus, cost advantage is project-specific (Raja, 2011; Bayraktar, 2020). Further, Ziegler (2017) advanced that the cost of maintaining an unreinforced structure (a civil infrastructure that did not integrate geosynthetics) over a long period can easily exceed the relatively small extra investment in having a reinforced structure (a civil infrastructure that integrated geosynthetics).

Moreover, the application of geosynthetics contributes to reducing the use of natural materials for civil infrastructures (Raja, 2011; Pinho-Lopes, 2018); low-cost and time-efficient projects (Raja, 2011; Elragi, 2000; Khan & Singh, 2020; Wu et al., 2020); improves slope stability, and generally modify the conditions of soil (GMA, 2002; Bayraktar, 2020; Oginni & Dada, 2021). The parameters usually improved include stiffness, shear strength, and permeability of the soil or the earth structure forming an integral part of the civil infrastructure (Schaefer et al., 2012; Michalcikova & Drochytka, 2018; Robbins et al., 2021; Kumar, 2023). In some forms of civil engineering contracts, for example, Design and Build (DB), and Build Operate and Transfer (BOT), applications of geosynthetics in civil infrastructures, according to Boyle et al. (2015), positively impact cost, quality, and time of the project and contractors could leverage on these for competitive advantage.

Furthermore, the application of geosynthetics is also known to contribute to carbon reduction (Raja, 2011). This was affirmed in the UK report on the Waste and Resources Action Programme (WRAP) in 2010 titled

'Sustainable Geosystems in Civil Engineering Applications'. The report informed that the application of geosynthetics reduces the environmental impact of construction projects including carbon reduction (WRAP, 2010; Raja, 2011; Rijk Gerritsen et al., 2023).

Geosynthetics come in the form of strips, straps, sheets, or three-dimensional structures (Oginni & Dada, 2021; The Constructor, 2022). A plethora of studies trace the root of the applications of geosynthetics to the days of the Pharaohs in ancient Egypt where natural materials made of jute, wood, and raffias, among others, were used as soil reinforcement and stabilizers in road works (Agrawal, 2011; Somiah et al., 2022; Kumar, 2023). The natural materials employed were referred to as natural geosynthetics (see Agrawal, 2011; Alao, 2011; Rawal et al., 2016; Somiah et al., 2022). However, the advent of polymers in the 1960s reinvented the applications of geosynthetics, as more sustainable and longer-lasting polymeric materials were used for the manufacturing of geosynthetics (Alao, 2011; Rawal et al., 2016). Notwithstanding the sustainability advantage the application of geosynthetics offers, studies in the past have shown a low level of awareness of geosynthetics among key stakeholders in the construction industry such as construction practitioners, academics, and graduating students in civil engineering and related disciplines at the Bachelor's level in both developing and developed countries (see GSI, 2015; Raja, 2011; Somiah et al., 2022); resulting in low levels of applications of geosynthetics globally (Oginni & Dada, 2021). Hence, the need to provide a more comprehensive account of geosynthetics to enhance its awareness level among industry stakeholders. Enhancing awareness of the main types, functional uses and project-level applications of geosynthetics has the potential to contribute to reducing waste generation through prevention, reduction, recycling, and reuse as geosynthetics offer alternative use for plastics that would have otherwise been wasted and polluted the environment; encouraging companies to adopt sustainable practices; promote public procurement practices that are sustainable as geosynthetics are scientifically proven to be environmentally friendly, cost-efficient and does not pose threat to life and society; and ensuring that people everywhere have the relevant information and awareness for sustainable development under SDG 12 (UNDP, 2024). Therefore, this desk study enhances the awareness level of geosynthetics among industry stakeholders as it seeks to give a more comprehensive literature account of geosynthetics highlighting the main types, functional uses, and project-level applications of geosynthetics in the development of sustainable civil infrastructures. The specific objectives that guided the study were:

- to ascertain the main types of geosynthetics for the development of sustainable civil infrastructures through a review of available relevant literature;
- to establish the functional uses of geosynthetics in the development of sustainable civil infrastructures through a review of available relevant literature; and,
- to establish the project-level applications of geosynthetics in the development of sustainable civil infrastructures through a review of available relevant literature.

MAIN TYPES, FUNCTIONAL USES AND APPLICATIONS OF GEOSYNTHETICS IN THE DEVELOPMENT OF SUSTAINABLE CIVIL INFRASTRUCTURES: A SURVEY OF EXISTING LITERATURE

Existing literature reveals a plethora of types of geosynthetics that could be employed in the development of sustainable civil infrastructures. However, they have been predominantly discussed under twelve (12) main types which included geotextile, geonet, geomat, geospacer, geogrid, geomembrane, geosynthetic clay liner, geofoam, geopipe, geocomposite, geocell (ASTM, 1994; CEN, 2018; Christoforidou et al., 2021; Ait, 2021; Qamhia & Tutumluer, 2021; Rimoldi et al., 2021; The Constructor, 2022), and Prefabricated Vertical Drain (PVD) (CEN, 2018; Kumar, 2023). Primarily, each of the main types has functional uses and it includes separation, protection, filtration, drainage, erosion control, and sealing or barrier (Ziegler, 2017; Kumar, 2023). The twelve (12) main types of geosynthetics are discussed below highlighting among others their functional uses and project-level applications.

Geotextile(s)

Geotextiles are permeable geosynthetic textile materials or fabrics that could be used to improve soil conditions or stabilize the earth's structure in sustainable civil infrastructures (Agrawal, 2011; Ministry of Textile, 2013; Somiah et al., 2022; Kumar, 2023). They are in contact with the soil, rock, earth, or any other geotechnical substance (ASTM, 1994; Rawal et al., 2016; Patel, 2019; Khan and Singh, 2020). The functional uses of geotextiles include reinforcement, filtration, separation, and drainage (ASTM, 1994; Rawal et al., 2016; Patel, 2019; Khan and Singh, 2020). Project-level applications of geotextiles include walls, roads, railroads, embankments, airfields, retaining structures, canals, pipelines, reservoirs, dams, bank protection, harbours, and landfills projects (Rawal et al., 2016; Qamhia & Tutumluer, 2021). Also, geotextiles have been applied in landfills, roads, harbours, and drainage structures (Muresan, 2020). Unpaved and paved roads in airport runways, sidewalks, sand drainage layers, landfills, stone base courses, parking lots and curb areas, green areas and recreational facilities, duct banks, pipe trenches, and retaining wall structures are also examples of project-level applications of geotextiles (Rodriguez, 2018).

Geogrid(s)

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 infrastructures (Khan & Singh, 2020). Geogrids primarily serve as a reinforcement and stabilizer material in addition to providing separation between soil and aggregate layers (CEN, 2018; Khan & Singh, 2020). Project-level applications of geogrids include roadways, railways, retaining walls, and buildings with shallow foundations (The Constructor, 2022). Geogrids can redistribute load over a wider area. They have high holding capacity, high tensile strength, and are eco-friendly in nature (The Constructor, 2022). When a geogrid is used as soil reinforcement, and placed at the bottom of an embankment, it improves stability and reduces the required width of the embankment (Rimoldi et al., 2021); thereby reducing embankment soil volumes and foundation preparation (Rimoldi et al., 2021). The costs of reduced fill material, reduced land area required, and increased embankment reliability provided by the inclusion of grids make the use of grids an economical choice (Rimoldi et al., 2021). Geogrids function as soil reinforcement for steep slopes, walls, roadway and railway bases, foundation soils, dykes, and levees among others (Oginni & Dada, 2021).

Geomembrane(s)

Geomembranes are low-permeability or impermeable geosynthetics, used in ground improvement to reduce or prevent the flow of fluid through the soil (Khan & Singh, 2020). Thus, this is a type of geosynthetic with an inherent impermeable membrane. Geomembranes are in the form of a sheet. They are commonly applied as cut-offs and liners (Khan & Singh, 2020). Geomembranes are also applied as hydraulic barriers (an example is when used as canal lining), field seaming, and minimization of installation damage (Khan and Singh, 2020; The Constructor, 2022). Geomembranes have been applied to improve ground conditions for the construction of ponds, landfill lining, dykes, levees, tunnels, canal lining, environmental, transportation, oil and gas containments, and general civil infrastructures (Jeon, 2016; Rimoldi et al., 2021; The Constructor, 2022).

Geonet(s)

Geonet is a polymeric structure formed by a set of continuous parallel polymeric ribs at acute angles to one another, forming a net-like pattern (Khan and Singh, 2020; The Constructor, 2022). It is used for in-plane drainage of gases or liquids (especially leachates from landfill and mining projects) and filtration of sediments contained within these fluids. Geonets are frequently laminated with geotextiles on one or both surfaces and are then referred to as drainage geocomposite (ASTM, 1994; GMA, 2002; Kumar, 2023). Generally, geonets are used for drainage behind retaining structures, plaza decks, or green roofs (Koerner, 2012). Project-level applications of geonets include road construction, road widening, asphalt work, building construction and foundations, dams, artificial ponds, and water reservoirs, among others (The Constructor, 2022).

Geospacer(s)

Geospacer is a three-dimensional structure made of polymer(s) with an interconnected air space in between. It is used to create air space in the earth or geotechnic substances (Rimoldi et al., 2021). It is used in contact with soil and/or other materials in geotechnical and civil engineering applications (CEN, 2018; Rimoldi et al., 2021). Project-level applications include stability in landfills (Rzepeckin et al., 2013). It has also been used in combination with other geosynthetics for applications in retaining structures, landfill capping systems, drainage, dykes, and levees, among others (Rzepeckin et al., 2013; Rimoldi et al., 2021).

Geofoam(s)

Geofoam is a closed-cell, super-lightweight, rigid, plastic foam (Elragi, 2000; Kumar, 2023). 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 (Elragi, 2000; Kumar, 2023). Primarily, geofoam provides a lightweight fill below a highway, bridge approach, bridge abutment, flood control levees, basement insulations, railways, embankment, and parking lot (Elragi, 2000; Oginni and Dada, 2021). It also serves as new fills in culverts and pipelines to reduce the load over the base structure (Elragi, 2000; Oginni and Dada, 2021). It is applicable in stadium seating, building foundations, and retaining structures (Elragi, 2000; Oginni and Dada, 2021). Using geofoam for retaining structures reduces lateral pressure, prevents settlement, and slope stabilization, and improves waterproofing (Elragi, 2000; Kumar, 2023).

Geocell(s)

Geocell is a three-dimensional geosynthetic cellular structure made with novel polymeric alloy (NPA) or ultrasonically welded high-density polyethylene (HDPE) strips (GMA, 2002; Yuu et al., 2008; Kumar, 2023). Functional uses of geocell include stabilization and reinforcement (CEN, 2018; Rimoldi et al., 2021). Geocell provides both a transfer of load through the cellular structures and physical containment of a depth of soil (Hegde, 2020). Applications of geocells include channel protection, erosion control, road construction, landfills, landscaping, mining operations, structural reinforcement for load support and earth retention, protective linings for channels and hydraulic structures, support for static and dynamic loads on weak subgrade soils, and green infrastructures (GMA, 2002; Hegde, 2020). Geocell is also applicable to foundations, waste containment, embankments, road, and railway structures according to Vibhoosha et al. (2021).

Geosynthetic Clay Liner(s)

Geosynthetic clay liners consist of thin layers of bentonite clay sandwiched between two layers of geotextiles and bonded to a geomembrane (United States Environmental Protection Agency, 2001; The Constructor, 2022; Kumar, 2023). The two layers of geotextiles are stitched together by a sewing process (needle-punched non-woven) thereby creating a perfectly balanced mat that has an internal shear resistance (United States Environmental Protection Agency, 2001; The Constructor, 2022). Anytime geosynthetic clay liners come into contact with water, the bentonite in the mat puffs up thereby creating a waterproof mineral layer (The Constructor, 2022; Kumar, 2023). Project-level applications of geosynthetic clay liners include canals, stormwater impoundments, constructed wetlands, highway construction, secondary containment, landfill liners, and landfill caps (United States Environmental Protection Agency, 2001; The Constructor, 2022).

Geopipe(s)

Geopipes are solid-wall or perforated polymeric pipes for the drainage of fluids. They are primarily used for leachate collection and in instances of high compressive loads (The Constructor, 2022; Kumar, 2023). Geopipes are preferred for landfill use as a means for the collection and quick drainage of the leachate to a sump, and removal system (The Constructor, 2022). Further applications of geopipes include subdrainage for buildings, roads, oil and gas production, sewer and wastewater transportation, and duct and irrigation systems (The Constructor, 2022).

Geocomposite(s)

Geocomposites are geosynthetics formed by a mixture of two or more geosynthetics such as geomembrane-geonet, geonet-geotextile, and geogrid-geotextile, among others (Oginni & Dada, 2021). Primarily, the functional uses of geocomposites include separation, reinforcement, drainage, filtration, stabilization, containment, and erosion control (Koerner, 2012; Somiah et al., 2022). The applications of geocomposites are prevalent in road construction, drainage segments, pavement base course or edge drains, rooftops, trench drains, tunnels in railways and roads, retaining walls, and bridge abutments, among others (The Constructor, 2022).

Geomat(s)

Geomat is also called Turf reinforcement mats (TRMs), erosion control mats, or 3D structure mats. It is a synthetic-based 3D structure mats that help in the prevention of soil erosion or loss of soil on steep slopes and drainage areas while enhancing vegetative growth through them (Rimoldi et al., 2021). It is a permeable structure (Rimoldi et al., 2021). They are made of randomly laid monofilaments, fused polymer nettings, or yarns woven or tufted into an open and dimensionally stable mat. Erosion protection can be increased by applications of geomats, which can provide more protection compared to that of plants grown normally (Shahkolahi et al., 2015; Kumar, 2023). Proven performance has resulted in the broad use and acceptance of geomat as a permanent, environmentally friendly, and cost-effective alternative to hard armour erosion protection solutions such as riprap and concrete (Rijk Gerritsen et al., 2023).

Prefabricated Vertical Drains (PVD)

The prefabricated vertical drain has the shape of a long tube (Kumar, 2023). It is made of an inner core that is surrounded by a woven or non-woven geotextile. The geotextile acts as a filter and the inner core acts like a drainage medium. This inner core could be made of a plastic core, a corrugated plastic sheet, or a more complicated system (Kumar, 2023). PVDs are applicable in soft soils with very low bearing capacity to improve the bearing capacity of the soil and to remove the excess water present in the soil (Kumar, 2023).

Thus, PVDs are inserted into soft soils to accelerate the consolidation of soft soil. PVDs are applicable in instances where the subgrade or foundation soil is soft clay, saturated soils, and/or cohesive soils (Kumar, 2023). PVDs are applicable in improving ground conditions for road, railway, airfield, land reclamation, and building projects (Turukmane et al., 2019).

SUMMARY OF LITERATURE FINDINGS

Objective one: to ascertain the main types of geosynthetics for the development of sustainable civil infrastructures through a review of available relevant literature.

Regarding objective one, it was revealed from the review of literature that there are in existence twelve (12) main types of geosynthetics that one can employ in the development of sustainable civil infrastructures. They are geotextile, geogrid, geomembrane, geonet, geospacer, geofoam, geocell, geosynthetic clay liner, geopipe, geocomposite, geomat, and prefabricated vertical drain.

Objective two: to establish the functional uses of geosynthetics in the development of sustainable civil infrastructures through a review of available relevant literature.

Concerning objective two, primarily the functional uses of geosynthetics could be organized under nine (9) main thematic uses namely: separation, filtration, containment, drainage, reinforcement, stabilization, fill material, erosion control, and protection (see Table 1).

Table 1. Summary of geosynthetics-primary functional uses matrix from previous studies.

Primary Functional Uses	Geosynthetics											
	1	2	3	4	5	6	7	8	9	10	11	12
Separation	x					x			x	x		x
filtration	x				x					x		
Containment				x			x			x		
Drainage	x	x			x			x		x		
Reinforcement	x		x						x	x		
Stabilization	x		x		x				x	x		
Fill material						x				x		
Erosion control	x			x	x				x	x	x	
Protection	x									x	x	

Source: Literature review (eg.: see Oginni and Dada, 2021, Qamhia & Tutumluer, 2021; Rimoldi et al., 2021; Somiah et al., 2022; Kumar, 2023)

Where: 1-geotextile, 2-prefabricated vertical drain, 3-geogrid, 4-geomembrane, 5-geonet, 6-geofoam, 7-geosynthetic clay liner, 8-geopipe, 9-geocell, 10-geocomposite, 11-geomat, and 12-geospacer. This labelling also applies to Tables 2a and 2b.

Objective three: to establish the project-level applications of geosynthetics in the development of sustainable civil infrastructures through a review of available relevant literature.

Table 2a. Project-level applications of geosynthetics from previous studies.

Civil Infrastructure	Geosynthetics											
	1	2	3	4	5	6	7	8	9	10	11	12
Highways	x	x	x		x	x	x	x	x			
Railroads	x	x				x		x	x			
Embankments	x					x						
Duct and irrigation systems								x				
Oil and gas transportation								x				
Airfields	x	x										
Retaining structures	x				x	x						
Canals	x		x	x		x				x		
Pipe projects	x											
Water reservoirs	x				x							
Harbours	x											
Dams	x				x							

Source: Literature review (eg.: see Oginni and Dada, 2021;Qamhia & Tutumluer, 2021; Rimoldi et al., 2021; Somiah et al., 2022; Kumar, 2023)

Table 2b. Project-level applications of geosynthetics from previous studies.

Civil Infrastructure	Geosynthetics											
	1	2	3	4	5	6	7	8	9	10	11	12
Waste landfill	x	x				x	x		x	x		
Green areas and recreational facilities	x					x			x			
Stormwater impoundment							x					
Constructed wetlands							x					
Sidewalks	x									x		
Parking lots and curb areas	x					x						
Stadia	x					x						
Bridges						x						
Levees (river)			x			x						
Dykes (sea)			x			x						
Buildings		x	x		x	x	x					
Tunnels				x								
Plaza decks					x							
Culverts						x						
Ponds				x								
Channels						x						
Drainage										x		
Earthen flood defence structures											x	
Land reclamation		x										

Source: Literature review (eg.: see Oginni and Dada, 2021, Qamhia & Tutumluer, 2021; Rimoldi et al., 2021; Somiah et al., 2022; Kumar, 2023)

From the review of existing literature, it was revealed that geosynthetics have been applied in the development of thirty-one (31) sustainable civil infrastructures which included: 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, drainage, earthen flood defence structures, and land reclamation (see Table 2a and 2b).

METHODOLOGY

Given the aim of the study, this desk study employed the Narrative Literature Review (NLR) approach to literature review. NLR is a qualitative research method and it is summative in findings. Like the other approaches to literature review such as meta-analysis, integrative review, and systematic literature review, the NLR approach is also systematic (Fan et al., 2022; Hiebl, 2023). It is informal and incremental in nature. It employs informal mechanisms to identify, organize, and analyse literature (Fan et al., 2022). Thus, it enables the researcher to follow different lines of inquiry as the literature search is expanded. NLR allows the researcher to investigate different themes, topics, and sub-topics alike as the knowledge expands. Also, through the snowballing technique of reviewing literature that NLR employs, the reading and understanding of the researcher about a field, theme, or topic is also broadened (Fan et al., 2022). According to Synder (2019), the NLR approach is appropriate for reviewing topics across diverse disciplines (Snyder, 2019), as it is not constrained by predetermined selection criteria (Snyder, 2019; Fan et al., 2022), which is typical of other literature review approaches such as the meta-analysis, integrative review, and systematic literature review. Thus, riding at the back of the strength of the NLR, this study found the NLR to be appropriate; thus employed it. In this study, the Google search engine, Google Scholar, and repositories/databases of journals, conferences, and institutions among others, were searched for existing, relevant, and related reference materials on the main types, functional uses, and project-level applications of geosynthetics in the development of sustainable civil infrastructures. The search was undertaken from December 2023 to March 2024. The sources of literature included journal papers, conference papers, and books. Most of the reference materials were not older than 10 years. The few that were more than 10 years old and were deemed very fundamental reference material were validated with a more recent one. This ensured that more recent information was referenced to make this study well-grounded in relevant literature.

Nonetheless, NLR could be flawed with selective assumptions and researcher biases (Snyder, 2019). As a result of which important and relevant research or literature may be missed or not included (Snyder, 2019; Fan et al., 2022). However, these limitations were addressed in this study as the researcher was transparent and reflexive in selecting and reviewing relevant and related literature. According to Fan et al. (2022) researcher's biases and selective assumptions that characterize NLR could be overcome when researchers are transparent and reflexive in literature selection.

CONCLUSION

The study revealed applications of twelve (12) main types of geosynthetics in the development of thirty-one (31) sustainable civil infrastructures. The main types of geosynthetics included geotextile, geospacer, and geogrid. Project-level applications of geosynthetics included highways, ponds, airfields, and retaining structures. Primarily, functional uses of the geosynthetics included soil reinforcement, stabilization, and filtration. This study informs construction practitioners, academics, and other stakeholders in the construction industry of the available geosynthetics that could be employed in the development of sustainable civil infrastructures. Moreso, it could serve as a guide to policymakers in enacting policies that seek to promote sustainable civil infrastructures. Again, it provides a more comprehensive basis for future country-specific studies that seek to evaluate project-level applications of geosynthetics in the development of sustainable civil infrastructures.

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