Validating the underlying properties of geosynthetics driving the applications of geosynthetics in the development of Sustainable Civil Infrastructures: A Delphi Study from Ghana

ABSTRACT

Whereas the comparative factors informing the choice of geosynthetics as a sustainable ground improvement material over traditional alternatives are known little is known, if any, of country-specific studies that validated the underlying properties of geosynthetics driving the applications of geosynthetics in the development of sustainable civil infrastructures. Thus, this Delphi study sought to ascertain whether the underlying properties of geosynthetics driving the applications of geosynthetics in the development of sustainable civil infrastructures in other national contexts do drive the applications of geosynthetics in the development of sustainable civil infrastructures in Ghana, and determine the relative influence level of each of the underlying properties of geosynthetics driving the applications of geosynthetics in the development of sustainable civil infrastructures in Ghana. Nineteen properties of geosynthetics were established to drive the applications of geosynthetics in the development of sustainable civil infrastructures in Ghana with varying relative influence levels. They included stiffness properties, chemical degradation resistance, and hydraulic properties. Chemical degradation resistance with an RII score of (0.83) ranked 1st among the nineteen geosynthetic properties driving the applications of geosynthetics in the development of civil infrastructures in Ghana while hydraulic properties of geosynthetics within RII of (0.68) ranked 19th. The uniqueness of the study also lies within the application of the Delphi technique in the study of the underlying properties of geosynthetics driving geosynthetics applications in sustainable civil infrastructure development.

Keywords: Civil infrastructures, Delphi technique, Geosynthetics, and Ghana.

INTRODUCTION

Geosynthetics are polymeric materials used for improving or stabilizing soil, rock, earth, or any geotechnical substance as an integral part of sustainable civil infrastructures (ASTM, 1994; Ziegler, 2017; Khan & Singh, 2020). They come in the form of strips, straps, sheets, or three-dimensional structures (Oginni & Dada, 2021; The Constructor, 2022). In recent times, intelligent geosynthetics have also been developed due to technological advancement, which makes it possible to monitor and evaluate the performance of civil infrastructures, even in concealed and difficult-to-reach areas where physical inspections are impossible such as substructure works, underground works, landfill sealing systems, and dams, among others (Ziegler, 2017). Intelligent geosynthetics are geosynthetics with integrated chips and sensors for measuring strains, temperature, and other environmental conditions (Ziegler, 2017). Whereas the comparative factors informing the choice of geosynthetics as a ground improvement material over traditional alternatives are known, which include sustainability, cost advantage, and superior material properties (see GMA, 2002; Morgan and Rickson, 2011; Nicholson, 2015; Boyle et al., 2015; Jeon, 2016; Ziegler, 2017; Adewumi, 2018; Khan and Singh, 2020; Bayraktar, 2020; Qamhia and Tutumluer, 2021; Ait, 2021; Oginni and Dada, 2021; Christoforidou et al., 2021). What is not known is the specific underlying properties of geosynthetics driving the applications of geosynthetics in the development of sustainable civil infrastructures. Hence the relevance of this current as it seeks to ascertain whether the properties of geosynthetics driving the applications of geosynthetics in the development of sustainable civil infrastructures in other national contexts do drive the applications of geosynthetics in the development of sustainable civil infrastructures in Ghana, and determine the relative influence level of each of the properties of geosynthetics driving the applications of geosynthetics in the development of sustainable civil infrastructures in Ghana. Sustainable civil infrastructures describe infrastructures, systems, or projects obtained in a manner that meets 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). Sustainable civil infrastructures do not negatively impact society, the environment, and the economy (Rimoldi et al., 2021). Moreover, none of the related studies in the past have ever employed the Delphi technique in ascertaining the underlying properties of geosynthetics driving the applications of geosynthetics in the development of sustainable civil infrastructures (see Agrawal, 2011; Adewumi, 2018). Thus, the uniqueness of this current study also lies within the application of the Delphi technique in the study of the underlying properties of geosynthetics driving the applications of geosynthetics in the development of sustainable civil infrastructures. The findings of this study contribute to country-specific literature on the geosynthetic properties driving the applications of geosynthetics in the development of sustainable civil infrastructures. Specifically, it informs construction stakeholders within the construction industry in Ghana of the properties of geosynthetics driving the applications of geosynthetics in the development of sustainable civil infrastructures. Also, promoting awareness about geosynthetics, a globally accepted sustainable material in the development of sustainable civil infrastructures contributes to addressing the Sustainable Development Goal (SDG) (12), target (8) which seeks to promote that by 2030 people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature (UNDP, 2024). Moreover, the findings from this study could be found useful by countries within the tropics such as Burkina Faso, Nigeria, and Ivory Coast whose climatic conditions and construction industry characteristics share close resemblances with that of Ghana.

The specific objectives that guided the study were:

- to ascertain whether the underlying properties of geosynthetics driving the applications of geosynthetics in the development of sustainable civil infrastructures in other national contexts do drive the applications of geosynthetics in the development of sustainable civil infrastructures in Ghana, and
- to determine the relative influence level of each of the underlying properties of geosynthetics driving the applications of geosynthetics in the development of sustainable civil infrastructures in Ghana.
- to determine the relative influence level of each of the underlying properties of geosynthetics driving the applications of geosynthetics in the development of sustainable civil infrastructures in Ghana.

LITERATURE SURVEY PROPERTIES OF GEOSYNTHETICS DRIVING THE APPLICATIONS OF GEOSYNTHETICS IN THE DEVELOPMENT OF CIVIL INFRASTRUCTURES

Properties driving the applications of geosynthetics in sustainable civil infrastructure projects are the unique inherent features of geosynthetics that impact the geotechnical engineering properties of the soil, rock, and earth, through the applications of geosynthetics as an integral part of sustainable civil infrastructures (Ait, 2021). These properties include degradation, physical, structural, hydraulic, and mechanical properties (Adewumi, 2018). The polymer used for the geosynthetics is a critical contributing factor to the properties of geosynthetics (Agrawal, 2011). Various international organizations provide standards for assessing the properties of geosynthetics.

Physical properties

The physical properties of geosynthetics drive the applications of geosynthetics in the development of civil infrastructures (Ait, 2021). The physical properties of geosynthetics are the fundamental properties that can be measured or observed without changing the composition of the materials (Agrawal, 2011; Adewumi, 2018; Ait, 2021). They describe geosynthetics (Adewumi, 2018). Physical properties include the thickness, mass per unit area, specific gravity, and stiffness of geosynthetics (Agrawal, 2011; Adewumi, 2018; Ait, 2021).

Mass per Unit Area

Mass per Unit Area is the ratio of the mass of a substance to the area of the same substance (Adewumi, 2018; Ait, 2021). This property aids in determining the bulk weight of the overall weight of the materials as well as the cost of production of geosynthetics (Adewumi, 2018). The cost and mechanical properties such as tensile strength, puncture strength, and tear strength of geosynthetics have a direct relationship with mass per unit area. Thus, the mass per unit area of the geosynthetics is an essential property of geosynthetics (Adewumi, 2018; Ait, 2021).

Specific gravity

Specific gravity is a measure of the ratio of the weight of a given volume of material (devoid of voids) to the weight of an equal volume of distilled water at 4 degrees Celsius (devoid of air). The specific gravity of a base polymer is an essential property as it assists in identifying the base polymer of geosynthetics (Agrawal, 2011; Adewumi, 2018; Ait, 2021). It also aids in computing strength–weight and cost–weight ratios. In the case of polyethylene (PE), specific gravity is an essential property, because it forms the basis upon which PE is classified as high, medium, low, or even very low density (Agrawal, 2011; Adewumi, 2018; Ait, 2021).

Thickness

The thickness of a geosynthetic is a measure of the distance between its upper and lower surfaces (Adewumi, 2018). It is measured normal to the surfaces of the geosynthetic (Adewumi, 2018). Thickness is used to determine the ability of a geosynthetic to withstand the loads it has been subjected to (Adewumi, 2018).

Stiffness

Stiffness is also known as flexural rigidity.it is a measure of the ability to resist bending (flexure) under its own weight. The single cantilever test is used to determine flexural rigidity of geosynthetics (Adewumi, 2018; Song et al., 2022). The flexural rigidity of a geosynthetic is an indication of the feasibility of providing a suitable working surface for installation. For example, a low-stiffness geotextile easily conforms to the contours of the ground thereby enhancing its performance to erosion control (Adewumi, 2018; Song et al., 2022). There are instances which high stiffness geosynthetics are required for application. Thus, stiffness is an essential property driving the applications of geosynthetics in sustainable civil infrastructures (Song et al., 2022).

Mechanical properties

Mechanical properties drive the applications of geosynthetics in the development of sustainable civil infrastructures (Agrawal, 2011; Ait, 2021). These are critical when geosynthetics are required to perform a structural role under applied loads or in instances where geosynthetics are to survive localized stresses and installation damage. Mechanical properties define the strength of geosynthetics and their interaction with soil, rock, and other geotechnical substances (Rosete et al., 2013). Mechanical properties of geosynthetics include compressibility, tensile strength, fatigue strength, burst strength, and tear strength (Carneiro et al., 2023); elongation resistance (Scholz et al., 2021); impact strength, puncture resistance, friction behaviour, and pull-out (anchorage) strength (Agrawal, 2011; Adewumi, 2018; Ait, 2021; Carneiro et al., 2023).

Compressibility

Compressibility of a geosynthetic is a measure of the rate of decrease of thickness as a result of increased stresses. Compressibility is determined by observing the change in thickness of a geosynthetic when subjected to conditions of varying applied normal stresses (Rosete et al., 2013). This property foretells the response of geosynthetics when subjected to loadings (Adewumi, 2018). It also informs the fluid transmissivity of geosynthetics. In particular to geotextiles, the more a fabric compresses when subjected to loading, the lower its transmissivity (Adewumi, 2018).

Tensile strength

Tensile strength is the maximum tensile load that the test specimen of a geosynthetic could sustain at the point of failure or the maximum load that can be applied per unit length along the edge of the geosynthetic in its plane (Carneiro et al., 2023). The tensile properties of geosynthetics are determined using a tensile strength test, whereby a geosynthetic specimen is subjected to loadings and the corresponding stress-strain curves are obtained. An example is the wide-width strip tensile test (Adewumi, 2018). The features of a tensile strength test include the maximum tensile stress (referred to as the strength of a geosynthetic), strain at failure (generally known as maximum elongation), toughness (the property of geosynthetics that aid in absorbing energy), and the modulus of elasticity (Agrawal, 2011; Adewumi, 2018; Ait, 2021; Carneiro et al.,2023).

Fatigue strength

The fatigue strength is the ability of geosynthetics to withstand repetitive loading before undergoing failure. Fatigue strength is determined by conducting a wide strip tensile test by applying a predetermined load (which should be less than the failure load) and then reducing it till it gets to zero. The load is again applied and then relaxed. This cycle is repeated till failure takes place (Kumar et al., 2021; Carneiro et al.,2023).

Puncture resistance

It is a measure of the ability of geosynthetics to withstand localized stresses generated by penetrating or puncturing objects, for example, stones, ballast, and stumps (Adewumi, 2018). This is more essential for geotextiles and geomembranes categories of geosynthetics.

Impact strength

The impact strength is also known as the dynamic puncture strength or dynamic perforation strength. It is a measure of the ability of geosynthetics to withstand or resist stresses generated by the sudden impact of falling objects such as tools, coarse aggregates, and other construction items during the installation process. The impact strength of geosynthetics can be evaluated by the cone drop test method (Adewumi, 2018).

Bursting strength

It is a measure of the normal stress at which the geosynthetic fails (Agrawal, 2011; Adewumi, 2018; Ait, 2021). Bursting strength is measured by the bursting test (multi-axial tensile test). This test is more important in the case of geomembranes (Agrawal, 2011; Adewumi, 2018; Ait, 2021).

Soil-geosynthetic interface characteristics

Anytime geosynthetics are used it is essential that the bond between the soil and geosynthetics is sufficient to stop the soil from sliding over geosynthetics or prevents geosynthetics from pulling out of the soil. The bond between geosynthetics and the soil depends on the interaction of their contact surfaces (Agrawal, 2011; Adewumi, 2018; Ait, 2021). The soil-geosynthetic interaction (interlocking characteristics and/or interface friction) is therefore an essential element in the performance of the geosynthetic-reinforced soil structures such as embankments, retaining walls, slopes, and other applications where the resistance of geosynthetics to sliding or pull out under simulated field conditions is important (Agrawal, 2011; Adewumi, 2018; Ait, 2021).

Hydraulic properties

This property of a geosynthetic influence its ability to function as filters and drains. Porosity, apparent opening size, percent open area, transmissivity, and permittivity are the key hydraulic properties of geosynthetics (Agrawal, 2011). This property is very essential for geosynthetics belonging to the categories of geotextiles, geonets and some geocomposites, which are normally used in filtration and drainage applications (Agrawal, 2011; Adewumi, 2018; Ait, 2021).

Degradation properties

Degradation properties indicate the rate at which geosynthetics will degrade with time when subjected to ultraviolet rays or some absurd environment (Agrawal, 2011). This property includes hydrolytic degradation (Cho et al., 2020), photodegradation (Carneiro et al., 2021), chemical degradation, biodegradation (Adewumi, 2018), mechanical degradation (Markiewicz et al., 2022), and other degradation forms occurring as a result of an attack by rodents, and termites (Agrawal, 2011).

Table 1: Properties of geosynthetics from previous studies

Properties of geosynthetics	Author(s)
Thickness	(Adewumi, 2018)
Stiffness	(Adewumi, 2018)
Specific gravity	(Adewumi, 2018; Ait, 2021)
Mass per unit area	(Adewumi, 2018; Ait, 2021).
Resistance to photodegradation	(Carneiro et al., 2021)
Chemical degradation resistance	(Markiewicz et al., 2022)
Hydrolytic degradation	(Cho et al., 2020)
Mechanical degradation resistance	(Markiewicz et al., 2022)
Biodegradation resistance	(Markiewicz et al., 2022)
Hydraulic properties	(Ait, 2021)
Elongation resistance	(Scholz, et al., 2021)
Soil-geosynthetic interaction characteristics	(Adewumi, 2018; Ait, 2021)
Puncture resistance	(Adewumi, 2018)
Bursting strength	(Adewumi, 2018; Ait, 2021)

Fatigue strength	(Kumar et al., 2021)
Tensile strength	(Adewumi, 2018; Ait, 2021).
Compressibility	(Rosete et al., 2013).
Tear strength	(Adewumi, 2018; Ait, 2021).
Abrasion strength	(Carneiro et al.,2023)

METHODOLOGY

This current study employed the Delphi technique and adapted to the detailed Delphi process outlined in Figure 1. Delphi technique's strength is anchored in the rigorousness of the methodology (Aigbavboa, 2014; Tengan & Aigbavboa, 2018; Somiah et al., 2022). The first step of the Delphi process was a literature review to identify the underlying properties of geosynthetics driving the applications of geosynthetics in the development of sustainable civil infrastructures. The second step was the selection of experts for the Delphi study who had a broad spectrum of opinions on the issue being investigated (see Aigbavboa, 2014; Tilakasiri, 2015; Somiah et al., 2022). According to Aigbavboa (2014) and Somiah (2019), critical to the selection of experts is the practical and theoretical knowledge of the experts. Hence, the checklist in Appendix 1 aided in prequalifying the experts on the Delphi panel. Initially, nineteen (19) experts freely responded in the affirmative via separate e-mails and/or phone calls to participate in the Delphi survey. However, only fifteen (15) experts participated in all the two rounds of the survey. The Delphi process ended after round two when a good consensus was attained. The sample size of fifteen experts for the study was based on the assumption that, according to Tengan and Aigbavboa (2018) and Somiah et al. (2021), the sample size for a Delphi study is not dependent on a statistical sample which ought to be representative of a population instead, it brings together experts to share their knowledge about the subject under investigation. Moreso, Delbecq et al. (1975) as affirmed by Aigbavboa (2014) argued that even 10 to 15 panellists are sufficient for a Delphi study provided the background of the panellists is homogenous. Thus, based on the recommendations from previous studies that employed the Delphi technique, and the homogeneous nature of the panellists, the fifteen panellists for this current study were deemed adequate and acceptable.

Concerning the demographics of the experts, none of the experts had work experience of 5 years and below. The results indicated that 53.3% had 6-10 years of work experience, 40.0% had 11-15 years of work experience in Ghana and 6.7% had 16 years and above of work experience. Thus, the demographic characteristics of the experts suggested that the experts engaged in the Delphi study were knowledgeable and well-experienced, regarding the issue being investigated.

Table 2: Respondents' demographic characteristics

Respondents' demographic characteristics	**Frequency(n=15)**	**Percentage (%)**
Place of work		
Academic institutions	5	33.3
Construction industry	10	66.7
Total	**15**	**100**
Level of Education		
Bachelor's Degree	1	6.7
Master's Degree	10	66.7

PhD	4	26.6
Total	**15**	**100**
Professional affiliation		
Institution of Engineering and Technology, Ghana	6	40.0
Ghana Institution of Engineering	5	33.3
Ghana Institute of Construction	4	26.7
Total	**15**	**100**
Work experience		
5 years	0	0
6-10 years	8	53.3
11-15 years	6	40.0
16 years and above	1	6.7
Total	**15**	**100**

Moreover, by comparing the demographic characteristics of the panel of experts with the checklist for selecting the experts (see Appendix 1), it was revealed that the minimum obtained mark for the level of education was 1 point (Bachelor's degree). All experts belonged to a professional association thus, the minimum obtained mark was 1 point, and the minimum obtained mark for work experience was 2 points (6–10 years), and all experts have worked on projects that applied geosynthetics so the minimum obtained mark was 1 point.

In all, a minimum expected mark of 4 points was expected of an expert before becoming part of the panel of experts (see Appendix 1). Thus, since the minimum obtained mark from the experts summed up to 5 points which was more than the minimum expected mark required, the experts were deemed fit for the Delphi study. A structured questionnaire aided in soliciting the views of the expert panellists through rounds of questionnaire surveys. This led to building consensus in the views of the experts (Miller, 1993; Tengan & Aigbavboa, 2018; Somiah et al., 2021). The instructions and the questionnaire for round one of the Delphi survey were sent to the experts (see Appendices 2 and 3). Fifteen experts responded to both round one and two of the survey. In determining consensus in the views of the experts, a combination of the mean, median, standard deviation, interquartile deviation (IQD), and relative importance index has been used in previous studies. At least two of the statistics have been used in estimating consensus in previous studies. Hence, this study adopted a combination of the median, standard deviation, interquartile deviation (IQD), and relative importance index in determining consensus. A similar approach was used by Raskin (1994) and even in quite recent studies (see Aigbavboa, 2014; Adnan et al., 2018; Tengan and Aigbavboa, 2018; Somiah et al., 2021; Somiah et al., 2022). Thus, in this study consensus was measured by:

1. Strong consensus - median 9-10, relative importance index 0.80-1.00, interquartile deviation (IQD) ≤ 1;
2. Good consensus - median 7-8.99, relative importance index 0.60-0.79, IQD$\geq 1, 1 \leq 2$; and
3. Weak consensus - median $\leq$ 6.99, relative importance index ≤ 0.59 and IQD$\geq 2, 1 \leq 3$.

This was based on a 10-point influence scale where 1 and 2 represent no influence; 3 and 4 represent low influence; 5 and 6 represent medium influence; 7 and 8 represent high influence; 9 and 10 represent very high influence. Furthermore, through constant communication with the experts individually, and offering the experts the opportunity to freely maintain or effect changes to their response and giving reasons for the latter, internal validity was ensured. A statistical estimate of the experts' views was computed and examined using the median, standard deviation, interquartile deviation, and relative impact index after each round of the Delphi survey. Ethically, the identity of the experts was kept confidential (Aigbavboa, 2014; Ameyaw et al., 2016; Tengan & Aigbavboa, 2018).

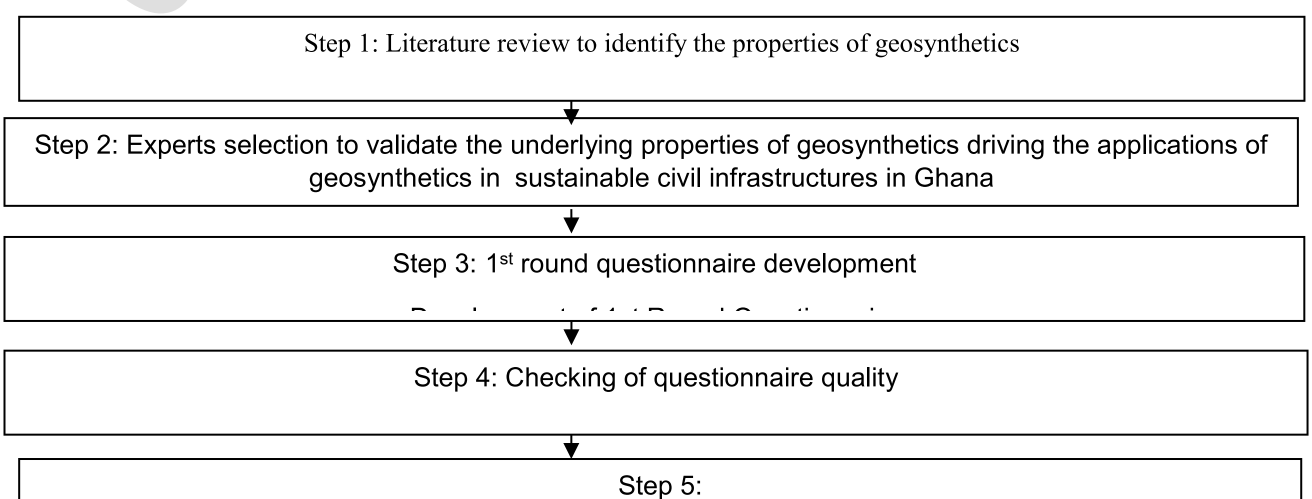

Figure 1: Process Diagram of the Delphi Study
Source: Adapted from Aigbavboa (2014) and Somiah et al. (2021).

RESULTS AND DISCUSSIONS

Delphi round one results

Round one of the Delphi survey sought to ascertain whether the underlying properties of geosynthetics driving the applications of geosynthetics in the development of sustainable civil infrastructures in other national contexts do drive the applications of geosynthetics in the development of sustainable civil infrastructures in Ghana. In all, nineteen underlying properties identified from the literature review were validated by the expert panellists during round one of the Delphi survey to be the underlying properties driving the applications of geosynthetics in the development of sustainable civil infrastructures in Ghana. All the nineteen underlying properties of geosynthetics driving the applications of geosynthetics in the development of sustainable civil infrastructures in Ghana recorded high influence (HI: 7.00–8.00). No further properties were suggested by the experts thus the nineteen properties were deemed comprehensive for Ghana.

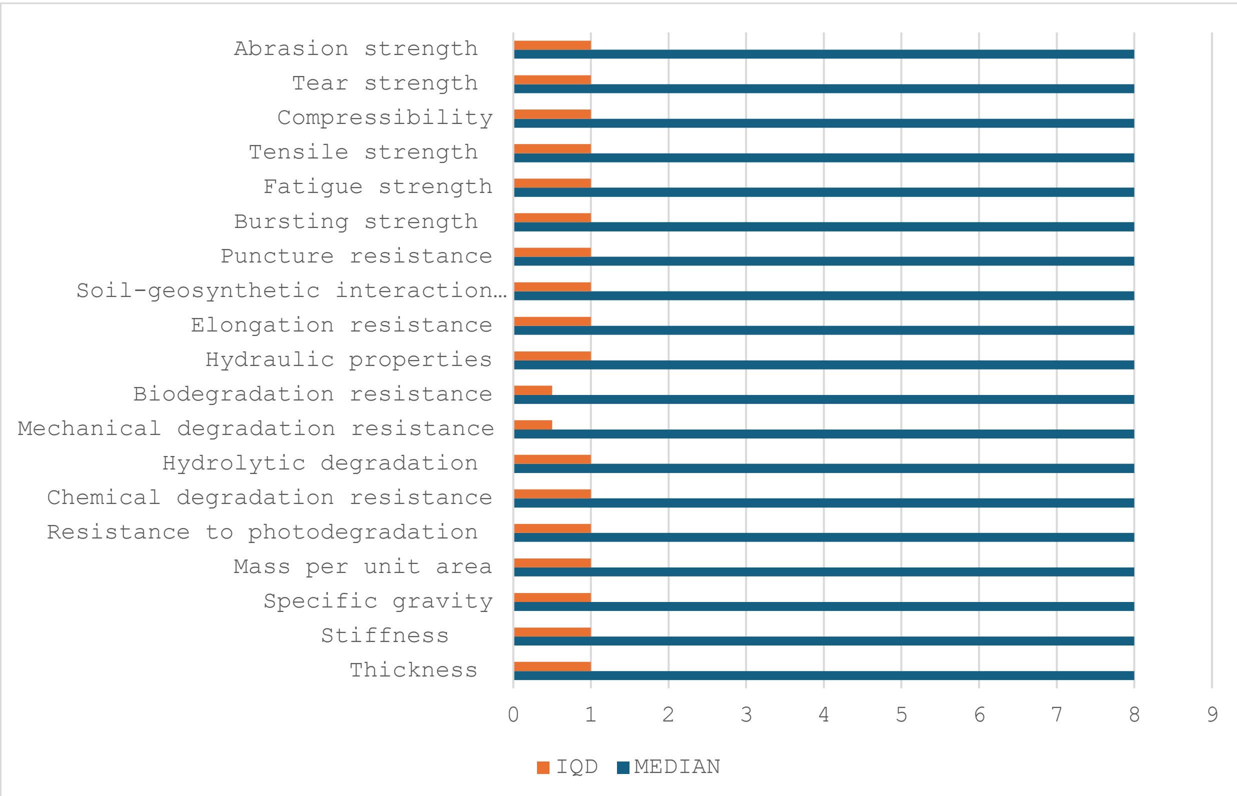

Figure 2. underlying properties of geosynthetics from round one of the Delphi survey

Delphi round two results

A total of nineteen properties of geosynthetics constituted the underlying properties of geosynthetics driving the applications of geosynthetics in the development of sustainable civil infrastructures in Ghana. All of them recorded a group median score of 8 (see Table 3). This suggests that all nineteen properties were deemed to have a high influence in driving the applications of geosynthetics in the development of sustainable civil infrastructures. The median, standard deviation and relative importance values indicate a good consensus in the views of the expert panellists regarding the nineteen underlying properties of geosynthetics driving the applications of geosynthetics in the development of sustainable civil infrastructures in Ghana.

Table 3: Underlying properties of geosynthetics driving the applications of geosynthetics in sustainable civil infrastructures in Ghana

	Median	Interquartile deviation	Standard deviation	Relative Importance Index (RII)	RII ranking
Thickness	8	1.00	0.20	0.79	6th
Stiffness	8	0.50	0.20	0.70	18th

Specific gravity	8	0.50	0.56	0.81	5th
Mass per unit area	8	1.00	0.63	0.82	2nd
Resistance to photodegradation	8	1.00	0.30	0.82	2nd
Chemical degradation resistance	8	1.00	0.30	0.83	1st
Hydrolytic degradation	8	1.00	0.35	0.72	16th
Mechanical degradation resistance	8	1.00	0.15	0.82	2nd
Biodegradation resistance	8	1.00	0.58	0.79	6th
Hydraulic properties	8	1.00	0.55	0.68	19th
Elongation resistance	8	1.00	0.34	0.78	10th
Soil-geosynthetic interaction characteristics	8	1.00	0.20	0.76	14th
Puncture resistance	8	1.00	0.44	0.78	10th
Bursting strength	8	1.00	0.24	0.79	6th
Fatigue strength	8	1.00	0.37	0.77	13th
Tensile strength	8	1.00	0.30	0.78	10th
Compressibility	8	1.00	0.40	0.79	6th
Tear strength	8	1.00	0.41	0.71	17th
Abrasion strength	8	1.00	0.32	0.75	15th

Discussions

This study aimed to ascertain whether the underlying properties of geosynthetics driving the applications of geosynthetics in the development of sustainable civil infrastructures in other national contexts do drive the applications of geosynthetics in the development of sustainable civil infrastructures in Ghana and determine the relative influence level of each of the underlying properties of geosynthetics driving the applications of geosynthetics in the development of sustainable civil infrastructures in Ghana. Nineteen (19) underlying properties of geosynthetics were found to be driving the applications of geosynthetics in the development of sustainable civil infrastructures in Ghana. Each of the nine underlying properties of geosynthetics recorded a high influence, median score range of (HI: 7.00–8.00). The properties included thickness, stiffness, specific gravity, mass per unit area, resistance to photodegradation, chemical degradation resistance, hydrolytic degradation, mechanical degradation resistance, and biodegradation resistance. Relatively, chemical degradation resistance with an RII score of (0.83) ranked 1st among the nineteen underlying properties of geosynthetics driving the applications of geosynthetics in the development of sustainable civil infrastructures in Ghana. This was consistent with the view of

Markiewicz et al. (2022) that an influential property driving the applications of geosynthetics is their ability to resist mechanical degradation. Jointly ranking 2nd were mass per unit area, resistance to photodegradation, and mechanical degradation resistance. Each recorded an RII score of (0.82). Markiewicz et al. (2022) found mechanical degradation resistance to be a critical property driving the applications of geosynthetics in the development of sustainable civil infrastructures. Ait (2021) contested that an indispensable property of geosynthetics is their mass per unit area. This is a physical property that has the potential to influence the durability of geosynthetics. Specific gravity with an RII score of (0.81) and thickness with an RII score of (0.79) ranked 5th and 6th respectively, thus found to be consistent with the view of Adewumi (2018) that specific gravity and thickness properties of geosynthetics drive the applications of geosynthetics in the development of sustainable civil infrastructures. Also, jointly ranking 6th with thickness of the geosynthetic were biodegradation resistance which was in tandem with Markiewicz et al. (2022), and bursting strength which affirms the view of Ait (2021). Elongation resistance, puncture resistance and tensile strength jointly ranked 10th with each recording an RII score of (0.78). In separate studies, Scholz et al. (2021) and Ait (2021) found elongation resistance, tensile strength and puncture resistance to be underlying properties of geosynthetics driving the applications of geosynthetics in the development of sustainable civil infrastructures. Further, fatigue strength with an RII of (0.77) ranked 13th. This aligns with the view of Kumar et al. (2021) that an essential property of geosynthetics is their fatigue strength. The fatigue strength relates to the ability of the geosynthetic not to succumb to loading. Soil-geosynthetic interaction characteristics with an RII of (0.76) ranked 14th, and abrasion strength recorded an RII of (0.75) and ranked 15th. Abrasion strength was consistent with Carneiro et al. (2023) while soil-geosynthetic interaction characteristics affirm the opinion by Adewumi (2018) and Ait (2021). Hydrolytic degradation property ranked 16th with RII score of (0.72). Hydrolytic degradation property according to Cho et al. (2020) is an essential property required of geosynthetics as it is a major contributor to the durability of the geosynthetics. Stiffness with an RII score of (0.70) ranked 18th in this study from Ghana, thus supporting the view by Adewumi (2018) that the stiffness of geosynthetics drives geosynthetics applications in the development of sustainable civil infrastructures. Ranking 19th was hydraulic properties of geosynthetics with an RII of (0.68). Hydraulic properties according to Ait (2021), drive applications of geosynthetics in the development of sustainable civil infrastructures.

CONCLUSIONS

The study concludes that nineteen properties of geosynthetics known to have driven the applications of geosynthetics within some national contexts do drive the applications of geosynthetics in the development of sustainable civil infrastructures in Ghana. The specific properties germane to Ghana included chemical degradation resistance, stiffness, hydraulic properties, bursting strength and abrasion strength. Relatively, chemical degradation resistance with an RII score of (0.83) ranked 1st among the nineteen underlying properties of geosynthetics driving the applications of geosynthetics in the development of sustainable civil infrastructures in Ghana while hydraulic properties of geosynthetics with an RII of (0.68) ranked 19th. Thus, whereas the under properties driving the applications of geosynthetics in the development of sustainable civil infrastructures were found to be consistent with that of previous studies, the relative level of influence of each property driving the applications of geosynthetics in the development of sustainable civil infrastructures varied in the case of Ghana. The findings of this study contribute to country-specific literature on the underlying properties of geosynthetics driving the applications of geosynthetics in the development of sustainable civil infrastructures. Specifically, it informs construction stakeholders within the construction industry in Ghana of the underlying properties of geosynthetics driving the applications of geosynthetics in the development of sustainable civil infrastructures. Also, promoting awareness about geosynthetics, a globally accepted sustainable material in the development of sustainable civil infrastructures contributes to addressing the Sustainable Development Goal (SDG) (12), target (8) which seeks to promote that by 2030 people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature (UNDP, 2024). Also, the uniqueness of this study is as a result of the application of the Delphi technique to study the underlying properties of geosynthetics driving the applications of geosynthetics in the development of sustainable civil infrastructure s.

References

Adewumi, A. O. (2018). *An assessment on the use of geosynthetic materials by construction industry stakeholders in Lagos State Nigeria .* Federal University of Technology. Akure: Adewumi, a. O. (2018). An assessment on the use of geosynthetic materials by construction industry stakeholders in lagos state nigeria (doctoral dissertation, federal university of technology, akure).

Agrawal, B. J. (2011). Geotextile: It's application to civil engineering–overview. *National Conference on Recent Trends in Engineering & Technology*, (pp. 1-6).

Aigbavboa, C. O. (2014). *An Integrated Beneficiary Centered Satisfaction Model For Publicly Funded Housing Schemes In South Africa.* University of Johanessburg. Johanessburg: University of Johanessburg.

Ait, M. (2021, June 24). *Industrial plastics*. Retrieved September 2, 2022, from Geomembrane Explained: https://industrialplastics.com.au/geomembrane-explained/

ASTM. (1994). *Annual Books of ASTM Standards, American Society Testing and Materials, Philadelphia, Pennsylvania.Volume 4.08 (1), Soil and Rock, Volume 4. No. (8), Soil and Rock, Geosynthetics, Volume 7, No. 1,Textiles.*

Bayraktar, O. Y. (2020). Use of geosynthetics in road construction. *Kastamonu University Journal of Engineering and Sciences, 6*(2), 107-113.

Boyle, S., Zornberg, J., Sandri, D., & Baillie, B. (2015). We Will See a Significant Growth in Geosynthetic Use if... *Geosynthetics 2015 Conference*, (pp. 1263-1277). Portland, Oregon.

Carneiro, J. R., Almeida, F., Carvalho, F., & Lopes, M. L. (2023). Tensile and Tearing Properties of a Geocomposite Mechanically Damaged by Repeated Loading and Abrasion. *Materials*, 7047.

Cho, H. W., Koo, H. J., Kim, H., & Kim, K. J. (2020). Lifetime prediction of high tenacity polyester yarns for hydrolytic degradation used for soil reinforcement. *Fibers and Polymers, 21*, 1663-1668.

Christoforidou, E., Bobet, A., Nantung, T., & Bourdeau, P. L. (2021). *Use of Geosynthetics on Subgrade and on Low and Variable Fill Foundations.* wEST Lafayette, IN: Purdue University.

GMA. (2002). *Handbook of Geosynthetics.* Geosynthetics Material Association.

Jeon, H. Y. (2016). Geotextile composites having multiple functions. In *Geotextiles* (pp. 413-425). Woodheadm Publishing, Elsevier.

Khan, G. A., & Singh, E. S. (2020). Use of geosynthetic materials in road construction. *IJSDR, 5*(8), 1-9.

Kumar, V. V., Saride, S., & Zornberg, J. G. (2021). Fatigue performance of geosynthetic-reinforced asphalt layers. *Geosynthetics International, 28*(6), 584-597.

Mansell, P., Philbin, S. P., & Konstantinou, E. (2020). Delivering UN sustainable development goals' impact on infrastructure projects: An empirical study of senior executives in the UK construction sector. *Sustainability, 12*(19), 7998.

Markiewicz, A., Koda, E., & Kawalec, J. (2022). Geosynthetics for filtration and stabilisation: a review. *Polymers, 14*(24), 5492.

Mohan, R. K., & Nair, C. R. (2021). Geotextile Applications. In *Encyclopedia of coastal science, Encyclopedia of Earth science series.* Dordrecht.: Springer.

Morgan, R. P., & Rickson, R. J. (2011). *Slope Stabilization and Erosion Control: A Bioengineering Approach.* London: Taylor & Francis.

Nicholson, P. (2015). *Soil improvement and ground modification methods.* Oxford: Butterworth-Heinemann.

Oginni, F. A., & Dada, T. T. (2021). Comparative study of continental involvement in using geosynthetics and implications for Africa and Nigeria. *International Journal of Engineering Applied Sciences and Technology, 5*(9), 88-95.

Qamhia, I. I., & Tutumluer, E. (2021). *Evaluation of Geosynthetics Use in Pavement Foundation Layers and Their Effects on Design Methods.* Illinois Center for Transportation/Illinois Department of Transportation.

Rimoldi, P., Shamrock, J., Kawalec, J., & Touze, N. (2021). Sustainable use of geosynthetics in dykes. *Sustainability, 13(8), 4445., 13*(8), 4445.

Rosete, A., Mendonça Lopes, P., Pinho-Lopes, M., & Lopes, M. (2013). Tensile and hydraulic properties of geosynthetics after mechanical damage and abrasion laboratory tests. *Geosynthetics International , 20*(5), 358-374.

Scholz, P., Putna-Nimane, I., Barda, I., Liepina-Leimane, I., Strode, E., Kileso, A., . . . Simon , F. G. (2021). Environmental impact of geosynthetics in coastal protection. Materials. *Materials, 14*(3), 634.

Somiah , M. K., Aigbavboa, C., & Eshun, J. F. (2022). A qualitative inquiry into the drivers of sustainable competitive advantage in the construction industry: the example of Ghana. *Sustainable Education and Development–Making Cities and Human Settlements Sustainable Education and Development–Making Cities and Human Settlements Inclusive, Safe, Resilient, and Sustainable: Proceedings of the Applied Research Conference in Africa 2021* (pp. 89-98). Springer International Publishing.

Somiah, M. K., Aigbavboa, C., & Thwala, W. D. (2021). Validating elements of competitive intelligence for competitive advantage of construction firms in Ghana: A Delphi study. *African Journal of Science, Technology, Innovation and Development, 13*(3), 3.

Song, F., Chen, W., Nie, Y., & Ma, L. (2022). Evaluation of required stiffness and strength of cellular geosynthetics. *Geosynthetics International, 29*(3), 217-228.

UNDP. (2024). *The SDGs in Action*. Retrieved from United Nations Development Programme: https://www.undp.org/sustainable-development-goals

Ziegler, M. (2017). Application of geogrid reinforced constructions: history, recent and future developments. *42-51., 172*, Procedia Engineering,.

APPENDIX

APPENDIX 1: Criteria/checklist for constituting the panel of experts for the Delphi study

Questionnaire items	Possible marks	Maximum expected mark	Minimum expected mark	Minimum obtained marks
Q1. Please indicate your highest level of education				
Bachelor's Degree	1 point		1 point	1 point
Master's Degree	2 points			
Doctoral Degree	3 points	3 points		
Q2. Are you a member of any professional body in Ghana				
Yes	1 point	1 point	1 point	1 point
No	0 point			
Q3. Please indicate your years of experience in geosynthetics issues in Ghana				
5 years	1 point		1 point	
6 to10 years	2 points			2 points
11 to 15 years	3 points			
16 years and above	4 points	4 points		
Q4. Have you worked on projects that applied geosynthetics in Ghana				`
Yes	1 point	1 point	1 point	1 point
No	0 point			
Total points		9 points	4 points	5 points

Note: the minimum obtained mark of 5 points qualified an expert to be part of the Delphi panel

Q1. Please also list the underlying properties of geosynthetics driving the applications of geosynthetics in the development of sustainable civil infrastructures in Ghana.

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Note: Reference can be made to the attached list generated from the literature review. Underlying properties of geosynthetics emanating from the literature review:

1. Thickness
2. Stiffness
3. Specific gravity
4. Mass per unit area
5. Resistance to photodegradation
6. Chemical degradation resistance
7. Hydrolytic degradation
8. Mechanical degradation resistance
9. Biodegradation resistance
10. Hydraulic properties
11. Elongation resistance
12. Soil-geosynthetic interaction characteristics
13. Puncture resistance
14. Bursting strength
15. Fatigue strength
16. Tensile strength
17. Compressibility
18. Tear strength
19. Abrasion strength

APPENDIX 2: Delphi round one and questionnaire instructions

Based on your knowledge and experience please indicate the extent to which the under-listed properties of geosynthetics influence the applications of geosynthetics in the development of sustainable civil infrastructures in Ghana by placing "X" in the boxes provided against each underlying property using a 10-point scale. Other underlying properties of geosynthetics that have not been listed could also be suggested.

No influence		**low influence**		**medium influence**		**high influence**		**very high influence**	
1	2	3	4	5	6	7	8	9	10

Q1. Please indicate the extent to which the underlying properties of geosynthetics influence the applications of geosynthetics in the development of sustainable civil infrastructures in Ghana.

Underlying properties of geosynthetics	**From no influence to very high influence**									
	1	2	3	4	5	6	7	8	9	10
Thickness								X		
Stiffness								X		
Specific gravity								X		
Mass per unit area								X		
Resistance to photodegradation								X		
Chemical degradation resistance								X		
Hydrolytic degradation								X		
Mechanical degradation resistance								X		
Biodegradation resistance								X		
Hydraulic properties								X		
Elongation resistance								X		
Soil-geosynthetic interaction characteristics								X		
Puncture resistance								X		
Bursting strength								X		
Fatigue strength								X		
Tensile strength								X		
Compressibility								X		
Tear strength								X		
Abrasion strength								X		
Other underlying properties										

APPENDIX 3: Delphi round 2 and questionnaire instructions

Attached is the response computed group median for each of the underlying properties of geosynthetics driving the applications of geosynthetics in the development of civil infrastructures in Ghana. You are at liberty to either accept the group response as computed, indicate a new response, or maintain your response in round one. In case your response differs from the group median please provide a reason/comment.

Q1. Please indicate the extent to which the underlying properties of geosynthetics influence the applications of geosynthetics in the development of civil infrastructures in Ghana. 1 =no influence to 10 very high influence.

Underlying properties of geosynthetics	**From no influence to very high influence**										**Group median**
	1	2	3	4	5	6	7	8	9	10	
Thickness											8
Stiffness											8
Specific gravity											8
Mass per unit area											8
Resistance to photodegradation											8
Chemical degradation resistance											8
Hydrolytic degradation											8
Mechanical degradation resistance											8
Biodegradation resistance											8
Hydraulic properties											8
Elongation resistance											8
Soil-geosynthetic interaction characteristics											8
Puncture resistance											8
Bursting strength											8
Fatigue strength											8
Tensile strength											8
Compressibility											8
Tear strength											8
Abrasion strength											8
Other underlying properties											