Validating the Underlying Properties Driving the Applications of Geosynthetics as a Sustainable Ground Improvement Material: A Delphi Study from Ghana

ABSTRACT

While 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 have validated the underlying properties driving the applications of geosynthetics as a sustainable ground improvement material. This Delphi study sought to ascertain whether the underlying properties driving the applications of geosynthetics as a sustainable ground improvement material in other national contexts do drive their applications in Ghana and determine the relative influence of each of the underlying properties. Nineteen (19) properties were found to be driving the applications of geosynthetics as a sustainable ground improvement material in Ghana with varying relative influence. They included stiffness properties, chemical degradation resistance, and hydraulic properties. Chemical degradation resistance with an RSI score of (0.83) ranked 1st among the (19) properties driving the applications of geosynthetics as a sustainable ground improvement material in Ghana while hydraulic properties with an RSI of (0.68) ranked 19th. The findings of this study contribute to country-specific literature on the properties driving the applications of geosynthetics as a sustainable ground improvement material. Practically, the study unravelled the (19) underlying properties driving the applications of geosynthetics as a sustainable ground improvement material in Ghana with chemical degradation resistance being the most influential property. The uniqueness of the study also lies within the application of the Delphi technique in the study of the underlying properties driving the applications of geosynthetics as a sustainable ground improvement material.

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

INTRODUCTION

Geosynthetics are polymeric materials or products used for improving or stabilizing soil, rock, earth, or any geotechnical material (ASTM, 1994; Ziegler, 2017; Khan & Singh, 2020). They come in the form of strips, sheets, or three-dimensional structures (Oginni & Dada, 2021; The Constructor, 2022). Examples include geomembranes, geotextiles, and geofoams. There are general properties as well as product-specific properties driving the applications of geosynthetics as a sustainable ground improvement material. In recent times, intelligent geosynthetics have also been developed due to technological advancement, which makes it possible to monitor and evaluate the performance of geosynthetics, even in concealed and difficult-to-reach areas where physical inspections are impossible (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 sustainable 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); little is known, if any, of country-specific studies that validated the underlying properties driving the applications of geosynthetics as a sustainable ground improvement material. Hence the relevance of this current study is to ascertain whether the underlying properties driving the applications of geosynthetics as a sustainable ground improvement material in other national contexts do drive their applications in Ghana and determine the relative influence of each of the underlying properties. Sustainable ground improvement materials 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 driving the applications of geosynthetics as a sustainable ground improvement material (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 driving the applications of geosynthetics as a sustainable ground improvement material. The findings of this study contribute to country-specific literature on the properties driving the applications of geosynthetics as a sustainable ground improvement material. Specifically, it informs construction stakeholders within the construction industry in Ghana of the properties of driving the applications of geosynthetics as a sustainable ground improvement material. Promoting awareness among construction stakeholders about the properties driving the applications of geosynthetics, a globally accepted sustainable ground improvement material, through this study contributes to addressing the Sustainable Development Goal (SDG) (12), target (8) which seeks to achieve by 2030 that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature (UNDP, 2024). 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 driving the applications of geosynthetics as a sustainable ground improvement material in other national contexts do drive their applications in Ghana, and
- to determine the relative influence of each of the underlying properties driving the applications of geosynthetics as a sustainable ground improvement material in Ghana.

PROPERTIES DRIVING THE APPLICATIONS OF GEOSYNTHETICS AS A SUSTAINABLE GROUND IMPROVEMENT MATERIAL

Properties driving the applications of geosynthetics as a sustainable ground improvement material are the unique inherent features of geosynthetics that impact the geotechnical engineering properties of the soil, rock, earth, or any geomaterial (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).

Physical properties

The physical properties of geosynthetics drive the applications of geosynthetics as a sustainable ground improvement material. 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 or the overall weight of geosynthetics 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 the 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 (Adewumi, 2018; Song et al., 2022). The single cantilever test is used to determine the flexural rigidity of geosynthetics (Adewumi, 2018; Song et al., 2022). The flexural rigidity of a geosynthetic is an indication of the ability to provide a suitable working surface for installation (Adewumi, 2018; Song et al., 2022). For example, a low-stiffness geotextile easily conforms to the contours of the ground thereby enhancing its performance in erosion control (Adewumi, 2018; Song et al., 2022). There are instances too where high-stiffness geosynthetics could be required for applications (Adewumi, 2018; Song et al., 2022). Thus, stiffness is an essential property driving the applications of geosynthetics as a sustainable ground improvement material (Song et al., 2022).

Mechanical properties

Mechanical properties drive the applications of geosynthetics as a sustainable ground improvement material (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 materials (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
The compressibility property of a geosynthetic is a measure of the rate of decrease in thickness as a result of increased stresses (Rosete et al., 2013). 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. The more a geosynthetic compresses when subjected to loading, the lower its transmissivity (Adewumi, 2018).

Tensile strength
Tensile strength is the maximum tensile load that a 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 property of geosynthetics is 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 (Kumar et al., 2021; Carneiro et al., 2023). 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 (Kumar et al., 2021; Carneiro et al., 2023). 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 (Đorđić et al., 2016). Puncture resistance includes resistance to both static puncture and dynamic puncture (Đorđić et al., 2016).

Impact strength
The impact strength is also known as the dynamic puncture strength or dynamic perforation strength (Đorđić et al., 2016; Adewumi, 2018). 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 (Đorđić et al., 2016; Adewumi, 2018). The impact strength of geosynthetics can be evaluated by the cone drop test method (Đorđić et al., 2016; Adewumi, 2018).

Bursting strength
It is a measure of the normal stress at which a 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 field conditions is important (Agrawal, 2011; Adewumi, 2018; Ait, 2021).

Hydraulic properties

This property of a geosynthetic influences its ability to function as a filter and drain. Porosity, apparent opening size, percentage 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 deteriorate 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	(Đorđić et al., 2016; 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. In a Delphi study, the respondents or panellists are called experts hence used interchangeably in this study. Delphi technique's strength is anchored in the rigorousness of the methodology (Aigbavboa, 2014; Somiah et al., 2022). The first step of the Delphi process was a literature review to identify the underlying properties driving the applications of geosynthetics as a sustainable ground improvement material. 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 (2018), 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 (15) experts or panellists for the study was based on the assumption that, according to 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 panellists 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 had 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 (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 significance index has been used in previous studies. At least a combination of 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 significance index in determining consensus. A similar approach was used by Raskin (1994) and even in quite recent studies (see Aigbavboa, 2014; Somiah et al., 2021; Somiah et al., 2022). Thus, in this study consensus was measured by:

1. Strong consensus - median 9-10, relative significance index 0.80-1.00, interquartile deviation (IQD) ≤1;
2. Good consensus - median 7-8.99, relative significance index 0.60-0.79, IQD≥1,1≤2; and
3. Weak consensus - median ≤ 6.99, relative significance index ≤0.59 and IQD≥2,1≤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. Through constant communication with the experts individually, and offering the experts the opportunity to freely maintain or effect changes to their response and give 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 significance index after each round of the Delphi survey. In determining the relative influence of each of the underlying properties of geosynthetics, the relative significance index (RSI) for each of the underlying properties was ranked. Ethically, the identity of the experts was kept confidential (Aigbavboa, 2014).

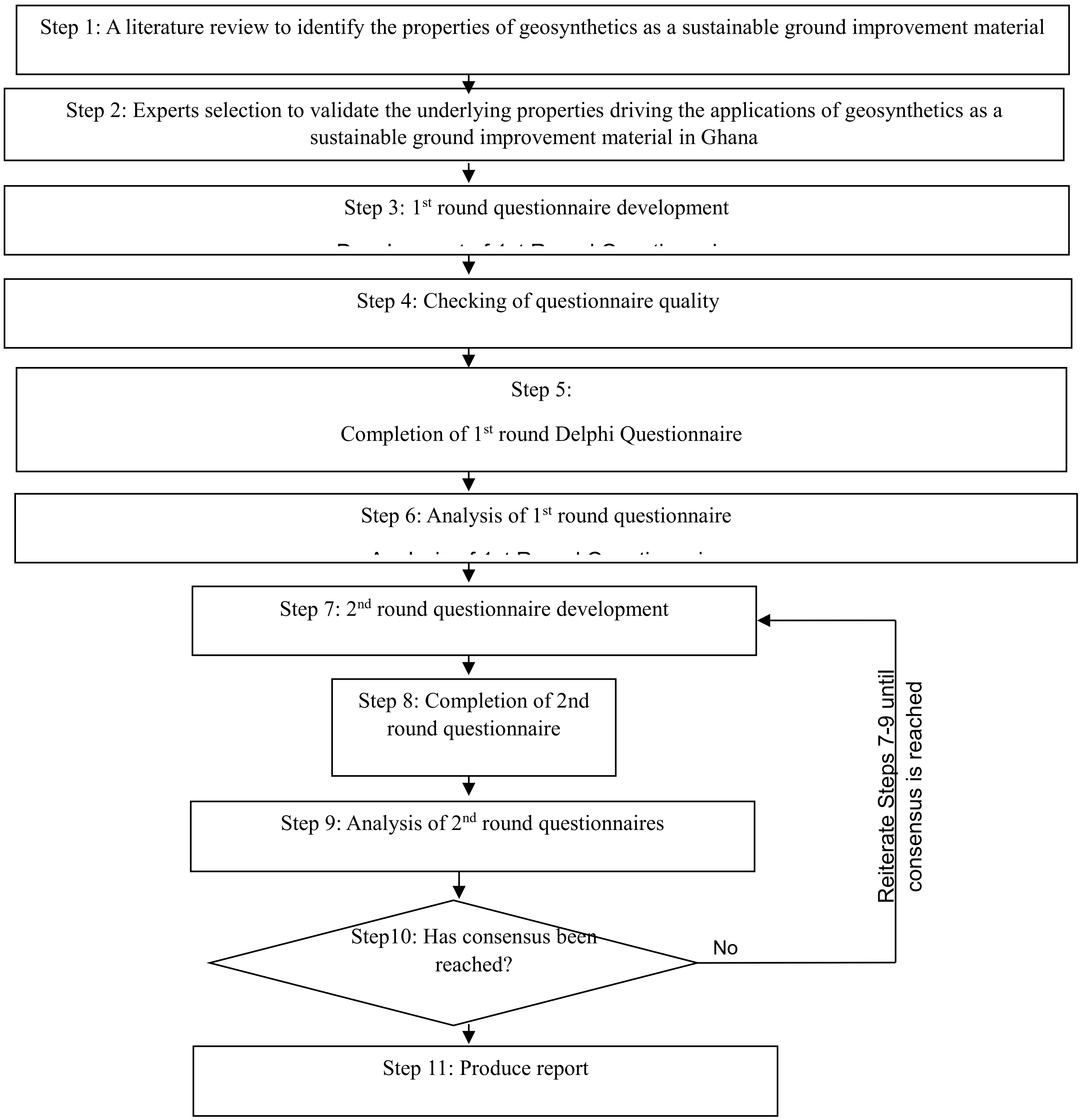

Figure 1: Process Diagram of the Delphi Study
Source: Adapted from Aigbavboa (2014) and Somiah et al. (2021).

RESULTS AND DISCUSSIONS

Delphi round one results

Round one of the Delphi survey sought to ascertain whether the underlying properties driving the applications of geosynthetics as a sustainable ground improvement material in other national contexts do drive their applications 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 as a sustainable ground improvement material in Ghana. All the nineteen underlying properties 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.

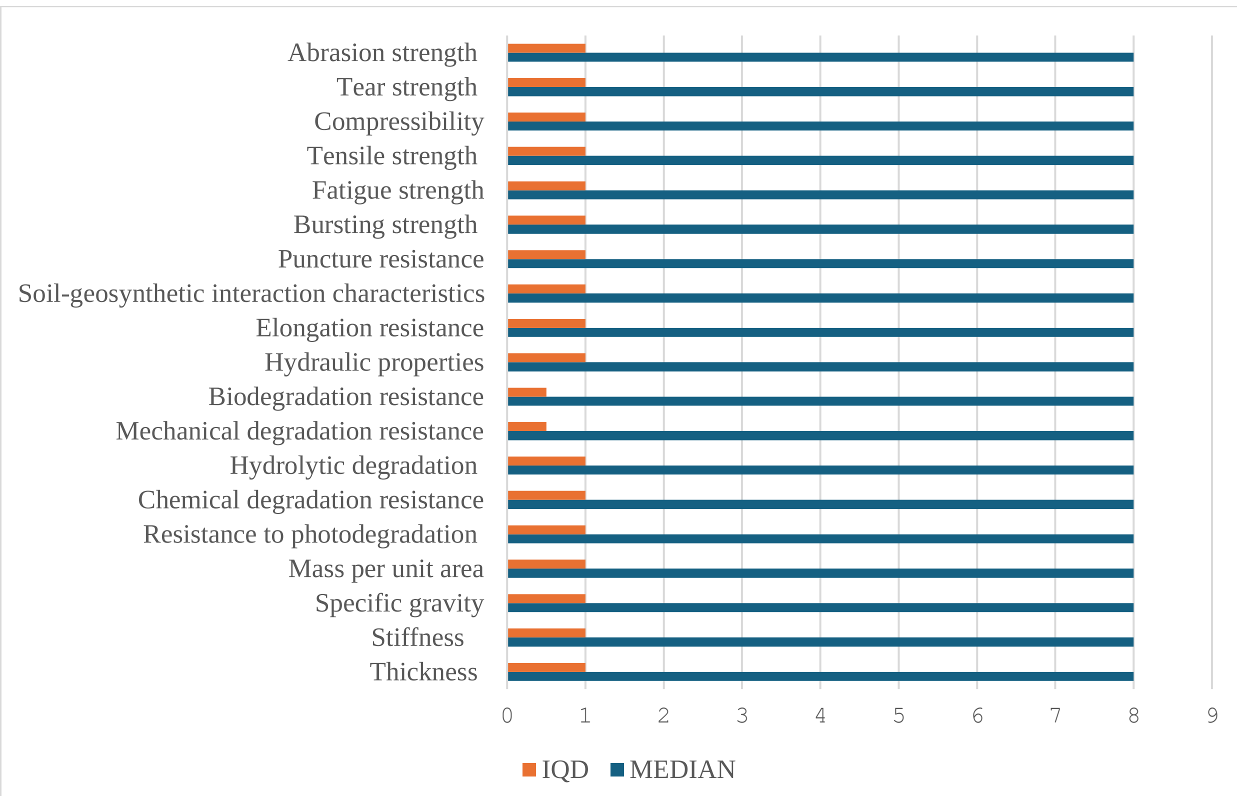

Figure 2. Underlying properties driving the applications of geosynthetics as a sustainable ground improvement material in Ghana from round one of the Delphi survey

Delphi round two results

A total of nineteen properties constituted the underlying properties driving the applications of geosynthetics as a sustainable ground improvement material in Ghana. Each 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 as a sustainable ground improvement material in Ghana. The median, standard deviation and relative significance index indicate a good consensus in the views of the panellists regarding the nineteen underlying properties driving the applications of geosynthetics as a sustainable ground improvement material in Ghana.

Table 3. Underlying properties driving the applications of geosynthetics as a sustainable ground improvement material in Ghana

Underlying properties	Median	Interquartile deviation	Standard deviation	Relative Significance Index (RSI)	RSI ranking
Chemical degradation resistance	8	1.00	0.30	0.83	1st
Mass per unit area	8	1.00	0.63	0.82	2nd
Resistance to photodegradation	8	1.00	0.30	0.82	2nd
Mechanical degradation resistance	8	1.00	0.15	0.82	2nd
Specific gravity	8	0.50	0.56	0.81	5th
Thickness	8	1.00	0.20	0.79	6th
Biodegradation resistance	8	1.00	0.58	0.79	6th
Bursting strength	8	1.00	0.24	0.79	6th
Compressibility	8	1.00	0.40	0.79	6th
Elongation resistance	8	1.00	0.34	0.78	10th
Puncture resistance	8	1.00	0.44	0.78	10th
Tensile strength	8	1.00	0.30	0.78	10th
Fatigue strength	8	1.00	0.37	0.77	13th
Soil-geosynthetic interaction characteristics	8	1.00	0.20	0.76	14th
Abrasion strength	8	1.00	0.32	0.75	15th
Hydrolytic degradation	8	1.00	0.35	0.72	16th
Tear strength	8	1.00	0.41	0.71	17th
Stiffness	8	0.50	0.20	0.70	18th
Hydraulic properties	8	1.00	0.55	0.68	19th

Discussions

This study aimed to ascertain whether the underlying properties driving the applications of geosynthetics as a sustainable ground improvement material in other national contexts do drive their applications in Ghana and determine the relative influence of each of the underlying properties. Nineteen (19) underlying properties were found to be driving the applications of geosynthetics as a sustainable ground improvement material in Ghana. Each of the nineteen underlying properties recorded a high influence (HI) median score. 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 RSI score of (0.83) ranked 1st among the nineteen underlying properties driving the applications of geosynthetics as a sustainable ground improvement material 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 chemical degradation. Jointly ranked 2nd were mass per unit area, resistance to photodegradation, and mechanical degradation resistance. Each recorded an RSI score of (0.82). Markiewicz et al. (2022) found mechanical degradation resistance to be a critical property driving the applications of geosynthetics as a sustainable ground improvement material. 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 RSI score of (0.81) and thickness with an RSI 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 drive the applications of geosynthetics as a sustainable ground improvement material. 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 RSI score of (0.78). In separate studies, Scholz et al. (2021) and Ait (2021) found elongation resistance, tensile strength, and puncture resistance to be among the underlying properties driving the applications of geosynthetics as a sustainable ground improvement material. Further, fatigue strength with an RSI 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 easily succumb to loading. Soil-geosynthetic interaction characteristics with an RSI of (0.76) ranked 14th, and abrasion strength recorded an RSI of (0.75) and ranked 15th. Abrasion strength was consistent with Carneiro et al. (2023) while soil-geosynthetic interaction characteristics affirm the opinion of Adewumi (2018) and Ait (2021). Hydrolytic degradation property ranked 16th with an RSI 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 RSI score of (0.70) ranked 18th in this study from Ghana, thus supporting the view by Adewumi (2018) that the stiffness of geosynthetics drives the applications of geosynthetics as a sustainable ground improvement material. Ranking 19th was hydraulic properties of geosynthetics with an RSI of (0.68). Hydraulic properties according to Ait (2021), drive applications of geosynthetics as a sustainable ground improvement material.

CONCLUSIONS

The study concludes that nineteen (19) properties of geosynthetics, known to have driven the applications of geosynthetics within some national contexts, do drive the applications of geosynthetics as a sustainable ground improvement material 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 RSI score of (0.83) ranked 1st among the nineteen underlying properties driving the applications of geosynthetics as a sustainable ground improvement material in Ghana while hydraulic properties with an RSI of (0.68) ranked 19th. Thus, whereas the under properties driving the applications of geosynthetics as a sustainable ground improvement material were found to be consistent with that of previous studies, the relative influence of each underlying property driving the applications of geosynthetics as a sustainable ground improvement material varied in the case of Ghana. The findings of this study contribute to country-specific literature on the underlying properties driving the applications of geosynthetics as a sustainable ground improvement material. Specifically, it informs construction stakeholders within the construction industry in Ghana of the underlying properties driving the applications of geosynthetics as a sustainable ground improvement material. It promotes awareness about the properties of geosynthetics, a globally accepted sustainable ground improvement material thereby contributing to addressing the Sustainable Development Goal (SDG) (12), target (8) which advances that by 2030 all 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 lies within the application of the Delphi technique to study the underlying properties driving the applications of geosynthetics as a sustainable ground improvement material in Ghana.

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 driving the applications of geosynthetics as a sustainable ground improvement material 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 influence the applications of geosynthetics as a sustainable ground improvement material in Ghana by placing "X" in the boxes provided against each underlying property using a 10-point scale. Other underlying properties 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 influence the applications of geosynthetics as a sustainable ground improvement material in Ghana.

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

APPENDIX 3: Delphi round 2 and questionnaire instructions

Attached is the response computed group median for each of the underlying driving the applications of geosynthetics as a sustainable ground improvement material 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 influence the applications of geosynthetics as a sustainable ground improvement material in Ghana based on a 10-point scale with 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:											

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