Feasibility of a Sustainable Geotextile Matrix: An Analytical Approach to Biodegradable Material Compositions

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***Abstract*: Concerns about microplastic residues from synthetic polymers like polyester and polypropylene have been highlighted by the expanding usage of geotextiles in civil engineering. Creating a sustainable geotextile matrix with the use of a software program that can digitize material composition testing and design is investigated in this research. 47 articles on software integration and sustainable geotextiles were found after a systematic review of 314 studies was filtered using PRISMA principles. Key research trends were found through topic modeling and collocation analysis, such as the continued concern about microplastics, the slow uptake of biodegradable fibers, and the lack of digitalized material design frameworks. Opportunities to integrate natural fibers, recycled materials, and computational design tools are further highlighted by a SWOT analysis, which also reveals shortcomings in cost estimation and a lack of consistent procedures. The results indicate that by facilitating virtual prototyping, optimizing compositions, and promoting ecologically conscious building methods, a sustainable geotextile matrix program could close a significant gap.**

***Keywords*: Geotextiles, Sustainable Materials, Biodegradable Composites, Geotechnical Software, Digital Manufacturing.**

1. Introduction

The usage of geosynthetics, especially geotextiles, in a variety of civil engineering applications has increased due to the quick development of global infrastructure. These materials play a crucial role in geotechnical projects and are widely used for soil stabilization, erosion control, drainage, separation, and reinforcement. Geotextiles' annual global utilization has topped 1.4 billion square meters (Wu et al., 2020). Large-scale road, embankment, and slope stabilization projects in particular benefit greatly from their adaptability, affordability, and simplicity of installation (Gong et al., 2024). To offer the mechanical durability, chemical resistance, and lifespan needed for infrastructure projects, conventional geotextiles are mostly made from synthetic polymers like polypropylene (PP), polyethylene terephthalate (PET), and polyethylene (PE) (Tanasă et al., 2022).

The significant dependence on geotextiles based on polymers has caused significant environmental issues. Naturally non-biodegradable, synthetic geotextiles may stay in soil for decades and frequently break down into microplastics that build up in both terrestrial and aquatic environments (Ngoma et al., 2025; Prasittisopin et al., 2023). Furthermore, stabilizers, plasticizers, and other chemicals included into these textiles are not chemically bonded to the polymer matrix and may leak into the surrounding environment, posing a danger to human health (Chen et al., 2022). Residues and microplastic particles from the removal of synthetic geotextiles from building sites persist, causing long-term ecological effects (Monkul & Özhan, 2021). The necessity for sustainable solutions that may satisfy technical goals without producing long-term pollution is highlighted by this persistence.

The development of biodegradable geotextiles from natural fibers and bio-based polymers has advanced significantly in response to this persistence. In response, efforts have been made in creating biodegradable geotextiles from natural fibers and bio-based polymers. Natural fibers like jute, coir, hemp, flax, and sisal have been successfully tested in slope stabilization and erosion control projects, providing temporary soil reinforcement before decomposing innocuously into the environment (Daria et al., 2020). These fibers provide short-term soil reinforcement before releasing harmlessly into the environment (Nguyen & Indraratna, 2023) or sustainable alternatives that can satisfy engineering needs without producing long-term pollution. For example, compared to other natural fibers, coir has a comparatively high lignin concentration, which makes it durable in damp conditions and prolongs its service life by many years (Nguyen & Indraratna, 2023). While their expense and restricted scalability continue to be challenges, biopolymers like polylactic acid (PLA) and polyhydroxyalkanoates (PHA) are being investigated for geotextile applications because they provide better homogeneity and controlled degradation rates (Naser et al., 2021). Although research shows that biodegradable alternatives have not been standardized and their long-term performance is not well understood, these advances show promise for environmentally friendly geotextiles (Prambauer et al., 2018).

Alongside the development of new materials, the construction sector has rapidly digitized through technologies like digital twins, finite element analysis, and building information modeling (BIM). Predictive performance analysis, lifespan monitoring of infrastructure projects, and virtual prototyping are made possible by these technologies (Broo et al., 2022). Nevertheless, the design and prototypes of geotextile materials themselves have not yet benefited from such developments. In contrast to structural parts, which frequently use digital twins and simulations, geotextiles are still mostly produced by field testing and actual experimentation. A significant research need is the absence of computational frameworks for evaluating recycled and biodegradable geotextiles, especially as industry looks for sustainable solutions in the face of mounting environmental and regulatory demands (Abedi et al., 2023)

2. Objectives of the Study

To explore the viability of creating a sustainable geotextile matrix program that can facilitate the digital design, optimization, and assessment of biodegradable and recycled geotextile compositions.

Specific Objectives

1. To review the current state of knowledge on conventional, biodegradable, and recycled geotextile materials, highlighting their strengths and limitations.
2. To analyze the environmental and technical challenges posed by polymer-based geotextiles and the opportunities presented by sustainable alternatives.
3. To identify and synthesize the strengths and limitations of biodegradable and recycled geotextiles for engineering applications.
4. To examine and integrate methodological trends from prior studies, including laboratory testing, field validation, life-cycle assessments, and decision-analysis frameworks.
5. To evaluate the feasibility of such a digital tool through a SWOT analysis, considering technical, environmental, and industry perspectives.

Significance of the Study

This study holds significance in multiple dimensions:

A. For Academic Research

It adds to the expanding body of literature on sustainable geotextiles by combining conventional, biodegradable, and recycled materials into an organized knowledge base. The use of systematic review methods and topic modeling provides a unique methodological lens, revealing how data-driven research may supplement standard reviews in civil and geotechnical engineering.

B. For Engineering Practice

By presenting a conceptual software matrix for geotextile material selection, the work fills a long-standing need in digital geosynthetic design resources. The proposed software system can help engineers evaluate material compositions online, decreasing laboratory trial-and-error and increasing efficiency in field applications.

C. For Sustainability and Policy

The study promotes the ideas of circular economy and green engineering by assessing biodegradable and recyclable alternatives that might replace or lessen reliance on petrochemical-based geotextiles. The feasibility analysis, particularly the SWOT analysis, provides information that governments and industry leaders may utilize to guide sustainable material uptake and standardization.

Overall, this study is notable since it combines material science, sustainability, and computational innovation. By creating the basis for sustainable geotextile matrix software; paving the way for future study, practical application, and policy formulation in support of environmentally friendly infrastructure.

1) Scope and Delimitations

To determine the bounds of this research and guarantee clarity of focus, the study's scope and constraints must be defined. The scope defines the areas of inquiry that the research actively pursues, such as the materials, techniques, and frameworks used to examine the viability of a sustainable geotextile matrix software. In contrast, the delimitations explain the researcher's deliberate bounds, defining which topics are not included and why they lie outside the scope of the present examination. Together, these factors promote transparency, emphasize the study's strengths, and identify its limits, assisting readers in understanding the intended contributions and opportunities for future research.

2) Scope

This study investigates the viability of creating a sustainable geotextile matrix program that can aid in the digital development, selection, and optimization of biodegradable and geotextile formulations. The review is confined to academic and industrial sources published during the previous ten (10) years, assuring relevance to current practices and developing technology. The topics covered include conventional polymer-based geotextiles, biodegradable natural fiber and biopolymer alternatives, recycled materials, and the use of digital tools in civil and material engineering. The methodological scope includes a systematic literature review following PRISMA recommendations, topic modeling and collocation analysis with Voyant Tools, and a SWOT analysis to assess feasibility. The proposed software framework is conceptual, intended as a design model rather than a fully developed application.

3) Delimitations

Geotextile samples are not fabricated in the laboratory or tested experimentally in this work. While it combines data from previous empirical investigations, no new physical prototypes are created. The suggested software application is still in the feasibility and conceptual design stages; complete development, coding, and user testing are not within the scope of this research. Furthermore, economic cost modeling and extensive life-cycle assessments (LCA) are not carried out, despite being indicated as critical areas for future validation and implementation. The findings are thus meant to influence academic study, industry consideration, and future development rather than providing a commercially deployable solution currently.

3. Review of Related Literature

As the need for ecologically friendly materials in civil engineering increases, the development of sustainable geotextiles has become a top research goal. Despite being extensively used for soil stability, filtration, and reinforcement, conventional geotextiles are mostly made of synthetic polymers like polyester, polypropylene, and polyethylene, which persist in the environment and cause microplastic pollution. As a result, researchers have investigated substitutes such recycled materials, biodegradable natural fibers, and composites made of biopolymers. Each of these materials has benefits and disadvantages in terms of scalability, durability, and environmental effect. However, there are still few equivalent tools for geotextile design and prototype, even though the larger field of civil engineering has adopted digital advances like Building Information Modeling (BIM), finite element analysis (FEA), and digital twin technologies.

In addition to analyzing methodological traditions like laboratory testing, field validation, systematic reviews, life-cycle assessment, and computational modeling, the review that follows summarizes the body of research on these topics: conventional, biodegradable, and recycled geotextiles, environmental assessments, and digital approaches. This synthesis lays the groundwork for the suggested feasibility study on sustainable geotextile matrix software in addition to highlighting gaps in material performance and design procedures.

A. Conventional Geotextiles: Synthetic Materials and Environmental Challenges

In civil engineering, geotextiles are now a crucial component for drainage, erosion management, soil stabilization, reinforcing, and other related tasks (Daria et al., 2020). These geotextiles are often manufactured using synthetic polymers generated from fossil fuels, namely polypropylene (PP), polyethylene terephthalate (PET), polyethylene (PE), and polyamides (Hasheminezhad et al., 2024). These traditional geotextiles are preferred because, in comparison to natural materials, they provide excellent tensile strength, durability, and economical performance (Dąbrowska et al., 2023). Indeed, more than 90% of currently used geosynthetic materials are non-biodegradable and based on polymers. However, there are sustainability concerns with this reliance on petrochemical resources. Only around 2% of geosynthetics are now made from renewable or biodegradable resources, even though these polymers are persistent in the environment (Dejene, 2025), reflecting a major gap in greening the geotextile industry.

The impact of synthetic geotextiles after the end of their useful lives is a major environmental problem. Although they are not biodegradable, they can slowly deteriorate physically and chemically when exposed to environmental elements such moisture, UV light, mechanical wear, and temperature changes. Over time, this causes fragmentation and the release of microplastic fibers and particles into the surrounding soils and water systems (Wijayanti et al., 2025). According to studies, geotextiles made of polymers may contribute significantly to soil environments' microplastic pollution, which would be harmful to the environment and human health (Palmeira, 2025). Furthermore, when plastics deteriorate, chemical additives may leak out, further affecting the quality of the soil. Calls for new environmentally friendly geotextile systems that preserve engineering performance while reducing long-term hazards have been sparked by these problems (Ata, 2023).

Conventional geotextiles nevertheless rule the market today despite these disadvantages because of their established standards and track record of performance. By substituting bulk natural elements such as filters for thick gravel layers, they successfully extend the life of infrastructure and save expenses (Kiersnowska et al., 2025). Using geotextile layers in roads or embankments, for instance, can increase stability and longevity while using less material, which indirectly contributes to sustainability by lowering greenhouse gas emissions during construction. Research into new geotextile materials is being driven by the need to strike a balance between environmental responsibility and performance.

B. Biodegradable Geotextiles: Natural Fibers and Biopolymer Alternatives

Studies have investigated biodegradable geotextiles constructed from natural fibers and biopolymers as a solution to the problems with persistent polymers. Today, there is a vast array of geotextile goods made from renewable resources, such as those made from cotton, wool, sisal, flax, hemp, straw, jute, coir (coconut fiber), and flax (Dejene, 2025b). These materials can perform comparable duties to synthetics (e.g. erosion control mats, slope stabilization fabrics) but are meant to degrade after their service life. In short-term applications like erosion control blankets, where the material must survive until vegetation is grown and can then safely decompose without leaving hazardous residues, biodegradable geotextiles are very desirable. Following their function, they decompose into ecologically safe components (such as cellulose, CO_2, and water), removing the need for field retrieval and preventing the production of microplastics or persistent trash (Anand et al., 2023).

Jute, coir, and sisal fibers, for example, have comparatively high tensile strengths because of their high cellulose content. Natural fiber geotextiles have shown strong initial mechanical capabilities (Elfaleh et al., 2023). Early on after installation, these fibers can offer significant erosion protection or reinforcement. Their quick strength loss once biodegradation sets in, however, is a well-known drawback. In soil settings, high-cellulose fibers quickly deteriorate and age, particularly when there is moisture and microbial activity present. Additionally, natural fibers can absorb water and are hygroscopic, which might decrease their efficiency in filtering or drainage functions and hasten deterioration (Himabindu et al., 2024). Challenges are further compounded by the inherent variety in natural fiber quality (due to source, growth circumstances, etc.) and the difficulty in precisely estimating their rate of deterioration under various field situations. As a result, even though there are numerous alternatives on the market, popular projects have only partially adopted these biodegradable solutions (Sehlin & Hashemi, 2025).

Hybrid and biopolymer-based geotextiles are being researched to bridge the durability gap while maintaining biodegradability. Combining natural fibers with biodegradable synthetic fibers or binders is one method. Natural nettle fibers and polylactic acid (PLA), a biodegradable bioplastic, are used in nonwoven geotextiles, for instance, to combine the strength of natural fiber with PLA's regulated breakdown profile. For geotextiles, PLA is viewed as a potential biopolymer; it is made from renewable resources (corn starch, etc.), and although it biodegrades in some situations, it also has a high modulus and tensile strength that are on par with some petroleum polymers (Kumar & Das, 2017). According to Wodag et al. (2025), PLA-based fibers can maintain their structural integrity for a while to perform reinforcing tasks before completely decomposing into biomass, CO2, and water. Polybutylene succinate (PBS), a biodegradable polyester renowned for its balanced mechanical qualities and superior soil biodegradability, is another new material (Makgwane et al., 2025). According to research, PBS nonwoven geotextiles may function similarly to PP/PET geotextiles during installation and usage, and they can also break down without leaving any negative residues.

Overall, by removing persistent pollutants, biodegradable geotextiles offer a strong sustainable substitute. Their effective use, however, hinges on coordinating the material's rate of deterioration with the requirements of the project (ensuring the geotextile functions for the appropriate time). Enhancing the durability and uniformity of natural and bio-based geotextiles is the subject of ongoing studies. The goal of these initiatives is to increase the application of biodegradable geotextiles in civil engineering without sacrificing performance or safety.

C. Recycled Materials and Circular Economy Approaches

Using recycled materials as inputs is another aspect of developing geotextiles in an environmentally friendly manner. Through the conversion of waste streams into useful building materials, this is consistent with the concepts of the circular economy (Rahman et al., 2022). Making geotextiles or reinforcing fibers from textiles and plastic waste is an important research direction. Large volumes of scrap and post-consumer trash are produced by the fashion and textile sectors; today, only around 1% of this garbage is recycled; the bulk is landfilled (Damayanti et al., 2021). The resulting waste may be diverted to civil engineering applications, which will lessen the load on landfills and provide substitute raw materials for composites or geotextiles. Rahman et al. (2022) conducted a recent systematic review that found several creative ways to "cascade" the utilization of textile waste fibers into non-hazardous secondary raw materials for use in geotechnical engineering and construction. The disposal of textile waste and the demand for more environmentally friendly building materials are two issues that such methods can assist in resolving. Researchers Varnaitė-Žuravliova and Baltušnikaitė-Guzaitienė (2024) pointed out that to guarantee constant quality and performance in their new uses, waste fibers must be carefully characterized.

Geotextile fibers are another useful way to recycle plastic waste. Nonwoven geotextiles can be made by reprocessing PET polymers (found in bottles, packaging, etc.) into fibers (rPET), which can replace virgin resin. Research suggests that geotextiles composed of recycled PET have somewhat worse long-term durability than those constructed of virgin PET; for example, one research estimated that rPET geotextiles would have an approximately 30% shorter service life because of greater rates of deterioration. However, recycled PET products still beat untreated natural fibers in terms of lifetime and may attain at least 75% of the durability of virgin-fiber geotextiles (Abbas-Abadi et al., 2025). Nonwoven samples composed of virgin, recycled, and blended PET fibers were exposed to accelerated aging (hydrolysis over weeks) in one experiment; the recycled PET fibers did exhibit a slightly higher strength loss, but they still maintained significant tensile strength and puncture resistance, confirming their suitability for a wide range of applications (Serralta-Macias et al., 2024). These results point to a fair compromise: rPET geotextiles reuse plastic waste and lessen the need to produce new polymers, but at the expense of a little lifespan loss that could be tolerable in many situations. Furthermore, LCA studies comparing geosynthetics to traditional solutions have shown that using recycled plastics in geosynthetics may drastically reduce the carbon footprint compared to creating all-new polymers.

Waste tire fibers have drawn interest as a unique geotextile input, in addition to recycling textiles and bottles. When end-of-life tires are manually shred for recycling, they produce both rubber crumb and a fibrous reinforcing byproduct made of polyester/nylon tire cord fibers, which usually accounts for 10–15% of the tire mass (Fazli & Rodrigue, 2022). Due to their classification as special trash, these waste tire textile fibers (WTTF) frequently wind up in landfills or burned, which presents environmental problems. Fazli and Rodrigue's (2022) recent evaluations of the literature stress the significance of identifying useful applications for WTTF as inexpensive, plentiful reinforcing material. When it comes to soil reinforcement, asphalt reinforcement, or even the production of geotextiles, tire fibers might theoretically replace conventional synthetic or natural fibers. According to laboratory research, adding WTTF can improve the characteristics of expansive clay soils (by limiting swelling) and increase the resilience of concrete and asphalt mixtures to cracking (Ma et al., 2021). Nevertheless, there are challenges to overcome: residual rubber particles (~65% by weight) and contaminants frequently contaminate raw tire fibers, reducing their efficacy and making handling more difficult. Current research is examining blending techniques to include WTTFs into composite geotextiles as well as treatment procedures to clean and separate the fibers. If these issues are fixed, discarded tire fibers offer a viable way to produce inexpensive, recycled geotextiles and address the issue of trash disposal.

In conclusion, using recycled materials to create geotextiles is an example of circular economy innovation in the building industry. It is feasible to lower landfill volumes and save raw materials by upcycling trash like used tires, plastics, and textiles into geotextile products (Marczak et al., 2024). Although literature emphasizes the need for rigorous evaluation of the material attributes of recycled inputs (strength, variability, and pollutants), several studies have shown promising outcomes when appropriate processing is used. These strategies, together with biodegradable alternatives, are opening several avenues for sustainable geotextiles that reduce environmental damage at the start and finish of their life cycles.

D. Digital Tools in Engineering and the Geotextile Software Gap

Many areas of civil and materials engineering are changing because of digital technology, which is also boosting infrastructure management, simulation, and design. For instance, Building Information Modelling (BIM) is now widely used in structural and architectural engineering to produce integrated 3D models of projects, allowing for thorough evaluations of designs, materials, and life-cycle performance prior to construction (Wang et al., 2025). Engineers can use specialized software for slope stability, foundation design, and finite element analysis (FEA) of soil-structure interaction, as well as integrate subsurface data into BIM and conduct stability analyses within virtual models. Geotechnical engineering has started to embrace similar digital workflows (Satyanaga et al., 2023). In-depth modeling of the behavior of geosynthetic reinforcement under loads is made possible by sophisticated simulation tools (such as PLAXIS, GeoStudio, or bespoke FEA algorithms), which can supplement or even eliminate the requirement for lengthy physical experiments. In addition to improving accuracy and efficiency, these computerized methods provide rapid evaluation of several situations (alternative materials or geometries).

The use of smart sensor systems and digital twins to infrastructure is yet another frontier. A virtual duplicate of a physical object that is updated in real time is called a digital twin. In keeping with this, scientists have suggested "smart geosynthetics" that are embedded with sensors (such fiber optics or piezoresistive fibers) that may track damage, strain, or stress in soil structures and send the data for analysis (Botín-Sanabria et al., 2022).

In their thorough analysis of these intelligent geosynthetics, Abedi et al. (2023) point out that they can serve as "vital arteries" of information, informing engineers about the state of foundations or earthworks to support proactive maintenance and safety management. An example of how digital tools are expanding into material functions is the intersection of material science and IoT (Internet of Things) technologies. Furthermore, new visualization technologies like augmented reality (AR), which can superimpose design data or material placement instructions on a site's real-world view, are being investigated in the construction industry. An engineer may employ augmented reality (AR) in future geotechnical practice to see where geotextile layers would be placed underground or to see how a proposed geotextile-reinforced slope would appear and function in situ.

Despite these developments, there is still a significant lack of digital tools tailored to geotextile design and research. The selection and formulation of geotextile materials have mostly depended on empirical trial-and-error and conventional index tests, in contrast to structural steel or concrete, which have specialized tools for design optimization. There is presently no readily accessible software that enables engineers to enter desired performance parameters and obtain a recommendation for the best geotextile composition or configuration. Instead of being driven by a single digital framework, producers' experience and laboratory testing often lead to the design of geotextiles (e.g., choosing fiber type, mix ratios, manufacturing technique). Recent research has started advocating for digitization in this area in recognition of this need. As noted by Palmeira et al. (2021), the integration of geosynthetics into sustainable design necessitates not just new materials but also contemporary design techniques and tools. The current study envisions a software matrix that may digitalize the design and testing of sustainable geotextile materials, therefore directly addressing this gap. Similar to what BIM or FEA software does in their respective fields, such a tool would enable practitioners to model various geotextile material combinations, forecast their mechanical, hydraulic, and durability performance, and optimize compositions prior to physical construction. Accelerating innovation and the use of greener materials is the goal of offering a virtual platform for geotextile development. In conclusion, geotextile engineering may gain from specialized software solutions that close the gap between material research and real-world design integration, even while civil engineering as a whole embraces digital transformation.

E. Research Methodologies in Sustainable Geotextile Studies

The multidisciplinary nature of the area is reflected in the wide range of research approaches used in the body of literature on geotextiles and sustainable materials. Systematic literature review is a popular method for identifying research gaps and synthesizing current knowledge. For instance, Ahmad et al. (2020) compiled research from all around Asia to do a comprehensive evaluation of soil erosion management techniques, determining which approaches—such as cover crops and geotextile mats—were the most successful. Similar to this, Rahman et al. (2022) conducted a systematic review that categorized the different types of waste fibers and their proven usage in geotechnical and construction applications. These systematic reviews adhere to predetermined processes (typically guided by PRISMA guidelines) to guarantee complete coverage and fair selection, resulting in high-level insights and evidence aggregation for decision-makers.

Laboratory testing is critical in geotextile research. Standardized tests assess geotextile samples' tensile strength, rip resistance, puncture resistance, permeability, and biodegradation rate. For example, Sayida et al. (2020) investigated the endurance of coir fiber geotextiles by embedding them in various soil types and regularly measuring strength loss, illustrating how the soil environment influences natural fiber lifetime. Other research has exposed prototype geotextiles to accelerate weathering in the lab (e.g., cycles of wetting-drying, UV exposure) to imitate long-term aging in a shorter period. Laboratory experiments are frequently supplemented by field trials, in which geotextiles are deployed under real-world settings (such as a slope or road) and monitored over months or years. Field trials give essential performance data that account for complicated elements such as climate, soil fluctuation, and installation techniques, which are difficult to fully recreate in the lab.

For example, field research on jute and coir erosion mats have monitored how rapidly they biodegrade and how well they buffer slopes until vegetation grows. Both lab and field data are important: lab testing allows for controlled comparisons of materials, while field investigations demonstrate practical practicality. Beyond empirical testing, computer modeling has become more significant. Finite element analysis (FEA) and other numerical simulation techniques are commonly utilized to simulate geotextile-reinforced structures. Researchers developed models to anticipate how inserting a geotextile alters stress distribution in soil or delays the beginning of failure in an embankment. For example, Leonardi et al. (2020) used laboratory tests and numerical modeling to evaluate how adding geogrids and geocells enhanced the performance of machine foundations on poor soil. Their simulations, validated with lab data, helped to demonstrate the reinforcing processes and ideal layouts. Such numerical simulations save money and time by allowing several possibilities to be analyzed in silico. In addition, several research employ multi-criteria decision analysis (MCDA) frameworks to systematically analyze various material possibilities. MCDA can use technical criteria (strength, durability), economic aspects (cost, availability), and environmental effect (renewability, carbon footprint) to rank options. While there are few instances of geotextiles in the literature, the approach has been used to solve material selection difficulties in civil engineering and might also be used to determine the "best" sustainable geotextile alternative for a given project.

Life-cycle assessment (LCA) is an important approach for evaluating environmental sustainability. LCA studies calculate a product's complete environmental effect, beginning with raw material extraction and continuing through manufacture, usage, and disposal. In the field of geosynthetics, LCA has been used to compare geotextile-reinforced designs to conventional designs. Dąbrowska et al. (2023) suggest that employing geosynthetics can lower the carbon footprint and resource consumption of infrastructure projects by substituting or decreasing natural resources such as gravel or cement. They describe methodological methods for doing LCA on geosynthetic solutions, demonstrating savings in greenhouse gas emissions and energy consumption in scenarios where geosynthetics allow for thinner structures or less material trucking. Some comparative LCAs have discovered, for example, that a geotextile layer in a road may provide the same performance as several inches of extra aggregate, saving resources and emissions related to its production and transportation. As sustainable geotextiles (whether biodegradable or recycled) are created, LCA will be critical to ensure that these innovations have reduced environmental consequences across their life cycle compared to the status quo.

Table 1
Research gaps identified in sustainable geotextile studies

Key Themes	Researchers	Summary and Synthesis of Findings
Conventional Geotextiles and Environmental Impacts	Wiewel & Lamoree (2016); Scholz et al. (2021); Markiewicz et al. (2022); Wu et al. (2020)	Synthetic geotextiles made from PP, PET, and PE dominate the market due to durability and cost-effectiveness, but they persist for centuries, fragment into microplastics, and leach additives. Research agrees on their efficiency but highlights urgent sustainability and end-of-life challenges.
Biodegradable Geotextiles (Natural Fibers)	Prambauer et al. (2019); Indraratna et al. (2023); Sayida et al. (2020)	Jute, coir, sisal, and other natural fibers are effective for short-term applications such as erosion control but degrade rapidly and inconsistently in soil environments. Performance variability and short service life limit mainstream adoption.
Biopolymer-Based Geotextiles	Prambauer et al. (2019); Indraratna et al. (2023)	PLA, PHA, and PBS provide more controllable degradation and mechanical properties compared to natural fibers, but remain costly and lack large-scale commercial application. Research demonstrates potential but highlights issues of scalability and economic feasibility.
Recycled Materials in Geotextiles	Rahman et al. (2022); Chmura et al. (2022); Khalid & Alshawmar (2024); Balčiūnas et al. (2025)	Textile waste, rPET, and waste tire fibers have been repurposed into geotextiles, aligning with circular economy principles. Recycled PET shows slightly reduced durability (~30% shorter service life), but remains viable. Waste tire fibers show potential but require processing to remove impurities. Gaps exist in long-term durability testing and industrial standardization.
Digital Tools and Computational Approaches	Bado et al. (2022); Abedi et al. (2023); Palmeira et al. (2021)	Civil engineering has adopted BIM, FEA, and digital twins, yet no dedicated digital tool exists for geotextile design. While "smart geosynthetics" and IoT applications have been proposed, research lacks frameworks for digital prototyping or software-guided material selection.
Methodological Approaches	Ahmad et al. (2020); Rahman et al. (2022); Venkateswarlu et al. (2018)	Existing studies rely on lab tests, field trials, and systematic reviews. Few integrate advanced methods like PRISMA-guided topic modeling, multi-criteria decision analysis (MCDA), life-cycle assessment (LCA), or machine learning. There is a methodological gap in combining computational tools with experimental validation.

Modern data-driven methods are also emerging. Machine learning (ML) and statistical modeling have begun to appear in civil engineering research as tools for pattern detection and prediction. While geotextile design applications are still in their early stages, the larger area has shown the potential of machine learning. Amasyali and El-Gohary (2018) examined hundreds of studies that used data-driven models to forecast building energy usage, demonstrating how algorithms may learn complicated correlations from vast datasets. In materials engineering, researchers have begun to use machine learning to forecast the attributes of novel material formulations or optimize mix designs faster than repeated tests. The climate change research community has even recognized materials discovery and optimization as areas where machine learning might make a substantial contribution to sustainable solutions. Extrapolating these trends, one can see ML being used in sustainable geotextiles, such as training a model on existing experimental data to predict the strength or durability of a new fiber blend or using algorithms to recommend optimal compositions that balance performance and biodegradability. Although such techniques are in their early stages, they constitute a compelling methodological frontier.

In summary, previous research on sustainable geotextiles has used a diverse set of methods, including systematic reviews that map the knowledge landscape, laboratory and field experiments that provide empirical evidence, and analytical and computational methods (MCDA, LCA, simulations) that aid in evaluation and decision-making. Each technique adds to a better knowledge and application of geotextiles. The current work expands on this foundation by integrating many of these approaches in an innovative manner to create and evaluate a suggested geotextile matrix software.

F. Synthesis of Literature and Identified Gaps

The studied literature demonstrates a clear development in geotextile research: from the widespread use of synthetic polymer-based textiles for mechanical dependability to the investigation of biodegradable and recyclable alternatives with the goal of decreasing long-term environmental impact. Natural fiber and biopolymer geotextiles show promise for short-term applications, whilst recycled PET and tire fibers demonstrate the possibility of circular economy techniques. However, all options confront issues of durability, scalability, and standardization. At the same time, whereas civil and materials engineering benefit greatly from modern digital tools such as BIM, finite element modeling, and digital twins, there is no matching software for geotextile prototyping and material optimization. Previous research focused mainly on laboratory and field testing, systematic reviews, and life-cycle evaluations, with little use of data-driven methodologies like topic modeling or machine learning. This synthesis reveals two critical gaps: the lack of standardized methods for evaluating sustainable geotextiles, and the absence of digital platforms for material selection and virtual prototyping. These gaps serve as the basis for the current feasibility research, which aims to bridge material science with computational innovation by developing a sustainable geotextile matrix software.

To condense the information from the evaluated studies, the table below highlights the important themes, the researchers who contributed to these areas, and the synthesis conclusions about the possibility of constructing a sustainable geotextile matrix software.

The literature review and highlighted research gaps underscore the urgent need for alternatives to traditional geotextiles, as well as the lack of digital tools to facilitate their design and assessment. While biodegradable and recycled materials show promise, their performance, scalability, and standards remain unknown. Similarly, the absence of computational frameworks for material prototyping limits innovation in this area. These gaps serve as the foundation for establishing the research challenge for this study and outlining the objectives lead to the feasibility evaluation of a sustainable geotextile matrix software

4. Statement of the Problem

The review of literature and identified gaps reveals the following main difficulties in sustainable geotextile research and practice:

1. Limited synthesis of knowledge on conventional, biodegradable, and recycled geotextiles makes it difficult to establish a comprehensive foundation for material selection.
2. The environmental and technical challenges posed by conventional polymer-based geotextiles remain unresolved, particularly their persistence, microplastic generation, and chemical leaching.
3. The strengths and weaknesses of biodegradable and recycled geotextiles are not systematically compared, leaving uncertainty about their engineering reliability and sustainability.
4. Research methodologies in this field remain fragmented, relying heavily on laboratory and field testing, with limited integration of systematic review protocols or advanced analytical methods.
5. The feasibility of such a digital tool has not been critically evaluated through a structured analytical framework such as SWOT analysis.

5. Methodology

This study uses a feasibility research design to assess the viability of building a sustainable geotextile matrix software. Given that the research aims to synthesize current information and provide a conceptual framework rather than conduct laboratory trials, the technique includes a systematic literature review, computational text analysis, and a SWOT analysis. This method guarantees that the study not only maps the present level of knowledge about geotextiles, but also critically assesses their sustainability potential and finds areas where digital tools might be used. While this technique excludes experimental prototyping and economic modeling, it does give a solid framework for conceiving a digital solution.

A. Research Design

The study design is qualitative-descriptive with systematic data collection and analysis. The study examines peer-reviewed geotextile literature to determine feasibility, with a focus on sustainable material trends and computational approaches. Unlike experimental investigations, which create new data through laboratory or field testing, this study assesses the current evidence to inform software development for material selection and optimization.

B. Data Collection

Relevant literature was acquired from top academic databases such as Scopus, Web of Science, ScienceDirect, MDPI, ProQuest, and Google Scholar. The search strategy used Boolean operators with keyword combinations such as "geotextile," "biodegradable," "recycled materials," "digital prototyping," and "software design." The timeframe 2015-2025 was chosen to capture recent advances in sustainable materials and computational applications.

Inclusion criteria consisted of peer-reviewed journal articles, conference proceedings, and technical reports that examined geotextile materials, sustainability, or digital tools in material engineering.

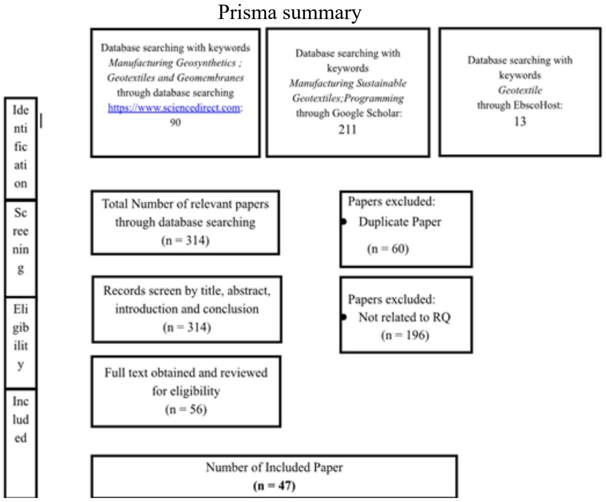
Exclusion criteria included non-English publications, grey literature without peer review, and duplicate records across databases.

C. Screening and Selection

The screening method followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach. Initially, all retrieved records were entered into a reference manager, where duplicates were deleted. A three-stage screening was conducted:

1. Title screening to remove irrelevant works.
2. Abstract review to assess potential relevance.
3. Full-text evaluation to ensure alignment with the study's objectives.

Table 2
Prisma summary



Only research that specifically addressed geotextile materials (synthetic, biodegradable, or recycled), environmental implications, or computational methods were included. To further assure the eligibility of the related literature, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement was used (Page et al., 2021), Table 1 illustrates a summary of the literature considered.

D. Data Extraction and Organization

Data from the final pool of research included were methodically retrieved and sorted into the following categories:

- Geotextile materials might be synthetic, biodegradable, recycled, or hybrid.
- Methodological method (lab testing, field trials, reviews, and simulations).
- Key discoveries (performance measurements, environmental effect, and scalability).
- Reported drawbacks include durability, expense, and a lack of standards.

Summary tables of the featured studies will be created to give transparency and allow for cross-theme comparisons.

E. Data Analysis

The study employed a multi-layered analytical process:

Topic Modeling and Collocation Analysis were conducted using Voyant Tools, a text mining software, to identify recurring keywords, thematic clusters, and co-occurrence networks across abstracts and keywords of the included studies. Latent Dirichlet Allocation (LDA) was applied to classify documents into thematic groups, revealing dominant research streams (e.g., microplastics, biodegradable fibers, recycled polymers, digital tools).

Thematic Synthesis complemented computational analysis by manually coding recurring ideas and categorizing them under environmental, technical, and digital feasibility dimensions.

SWOT Analysis was applied to evaluate the strengths, weaknesses, opportunities, and threats associated with the proposed geotextile matrix software. This analysis integrated insights from both literature synthesis and text mining results, providing a structured feasibility framework.

F. Justification of Analytical Tools

The use of PRISMA guarantees scientific rigor and transparency in literature selection, reducing bias and boosting repeatability. Topic modeling and collocation analysis offer an objective, quantitative layer to the review, enabling for the detection of patterns that would not be apparent from manual reading alone. SWOT analysis is ideal for feasibility studies because it balances internal (strengths, weaknesses) and external (opportunities, threats) aspects affecting software development and adoption.

While the current study relies on these methods, it also acknowledges alternative approaches that could be used in future research, such as Multi-Criteria Decision Analysis (MCDA) for material selection, Life Cycle Assessment (LCA) for environmental footprint analysis, and expert validation methods like the Delphi technique or focus group discussions for industry alignment.

for material design, this systematic review through topic modelling and feasibility analysis

To anchor these results in the larger database, it is necessary to revisit the research summarized in this review. Table 2 summarizes the relevant literature included, summarizing the significant topics, the researchers that contributed to each area, and the major discoveries in terms of sustainable geotextiles. This tabular summary serves as both a basis for the study's results and a point of reference for identifying the gaps that the suggested geotextile matrix software seeks to fill.

Table 3
Summary of included studies on sustainable geotextiles

Author(s), Year	Type of Geotextile Material	Methodological Approach	Key Findings	Reported Limitations
Wiewel & Lamoree (2016)	Synthetic (PP, PET)	Literature review & ecotoxicological analysis	Identified additives in synthetic geotextiles that leach into soil and water; highlighted microplastic generation.	Lack of ecotoxicological data on many additives; long-term degradation poorly studied.
Scholz et al. (2021)	Synthetic (PP) in coastal protection	Field trials & laboratory aging	Demonstrated geotextiles' effectiveness in slope protection but confirmed microplastic residues after removal.	No sustainable alternative tested; site-specific results only.
Prambauer et al. (2019)	Biodegradable (jute, coir, PLA)	Comparative review	Found natural fibers effective for short-term erosion control; PLA biopolymers promising for controlled degradation.	Natural fibers degrade too quickly; PLA is still costly and underdeveloped for large scale.
Indraratna et al. (2023)	Biodegradable (coir, sisal, hybrids)	Field trials & case studies	Coir geotextiles showed strong durability in wet environments; hybrid composites extended service life.	Performance varies with soil and climate; lack of standardized testing protocols.
Rahman et al. (2022)	Recycled (textile waste fibers)	Systematic review	Textile waste fibers reused successfully in civil works; potential for nonwoven geotextiles.	Quality of waste fibers inconsistent; scaling up not addressed.
Khalid & Alshawmar (2024)	Recycled PET fibers	Laboratory testing (accelerated aging)	rPET geotextiles retained ~75% durability compared to virgin PET; viable for many applications	Shorter service life (~30% less) than virgin fibers.
Balčiūnas et al. (2025)	Recycled tire fibers	Prototype fabrication & material testing	Tire-derived fibers incorporated into nonwoven mats; adequate tensile strength and thermal properties.	Contamination from residual rubber; requires processing.
Bado et al. (2022)	Digital/Computational (civil infrastructure)	Review of digital twin applications	Showed potential for digital twins in monitoring infrastructure and materials.	No application yet to geotextile prototyping.
Abedi et al. (2023)	Smart geosynthetics (sensor-embedded)	Review & case studies	Smart geosynthetics can provide real-time monitoring of stress/strain.	Still conceptual; expensive sensor integration.

G. Limitations of Methodology

The study is restricted by its dependence on secondary data and published literature, since no laboratory or field validation was performed. Topic modeling, while effective for detecting topic clusters, is limited by keyword frequency and may oversimplify subtle results. The suggested software framework remains conceptual, with implementation and coding falling outside the scope of this study. Furthermore, cost modeling and complete LCA are absent, despite being listed as objectives for future development.

H. Ethical considerations

This study did not include human volunteers or animal experimentation; therefore, no formal ethical approval was necessary. However, the research adhered to academic integrity criteria, such as accurate source credit and clear method reporting. Should further validation be provided by professional assistance, informed permission and data privacy measures would be scrupulously followed.

6. Conclusion

Exploring the gaps in geotextile development with an emphasis on sustainable alternatives and the use of digital tools

As indicated in Table 3, the evaluated papers illustrate both progress and ongoing limits in geotextile research. While synthetic polymers remain dominant due to their mechanical durability, the research continually highlights their long-term environmental impact. At the same time, biodegradable and recyclable alternatives emerge as viable options, however limited by concerns of durability, scalability, and standards. Building on these insights, the following discussion delves deeper into the environmental and technological constraints of polymer-based geotextiles, as well as the opportunity offered by sustainable alternatives.

Environmental and Technical Challenges of Polymers and Opportunities for Sustainable Alternatives

Traditional geotextiles composed of polypropylene (PP), polyethylene terephthalate (PET), and polyethylene (PE) are popular owing to their strength, durability, and low cost. However, these benefits result in long-term environmental issues: they endure for years, fragment into microplastics, and leak chemical additives into soils and rivers (Wiewel &

Lamoree, 2016; Scholz et al., 2021).

Their disposal at the end of life is expensive, and recycling is seldom possible owing to soil contamination.

Biodegradable geotextiles made of jute, coir, sisal, and other natural fibers, on the other hand, provide short-term reinforcement and degrade safely, but their quick loss of tensile strength restricts their application in long-term projects (Prambauer et al., 2019; Indraratna et al., 2023). Biopolymers provide more control over mechanical qualities and degradation, but they remain expensive and lack systematic assessment.

Recycled materials offer a medium ground, decreasing waste while producing profitable geotextile products. Recycled PET (rPET) geotextiles retain approximately 75% of the durability of virgin PET, making them ideal for a wide range of applications with only a little decrease in service life (Khalid & Alshawmar, 2024). Textile waste and tire-derived fibers (Rahman et al., 2022; Balčiūnas et al., 2025) have been combined into geotextile prototypes, although feedstock quality and contamination are still issues.

This body of literature highlights a critical gap: while sustainable alternatives address environmental concerns, they lack consistency, scalability, and standardized evaluation methods, emphasizing the need for a digitalized geotextile matrix that combines environmental and technical performance data.

Table 4 shows that, while biodegradable geotextiles provide significant environmental benefits through natural degradation, their practical deployment is limited by short service lifetimes, unpredictability in performance, and higher biopolymer prices. When compared to the recycled geotextiles discussed previously, both sustainable approaches provide distinct benefits and confront unique problems. This comparison emphasizes the importance of an integrated framework for rigorously evaluating these materials, balancing technical performance and environmental effect, and guiding the selection of geotextile compositions for specific engineering applications.

Table 4
Strengths and limitations of recycled geotextiles for engineering applications

Recycled Material	Strengths	Limitations	Key References
Recycled PET (rPET)	Reduces plastic waste; retains ~75% of virgin PET durability; cost-effective	Shorter service life (~30% less); may degrade faster under stress	Khalid & Alshawmar (2024)
Textile Waste Fibers	Diverts landfill waste; can be processed into nonwovens for erosion control	Inconsistent quality; variability in fiber strength; limited industrial adoption	Rahman et al. (2022)
Waste Tire Textile Fibers (WTTF)	Abundant, low-cost feedstock; high intrinsic strength; potential for soil reinforcement	Contamination with rubber residues; requires cleaning and processing; limited field validation	Balčiūnas et al. (2025)

Table 5
Strengths and limitations of biodegradable geotextiles for engineering applications

Biodegradable Material	Strengths	Limitations	Key References
Jute	High tensile strength initially; widely available; cost-effective	Rapid degradation in moist soil; short service life	Prambauer et al. (2019)
Coir (Coconut Fiber)	High lignin content provides slower biodegradation; durable in wet conditions; effective for slope stabilization	Loses strength after 2–5 years; bulkier and heavier than synthetic fibers	Indraratna et al. (2023)
Sisal & Flax	Good reinforcement capacity; renewable and low-cost	Rapid strength loss; highly variable quality	Prambauer et al. (2019)
Polylactic Acid (PLA)	Controlled degradation; tensile strength comparable to PET; derived from renewable resources	Expensive; requires industrial composting for full biodegradation	Prambauer et al. (2019)
Polyhydroxyalkanoates (PHA)	Tunable degradation rates; produced by microbial fermentation	High production costs; limited large-scale testing	Indraratna et al. (2023)
Polybutylene Succinate (PBS)	Balanced flexibility and durability; effective soil biodegradability	Limited availability; lacks standardized testing	Indraratna et al. (2023)

A. Methodological Trends in Sustainable Geotextile Research

Geotextile research has used a variety of methodological techniques, demonstrating the field's multidisciplinary character. Understanding these methodologies is essential not just for determining the strengths and limits of previous studies, but also for situating current research within established academic traditions.

1) Laboratory Testing

Laboratory trials remain the most popular method for assessing geotextile performance. Tensile strength, puncture resistance, filtering capacity, permeability, and biodegradation are all evaluated using standardised testing under controlled settings. For example, Sayida et al. (2020) tested the endurance of coir geotextiles buried in various soil types, illustrating how soil composition affects degradation rates. Accelerated aging procedures, such as UV exposure, wet-dry cycles, and hydrolysis, are also commonly employed to model long-term environmental impacts on synthetic and recycled geotextiles. While laboratory testing produces consistent, repeatable results, it frequently fails to reflect the full complexity of real-world settings, limiting the generalizability of findings.

2) Field Validation

Field trials, like laboratory research, provide insights on geotextile performance under natural settings. These studies investigate the impact of climate, soil variability, vegetation, and human activities on material behavior. Indraratna et al. (2023), for example, reported on case studies in which coir and hybrid geotextiles were used in slope stabilization projects, proving their efficiency in erosion management while emphasizing their limited-service life. Field trials provide essential ecological and practical data, but they are generally time-consuming, expensive, and limited by site-specific characteristics, making cross-study comparability difficult.

Table 6
Methodological approaches in sustainable geotextile research

Method	Strengths	Limitations	Representative Studies
Laboratory Testing	Standardized, repeatable; precise measurement of tensile strength, permeability, biodegradation, etc.	Does not capture full complexity of real-world conditions; limited long-term predictive power.	Sayida et al. (2020); Won et al. (2025)
Field Validation	Provides real-world performance data; accounts for soil variability, climate, and vegetation.	Costly, time-intensive, site-specific; results not easily generalizable.	Indraratna et al. (2023); Scholz et al. (2021)
Life-Cycle Assessment (LCA)	Quantifies environmental impacts across full life cycle; aligns with sustainability frameworks.	Few LCAs specific to geotextiles; inconsistent boundaries/criteria across studies.	Dąbrowska et al. (2023); Rahman et al. (2022)
Decision-Analysis Frameworks (e.g., MCDA)	Balances technical, economic, and environmental factors; supports transparent decision-making.	Rarely applied to geotextiles; requires robust input data to be effective.	Palmeira et al. (2021); Khalid & Alshawmar (2024)

3) Life Cycle Assessment (LCA)

In recent years, life-cycle assessment has developed an important approach for assessing the environmental effect of geotextiles. LCA measures emissions, energy consumption, and environmental impact from raw material extraction to end-of-life disposal. Dąbrowska et al. (2023) found that geosynthetics can minimize greenhouse gas emissions by replacing bulk natural materials like gravel or cement. However, LCAs on biodegradable and recycled geotextiles are few, and extant studies differ significantly in system bounds and evaluation methods. The absence of standardization hampers attempts to draw accurate comparisons between material kinds.

4) Decision-Analysis Frameworks

Decision-support approaches, notably multi-criteria decision analysis (MCDA), have been employed in other fields of material selection, although they are rarely used for geotextiles. MCDA allows academics and practitioners to consider technical, economic, and environmental issues all at once, offering an organized approach to ranking material solutions. Such frameworks have been used to evaluate alternative materials in sustainable building, and applying them to geotextiles might help with transparent, evidence-based decision-making. The limited use of MCDA reveals an opportunity to include structured decision frameworks into future geotextile research and software solutions.

B. Synthesis of Methodological Trends

Taken together, the literature shows that, while laboratory and field testing provide crucial empirical data, they are resource-intensive and dispersed among researches. Although less prevalent, LCAs and decision-analysis frameworks contribute value by contextualizing technical results in terms of environmental and economic factors. The integration of these techniques is still insufficient, leaving gaps in how sustainable geotextiles are appraised. This highlights the necessity for a unified platform, such as a software matrix, to combine technical data, environmental measurements, and decision-support frameworks into a single tool for academics and practitioners.

C. Feasibility Evaluation of the Proposed Geotextile Matrix Software

A SWOT analysis was used to determine the feasibility of constructing sustainable geotextile matrix software. This methodology combines findings from a systematic review, computational text analysis with Voyant Tools and Latent Dirichlet Allocation (LDA), and conceptual software design. The study considers the technological, environmental, and industry characteristics that impact the proposed tool's acceptance and long-term viability.

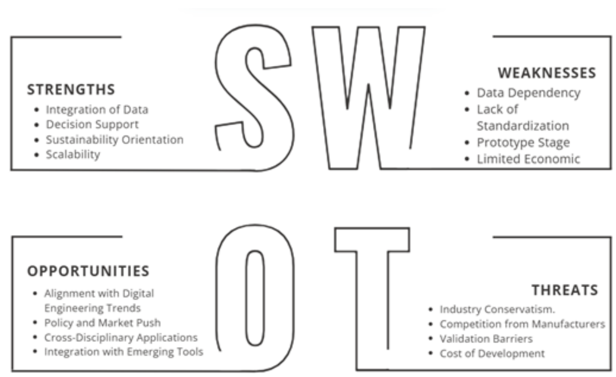


Fig. 1. SWOT Analysis

The SWOT analysis identifies both the potential and difficulties of the proposed geotextile matrix software. Among its strengths, the program may combine disparate experimental results and literature into a single database for material selection. This consolidation, together with its decision-support features, would enable engineers to perform simulations and produce comparison results, avoiding the need for costly trial-and-error laboratory testing. The program is also environmentally conscious, prioritizing biodegradable and recyclable geotextile choices while directly addressing issues about microplastics and trash. Furthermore, its modular architecture makes it intrinsically expandable, allowing for the incorporation of new materials and updated performance data over time.

In terms of weaknesses, the simulations' accuracy will be strongly reliant on the availability and quality of published data, which is uneven among investigations. The absence of uniform testing methodologies for biodegradable and recycled geotextiles hampers efforts to standardise the dataset. Furthermore, the tool is still in the prototype stage, requiring further coding, validation, and user testing before it can be put into practice. The lack of integrated economic cost modeling is also a constraint, since industry stakeholders frequently demand financial feasibility to influence adoption.

The tool is in line with wider civil engineering developments, specifically the use of digital twin technologies, finite element analysis, and building information modeling (BIM). Growing market and regulatory pressure to cut down on plastic waste also raises demand for sustainable alternatives, which the software may assist speed up. The framework might be used to larger material selection issues in construction as well as other geosynthetics like geomembranes and geogrids. Furthermore, it may be able to improve its prediction and optimization skills through future integration with cutting-edge techniques like machine learning, multi-criteria decision analysis, and life-cycle assessment (LCA) modules.

However, several risks might impede growth and uptake. Due to their conservative heritage, the geotechnical and construction industries may be sluggish to adopt new digital technologies. Large geosynthetic producers' proprietary selection systems may also rival or supplant an open-source or academic platform. Another obstacle is validation since field and laboratory data required for calibration are not always uniform or available. Finally, implementation may be severely hampered by the expense of development, continuing upkeep, and the requirement for stakeholder support.

The suggested geotextile matrix software offers distinct technological advantages and sustainability-driven prospects, according to the SWOT analysis, but its viability hinges on resolving significant flaws and reducing outside risks. Its development is facilitated by its excellent compatibility with digital engineering trends and the pressing need for ecologically responsible solutions. Therefore, to guarantee that the tool achieves both academic relevance and practical application, future efforts should concentrate on experimental validation, the inclusion of cost modeling, and close cooperation with industry partners.

Although the SWOT analysis offers a methodical review of the viability of the suggested geotextile matrix software, it is equally crucial to base this assessment on actual trends found in the literature. Text-mining methods were used with Voyant Tools and Latent Dirichlet Allocation (LDA) to supplement the qualitative synthesis. By identifying recurrent keywords, thematic clusters, and co-occurring topics throughout the examined publications, these tools provide quantitative proof of the research gaps and trends that influence the creation of sustainable geotextiles.

The Topic Models are illustrated in Figure 1 wherein four topics were derived from 100 iterations. The four (4) words which most occurred in Topic 1 were: geosynthetics, microplastics, soil, and analysis, thus labeling this topic as microplastic residues in the soil of geosynthetics. Topic 2 had the following as its most occurring words: materials, construction, sustainability, and review, thus these abstracts are summarizing concepts with regards to review on sustainable construction materials. Topic 3 was mostly concerned with topics containing the words: materials, geomembrane, shear, and technology, wherein this topic dwells with parameters and material technologies concerning the shear strength of geomembranes. Lastly, for Topic 4: geosynthetics, nanotechnologies, smart, and improvement, making way for a topic concerning improvements in the technologies concerning geosynthetics.

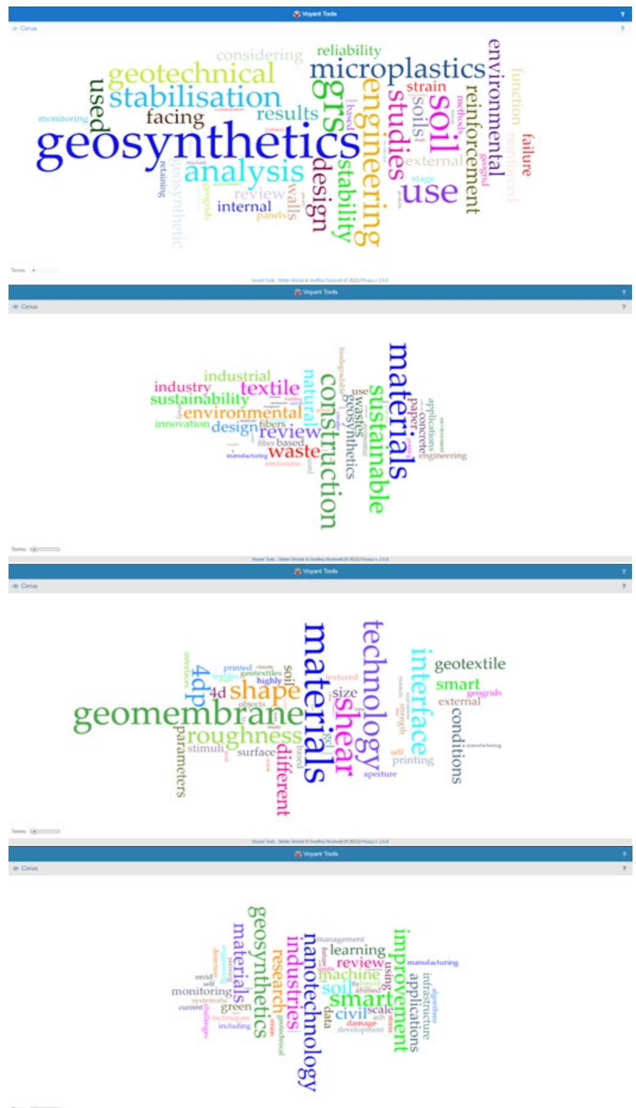
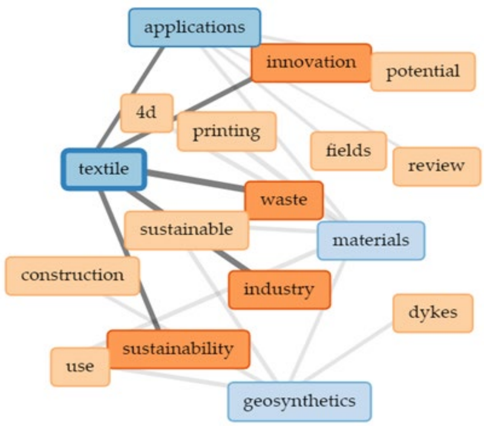
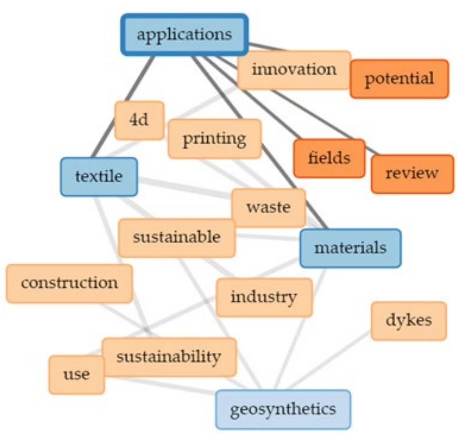
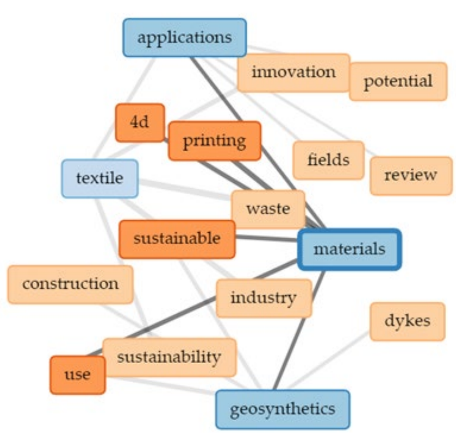


Fig. 2. Topic models for sustainable geotextiles and softwares

Using a corpus with all combined topics, a collocation graph was generated using Voyant Tools. The collocation graph is an illustration of the connectivity of certain words, providing a starting point in research (Brezina, 2018). This shows a graphic network of cross-association between words that are most occurring in the corpus, top words among all these topics were: applications, textiles, materials, and geosynthetics. Figure 2 illustrates the correlation between these words, and the words also present in the corpus which relate most to the top words.







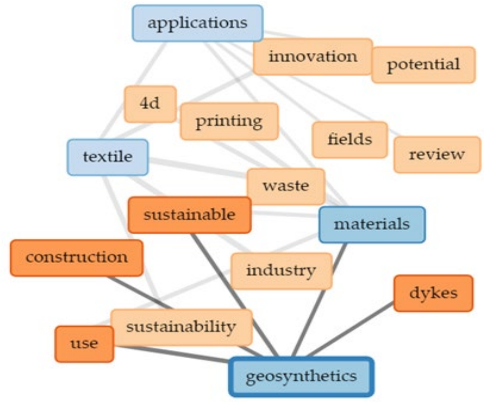


Fig. 3. Linking model for sustainable geotextiles and software

Through this, the related and relevant journals were read extensively to find a connection between the concepts of biodegradable geotextile manufacturing and the digitalization of the manufacturing process of samples.

Although the need for geotextiles has increased due to the quick speed of infrastructure development and construction, environmental issues are still raised by their extensive use. Traditional geotextiles, which are mostly made of synthetic polymers, offer mechanical strength and durability but can leave behind chemical residues and persistent microplastics long after vegetation has taken hold. As a result, scientists have examined a variety of sustainable substitutes, including biodegradable fibers and materials recovered from associated industries, many of which exhibit performance on par with commercially available synthetic goods.

- Conventional geotextiles are technically effective but contribute to microplastic pollution and long-term ecological risks.
- Sustainable alternatives such as biodegradable fibers and recycled materials demonstrate promising performance, in some cases comparable to marketed products.
- Economic factors remain underexplored, as most studies do not assess the cost of acquiring or processing sustainable base materials, some of which may carry hidden environmental burdens.
- Standardization of testing and production methods is lacking, limiting scalability and widespread industrial adoption of sustainable geotextiles.
- Digitalization gaps persist, since there is no existing software for virtual design and testing of geotextiles, despite the adoption of BIM, FEA, and augmented reality in broader construction fields.
- The proposed geotextile matrix software could address these gaps by offering a digital platform to simulate material blends, optimize compositions, and predict performance outcomes, aligning geotextile development with global trends in sustainable and

digital engineering.

In conclusion, even if sustainable alternatives have promises, advancement is still hampered by the lack of digital tools and established procedures. This work establishes the theoretical underpinnings of a geotextile matrix program that has the potential to revolutionize the design and assessment of materials, hastening the transition to digitally integrated and ecologically conscious infrastructure.

In the end, connecting sustainable material breakthroughs with digital design tools not only fills in existing research gaps in geotextiles but also lays the groundwork for a new paradigm in civil engineering, one in which technical progression and environmental responsibility go hand in hand.

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