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Holistic engineering with geosynthetics in the pursuit of sustainable development: The 2030 Agenda and indicators of sustainable cities and communities

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ABSTRACT

Historical discussions about emerging sustainable development practices address the need to transform the Earth's surface into habitable conditions. However, this transformation has occurred rapidly with numerous socioenvironmental impacts that are reflected in extreme weather events and imminent water and food shortages. Civil engineering is one of the major industries that induces economic and social growth and therefore requires the adoption of projects with a bias towards sustainable development. In this context, engineering with geosynthetics enables numerous civil, geotechnical, and environmental works with technical, economic, and socioenvironmental feasibility in response to the growing need for sustainable development to benefit current and future generations. This article discusses six applications of engineering with geosynthetics in line with the global sustainable development goals expressed in the 2030 Agenda and the normative indicators of sustainable cities and communities. The exemplified applications cover 47% of the main thematic axes of sustainable community indicators and 53% of the global sustainable development goals, with macro approaches to protecting the planet. Among the normative indicators, the thematic axes of environment and climate change and solid waste are the most directly related to projects that use geosynthetics. Holistic engineering with geosynthetics adds to technical and sustainable solutions that are accessible to the entire population and in harmony with the environment.

KEYWORDS: Sustainable Development. Geosynthetics. 2030 Agenda.

1 INTRODUCTION

Geosynthetics (GSY) are products manufactured primarily with synthetic polymers (“geo + synthetic”) or natural polymers and commonly come into contact with soil. They can have the shape of a blanket, strip, or three-dimensional structure and perform functions of reinforcement, filtration, drainage, protection, separation, a barrier, surface erosion control, stress relief, and stabilization (ABNT NBR ISO 10318-1, 2021). The first applications of geosynthetics date back to the 1950s, with the manufacturing of fabrics for use as separation and filtration layers between granular and low-bearing capacity soils, as well as in coastal projects in the Netherlands and the United States (PALMEIRA, 2018).

Despite their recent origin, geosynthetics are comparable to other conventional materials in civil engineering and have developed rapidly due to such factors as their ease of installation and transportation, potential applications in emergency projects, competitive costs, and their ability to replace scarce natural resources, such as soils and rocks, and enable more complex sustainable projects (TOUZE, 2021).

In the current era of the Anthropocene, a term that came into use in the 1990s and characterizes a new biogeological era governed by the role of humans in the transformation of geographic space, ecosystems, and the scale of geological time (CHICK; SAUCER; GEORGES, 2020), civil engineering projects have been guided by the goal of solving numerous societal needs, such as housing, accessibility, urban infrastructure, basic sanitation, and leisure. Therefore, a search is underway for sustainable development that can mitigate negative socioenvironmental and economic impacts for current and future generations.

The concept of sustainable development was consolidated by the United Nations (UN) World Commission on Environment and Development through the Brundtland Report (1987), which refers to considering current needs without compromising the need of future generations to meet their own demands. Discussions about sustainable development and actions aimed at mitigating the anthropogenic impacts on planet Earth have been the focus of discussions with UN member countries since the 1970s. These topics include the exponential acceleration in global warming due to greenhouse gas emissions (GHG) and extreme weather events, as well as alternatives that absorb these excesses in the atmosphere and the protection of natural resources (MARQUES, 2022).

These discussions also address the United Nations Framework Conventions on Climate Change, a treaty signed in Rio-92 to establish multilateral commitments and obligations to the 189 member countries regarding climate change. These conventions take place annually to assess progress and establish new joint obligations. In November 2022, the 27th United Nations Conference of the Parties (COP) on Climate Change (COP 27) took place as part of these annual conventions. Brazil started to have a more systemic legal approach to public policies associated with urbanization and environmental preservation after the publication of the Constitution of the Federative Republic of Brazil in 1988, which stood out as a turning point in the regulation of public policies that align urban development, quality of life and preservation of natural resources for current and future generations, joint responsibilities from the federal to municipal levels, and the right to access an ecologically balanced environment for quality of life (BRAZIL, 1988).

Civil engineering is one of the largest industries in Brazil and contributes directly to the generation of millions of jobs and the structuring of basic and essential infrastructure for a dignified quality of life in communities and cities. However, it is responsible for approximately one-third of GHG emissions due to conventional construction methods, which indicates the urgency to adopt resilient engineering solutions that support sustainable development (MACIEL *et al.*, 2018). The 2030 Agenda published by UN member countries in 2015 addresses the new Sustainable Development Goals (SDGs) at global levels (UNITED NATIONS, 2015), as well as the ABNT NBR ISO 37120 standard (2021), which addresses indicators that help cities to manage urban services and pursue sustainability and quality of life. In this context, civil, geotechnical, and environmental engineering projects are coming in line with normative indicators and the new global SDGs in the pursuit of sustainable development.

Engineering with geosynthetics plays a leading role in these scenarios because its numerous applications improve the population's quality of life and mitigate climate change. Examples are reductions in the extraction of natural resources and GHG emissions via large-volume transportation, protection of natural vegetation with CO_2 capture and erosive process mitigation, and the implementation of economic alternatives in numerous geotechnical interventions (DIXON; FOWMES; FROST, 2017; TOUZE, 2021). In addition, polymeric product manufacturing consumes less energy than other engineering materials, such as metallic products, and construction is faster and easier, with a high level of efficiency in terms of behaviour and durability (PALMEIRA, 2018).

The article aims to discuss the applicability of engineering with geosynthetics and its biases in relation to the new global SDGs advocated in the 2030 Agenda and the normative indicators of sustainable cities and communities of ABNT NBR ISO 37120 (2021); the goal is to disseminate information regarding its numerous technological and sustainable possibilities for improving living conditions and remediating environmental impacts for current and future generations. Therefore, the approach was based on six geosynthetic applications in which geotechnics and geosynthetic products are used in the environment, addressing the main advantages and providing examples of these applications in Brazil, while showing how such engineering projects are in line with the indicators and precepts of sustainable development.

2 NEW GLOBAL SUSTAINABLE DEVELOPMENT GOALS AND INDICATORS OF SUSTAINABLE CITIES AND COMMUNITIES

In a meeting at the United Nations headquarters in 2015, the 2030 Agenda was declared. It included a set of seventeen goals and one hundred and sixty-nine integrated and inseparable goals to be put into practice over the subsequent fifteen years and was called the new global SDGs. The new agenda entitled “Transforming Our World: The 2030 Agenda for Sustainable Development” comprises an action plan for the evolution of the eight Millennium Development Goals (MDGs) of the Global Development Agenda 2000-2015 and seeks to achieve unfinished goals (UNITED NATIONS, 2015).

The greatest global challenges of the new global SDGs are the eradication of poverty; the guarantee of human rights and peaceful societies; environmental and urban protection and sustainability; the production of clean energy; gender equality; and inclusive education, among others, in the search for a sustainable society and resilience at global levels. To this end, the new SDGs are organized in terms of the “five Ps” of sustainability to facilitate understanding this new universal Agenda: People, Prosperity, Peace, Partnership, and Planet (MENEZES, 2019).

In 2021, the second edition of the ABNT NBR ISO 37120 standard was published; it addresses indicators to measure urban services and quality of life in cities. In this integrated approach to the new global SDGs in pursuit of sustainable development, ABNT NBR ISO 37120 (2021, p. 4) states that "sustainability is considered as the general principle, and intelligence and resilience as guiding concepts in the development of cities". The normative instrument presents indicators classified as essential, supporting, and profile, grouped into nineteen thematic axes. The indicators can be used to track, monitor and plan the sustainable development of a municipality, as well as plan for its future needs based on levels of current consumption and the efficient use of available natural resources without depleting them for future generations (ABNT NBR ISO 37120, 2021).

3 APPLICATIONS OF GEOSYNTHETICS IN HARMONY WITH SUSTAINABLE DEVELOPMENT

3.1 Coastal works

The application of geosynthetics in coastal infrastructure and mitigation of erosive processes, such as the protection of banks and breakwaters, involves geotextile (GTX) bags or tubes filled with granular materials and deposited one on top of the other to form coastal protection structures. These structures are nonrigid and usually long-term, and they replace compositions made with rocky masses (BEZUIJEN; VASTERNBURG, 2013). GTX are flat polymeric geosynthetic textiles used in contact with soil or other materials (ABNT NBR ISO 10318-1, 2021). The first field application in Brazil occurred with geotextile tubes filled with sand to contain a hydraulic landfill in São Luiz (MA) in 1981 (VERTEMATTI, 2015). In 2015, geotextile bags were used to mitigate coastal erosive processes of an urgent nature and to protect historic heritage sites on Pau Amarelo Beach (PE), with a total length of 2.7 km (SOUZA; SOUZA FILHO, 2015).

Among the indicators of sustainable cities and communities, engineering with geosynthetics in coastal infrastructure applications has a direct bias towards the environment and climate change (ABNT NBR ISO 37120, 2021), as it contributes to reducing GHG emissions, which are an essential indicator measured in tons *per capita* when mitigating extractions of rocky material from deposits. Such practices demand the use of explosives and transportation-related fuel. In addition, SDG 11 can be met, as it is to [...] "make cities and human settlements inclusive, safe, resilient and sustainable" (UNITED NATIONS, 2015, p. 14); and SDG 13 can also be met, as it is to [...] "take urgent action to combat climate change and its impacts" (UNITED NATIONS, 2015, p. 14).

Another indicator of the environment and climate change is the percentage of areas designated for natural protection (ABNT NBR ISO 37120, 2021) because such coastal works with geosynthetics act to mitigate erosive processes caused by human activities. This contributes directly to the conservation of biodiversity and the numerous ecological processes essential for the maintenance of life. Thus, SDG 15 is also met, as it aims to [...] "protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss (UNITED NATIONS, 2015, p. 14).

3.2 Waste containment systems

The use of GTX or geocomposites (GCO), in this case as a double layer composed of woven (GTX-W) and nonwoven (GTX-NW) geotextiles, for the dewatering and confinement of waste and tailings, is known as geotextile tubes or waste containment systems (WCS). Geotextile tubes are structured to receive liquid or semisolid, cohesive waste and tailings with a high liquid content compared to the solid portion and high resistance to filtration (LAWSON, 2008; IGSBRASIL RECOMMENDATION 004, 2016). Below this system, a drainage berth is structured with granular material and a polymer geosynthetic barrier layer, or geomembranes (GBR-P), produced in the shape of a sheet and with the main property of very low permeability to prevent or limit the migration of fluids, as well as protect the environment from contamination-linked damage (ABNT NBR ISO 10318-1, 2021).

Geotextile tubes are a sustainable alternative to reduce the large volumes of waste and tailings routinely generated in industrial processes and provide for their proper final disposal; if this waste were deposited in the environment, proportionally higher impacts would occur. There are reports of silting of water courses, soil and urban springs contamination by solid particles and toxic metals, scarcity of water resources for water supplies and drinking, and mortalities in major environmental disasters (KIFFLE; BHATIA; LEBSTER, 2023). Compared to traditional techniques (natural and mechanical), geotextile tubes are easy to implement and have low costs and environmental impacts; furthermore, they require smaller areas for the dewatering and consolidation processes and function independently of climate and electricity dynamics, among other benefits (GUIMARÃES; URASHIMA; VIDAL, 2014).

This technique has been widely used since its first applications were recorded in the 1990s for sludge from wastewater treatment plants (WWTPs), with promising results (LAWSON, 2008); it has also been applied for the dewatering and confinement of sludge and washing water filters in water treatment plants (WTPs). Applications in WWTPs and WTPs in Brazil are numerous, with increasing expansions from smaller installations to larger operational sizes, due to either the lack of physical spaces for robust installations of natural and mechanical treatments or the expansion of operating systems, as well as the search for techniques with better cost-benefit ratios. An example is the dewatering of sludge collected in septic tanks by vacuum trucks and leachate from landfills in the city of Rio das Ostras (RJ) in 2007 as sanitation remediation and urban infrastructure due to large population growth (CASTRO; MELO; ESCOBAR, 2008). Additionally, WCS is used in the WTP of Piquete (SP) as an auxiliary treatment to the sludge deposited in the flocculating unit to increase the water treatment capacity (GUANAES; SAMPAIO, 2012).

Solid and semisolid waste and tailings from any industrial process must be adequately treated and deposited without causing socioenvironmental impacts, together with sustainable consumption patterns of natural resources. SDG 12 is to [...] "ensure sustainable consumption and production patterns" (UNITED NATIONS, 2015, p. 14). Although the solid waste normative indicator directly addresses municipal or household solid waste, it also addresses the need for integrative management, treatments, and final dispositions for quality of life, such as for the percentage of solid waste disposed by other means (ABNT NBR ISO 37120, 2021). Furthermore, SDG 11 stresses the need to [...] "make cities and human settlements inclusive, safe, resilient and sustainable" (UNITED NATIONS, 2015, p. 14).

Engineering with geosynthetics meets the need for sustainable development by applying technologies with lower costs and environmental impacts than traditional techniques to treat and dispose of such solid and semisolid waste, thus preventing its release into the environment and offering adaptations for places with few available areas and difficult access. In line with the increases in the percentage of the population served by drinking water supply services and sewage collection and removal systems, accessible technologies with lower socioenvironmental impacts, such as WCS, are needed. That is, engineering with geosynthetics directly meets SDG 9 addressed in the United Nations (2015, p. 14), which adds "build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation"; SDG 14, which adds [...] "conserve and sustainably use of oceans, seas and marine resources for sustainable development" (UNITED NATIONS, 2015, p. 14); and SDG 15, for which WCSs can [...] "protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss" (UNITED NATIONS, 2015, p. 14).

In particular, the waste generated in WWTPs and WTPs is a direct byproduct of the population's enjoyment of using and drinking water, which are essential elements for maintaining a dignified life and public health. Such basic sanitation infrastructures are essential indicators to guarantee the health, cleanliness, quality of life and dignity of the population (ABNT NBR ISO 37120, 2021); they are stated in SDG 6, which aims to provide [...] "ensure availability and sustainable management of water and sanitation for all" (UNITED NATIONS, 2015, p. 14).

3.3 Reinforced walls and slopes

Due to the exponential growth of cities, numerous geotechnical projects underway in recent decades have demanded containment structures which, together with the scarcity of soils with geotechnical characteristics compatible with the constructive demands, have made geosynthetic engineering leader in geotechnical and socioenvironmental solutions (KOERNER; SOONG, 2001).

The incorporation of geosynthetics in soil masses can strengthen and stabilize solids, as they globally reduce stresses and deformations that result from the low shear strength of soils; thus, this process enables the structuring and stability of walls with vertical or near-vertical surfaces, as well as slopes with steeper massifs (ABNT NBR 16920-1, 2021). Other functions associated with geosynthetic products in reinforced walls and slopes are the filtration of rainwater and its drainage in suitable geosynthetic systems. The geosynthetics used are GTX and, more broadly, geogrids (GGR), flat structures with open and rectangular meshes (ABNT NBR ISO 10318-1, 2021). The filtration and drainage systems employ GTX-NW, geonets (GNT) consisting of parallel elements superimposed at various angles, geospacers (GSP), which are three-dimensional structures with interconnected air spaces, and GCO via the association of the aforementioned geosynthetic materials.

An emblematic Brazilian work that used walls reinforced with geosynthetics was the implementation of a toll plaza on Rodovia of Tamoios (SP-099), Paraibuna (SP), between 2015 and 2016. Because the construction site has an environmental restriction area and uneven relief, the project included the construction of a wall with a total height of 25 meters over two main spans and using local soil (GEROTO *et al.*, 2018). In terms of reinforced slopes, the stabilization of a natural slope with a difference of approximately 50 meters located on cliffs in the city of São José de Ribamar (MA) using geosynthetics is exemplified (PEREIRA; AVESANI NETO; FRANÇA, 2016).

The main advantages of geosynthetics in this application include the improvement of existing techniques, the use of available local deposits, an increase in geotechnical load capacity, a reduction in the consumption of concrete in retaining structures, and competitive costs, among others. In addition, geosynthetics applications for stabilizing natural slopes are aimed at preventing landslides and, thus, numerous socioenvironmental impacts, including possible human losses in places with existing buildings (DAMIANS *et al.*, 2017).

Among the indicators of sustainable communities and cities, engineering with geosynthetics adds directly to the environment and climate change, as it helps in reducing the emission of GHG and protecting natural areas by using local soils in geotechnical works, specifically, the CO_2 that accelerates global warming and its numerous implications and extreme weather events, whose current contexts have been guidelines in global conventions. In addition, reducing the consumption of cement compounds, in which the production processes require large volumes of deposits of limestone rocks, clays, and burning in blast furnaces, also affects GHG emissions and the emission of fine particles into the atmosphere. In a holistic way, engineering with geosynthetics corroborates the achievement of SDGs 11 and 15, as well as SDG 13 (UNITED NATIONS, 2015, p. 14), which aims to "take urgent action to combat climate change and its impacts".

Nevertheless, in this context, the use of geosynthetics in containment structures and reinforced slopes are subsidies for geotechnical infrastructures: they guarantee adequate and accessible housing conditions for the population because they are economical solutions that guarantee the use of local resources while improving the geotechnical conditions of the soil through elements of reinforcement, stabilization, filtration, and drainage. Therefore, engineering with geosynthetics makes the new global SDGs 10 and 11 tangibles by reducing inequalities in housing settlements and making them inclusive, safe, resilient, and sustainable.

3.4 Control of superficial soil erosion

The processes of superficial soil erosion can occur in rural or urban areas and are commonly associated with disordered human occupation, higher rainfall, and geological-geotechnical formation of soils susceptible to erosion, among others (PALMEIRA, 2018). The use of geosynthetics on steeper slopes that are subject to erosion is in line with the prevention of surface erosive processes and soil stabilization due to damage by surface mass movements (KOERNER, 2012).

Among the simplest applications is the surface coating of slopes with geomats (GMA) and biomats to support the development of the vegetation layer and its protection against the weather in areas susceptible to surface erosion, as well as the use of geocells (GCE) as temporary or permanent protection from the action of erosive agents, as is the case for revegetation on steeper slopes and other coastal coverings (THEISEN, 1992; VERTEMATTI, 2015). Geomats are three-dimensional structures made of synthetic or natural polymeric monofilaments, and biomats are permeable structures of natural loose fibres. Geocells are three-dimensional fibres commonly filled with soil and vegetation (ABNT NBR ISO 10318-1, 2021).

Almeida, Maia, and Gusmao (2019) reported the use of geomats and biomats in the structuring of a green nailing soil on a slope within a food-related industrial area in the urban area of Maceió (AL) to ensure the overall stability and safety of industrial facilities and employees. Luz *et al.* (2022) evaluated the vegetative cover index of cut slopes coated with biomats in association with organic sediment retainers near a hydroelectric plant in Minas Gerais.

Another relevant application of geosynthetic materials is the structuring of silt fences, which are formed by GTX piled up by stilts embedded in the soil to contain solid particles and thus mitigate particle transport. When soils are dispersed in liquid fluids, filtration occurs by retaining solid particles. Silt fences are positioned linearly and adjacent to sites with occurrences of surface erosion or other earth movements (THEISEN, 1992; VERTEMATTI, 2015). Silva *et al*. (2022) used this application as a technical alternative with a low environmental impact to control surface runoff in land adjacent to a residential sector in Caetité (BA), which had a history of disturbances arising from sediment transport in the rainy seasons.

Among the indicators of sustainable development in communities and cities, emphasis is placed on the environment, climate change, and housing in the discussions of applying geosynthetics in reinforced walls and slopes, as well as in relation to the new global SDGs 10, 11 and 13 associated with these respective indicators. Engineering with geosynthetics aims to mitigate the contamination of soils and water sources, silting of drainage lines, and destruction of public and private buildings and urban infrastructures, which may affect transport routes, anthropogenic losses, fauna and flora (BARBOSA *et al*., 2022). Therefore, the prevention of erosive processes is highlighted by the new global SDG 15, which aims to "[...] halt and reverse land degradation and halt biodiversity loss" (UNITED NATIONS, 2015, p. 14).

In addition, the use of geosynthetics to control surface erosion directly adds to the urban planning indicator in terms of green areas and SDGs 11 and 15 because "[...] they improve the urban climate, capture atmospheric pollutants, reduce surface runoff and improve the quality of life, providing leisure for urban inhabitants" (ABNT NBR ISO 37120, 2021, p. 90); furthermore, green areas are considered basic services to the population and the promotion of sustainable cities (ABNT NBR ISO 37120, 2021).

3.5 Disposal of solid waste

The final and environmentally sound disposal of solid waste is a major global challenge, along with exponential growth in the consumption and generation of waste in modern society, environmental toxicity, and accessible public health for the entire population (JACOBI; BESEN, 2011). Among these, we highlight municipal solid waste (MSW), originating from household and urban cleaning waste, as well as numerous industrial wastes (IR). In Brazil, a total health expenditure of US$ 1.85 billion was estimated for the treatment of problems triggered by practices of inadequate disposal of MSW between 2016 and 2021. The country generated 81.8 million tons of MSW in 2022, and the amount collected corresponded to 76.1 million tons. Of this collection, 61% was sent to landfills, and the remaining 39% was disposed of in dumps and controlled landfills (ABRELPE, 2022).

The geosynthetics used in the disposal of solid waste function as a fluid barrier due to their low permeability coefficients (ABNT NBR ISO 10318-1, 2021), whose configurations encompass both the internal bottom and side coverage of the disposal landfills, as well as the upper final cover of the landfill, both to ensure the isolation of deposited waste and protection of the environment. These materials include GBR-P, or geomembranes, and clay geosynthetic barriers (GBR-C), also called clayey geosynthetic liners. Geomembranes in landfills are distinguished by their chemical and mechanical resistance, ease of installation, transportation, and field splicing. The clay geosynthetic barriers are formed by a layer of clay powder, usually sodium bentonite, between two layers of geotextile (ABNT NBR ISO 10318-1, 2021). The advantages of clay geosynthetic barriers are self-healing, and their high clayey expansion capacity minimizes the possible impacts associated with mechanical damage during installation (PALMEIRA, 2018; VERTEMATTI, 2015). Other geosynthetic products are also used in sanitary and industrial waste landfills, such as GTX-NW for the mechanical protection of fluid barriers and filtration and drainage systems with nonwoven geotextiles, geonets, and geocomposites.

This applicability presents a significant geotechnical and environmental gain because it reduces the extraction of clay deposits of low permeability, whose final compacted thicknesses are between 0.6 m and 2 m, even in places with a shortage of these natural materials or that are difficult to access; it increases the ease of transport and installation, as well as the strict quality controls of geosynthetic materials (KOERNER, 2012; PALMEIRA, 2018). As an example of the disposal of MSW structured with geosynthetics, the city of Varginha (MG) inaugurated a 20-hectare sanitary landfill in July 2017 as part of the Municipal Plan for Integrated Management of Solid Waste (MPIMSW) for the deactivation of the former municipal waste dump (MUNICIPALITY OF VARGINHA, 2013). This industrial waste landfill allowed for the closure of a blast furnace waste landfill in the city of Cariacica (ES) after it reached a storage capacity of 26,000 m³ (CARESSATO JUNIOR; PANTA, 2018).

In this holistic approach, engineering with geosynthetics adds to numerous practices aimed at sustainable development because the management and proper final disposal of MSW and other industrial waste are universal issues for which there are public health guidelines, as well as indicators that measure the percentage of MSW disposed of in sanitary landfills and open dumps. The normative indicator solid waste (ABNT NBR ISO 37120, 2021, p. 66) directly states that "solid waste systems contribute in many ways to public health, the local economy, the environment, and to social understanding and education about the environment", as well as directly correlates with the new global SDG 11 (UNITED NATIONS, 2015, p. 14). According to ABNT NBR ISO 37120 (2021, p. 69), "open dumps and uncontrolled sanitary landfills are sometimes the main disposal methods, particularly in lower-income cities". The geosynthetic materials enable environmentally appropriate disposal of solid waste due to the numerous advantages mentioned above, including in places that are difficult to access or do not have clay deposits for permeability barriers; furthermore, the durability of the materials is compatible with the service life of the landfills.

In addition, efficient systems for the disposal of solid waste in landfills structured with geosynthetics act to mitigate harmful socioenvironmental impacts in the short to long-term, such as pollution of water courses, fauna and flora, as well as greenhouse gas emissions in irregular deposition. That is, they are in line with the new global SDGs 12 and 14 (UNITED NATIONS, 2015, p. 14).

3.6 Reinforcement of flexible paving in road, urban, and airport infrastructure

Modal transport systems are important infrastructures that ensure the socioeconomic growth of cities and communities, as they allow the interconnection between them and the flows of industrialized, agricultural, and mineral products and access to social, health, labor, and tourism services and, therefore, numerous socioeconomic gains (BERTUSSI; ELLERY JUNIOR, 2012).

Flexible pavements reinforced and stabilized for stress relief with geosynthetics may have a three- to tenfold-fold increase in service life compared to works without these inclusions. The geosynthetics used are geogrids (GGR), and nonwoven geotextiles (GTX-NW) impregnated with asphalt, either for the construction of new traffic lanes or for the repair of damaged pavements (KOERNER, 2012). Numerous realities of unpaved roads represent more than 80% of the Brazilian road system; for example, access to social services in large urban centres is impacted by the lack of adequate transport infrastructure (GONGORA; PALMEIRA, 2019). In this scenario, geosynthetics are used to provide the minimum infrastructure necessary for increasing load capacity and constructing emergency roads under trafficable conditions, including in places that are difficult to access or have lower soil transport demands, among others (PALMEIRA, 2018).

Carmo *et al*. (2019) evaluated the structural behaviour of flexible pavement in an urban road reinforced with geogrids after ten years in Viana (ES), whose road system is responsible for transporting relevant products and providing service access to the local population. For airport infrastructure, Carmo *et al*. (2015) addressed the use of geogrids for take-off and landing as part of the runway restoration at Congonhas Airport, which is the second busiest nationally.

The guarantee of longer and safer service lives in urban, road transport, and airport infrastructure are a relevant indicator of sustainable development of cities and communities, as this factor directly increases the kilometres within the public transport system and the annual number of trips (ABNT NBR ISO 37120, 2021). Regarding the economy, the ABNT NBR ISO 37120 standard (2021, p. 11) addresses the relevance of air transport because "cities with high commercial air connectivity generally have robust economies and are able to provide a higher level of service to the inhabitants". Resilient and adequate transport infrastructures promote the population's well-being and industrialization that is inclusive, sustainable, and with innovations, in line with the new global SDGs 3, 9, and 11 (UNITED NATIONS, 2015). In this context, engineering with geosynthetics enables more durable works, estimated reductions of 20% to 50% in the thickness of granular layers and, consequently, in soil deposits for compacted landfills and eminent emissions of greenhouse gases, as well as larger areas of natural protection (DIXON; FOWMES; FROST, 2017; VERTEMATTI, 2015). Therefore, this type of engineering benefits the environment and climate change indicator and the new global SDGs 11, 13 and 15 (UNITED NATIONS, 2015).

4 GLOBAL DIAGNOSIS

Table 1 shows the interrelationships of the six geotechnical and environmental applications with geosynthetics to the thematic axes of sustainable cities and communities of ABNT NBR ISO 37120 (2021) and to the new global SDGs recommended in the 2030 Agenda.

Among the thematic axes of sustainable cities and communities and their respective indicators, engineering with geosynthetics directly addresses nine of the nineteen listed in ABNT NBR 37120 (2021), corresponding to 47% of these axes. The indicators present in the thematic axes environment and climate change and solid waste are the most directly related to the projects with geosynthetics, listed in Table 1.

Regarding the new global SDGs, geosynthetic applications exhibit direct trends associated with nine of them: 53% of the seventeen SDGs launched in the 2030 Agenda. The new global SDG 11 corresponds to 23% of this holistic interrelationship, followed by 19% of the new global SDG 15 and 15% of SDG 13. These three new SDGs have a macro focus on protecting the planet from degradation through sustainable consumption and production and sustainable management of natural resources, along with urgent measures to combat climate change (UNITED NATIONS, 2015).

This holistic view of the six applications of engineering with geosynthetics directly illuminates numerous relevant perspectives related to the new global SDGs and the normative thematic axes and their respective indicators that measure the practices and services of sustainable cities and communities. The essential, supporting, and profile indicators must be analysed in a timely manner for each civil, geotechnical, and environmental work situation and its socioenvironmental, technical, and economic gains in line with the movement towards local and global sustainable development.

Notably, the new global SDGs are indivisible and inseparable. In other words, the actions must be guided by achieving equally the numerous challenges of sustainable development. The discussions held are not intended to exclude the other new global SDGs but rather to highlight the main directions of these civil, geotechnical and environmental engineering projects with geosynthetic materials as they related to the new SDGs and their socioenvironmental and technical feasibility for satisfying the indicators of sustainable development in cities and communities.

Table 1 - Interrelationship between engineering with geosynthetics and the thematic axes of sustainable development.

Applications[1]	**Geosynthetic products**	**Functions**	**Sustainable cities and communities through ABNT NBR ISO 37120 (2021)**		**New global SDGs**
			Thematic axes	**Indicators**	
3.1	Geotextiles	Protection	Environment and climate change	Emission of greenhouse gases Percentage of areas designated for natural protection	SDG 11 SDG 13 SDG 15
3.2	Geotextiles Geocomposites Geomembranes	Filtration Drainage Barrier Protection	Solid waste Sewage Water	Percentage of solid waste disposed of by other means Percentage of the population served by sewage collection and removal systems Percentage of population with drinking water supply service	SDG 6 SDG 9 SDG 11 SDG 12 SDG 14 SDG 15
3.3	Geogrids Geotextiles Nonwoven geotextiles Geonets Geospacers Geocomposites	Reinforcement Stabilization Filtration Drainage	Environment and climate change Housing	Emission of greenhouse gases Percentage of areas designated for natural protection Percentage of the population living in affordable housing	SDG 10 SDG 11 SDG 13 SDG 15
3.4	Geomats Biomats Geocells Geotextiles	Surface erosion control Stabilization Filtration	Environment and climate change Housing Urban planning	Emission of greenhouse gases Percentage of areas designated for natural protection Percentage of the population living in affordable housing Green areas per 100,000 inhabitants	SDG 10 SDG 11 SDG 13 SDG 15
3.5	Geomembranes Clay geosynthetic barriers Geotextiles Geogrids Geocomposites	Barrier of fluids and gases Drainage Filtration Protection	Solid waste	Percentage of municipal solid waste disposed of in landfills Percentage of municipal solid waste disposed in open dumps	SDG 11 SDG 12 SDG 14
3.6	Geogrids Nonwoven geotextiles	Reinforcement Stress relief	Transport Environment and climate change Economy	Kilometres of public transport system per 100,000 inhabitants Annual number of trips in public transport *per capita* Emission of greenhouse gases Percentage of areas designated for natural protection Air connectivity	SDG 3 SDG 9 SDG 11 SDG 13 SDG 15

NOTE: [1] Subitems of topic 3 "Applications of geosynthetics in harmony with sustainable development".
Source: Prepared by the authors.

5 FINAL CONSIDERATIONS

The interpretation of sustainable city and community indicators and their guidelines for the new global SDGs are essential both for understanding the current local realities and for planning and adopting public policies that can improve the lives of the population, as well as globally. Intergovernmental organizations are responsible for the commitments assumed by the UN member countries. The guarantee of equitable access to basic services for the population, their quality and essential infrastructure and the preservation of water quality, oceans, fauna and flora, among others, require civil, geotechnical and environmental engineering works in line with the technical feasibility and environmental issues of current and future generations.

The examples of engineering with geosynthetics point to socioenvironmental, economic and technical gains and provide numerous projects with technical and sustainable solutions, including in places that are difficult to access, with accessible costs and lower environmental impacts than other geotechnical and civil construction technologies. In addition, they contribute to lower greenhouse gas emissions by applying deposits of local soils and incorporating lower levels of cementitious materials, thus mitigating extreme weather disasters, which have occurred more frequently in large urban centres and remote areas, among others.

The six applications discussed are not intended to cover all situations but to elucidate the numerous advantages of these projects and their biases to sustainable development, as well as to disseminate themes and indicators of sustainable communities and cities and the new global SDGs. Therefore, the holistic approach of engineering with geosynthetics meets the urgent need for sustainable, long-lasting practices that are equally accessible to the entire population; furthermore, it provides an understanding of the joint responsibilities of civil, geotechnical, and environmental engineering projects in the search for quality of life and harmony with the environment.

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