MATHEMATICS AND BASIC SCIENCES IN GEOMATICS ENGINEERING: CONTRIBUTIONS TOWARDS SUSTAINABLE DEVELOPMENT GOALS

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Abstract

Mathematics and basic sciences form an integral part of the Geomatics Engineering curriculum, serving as the cornerstone not only in shaping the educational framework of the discipline but also in making substantial contributions toward achieving the Sustainable Development Goals (SDGs) by gathering and analyzing geospatial data. This study examines the central role of these subjects by emphasizing their profound importance in both theory and practical applications, promoting a harmonious incorporation of core scientific and engineering courses. The study also highlights how geospatial data, one of the main end-products of the Geomatics engineering discipline, contributes to the accomplishment of a majority of SDGs, including eliminating poverty, climate action, smart cities, promoting sustainable agriculture, enhancing public health, and mitigating climate change. Remote sensing, geographical information systems (GIS), and global navigation systems (GNNS) can provide significant benefits in the pursuit of certain SDGs. The incorporation of cutting-edge technologies, including Internet of Things (IoT), artificial intelligence, and computer vision, into Geomatics engineering is required to promote sustainable environmental management and foster innovation in a wide spectrum of research fields. The study also advocates for further investigation into state-of-the-art technologies to achieve a better and more sustainable future in line with the SDGs.

Keywords

Basic science, engineering, geomatics engineering, sustainability, education

Introduction

Engineering is the transformation of materials and forces/energies in nature into structures, machines, products, and processes in the most efficient way by using knowledge gained through education and experience in basic sciences (Özçep et al., 2003). The Arabic word for engineer (hendese) means a person engaged in geometry. On the other hand, the English word engineer is known to have been first used in the Middle Ages. The origin of the word is engine and ingenious and comes from the Latin word *in generare*, which means to generate. Dealing with the practical application of scientific knowledge, engineering aims to deliver safe, efficient, and viable answers to various issues by employing the principles uncovered through scientific exploration. Proficiency in defining, conceptualizing, and resolving engineering problems arises from fundamental scientific knowledge. Therefore, basic sciences hold a crucial position in engineering education and the practical utilization of engineering knowledge, warranting adequate attention.

Having a deep-rooted history tracing back to 300 B.C., Geomatics Engineering is one of the oldest scientific disciplines at the intersection of basic sciences and specialized branches, including mathematics, geometry, trigonometry, geography, astronomy, and physics. It is internationally recognized under different names, including Geodesy and Photogrammetry Engineering, Geoinformatics Engineering, and Surveying Engineering. The important areas of research in Geomatics Engineering include photogrammetry, remote sensing, digital image processing, geographic information systems (GIS), geodesy, Global Navigation Satellite Systems (GNSS), cartography, and land administration. Geomatics Engineering also supports environmental studies, safeguarding biodiversity conservation, ecosystem sustainability, climate change monitoring, and natural resource management. It is evident that the interdisciplinary nature of Geomatics Engineering links technology, science, and the environment, creating an intricate network of sustainability and innovation. In conclusion, Geomatics Engineering is a field with enormous potential and benefits for society globally. It offers a unique opportunity for professionals in science, technology, and engineering to come together and provide innovative solutions to pressing environmental challenges. The advancement of Geomatics Engineering will continue to provide critical information to advance environmental policies, risk management, and sustainable development.

This study aims to investigate the pivotal role of mathematics and basic sciences, encompassing physics, astronomy, and geography, in shaping the Geomatics Engineering curriculum and its main sub-branches. This exploration goes beyond theoretical discussions, delving deeply into the practical applications of Geomatics Engineering. It elucidates how these applications actively contribute to advancing and achieving seven specific targets among the United Nations' Sustainable Development Goals (SDGs). By examining the intersection of these disciplines, this study also unveils the nuanced ways in which Geomatics Engineering actively supports and drives progress toward sustainable global development.

Curriculum of Engineering Education

Courses in basic sciences empower students to initiate their path to becoming well-educated engineers, fostering the growth of their analytical thinking skills. For engineering, education in the basic sciences is essential, highlighting the critical significance of strengthening engineering education programs in the basic sciences. Clearly, basic sciences guide engineers in cultivating innovative and productive thinking while providing explanations for natural phenomena. Basic sciences courses are usually compulsory in the freshman and sophomore years of engineering programs. A lack of proper education in fundamental sciences represents a substantial drawback, impacting the technological growth of nations and the cultivation of productive critical thinking skills. From the perspective of the engineering profession, engineers with a deficit in basic sciences may encounter challenges in practical applications, constraining their success in interpretation and the generation of innovative ideas. Several authors (e.g., Zakharov, 2000; Uriel et al., 2020) have discussed the necessity of redesigning the courses of basic sciences in modern engineering education and suggested reforming engineering education.

Recognizing and adopting the fundamental sciences, which constitute the underpinning of engineering sciences, is highly essential for the effective conduct of R&D activities. The incorporation of basic sciences in both engineering education and the execution of engineering duties is critical for addressing cause-and-effect relationships in applications, improving production quality, and ensuring ongoing success. Basic sciences elucidate natural phenomena and lead engineers to innovative and productive thinking. Engineering graduates are equipped with the capability to integrate scientific and engineering principles, allowing them to design products and processes that advance environmental sustainability, while also innovating new technologies and solutions for emerging problems.

Basic sciences form the foundation of engineering, as knowledge generated by one is converted into skills by the other. Insufficient emphasis on basic sciences deprives a country of scientific standing, impedes the attainment of advanced technology, and hinders the development of an innovative society. Therefore, it is highly important that subjects such as mathematics, physics, chemistry, biology, and others, which serve as essential foundations for vocational education in engineering faculties, are taught by faculty members actively involved in research within the relevant basic sciences disciplines. Zakharov (2000) argues that when a professor employing an 'engineering' teaching style delivers a basic science lecture, another extreme perspective emerges. This tendency involves molding fundamental science to fit the demands of engineering. Such an approach causes science being taught to lose its foundational nature and should be avoided. Additionally, there is a need to elevate the quality of education and laboratory facilities to ensure that students pursuing basic sciences are trained with the requisite skills for employment and can progress in their path to becoming scientists.

According to the Accreditation Board for Engineering and Technology (ABET), the courses in an engineering degree program should be balanced between basic sciences and mathematics, engineering sciences, humanities, social sciences and communication, and departmental courses. In a comprehensive study for electrical engineering, Bilsel et al. (1998) reported that Turkish engineering programs are stronger in mathematics, and they generally allocate more courses to this subject in their curricula compared with North American universities. The mean number of required mathematics credit-hours for engineering students at Turkish universities was 22.7 (lowest 19, highest 30), whereas it was 17.8 (lowest 13, highest 26) at North American universities. A striking observation is that the pattern is reversed when it comes to credit-hours in physics and chemistry. While total physics and chemistry credit-hours at Turkish universities were 9.4 and 3.2, those at North American universities were 10.3 and 5.0, respectively.

At present, we are witnessing a digital transformation that is profoundly shaping all dimensions of engineering technologies, necessitating substantial changes in university curricula. For this reason, the educational philosophy of today's technological society has shifted from training engineers who are only capable of solving technical problems to training engineers who can comprehend the problem as a whole. Engineering education should broaden students' horizons and help them identify fundamental problems (Baran & Kahraman, 1999). Therefore, the main objective of modern engineering education can be defined as teaching engineering principles and learning.

Basic Sciences in Geomatics Engineering

The principal aim of the Geomatics Engineering discipline is to collect, interpret, analyze, and disseminate valuable geospatial information on the Earth by employing various technologies, such as GNSS, remote sensing, GIS, and spatial data analytics (Figure 1). G. Leibniz (1646-1716), a distinguished German mathematician, once stated, "Geodesy is an excellent application area of mathematics", underscoring the crucial role of mathematical expertise in the field of Geomatics. To date, geomaticians have consistently employed an array of calculation tools, ranging from logarithm tables and slide rules to electric calculators and computers, to execute diverse calculation methodologies. Additionally, *geometry* and *trigonometry*, sub-branches of *mathematics*, constitute the primary domains in which geomaticians are deeply engaged. The use of terms such as "Ingenieur Geometer" or "Trigonometer" in certain countries underlines the proximity of their work to these mathematical disciplines. Furthermore, cartographers have played a significant role in developing subjects such as probability calculation, statistical theories, and the Least Squares Method, which are more closely associated with cartography than with pure mathematics (Şerbetçi, 1999).

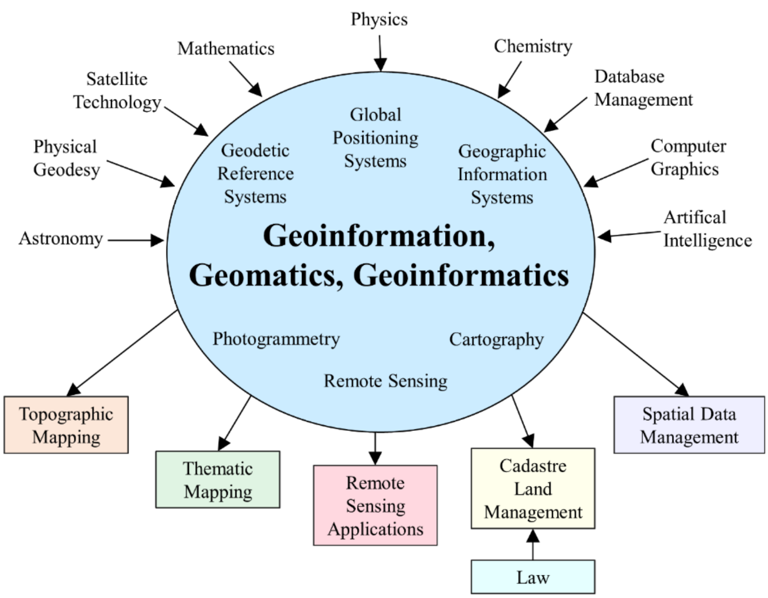
Within the domain of *astronomy*, geomaticians are tasked with the precise measurement of latitude, longitude, and azimuth values for specific points within established networks, such as the country triangulation network, during map creation. Geomaticians also calculate the amount of plumb deviation from these measured values and incorporate it into precise calculations on the ellipsoid. To determine the size of the Earth's ellipsoid, astronomical studies were conducted in conjunction with geodetic efforts. In contemporary measurements, positions are determined using the Global Positioning System (GPS) through Doppler measurements and dedicated satellites launched for this purpose.

The field of *geography* has been intertwined with Geomatics Engineering and exploration for centuries. In Greek, "Geo" translates to place, and "graphhein" to write or draw. While cartography remains highly significant in the realm of geography, it has evolved into a distinct discipline over time. The era of major discoveries has concluded, and there are no unexplored regions left on Earth. Consequently, Geomaticians have consistently relied on the definitions and descriptions provided by geographers, evaluating the discoveries and journeys undertaken. This symbiotic relationship has led to the acknowledgment of cartography as a scientific branch closely aligned with geography.

The field of *physics* also plays a crucial role in Geomatics, particularly in the context of measurements conducted in the physical environment. The precision achieved in measuring base lengths, even with tape elongation, owes its thanks to physicists who developed tools such as invar wires. Optical instruments such as levels, tachymeters, or theodolites are rooted in precision mechanics, with components such as binoculars and the paths of light through lenses, prisms, mirrors, etc., delving into the optical aspects of physics. Recent innovations, such as tools that use electro-optic and electromagnetic waves, are also entirely products of the field of physics. In geodesy, a range of topics related to physics finds application, reflecting the interdisciplinary nature of cartography and its reliance on principles from the physical sciences (Şerbetçi, 1999).

Figure 1.

Scientific fields and applications of Geomatics Engineering (Source: Konecny (2002))



Physics also plays a fundamental role in remote sensing, which involves acquiring information about the Earth's surface without direct physical contact. Remote sensing relies on the interaction between electromagnetic radiation and the Earth's surface features. Key physics concepts in remote observation include the spectrum of light, interaction with the atmosphere, sensor technologies, radiative transfer models, scattering and absorption, and thermal infrared remote observation. Remote sensing systems function across the electromagnetic spectrum, from visible light to microwaves. Understanding how different wavelengths interact with the Earth's surface and atmosphere is essential. Principles of physics are applied to model atmospheric effects such as absorption, scattering, and reflection, which can distort received signals. Multispectral sensors employ filters to identify particular wavelengths, whereas hyperspectral sensors offer more intricate spectral details. Physics-based radiative transfer models are employed to simulate the interactions of electromagnetic radiation with the Earth's surface and atmosphere. Remote sensing enables scientists to extract valuable information about the Earth's surface, monitor environmental changes, and investigate the risks and impacts of natural disasters (Kutlug Sahin et al., 2017; Kavzoglu et al., 2017; 2021; Kavzoglu & Teke, 2022).

Geomatics Engineering for Sustainable Development Goals

In 2015, all United Nations Member States adopted the 2030 Agenda for Sustainable Development Goals (SDGs), a comprehensive framework consisting of 17 goals and 169 targets aimed at addressing critical global challenges, including poverty, inequality, climate change, environmental degradation, peace, and justice (https://sdgs.un.org/goals) (Figure 2). The discipline of Geomatics Engineering, steeped in a rich history, and its sub-branches, have played a significant role, both directly and indirectly from various perspectives, in contributing to the effective achievement of most of these goals through the production, processing, and interpretation of its primary output–geospatial data. An essential question arises: What is the role of Geomatics Engineering, encompassing remote sensing, GIS, and earth observation, in this overarching pursuit?

Figure 2.

17 Sustainable Development Goals (SDGs) proposed by the United Nations (Source: https://www.un.org/sustainabledevelopment/news/communications-material/)

Geomatics Engineering, with its focus on geospatial data, plays a crucial role in contributing to the achievement of SDG 2, which aims to create a world free of hunger. Leveraging technology to enhance food security and increase crop yield in all farming practices significantly contributes to global economic advancement. Small-scale agricultural operators, empowered by precision farming technologies, have the potential to generate sufficient income to support their livelihoods. Introducing advanced agricultural practices in developing countries can effectively reduce the proportion of the population living below the global poverty line. Wang et al. (2022) conducted comprehensive research that introduced an approach for assessing the localization of SDG 1 in China, using various sources of geospatial data. This approach provides valuable information for the effective implementation of the 2030 Agenda for Sustainable Development. Moreover, the quantitative assessment approach proposed in this study can serve as a benchmark for developing medium- and long-term sustainable development policies, such as rural revival strategies. Furthermore, *SDG 2* specifically targets the aspiration of achieving "Zero Hunger", standing out as directly addressing the crucial aspects of secure food supply and sustainable agriculture. Earth observation data have played a longstanding role in numerous applications within the agricultural domain, including but not limited to plant disease detection (Hasanaliyeva et al., 2022), crop yield estimation, and inventory mapping of particular plant species (Kavzoglu & Tonbul, 2017; Colkesen et al., 2023). Moreover, the assessment of land cover connectivity, a key indicator for ecosystem services, derived from the processing of this data, may reveal trade-offs with SDG 2 concerning food provision at the national scale (Cochran et al., 2020).

SDG 3 aims to "Good Health and Well-being", particularly highlighting ensuring the healthy lives of people and promoting well-being for all ages. Geospatial data also play a pivotal role in promoting this goal by contributing to various aspects of public health and well-being. The discipline facilitates natural disaster mitigation through early detection and monitoring, thereby providing pre-disaster early warning or post-disaster relief (Teke & Kavzoglu, 2024). Additionally, it supports air and water quality monitoring, aiding in the assessment of environmental factors that impact public health (Mehmood et al., 2020). Accessibility to public health facilities can be enhanced through spatial analysis, optimizing their locations based on population distribution and health needs. It should be underlined that GIS are used as a powerful tool for determining the extent of land and people in order to facilitate improved health care planning. The study undertaken by Som (2019) aims to evaluate the geographical accessibility of health services and examine their influence on infant mortality and fertility rates. Specially designed GIS can be employed to facilitate the daily activities of disabled people and transportation planning by integrating data from various sources and formats, such as environmental, census, traffic, land use and land cover and social data.

Geomatics Engineering is also instrumental in addressing *SDG 6* "Clean Water and Sanitation" by providing essential tools for effective water resource management. Remote sensing and earth observation technologies enable the monitoring and assessment of water bodies, identifying marine pollution sources and ensuring water quality (Kavzoglu & Goral, 2022; Dube et al., 2023; Sefercik et al., 2023). To achieve this objective, the integration of remotely sensed imagery (i.e., satellite and UAV imagery) with field survey data is being employed to generate up-to-date and cost-effective datasets for the purpose of monitoring water resources, particularly those used for water supply, in accordance with SDG6 (van den Homberg et al., 2020; Osiakwan et al., 2022). Also, GIS aids in the spatial analysis of water distribution and sanitation infrastructure, optimizing their planning and implementation. For instance, the study conducted by Wijesinghe et al. (2023) demonstrated that the utilization of GIS and geospatially based analysis enables the identification of possible groundwater zones and the generation of data that can aid in the development of a groundwater management plan. GNSS, especially Real Time Kinematic (RTK)-GNSS, contribute to the precise tracking of water-related activities, facilitating efficient resource management and the development of sustainable solutions for clean water and sanitation (Meron et al., 2022).

Geomatics Engineering contributes significantly to *SDG 11*, “Sustainable Cities and Communities”, by supporting the development of sustainable and resilient urban areas. Implementing SDG 11 is transformative since it focuses on the step-by-step advancement of urban planning, the intricate provision of public space, access to essential services, and transit infrastructure for the expanding population in this unpredictable digital era (Avtar et al., 2019). Remote sensing and GIS assist in urban planning, land use mapping, and infrastructure development. Specifically, the analysis of spatial and temporal data in the geospatial big data domain is necessary to advance sustainable development in urban areas (Chang et al., 2023). Earth observation data provide valuable insights into environmental changes, helping cities adapt to climate variations and mitigate potential risks. Therefore, prior to establishing potential policies, it is necessary to conduct land use land cover classification and continuous change detection of cities with dynamic structures to protect sustainable cities from the impacts of climate and environmental changes (Kavzoglu, 2008; Kelly-Fair et al., 2022; Ramadan et al., 2022; Asuquo Enoh et al., 2023). On the other hand, GNSS navigation services have diverse uses encompassing aircraft, ships, and vehicle navigation, mapping, disaster prevention and management, emergency service geolocation, security management, communications, and people and object tracking (Alahmari et al., 2023). Thus, GNSS technologies play an important role in urban mobility and transportation planning, ensuring efficient and sustainable connectivity within cities (Olabi et al., 2023). On the other hand, a robust waste management system involves the use of GPS to track waste collection trucks in real-time (Joshi et al., 2022). In the context of smart cities, the field also becomes a driving force in harnessing technology for urban innovation. The integration of advanced technologies, such as the Internet of Things and Artificial Intelligence, into GIS and remote sensing technologies enhances the efficiency and effectiveness of urban planning processes (Gupta & Degbelo, 2023). These technologies facilitate real-time data collection, enabling cities to respond dynamically to changing conditions and optimize resource allocation (Mondejar et al., 2021; Papadopoulou, 2021; Bachmann et al., 2022).

Geomatics Engineering can also greatly contribute to *SDG 13*, "Climate Action", by providing essential tools for monitoring and mitigating climate change impacts. Remote sensing and earth observation technologies contribute to climate modeling, monitoring deforestation, and assessing changes in land cover. Moreover, remote sensing technology has demonstrated its utility in enhancing the comprehension of vegetation reactions to climate change and can provide crucial data for the sustainable management of ecosystems (Yang et al., 2020). GIS facilitates the analysis of climate-related data, supporting informed decision-making for climate adaptation and resilience strategies. For example, the integration of GIS and remote sensing data in forest canopy estimation studies proves to be a valuable approach for evaluating forest quality criteria and developing efficient forest conservation/management strategies, particularly for SGD 13 (Fasil et al., 2022). GNSS technologies aid in tracking and understanding climate-related phenomena, enhancing the accuracy of climate change assessments, and promoting effective climate action. In short, due to advancements in geospatial technology, the field of studying environmental change has progressed significantly through the use of satellite-based techniques such as remote sensing, GNSS navigation, and GIS (Taloor et al., 2022).

Moreover, Geomatics Engineering supports *SDG 14*, "Life Below Water", by providing crucial data for the sustainable management of marine and coastal ecosystems. Remote sensing and earth observation technologies assist in monitoring marine biodiversity, identifying critical habitats, and detecting changes in coastal areas. To exemplify, researchers have used remote sensing techniques to create indices and track environmental stressors that impact the health of corals in marine ecosystems. Additionally, the open access MODIS images were obtained using the Google Earth Engine (GEE) platform, which is a cloud-based solution for geospatial research. In order to support the objectives of SDG 14, GEE was employed to identify areas susceptible to coral bleaching (Callejas et al., 2022). Another study highlighted that remote sensing observations can aid in accomplishing the objectives outlined in SDG 14, which notably prioritize the restoration, preservation, and sustainable administration of aquatic and marine ecosystems. These observations offer openly available data that are very detailed and cover a wide range of time and space (Kulk et al., 2021). On the other hand, GIS contributes to the spatial analysis of marine resources and habitats, aiding in the development of conservation and management strategies. The combination of remote sensing and GIS could be applied to benefit the coastal community. Satellite imagery can be employed to visualize various water quality parameters, while a GIS system is able to interpolate and evaluate the accuracy of these parameters at known water sampling points. This approach greatly contributes to sustainable coastal planning and the estimation of natural resource productivity at the local level (Misbari & Hashim, 2023). In addition, GNSS technologies play a significant role in tracking maritime activities, modeling underwater ecology and supporting sustainable fisheries management and maritime safety. The study performed by Vozza et al. (2023) utilizes affordable intelligent sensors to acquire bathymetric data, while employing GNSS technology for three-dimensional modeling of both natural and artificial underwater habitats. Also, GNSS is employed to boost real-time geolocation accuracy. Through these applications, Geomatics Engineering makes a significant contribution to research on the preservation of life below water.

Lastly, the discipline plays a vital role in achieving *SDG 15*, "Life on Land", by contributing to the conservation and sustainable use of terrestrial ecosystems. Remote sensing and earth observation technologies, in particular, assist in monitoring land use and cover changes, identifying deforestation trends, and assessing biodiversity. The utilization of remotely sensed data for examining the spatial and temporal patterns and alterations of diverse ecological resources has significant value in terms of both cost and time (Liu et al., 2019). GIS enable spatial analysis for habitat conservation and land use planning, supporting sustainable practices. Within the scope of SDG 15, by analyzing geospatial data, it can be observed that areas that have been degraded align with regions of human activity, such as urban centers. Additionally, the influence of natural events, such as catastrophes, on land degradation may be studied (Kavzoglu et al., 2018; Wang et al., 2020). On the other hand, GNSS technologies contribute to monitoring wildlife movements and tracking conservation efforts. The objective of GNSS applications is to investigate the challenges associated with the examination of natural formations such as valleys, the potential risks they present to agriculture and nearby villages, and the significance of monitoring erosion events in the valley for both the ecosystem and the local community. This monitoring can be enhanced by using GNSS and UAV imaging technologies for topographic analysis (Naş et al., 2021). Through these applications, Geomatics Engineering fosters biodiversity conservation and sustainable land management, promoting life on land.

Conclusions

In an era of growing global interconnection and complexity, the necessity for enhanced decision-making is paramount. Geomatics engineering is equipped with tools and technologies vital for extracting insights and knowledge that are crucial in supporting decision-making across various domains. The synergy between Geomatics Engineering and the basic sciences underscores the essence of education. This discipline not only benefits but also contributes significantly to the development of basic sciences. Through its applications, Geomatics Engineering breathes life into theoretical concepts, transcending the boundaries of classrooms and laboratories to actively shape the world we inhabit. It stands as a beacon of innovation that leverages technological advancements and scientific principles to address the SDGs of the United Nations. The field strives to advance state-of-the-art research across diverse fields by harnessing the primary end-product – geospatial data – obtained through technologies such as remote sensing, Earth observations, and GIS. The discipline goes beyond mere technological pursuits, engaging in interdisciplinary efforts to enhance our comprehension of human societies and their interconnected ecosystems. The ultimate goal is to effectively manage these systems and foster sustainable development and environmental conservation. This aligns seamlessly with ongoing global initiatives at various levels aimed at achieving the SDGs for the Agenda 2030 proposed by the United Nations. In this spirit, future studies may explore the integration of state-of-the-art technologies, including artificial intelligence, the internet of things, and computer vision, within Geomatics Engineering applications. Through these future-oriented strategies, it is aimed to substantially enhance livability within the SDG framework, introducing a novel phase of inventive advancements. In conclusion, the holistic approach of Geomatics Engineering, entwined with mathematics and basic sciences, is a catalyst for transformative change. Its contributions reverberate across disciplines, resonating in the pursuit of a more harmonious and sustainable planet, poised to meet the challenges and aspirations of generations to come.

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