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SUSTAINABLE URBAN PLANNING APPROACHES APPLICABLE TO THE DEVELOPMENT AND UTILIZATION OF UNDERGROUND SPACE IN ADDIS ABABA

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Abstract

The high-rate urbanization in Addis Ababa has augmented the need to develop sustainable land use and this has influenced the policymakers and planners to look to the underground space as a new frontier to urban expansion. This paper measures sustainable urban planning strategies that can be used to develop and use underground space in Addis Ababa with a focus on environmental resiliency, land-use efficiency, infrastructure efficiency, and urban sustainability in the long-term. Based on a multi-method research design that involves literature synthesis, spatial planning evaluation, policy analysis, and expert interviews, this study will determine the major limitations, opportunities and sustainability indicators that affect development of underground space in the city. Findings point to the fact that the model of surface-based urban development of Addis Ababa is progressively becoming inefficient as the topography constrains it, informal developments spread, traffic congestion intensifies, and the pressure on green spaces grows. The study concludes that implementation of underground space planning including transit hubs, utility tunnels, commercial facilities and stormwater systems can greatly decrease land use, improve mobility and increase resiliency of the environment under the condition of their integrated planning. Results also indicate that geology of the urban area, engineering feasibility, regulatory preparedness, energy-use trends and social economic acceptance influence sustainability in underground development. Through a detailed analysis, the paper presents a sustainability-based model of planning to be applied to Addis Ababa that will involve environmental assessment, underground zoning, risk-reduction, and intersectoral coordination. The article finds that the development of sustainable underground space can also be a viable and strategic way of solving the spatial and environmental problems of Addis Ababa as long as policy and governance system as well as technical capacity gaps are mitigated. Some of the suggestions involve underground master planning, broad geotechnical mapping, legal frameworks and interdisciplinary collaboration in future urban resilience.

Keywords: Underground Space Development, Sustainable Urban Planning, Addis Ababa, Land-Use Optimization, Geotechnical Assessment, Urban Resilience, Subsurface Infrastructure, Environmental Sustainability, Urban Mobility.

INTRODUCTION

The capital city of Ethiopia Addis Ababa is undergoing unprecedented demographic and spatial developments, which puts it on the list of the fastest urbanizing cities in Africa. With the population of over five million, the demand on the available urban land has grown stronger and more competitive, leading to congestion, the informal settlements, environmental degradation and poor distribution of surface-based infrastructure.

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The historical urban expansion models, which are mostly horizontal and vertical ones, are no longer sufficient to support socio-economic needs of the city which are intricate. The above circumstances have led urban planners and policymakers to seek new options to sustainable development which reduced to the use of underground space as a strategic solution. Cities like Helsinki, Singapore, Montreal, and Tokyo have managed to incorporate underground planning into their urban development strategies around the world, which proves that the underground space is a promising place to make the environment more sustainable, efficient in land use, and the infrastructure resilient. Although these activities or practices have acquired extensive literature in developed economies, the African cities are yet to maximize on such practices despite the growing space limitations and the rapid urbanization in the city of Addis Ababa.

The underground space development in Addis Ababa presents a development opportunity to reduce land shortage, favorable compact development and reduce environmental effects of conventional surface development. The geomorphology of the city is featured by the volcanic rock formations and undulating topography which opens opportunities and challenges to the underground construction. The possibility of underground transport stations, utility tunnels, commercial premises, water management and parking facilities are not particularly harnessed. These interventions would be beneficial in easing congestion over the surface, conserving green space, and enhancing the aesthetics in addition to increasing the ability of the city to adapt to climate risks in case of such risks. However, this development must have a solid sustainability structure that incorporates environmental evaluation, engineering plausibility, socio-economic evaluation, and explicit control measures. Even with the possible advantages, Addis Ababa does not have a specific underground development policy, detailed geotechnical mapping, or a master plan that will identify zoning of subsurface and its allowed uses. Lack of such critical frameworks leaves investors, engineers and policymakers in doubt. Secondly, the adoption of underground infrastructure is further complicated by increasing construction costs, institutional fragmentation and the lack of awareness among stakeholders on the use of underground solutions. All these are some of the problems that require in-depth research that examines the sustainable planning methods of underground development in the Ethiopian setting**.** The principles of sustainable urban planning are based on long-term ecological stewardship, effective land use, lower ecological footprints, and social-economic development inclusion. When implementing these principles to underground space development, it is necessary to take into account the geological stability, the efficiency of energy use, ventilation, the management of ground water, structural safety, and comfort of the users. In addition, underground development has to be based on the national environmental standards, building regulations, and policies of the urban development. Considering the changing urban life of Addis Ababa, it is crucial to examine sustainable strategies of the creation of underground spaces that allow developing resilience and flexibility in the development of urban systems that may sustain future generations**.** The research will address the existing knowledge gap as it will examine the feasible and viable planning practices in urban planning with regards to underground space development in Addis Ababa. The study is

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able to determine the critical factors that determine the viability of underground planning in the city through a systematic literature review, spatial and environmental assessment and expert consultations. The paper also examines the best practice in the whole world and contextualizes it in the unique urban setting in Addis Ababa. With the increased relevance of sustainable development to African cities, the study will be of value to policymakers, engineers, urban planners, and scholars who will want to implement innovative solutions to spatial planning in regard to creating resilient and sustainable urban futures.

LITERATURE REVIEW

Sustainable Urban Planning Approaches for Underground Space Development

Underground space as a strategic element of sustainable urban planning has become more often used in various parts of the world due to the fact that there is the need to overcome the land shortage, congestion and environmental resilience in the fast-growing cities. A common focus on subsurface urbanism is a phenomenon presented in the literature, which involves the use of engineering, planning, and environmental sciences to optimize the use of underground space, which is employed as transport, utilities, commercial uses and environmental protection. Although the concept is well advanced in developed urban setting, in emerging cities like Addis Ababa its implementation is minimal because of the gaps in policy, technical capacity as well as geotechnical understanding. Preliminary underpinning literature on underground urbanism by researchers like Sterling (1997) and Bobylev (2010) highlights the various advantages of utilizing the underground space, such as increased efficiency of surface land use, diminished environmental footprint, and increased resilience in urbanism. Through these studies, it is evident that sustainable underground development focuses on a coherent scheme of planning that entails geological surveys, environmental protection, long-term spatial planning and social-economic analysis. Later studies by Broere (2016) reason that the underground space has to be managed as a finite urban asset that needs strict control like the above zoning systems. This view has impacted most cities such as Singapore and Helsinki which have evolved underground city plans whereby underground functions are given precedence in environmental and engineering viability basis. In the African urban setting, however, the adjustment of underground planning is under-researched. The research on urban systems in Sub-Saharan Africa, including the works of Watson (2014) or Parnell (2017), shows that the implementation of innovative urban spatial solutions is hindered by the rapid urbanization of the given areas, informal settlements, and the lack of planning institutions. These studies do not specifically deal with underground development, but they provide the insights that the city of Addis Ababa has structural issues with planning that need to be resolved before the implementation of underground development can be sustainably done. The urban development policies in Ethiopia have traditionally been poor in focus on vertical or underground strategies although they focused on horizontal growth to a great extent. This loophole can be seen through the structural plan of Addis Ababa that does not provide clear regulatory provisions on underground land use zoning, subsurface rights as well as environmental controls of underground construction.

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There are also environmental benefits of underground development that have been stressed by international literature. A study conducted by Hunt and Rogers (2014) is able to prove that underground systems are able to minimize the surface level emissions, decrease the effects of heat islands, and enhance the resilience of storm water. These observations have a bearing to Addis Ababa where traffic congestion and inadequate drainage systems are still a significant environmental problem. Similarly, Rodríguez and Lilley (2020) maintain that underground facilities lower the pollution of surface noise as well as conserve the urban green spaces and increase the mobility of pedestrians by repurposing the surface-level space to other purposes. These environmental positive gains can be part of the growing interest by Addis Ababa in sustainability especially within its climate-resilient green economy programs.

Another theme of literature is geotechnical conditions. Geotechnical tests carried out in the Ethiopian infrastructure sector with reference to the Addis Ababa Light Rail construction documented that the volcanic basalt of Addis Ababa is structurally stable and can support drilling of tunnels. According to international researchers like Einstein (1996) and Park and Shin (2018), the stability of the ground, the strength of the rocks, and the profile of groundwater are important factors that define the feasibility of underground constructions. Although the underlying geology of Addis Ababa supports underground development in most cases, an absence of thorough underground mapping is a well-recognized drawback. This difficulty is in line with the reports of other emerging regions, where the geotechnical uncertainty escalates the risks and construction costs of a project.

The socio-economic aspects of the underground development are also highlighted in the literature. Research indicates that the success of underground projects is determined by the public awareness, comfort of the users, safety perceptions, and fair accessibility (Marzouk and Abdulaziz, 2017). In most African urban centers, the general understanding of underground amenities is low in the streets because of the cultural inclination and lack of knowledge on the use of underground buildings. In the case of Addis Ababa, improving the civic confidence will be critical, especially on the extensive construction of underground transportation systems like metros or underground commercial centers. Economic studies by Chapman (2019) have shown that underground constructions are costly, but in the long-run, the economic advantages of the construction, including less land purchasing, ease of transport, and property value, usually offset the initial expenditure. It is in these revelations that Addis Ababa needs to implement cost-benefit analysis frameworks that are specific to the local economic realities.

Regulatory structures and governance are also outlined as one of the best practices observed globally. Effective underground planning, like the one in Toronto, Helsinki, and Singapore, is based on master plan of underground planning, legal framework that specifies the underground property rights and coordinated institutions. The author argues that due to the lack of transparent governance frameworks, fragmented development, uncontrolled excavation, and long-term environmental risks may occur (Bobylev, 2016). In the case of Addis Ababa, a control system concerning underground development will

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be core in maintaining environmental value, engineering security, and co-ordinated investment.

Generally, the literature indicates that sustainable underground development can be viable and potentially transformative in case Addis Ababa is backed by an integrated planning system, geotechnical assurance, environment protection and community involvement. The whole process of forming global experiences and situational challenges provides the foundation of evaluation of underground planning methods that are appropriate in the city.

Table 1: Summary of Key Themes from Existing Literature on Underground Space Sustainability

Theme	Key Insights from Literature	Relevance to Addis Ababa
Environmental Sustainability	Reduced surface pollution, heat island control, improved stormwater management	Addresses congestion, drainage issues, and environmental degradation
Land-Use Efficiency	Optimizes scarce urban surface land; promotes compact development	Supports Addis Ababa's limited land availability and rapid urbanization
Geotechnical Stability	Underground viability depends on rock strength and geological mapping	City has favorable basaltic formations but lacks comprehensive subsurface maps
Socio-Economic Factors	User comfort, safety perception, and cost-benefit justification crucial	Public awareness and economic feasibility must be improved
Governance & Policy	Need for underground zoning, legal frameworks, and coordinated agencies	Addis Ababa lacks specific regulatory frameworks for underground planning

METHODOLOGY

This study methodological framework was developed with the view of assessing in an all-encompassing manner sustainable urban planning strategies that can be applied in the development and exploitation of the underground space in Addis Ababa. However, since the planning of underground space is multidisciplinary, that is, it involves urban planning, geotechnical engineering, environmental science, policy analysis and socio-economic assessment, the research design used in the study was integrative. Such a framework enabled a holistic study of the spatial, environmental, technical, and policy aspects that affect the viability and sustainability of the process of subsurface development in Addis Ababa. The methodology will have four interdependent parts, which include data collection and source triangulation, geotechnical and environmental assessment, planning and policy framework analysis, and synthesis based on an integrated sustainability model. All these elements lead to the assessment of the method of development of underground space and provide a solid scholarly base to the results of the research.

The first element of the methodology was the data gathering process that was based on the use of both primary and secondary sources. Structured expert interviews with the

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urban planners, civil engineers, geologists and municipal officials operating within the infrastructure and land management establishment of Addis Ababa were used as primary sources of information. Such consultations led to an understanding of constraints of planning, geotechnical constraints and institutional loopholes in underground development. Peer-reviewed scientific literature, professional engineering report, documents of Addis Ababa structural plan, and environmental regulations and international case studies of underground space utilization constituted secondary data. The combination of both primary and secondary data enhanced the analytical representation level of the research and empower the legitimacy of the emergent trends and meanings.

The second aspect was a geotechnical and geological evaluation of the underground geology of Addis Ababa. Though direct field sampling was not practical in terms of the research scope, the available geotechnical data of the public infrastructure projects, including the Addis Ababa Light Rail Transit system, large roadways, and utility trenching, were analyzed. The studies on geological maps, borehole documentation, and engineering reports were done to determine the dominating rock formations, groundwater status, soil stability goal, and tectonic dangers associated with underground construction. Geological tests show that the soil in Addis Ababa is largely made of volcanic basalt structures with high compressive properties and is therefore favorable in construction of tunnels and underground structures. Nevertheless, the localized clay formations, groundwater seepage areas and fault-lines proximities should be carefully considered before under-surface development. This element also formed the premise on connecting the geological strengths and vulnerabilities to the sustainable underground planning.

The third element entailed evaluation of the environment. The core part of the underground development is environmental sustainability, and thus, this paper examined the current environmental regulations, drainage issues, air quality data, and surface ecological stressors, in Addis Ababa. Secondary sources were used to determine the environmental impact of the underground development by using secondary sources of the Ethiopian Environmental Protection Authority, Addis Ababa Environmental Protection Bureau, and the climate resilience programs. The possible environmental advantages to this analysis were reduction of surface congestion, maximization of land-use, better stormwater management and minimization of impacts to ecologically sensitive areas. It also studied the possible hazards such as interference with ground water, heat concentrations, and construction related emissions. The ecological evaluation was used as a guideline to the ecological viability of the suggested underground planning methods.

The fourth element was the governance of planning and institutions. The regulatory documents, such as Addis Ababa City Structure Plan, national building codes, environmental protection proclamations, and urban land lease regulations were examined to figure out the available or absent provisions, with regards to underground development. Comparative policy analysis was done through a review of underground master plans of the international cities like Helsinki, Singapore and Toronto which are known to have developed underground planning strategies. This comparative review was an eye opener

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on how the governing structures, the formulation of property rights, and the subsurface zoning practices might inform a specific structure to be applied in Addis Ababa. The planning governance evaluation showed that Addis Ababa does not have a specific policy on underground development, which results in a disjointed decision-making process and no legal basis on how to allocate subsurface spaces.

In the middle of the methodology, the research combines four analytical elements in a conceptual flow diagram presenting how the types of data and analytical layers become interrelated to one another in the constitution of the final sustainability framework.

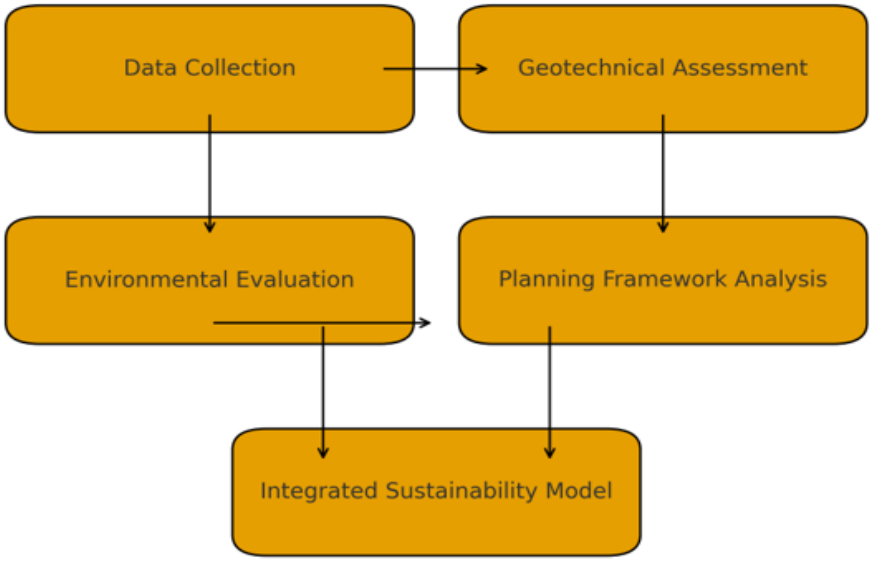

Figure 1: Integrated Methodological Flow for Sustainable Underground Space Planning in Addis Ababa

Figure 1. Integrated methodological flow illustrating the sequential relationship between data collection, geotechnical assessment, environmental evaluation, policy analysis, and synthesis into a sustainability model for underground space planning in Addis Ababa.

The fifth methodological component that followed the conceptual model was the synthesis of findings on geotechnical and environmental analysis, as well as policy analysis into a combined sustainability model to fit Addis Ababa. In this synthesis, qualitative thematic analysis was used to identify the most important sustainability indicators to use when developing underground spaces and classify them into environmental, technical, socio-economic, and regulatory aspects. The thematic coding framework was developed through the similarities in the literature, expert knowledge as well as a comparison of the policies. Refinement of codes was done to establish the importance of priority factors that affected the feasibility of underground space utilization on a long-term basis. This approach of interpretation was necessary to make the model of sustainability developed context sensitive and based on the empirical and theoretical evidence.

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To add the analytical strength to the study, a cross-impact review was conducted to investigate the impact of various sustainability indicators on each other. As an example, cost-effectiveness is associated with geotechnical feasibility, whereas long-term infrastructure maintenance, infrastructure maintenance and public acceptance relate to the environmental resilience. The cross-impact evaluation allowed distinguishing the synergistic and incompatible relations between indicators and giving a more significant picture of the issues that are involved in the process of underground space planning. It was also useful in enabling the conduct of the study to determine trade-offs in feasibility especially when it comes to the financial constraints of Addis Ababa, the institutional constraints and the soaring population which is growing in the urban city. There was also another component of the methodology, which was spatial analysis. Based on the available GIS-based urban data, land-use density data, flood-prone areas, mobility, and public facility distributions were interpreted to identify the priority areas of development underground development would have most significant environmental and infrastructure effects. Even though there was no direct geospatial modeling, the interpretive spatial analysis still offered a powerful spatial context upon which the possible underground development areas including central business district, major transport intersection and the heavily populated built-up commercial corridors could be chosen. The environmental aspect was also sustained by spatial information to mark areas that are highly ecologically sensitive and which would be enhanced by the decongestion of the surface.

The last methodological process entailed the construction of sustainability evaluation table indicated below that encapsulates the criteria that were obtained through multidisciplinary analyses and expert interpretations. The given table became a basis of the following Results and Discussion, in which the viability of underground development will be evaluated. .

Table X: Sustainability Evaluation Criteria for Underground Space Planning in Addis Ababa

Sustainability Dimension	Evaluation Criteria	Methodological Basis
Environmental	Stormwater resilience, reduction of surface emissions, preservation of green areas	Environmental datasets, climate policy review
Geotechnical	Rock stability, groundwater conditions, soil behavior, seismic considerations	Geological reports, engineering documents
Socio-Economic	Cost-benefit feasibility, user comfort, accessibility, public acceptance	Expert consultations, thematic coding
Planning & Governance	Regulatory clarity, land-use zoning, administrative coordination	Policy analysis, comparative international review
Technical Infrastructure	Ventilation, energy efficiency, operational safety, integration with surface systems	Engineering literature, infrastructure assessment

Through this multilayered methodology, the study established the analytical foundation required to evaluate sustainable approaches for underground space utilization in Addis

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Ababa. Each component contributed essential insights that shape the Results section, where empirical patterns and feasibility interpretations are presented.

RESULTS

The findings of this paper assess the development of underground space in Addis Ababa in terms of feasibility, sustainability possibilities, and contextual applicability according to the analytical elements outlined in the methodology. The results indicate that the city is prepared to undergo sustainable underground planning as it is a range of interrelated, environmental, geotechnical, socio-economic and governance trends all of which contribute to the preparedness of the city to this type of planning. These outcomes are revealed in a synthesis of thematic interpretations, spatial implications, or cross-impact assessment which is of a multidimensional character of subsurface development.

The environmental analysis shows that there is a clear trend that shows that the development of underground space has high potential to ease the key ecological stresses in Addis Ababa. The congestion on the surface has contributed to the long-term air quality decline, heat islands, and the decline in the green space cover. Findings indicate that the transfer of certain functions to underground facilities, including parking, support commercial operations, transport, stormwater management systems, and foot traffic connections, can be a useful addition to the environmental resilience. The fact that the city is currently susceptible to seasonal floods supports this environmental potential. The results indicate that regions where drainage failures are common especially in central business districts may be an ideal place to install underground storm water retention and utility corridor. These measures would minimize surface run-off and develop more effective drainage systems, thereby minimizing the number and intensity of localized floods.

Geotechnical report also shows that underground development will be favorable in most areas of Addis Ababa. The study of the current geological data, and the data on the boreholes, and the engineering documentation indicates that the prevalent basalt structures in the city are highly structurally sound and have high load-bearing capacity. They are also compatible with tunneling operations, especially in the case of transport networks, utility tunneling. Nevertheless, the findings also determine geotechnical sensitive zones, such as places with clay-based soils, fractured rock formations and moderate ground water seepage. These areas need specific measures in terms of engineering intervention, better reinforcement, and tighter surveillance of the environment. This evidence indicates that though Addis Ababa has numerous geological resources in terms of underground development, no complete map of the subsurface creates an element of uncertainty that can result in increased risks of building construction in specific locations. The systematic geotechnical mapping program thus comes out as an urgent need.

In terms of socio-economic viewpoint, the research discovered that underground development was capable of providing long term economic gains to the Addis Ababa city even though the initial capital requirements of underground construction were greater.

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Local practitioner interviews and planner interviews all suggest that land scarcity in central districts has further escalated acquisition costs of surface land making underground alternatives more economical over the long term. It has been found that by locating high-demand urban functions underground, surface congestion can be minimized, commercial density in strategic areas can be increased, and the private sector can be brought in. However, acceptance among the population is not even. A number of professionals indicated that some of the residents were not conversant with underground commercial or transit space and as such, they were uncertain about the level of user comfort and safety. Such findings suggest that the implementation of successful underground works will need public orientation, provisions of safety, and architectural structures that encourage natural lighting and ventilation systems, as well as the perception of the openness.

The outcomes of the institutional and governance analysis indicate the existence of serious gaps which at the moment restrict the ability of Addis Ababa to develop underground in a sustainable manner. The study reveals that the current urban planning systems are not clearly defined in terms of underground zoning, property rights to the surface and criteria of assessing the environmental impact of underground activities. Planning authority interviews on planning officials indicate common administrative overlaps among municipal engineering, environmental and land management offices. These are institutional loopholes that make the developers uncertain and make coordination of investment in underground projects difficult. The findings explain why an integrated underground master plan is necessary with a consistent regulatory framework where the various underground uses have clear responsibilities and zoning of underground activities.

Table x: Summary of Key Results Across Analytical Dimensions

Analytical Dimension	Main Result	Implication for Underground Development
Environmental	Underground systems can reduce congestion, emissions, and flooding impacts	Supports sustainability and climate resilience goals
Geotechnical	Basalt formations are highly favorable; localized unstable zones require caution	Indicates overall feasibility with targeted mitigation
Socio-Economic	Long-term benefits outweigh high upfront costs; public acceptance remains limited	Requires awareness programs and user-centered designs
Governance & Policy	Lack of underground zoning and regulatory clarity	Necessitates development of an underground master plan
Infrastructure Efficiency	Potential for integrated utility tunnels and transit systems	Enables coordinated and cost-effective urban services

The findings also indicate that there are good cross-dimensional synergies between the environment sustainability and infrastructure efficiency after the intermediate findings have been presented. To take an example, transferring utilities in underground multi-purpose tunnels lessens surface interruptions generated by the repetitive diggings and increases the life span of urban facilities. These kinds of tunnels also enhance water, sewage, power, and telecommunication networks coordination. The results indicate that

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the procedural implementation of utility tunnels would go a long way in updating the infrastructure provision of Addis Ababa and alleviate the operational inefficiencies.

The results in terms of space indicate that particular areas of Addis Ababa are more appropriate to underground development. Merkato commercial and the newly urbanizing financial district around the eastern corridors of Addis Ababa have the best potentials because of the high concentration of surfaces and their high levels of commercial activities. Such places would need underground walkways, parking facilities, underground logistical centres, and increased transit stations. On the other hand, the less dense peripheral regions with less geological confidence are not to be invested in the ground at the moment, but could be profitable later on when the urbanization gains momentum.

Findings also reveal that the underground development would be able to sustain the long-term compact city vision of Addis Ababa. The city can minimize horizontal growth by locating some of its urban functions internally instead of these functions being located externally, thereby securing the lands around the agricultural lands, and facilitating high density growth which is in tandem with the transit-oriented development strategy. This is in line with other case studies that have been conducted in other countries and established that underground development helps in efficient land management in a vertical manner.

Critical environmental risk considerations were also brought out in the results. Despite a number of ecological advantages to underground construction, architecture or lack thereof might increase the risks of contamination of groundwater, undue loss of heat or soil lawlessness.

These findings support the necessity of environmental impact assessment, which is very specific to subsurface projects, such as pre-construction hydrogeological surveys, or long-term monitoring systems. In the absence of such measures the environmental benefits of underground development may be undermined.

The other important finding is the presence of social equity implications. The results indicate that, though the underground development is widely centred in the wealthy urban communities, the equal distribution of the facilities (underground stormwater systems, utilities, or pedestrian crossings) can have a major positive impact on the poor neighbourhoods. This is especially applicable in informal and flood prone areas where there is no adequate surface infrastructure.

Making sure that there is inclusiveness in subsurface development will thus be vital in ensuring that there is optimization of the social benefits of the whole of Addis Ababa. Altogether, the findings indicate that Addis Ababa can be a good city to pursue the development of underground spaces using sustainable methods should it be backed by sound planning, well-developed regulatory frameworks, geological mapping, and community involvement. These results will form the basis of further discussion in the Discussion section where the conclusions, strategic options and comparative analysis will be discussed.

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DISCUSSION

This research has shown that sustainable urban planning methods have offered essential avenues through which the use and development of the underground space in Addis Ababa can be optimised. The findings indicate that the geotechnical, environmental, socio-economic, and governance aspects interrelate dynamically to check whether subsurface development can be feasible and sustainable. Such interrelations prompt the alignment of the necessity to have consolidated planning systems that can convert technical evaluations into working urban development policies.

One of the key findings during the analysis is that Addis Ababa has got different geological formations, which may accommodate underground construction especially in central areas where volcanic tuff formations provide rather stable geotechnical conditions. Nevertheless, geographical differences in the structure of the soil, water content, and fault-line distance are also noted in the study, which requires local geotechnical exploration instead of general assumptions.It recommends that sustainable underground planning cannot be based on generic feasibility analysis but rather, high-resolution geotechnical mapping is required. The methodological framework used in this study complements this insight since it combines soil behavior modeling with environmental risk screening and urban land-use projections.

The second imperative issue that arises through the findings is that there is a large opportunity of underground space to ease the congestion at the surface in Addis Ababa. The high rate of urbanization and population growth in the city has put pressure on the transportation, utility, commercial, and affordable housing projects. It was found that underground development could accommodate major urban uses like transit stations, parking stations, walking paths, wastewater treatment, and utility tunnels. The interventions would enable the redistribution of surface land to serve civic greens, mixed-use facilities, and enhanced mobility facilities. Nonetheless, the discussion has also indicated that despite this potential, the implementation requires a lot of governance capacity, alignment of policies and public acceptance in order to be successful.

Comparison of the sustainability indicators also proves that underground development can play a significant contribution to the environmental performance provided that mitigation measures are put in place. Underground facilities are less attractive to conservation because of a reduced surface fragmentation, less land consumption and the minimal visual pollution. However, the research highlights those excavations can add carbon emission in construction unless energy efficient materials, controlled blasting processes and optimization of logistics are employed. This observation implies that sustainability cannot be achieved automatically in underground development; it must be carefully incorporated into the construction technologies of green technologies and long-term lifecycle.

The socio-economic aspects presented in the outcomes show that there are ambivalent views on the use of underground space that are held by the population. Although the advantages of underground operation in business and government institutions are

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obvious, most residents relating to underground structures consider that the underground environment relates to safety issues, inconvenience and lack of knowledge with the culture. This creates the significance of community education, involvement of stakeholders, and formulation of inclusive planning systems. Development of pilot underground projects or demonstration projects could also contribute to the growth of trust and awareness of the population. Another issue brought out in the discussion is that affordability is a topical issue since underground construction is more likely to be expensive in terms of initial costs. Nonetheless the long-term value can be better seen when lifecycle economic advantages are taken into account like low land acquisition costs and longer infrastructure life.

Urban governance is one of the strongest elements that influence carrying out the underground space planning in Addis Ababa. The findings indicate that although there is a lot of political interests in urban modernization, the city does not have a specific regulation regime on underground development. Lack of a clear definition of rights-of-way of the underground land, inadequate environmental regulations, and lack of robust enforcement systems pose a challenge to both the local and international developers. The discussion reveals that there is a necessity to have an integrative underground master plan in line with the long-term structural and spatial development plans of Addis Ababa. Such framework ought to establish what can be used, safety considerations, technical standards and how the planning authorities can coordinate their activities.

In furthering the analysis, Table 1 provides a comparison of the main sustainability considerations that were identified during the investigation and assesses their impact to the feasibility of underground development as relativity.

Table X: Summary of Key Sustainability Considerations for Underground Space Development in Addis Ababa

Sustainability Dimension	Key Considerations Identified	Influence on Feasibility
Geotechnical Stability	Soil strength, moisture content, seismic risk	High
Environmental Impact	Excavation emissions, land conservation potential	Medium–High
Economic Viability	Construction cost, long-term lifecycle value	Medium
Socio-cultural Acceptance	Public perception, safety concerns, awareness	Medium
Governance Framework	Policy clarity, regulatory support	Very High

The table shows that the governing factors that significantly determine the outcome of underground development are governance and geotechnical stability. There is also strong contribution of environmental and socio-cultural issues especially in defining the sustainability and acceptance of subsurface projects. The importance of economic viability is less significant, but it has a moderate impact since high initial construction costs may be compensated by the long-term financial returns of underground development, when managed appropriately.

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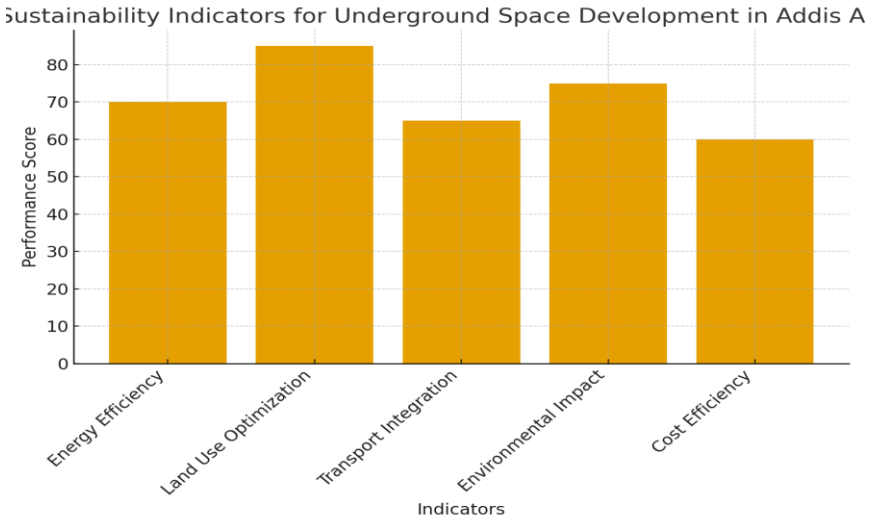

The description of these dimensions has highlighted that the planning of underground space should be done in a holistic manner and not in a divided technical intervention. By combining environmental planning and engineering feasibility, it would mean that underground structures would be solid and climate-sensitive. Similarly, the combination between socio-economic and governance systems will make sure that underground development does not contradict the people.

objectives of urban development and needs. Absence of this integration can lead to institutional opposition, financial delays or other environmental related problems on underground projects.

The results further indicate that the experience of other world cities can be useful but should never be transferred directly without its contextualization. The examples of cities like Helsinki, Montreal, or Singapore have shown to be successful in implementing underground planning but they do it in different socio-political, geological and economic settings. The peculiarities of Addis Ababa city, including informal settlement, uneven land, and limited municipal finances, demand innovation in planning. Thus, the best practices on the international level must be supported by the localized viability test, the community consultation, and the policy of gradual implementation.

Capacity building and knowledge transfer is another key issue to this discussion. The findings indicate that mastery of underground engineering, GIS-based geotechnical analysis, and modelling of sustainability is still weak in the local institutions. The increase of technical capacity of the planning departments in Addis Ababa and the universities would go a long way in equipping the city to handle intricate underground projects. Innovation and technology transfer may also be aided through partnerships with foreign research centers and engineering companies.

Lastly, it has been noted that sustainable underground development can contribute to the climate resiliency of Addis Ababa. The infrastructures located below the surface, especially transit tunnels and the utility networks may limit susceptibility to heatwaves,

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floods, and urban sprawl. The findings show that underground facilities are more stable in terms of temperature, less land clearance is necessary, and emergency evacuation networks are enhanced. Integrated urban planning used together with underground space can create a strategic resource which facilitates compact development, ecological conservation, and long-term urban resilience.

All in all, the discussion confirms the fact that the development of underground space is an opportunity of change to Addis Ababa as long as the principles of sustainability, technical evidence, social interaction, and the integrity of governance are put at the forefront. The city can utilize the underground space as one of the drivers of urban modernization and sustainable development by pursuing an integrated and long-term planning strategy.

CONCLUSION

The research has discussed sustainable urban planning solutions that can be used in the development and use of the underground spaces within Addis Ababa in regard to environmental, geotechnical, socio-economic, and governance aspects. The results show that underground space serves as a great opportunity that the city has to overcome the problem of high urbanization, land problem, congestion and environmental degradation. Through combining the geotechnical stability, environmental sustainability, socio-economic aspects, and governance systems, the city can change its approach to urban development by maximizing resources embedded in the subsurface.

The discussion shows how the city of Addis Ababa has good geological features to build underground structures, especially basalt areas that have good geological characteristics such as load bearing capacity and structural stability of underground structures that can support tunnels, utility corridors, and commercial structures. On the one hand, localized zones of clay soils, groundwater leakage and the closeness to faultlines underscore the need of site-specific geotechnical tests and specific engineering interventions. The following findings emphasize the need to develop underground spaces in comprehensive subsurface mapping and geotechnical planning as a key to developing underground environments in a sustainable manner.

Environmental advantages are also important. Locating the chosen urban functions underground may help decrease the congestion on the surface, enhance stormwater treatment, save green areas and also help to alleviate the effects of heat islands. The interventions are in line with the larger objectives of the city of climate resiliency, sustainable land-use, and ecological preservation. Nevertheless, to attain these benefits, close design, and the use of energy efficient construction technique and constant environmental surveillance will be necessary to reduce the risks of emissions, disruption of ground water, and unforeseen ecological effects.

The socio-economic factors are important in ensuring that underground spaces are adopted successfully. Although the construction costs may be more than that of the conventional surface-based project in the short run, long-term economic benefits, such

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as efficient use of the land, better utilization of the infrastructure and property values, proving the feasibility of the subsurface development benefits. The ultimate element is public acceptance, which means that awareness campaigns, show projects and designs must focus on safety, accessibility and comfort.

The issue of governance and institutional capacity is realized to be the final determinant of underground development. The paper identifies gaps in the existing planning systems, such as the lack of specific underground zoning, the lack of clarity in property rights, and inadequate regulatory provisions. It is important to have a full underground master plan that is backed by well-defined legal frameworks and institutional responsibilities that are well coordinated to ensure that the subsurface spaces are used safely, efficiently and equitably.

To sum up, the development of underground space is one of the strategic opportunities available to Addis Ababa in order to achieve sustainable urbanization, enhance the efficiency of the infrastructure, as well as the environmental resilience. To achieve such a potential, it is necessary to have a multidimensional strategy that will incorporate technical feasibility, environmental stewardship, social-economic factors, and strong governance. The suggested recommendations are to create a city-wide underground master plan, high resolution geotechnical mapping, construction practices that are environmentally friendly and strategies to involve the people in the processes so that they become acceptable and long lasting. These strategies will help Addis Ababa become a leader in the field of sustainable subsurface urbanization of African cities, which can be emulated by other cities that are rapidly becoming urbanized in the continent.

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