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Urban Underground Future: The Potential of Subsurface Utilization in Nairobi, Kenya.

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Abstract. Rapid urbanization in Nairobi city is exerting pressure on the existing infrastructure and resources such as parking areas, the natural environment, fresh water supplies, roads, sewerage networks, communication lines, power lines and the overall quality of life of city dwellers. Whilst such association is vital, the city needs a new frontier that could provide significant contribution to future spatial requirements as an essential part of improving the quality of the urban environment. Nairobi has long enjoyed being a hub of finance and culture in the East African region. It has high land values, clear and coherent legislation for surface solutions but lacks clear rules and standards for underground construction. The main aim of this study was to identify the main problems risking both the functionality and quality of life in Nairobi city and to explore the various approaches to development, planning, geology, policies and projects being delivered and considered globally focusing on the need for good and professional planning of underground space. The research was carried out in Nairobi. The study was designed as a survey that started with a desk study followed by semi structured interviews using an interview schedule. The findings show that underground space provides a strategic solution by providing an additional spatial and service layer for transportation and utility infrastructure freeing up surface space which can be used more efficiently and effectively. This has the potential to improve accessibility, safety, the competitiveness of cities and the overall quality of life of the city dwellers. However, this comes at huge initial costs but lower lifecycle costs. This paper concludes that underground space can contribute to making the city sustainable, more resilient and cope with rapid urbanization. The paper recommends that in the not too distant future, the implementation of underground facilities should be considered equally as valuable as surface solutions in Nairobi, Kenya.

Keywords: Urbanization, Underground Urbanism, Geology, Planning, Sustainable Development.

1 Introduction

Today, 55% of the world's population lives in urban areas, this proportion is expected to increase to 68% by 2050. Studies show that urbanization, the gradual shift in residence of the human population from rural to urban areas, combined with the overall growth of the world's population could add another 2.5 billion people to urban areas by 2050, with close to 90% of this increase taking place in Asia and Africa [1].

More than half of the global population growth between now and 2100 is expected to occur in Africa [2]. In 2017, the urban population growth rate for Kenya was 26.6%, this was an increase from 9.5% in 1968. This shows that that the average annual urban population growth rate in Kenya is 2.12%. Nairobi, which is the Kenya's largest city by population, has over 6.5 million residents, the number is expected to rise to 8.5 million by 2035 [3]. From the foregoing, Nairobi city will need to meet the increased demand for infrastructure. With the lack of an adequate and efficient infrastructure, Nairobi city will sprawl away from the urban core which will strain the environment by creating more traffic congestion and travel time, loss of valuable farmland and unbalanced allocation of resources [4].

The construction of sustainable urban areas which can survive a huge population growth rate, natural disasters and the effects of climate change through urban resilience building is critical for urban planning and engineering in Nairobi. The urban underground contains a large intact potential that, if correctly managed and used, would contribute considerably to the urban sustainable development [5]. This paper explores the best practices of designing and planning underground spaces for the achievement of a sustainable urban development and the creation of a resilient city.

While the history of underground construction dates back centuries, evolution of technology and construction methods has expanded its horizons. A vision once reserved for transport, storage and utility solutions has grown to encompass limitless possibilities for future development, fueled by necessity in many cases [6].

2 Background

Humans first used underground space as shelter and food storage, they resided in underground spaces such as caves for protection from harsh weather conditions and wild animals. In 4000 BC, people lived in semi-underground pit dwellings [7]. Urban services such as drainage and water supply, can be traced back to the ancient Babylonians who constructed water supply tunnels in about 2500 BC and to the Romans who had well developed water and sewerage systems. Wherever civilization flourished, people found a use for underground space [5].

During the industrial revolution, tunnels were developed to facilitate transportation in Western Europe. The relatively flat grades requirements of canals and railways increased the use of tunnels in the 19th century. As excavation techniques evolved and became more reliable, underground transport systems became more extensive [8]. Urbanization followed the industrial revolution and major cities of the world such as London, Paris and New York turned to subways to manage their congested traffic, with the first subway system being opened in London in 1863 [9].

Globally, underground space has continually become more attractive for development. The reasons sometimes differ among the countries but one major similarity is that the use of underground space is a means for achieving quality aspects such as an improved environment [10]. In countries like Japan and Italy, geographical conditions are some of the factors that make the use of underground space important. Extreme weather conditions in countries like Australia and Canada has led to an increase in the use of underground space for safety reasons. The city of Montreal, Canada has underground streets that also reduce traffic congestion, parking demands and air pollution, this is similar to big cities in Germany, France and Britain

[11]. In this context, underground development offers a feasible, long-term solution for Nairobi in line with sustainable development principles.

3 Methods

An inductive qualitative approach was used to provide for an enhanced understanding of the use of underground space in the global context. An interpretivist research philosophy was also adopted and since there was no prior hypothesis to be tested, an exploratory study was used to inform the research. Literature review was conducted to examine the definition, concepts, application and all related issues of the use of underground spaces. Exploratory interviews were conducted to collect data from the perspectives of purposefully sampled construction industry players (The Government, Urban planners, Project Managers, Architects and Engineers) in Nairobi, Kenya. 12 semi-structured face to face interviews were conducted over a 1-month period. An interview guide was used to collect data for the fulfillment of the research objectives. Materials from pervious desk studies were used to prepare for the interviews, all interviews were approximately 1 hour in length for each respondent. The data was then analyzed by the authors using the technique of context mapping.

4 Findings

The main aim of this study was to identify the main problems risking both the functionality and quality of life in Nairobi city and to explore the various approaches to development, planning, geology, policies and projects being delivered and considered globally focusing on the need for good and professional planning of underground space. The findings show that the major challenges for Nairobi as an urban area are transportation, water supply and sanitation.

4.1 The Case of Urban Transportation

Public transportation is an essential service and is very vital in the development of Kenya in line with vision 2030 and the millennium development goals. In Nairobi, majority of the population use the public transport since they do not own automobiles, this is because 60% of the residents live on less than 2 dollars a day in informal settlements [3]. The findings show that the main causes of urban public transport problems in Nairobi are rapid urbanization, inadequacy of the transport infrastructural facilities and high concentration of economic activities within the central business district, Westlands, Upper hill and Industrial areas of the city resulting in huge volumes of people and goods movements that become difficult to accommodate efficiently. As a result, this imposes an annual cost of Kenyan Shillings 40 billion o the economy. This is attributed to poor planning which includes construction of bypass roads that divert traffic from the city center, expanded feeder roads and reduced junctions which only create bottlenecks in parts of the city, for example, Pangani and serve as short term solutions.

From the foregoing, the only viable solution is underground mass transit systems. Globally, metros are considered a necessary and indispensable part of every large city's transit network. There are more than 12,000 km of metro lines providing services to over 150 cities around the world [12].

4.2 Infrastructure

Today, Nairobi has a huge requirement in terms of infrastructure which includes but is not limited to energy, telecommunications, water supply and waste management. The sustainability goals of the city can only be achieved if the infrastructure is placed in the underground space. The findings from the study indicate that Nairobi is trying to utilize underground space for fresh water collection from Murangá using the Northern collector tunnel of which the construction is ongoing at a cost of Kenya shillings 6.3 billion, the Kenya power electricity supplying company is building underground cables at a cost of Kenya shillings 13 billion, this is aimed at increasing power reliability, the city has been running sewer improvement programs aimed at upgrading underground sewer infrastructure and Safaricom, a telecommunication company has laid underground fibre-optic cables reaching thousands of homes in Nairobi.

However, the absence of an integrated land use plan for the underground space can result in significant problems. As stated by Kaliampakos [12], the "spaghetti subsurface" problem compromises subsurface future utilization and utility tunnels are an efficient solution to it. The tunnels are meant to host a range of urban services and different cable links. This has many advantages such as centralized operational control, increased durability of utilities, enhanced safety, easier maintenance and repairs which is done without any interference with the city environment and traffic. All expenses can be mutually divided to all the services providers involved in the project.

From the foregoing, subsurface utilization should be based on the principles of sustainable development aiming to minimize environmental hazards, saving energy, increasing the functional diversity of the urban structure, reducing the need for local transportation, making services more accessible to residents and protecting the urban landscape and culture. However, underground development is not an end in itself. It must be viewed as a means of achieving strategic objectives of the government [10]. Below is a brief SWOT analysis of building underground in the Kenyan context.

Strengths	**Weaknesses**
• Allows for a compact urban structure • The underground streets improve efficiency for the city's infrastructure services • Reduces pollution	• Connections with the above ground traffic may be challenging to arrange • High initial costs • Prejudice against underground solutions

• Improves safety • Helps protect the natural landscape • Protects the townscape and cultural heritage of citied • Saves time for the residents • Reduces operational and maintenance costs for the town infrastructure	• Geological limitations in some locations • Job satisfaction of the workers is lower because of the lack of windows and sunlight
Opportunities • Formulation of underground planning policies • Job opportunities in underground construction • Formulation of an underground legal framework • Freeing up above ground space for other uses	**Threats** • Unclear legal provisions regarding underground construction • Planning policies are only focused on above ground activities • lack of integrated decision making procedures for underground space • Unfamiliarity with the possibilities of underground construction

Figure 1: Underground construction in Nairobi, Kenya - SWOT analysis (Source: Authors).

4.3 Planning for Underground Space Use in Nairobi

As Nairobi looks forward towards a sustainable future, planners have to look for various ways to allow for economic growth while preserving the natural environment. However, underground development can only be realized if its socially and politically acceptable, economically viable and legally possible [13]. On the other hand, planning, zoning and building code regulations and standard forms of contracts do not necessarily reflect the nature of underground projects and they should be revised to reflect as such. Underground space can be divided into a number of different categories according to the user requirements.

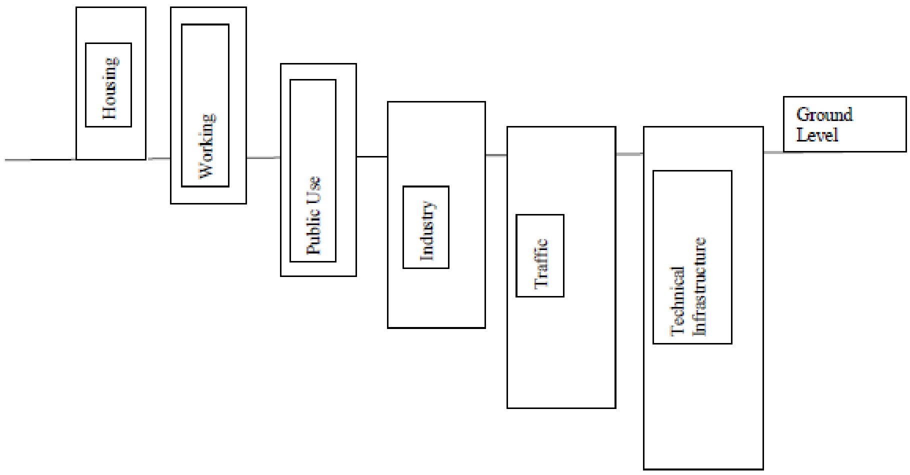

Figure 2: Feasible Depths of different activities in the urban structures (Source: [14]).

From the figure above, housing, working and public use should focus more on surface development with underground space being developed only for parking's, storage and service facilities. However, for the industry, traffic and infrastructure, underground space plays a major role in maximizing land use. Therefore, in developing the underground space in Nairobi, a holistic approach has to be promoted which not only considers the geological and environmental effects but also the economic, political and social acceptability of the underground developments. The rural to urban migration is an important factor in the developing Kenyan economy and the major goal should be to keep the growing Nairobi city functioning. Whilst this study is far from exhaustive, it shows that underground space should be considered in future developments of Nairobi city and cooperation between urban planners, engineers, architects and all the stakeholders in the city is required to exploit the potential of the societal and spatial asset.

4.4 Engineering by Substraction

Nairobi city is mainly underlain by plyroclastic volcanic rocks that were deposited during the formation of the East African Rift Valley [15]. The city also has several spots of sensitive soils and variable ground profiles. Many borings and trial pits beneath and around building sites show that the thickness of the soft and sensitive deposits varies from 0.8 to 21 meters below the ground surface [16].

In any underground project, ground water is a prime factor in its successful development and use, this is since ground water pressure and inflow affects the stability of excavation faces and the strength of the support structures required. In Nairobi city, ground water levels vary considerably with surface topography and season and lie between 0.5 to 18 meters below the ground surface [16]. The variability of engineering properties of the subsurface materials in Nairobi calls for thorough geotechnical investigations before designing any underground structures.

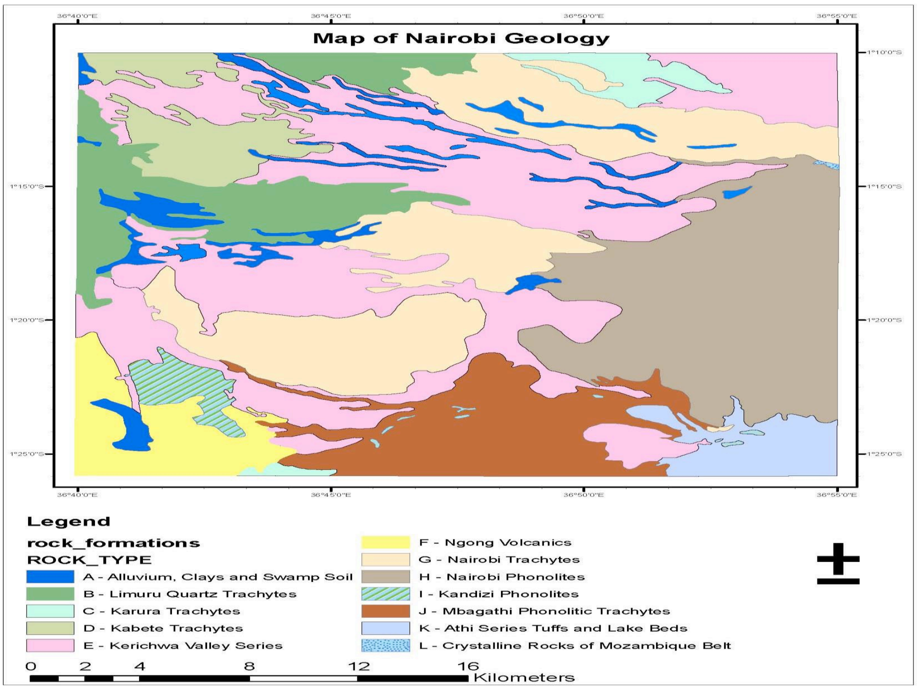

Figure 3: Geological Map of Nairobi City (Source: [16].

From the foregoing, a three-dimensional soil and rock structure data system should be developed and integrated into the city's Geographical Information System (GIS), this will assist in underground master planning of the city. The development of a better knowledge and representation of the geological medium and of existing underground structures is a critical need for Nairobi.

4.5 The Case of Urban Transportation

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5 Conclusions

Urban underground space can contribute to making Nairobi city more resilient and cope with rapid urbanization. A displinary approach is required to make this a reality by coordinating the different interests and needs for building under the city, improving the legislative and administrative regulations. Placement of infrastructure and other facilities underground presents an opportunity for realizing new functions in urban areas without destroying heritages or negatively impacting the surface environment.

References

1. W. Broere, “Urban underground space: Solving the problems of today’s cities,” *Tunn. Undergr. Sp. Technol.*, vol. 55, pp. 245–248, 2016.
2. 林伸行, “病院・介護施設におけるノロウイルス感染症の拡大防止対策を目的とした吐物の飛散状況に関する研究No Title,” 感染症誌, vol. 91, pp. 399–404, 2017.
3. UNFPA, “Kenya - Population,” *Unfpa*, pp. 3–5, 2014.
4. L. Huanqing, “An Integrated Strategy for Sustainable Underground Urbanization,” *[PhD Thesis]*, vol. 5869, p. 250, 2013.
5. M. Montazerolhodjah, M. Pourjafar, and A. Taghvaee, “Sustainable Development Urban underground development ; an overview of historical underground cities in Iran,” vol. 25, no. 1, 2015.
6. D. V. L. Hunt, D. Nash, and C. D. F. Rogers, “Sustainable utility placement via Multi-Utility Tunnels,” *Tunn. Undergr. Sp. Technol.*, vol. 39, pp. 15–26, 2014.
7. H. A. Heba, A. Aly, Y. Akashi, T. Arima, and D. Sumiyoshi, “The Possibility of Applying the Earth-Sheltered Building Type for Housing Projects between Humid and Dry Climates - Case Study Egypt and Japan -,” *Int. Soc. Habitat Eng. Des. Conf. ISHED*, p. 8, 2012.
8. G. T. T. Granny, “Urban Underground Space Design,” p. 256, 1997.
9. F. A. Dhabi, H. Kong, A. Foss, and C. Metro, “Metro for the metropolitans,” 1863.
10. International Tunnelling Association, “Planning and Mapping of Underground Space - an Overvie,” *Tunn. Undergr. Sp. Technol.*, vol. 15, no. 1, pp. 271–286, 2000.
11. Z. Zhang, “Study on Urban Underground Streets in Modern Cities,” *Am. J. Civ. Eng.*, vol. 6, no. 2, p. 60, 2018.
12. D. Kaliampakos, “Underground Development: A Springboard to Make City life Better in the 21st Century,” *Procedia Eng.*, vol. 165, pp. 205–213, 2016.
13. M. R. Doyle, P. Thalmann, and A. Parriaux, “Underground potential for urban sustainability: Mapping resources and their interactions with the Deep City method,” *Sustain.*, vol. 8, no. 9, 2016.

14. R. K. Goel, “Use of underground space for the development of cities in India,” *Water Energy Int.*, vol. 58RNI, no. 9, pp. 41–45, 2015.
15. K. Caroline, “Geological and Geotechnical Conditions of Nairobi Subsurface By,” 2012.
16. C. K. Onyancha(a), E. M. Mathu, S. K. Mwea, and W. M. Ngecu, “Dealing with Sensitive and Variable Soils in Nairobi City,” *Int. J. Res. Rev. Appl. Sci.*, vol. 9, no. 2, pp. 282–291, 2011.