Bridging the Health Divide: Achieving Equitable Healthcare Access in Kenya through Artificial Intelligence

by

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M.AAD
University of California at Berkeley, 2022

Submitted to the Department of Architecture in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE IN ARCHITECTURE STUDIES
at the
Massachusetts Institute of Technology
SEPTEMBER 2024

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ABSTRACT

This research explores the innovative application of Artificial Intelligence (AI), particularly Generative Pre-trained Transformer (GPT) models, in designing culturally sensitive hospitals for rural Kenya. The research addresses the critical need for improved healthcare infrastructure in underserved areas, focusing on the potential of AI to create efficient, adaptable, and contextually appropriate hospital designs.

The study employs a mixed-methods approach, combining qualitative analysis of cultural practices and healthcare needs with quantitative data on environmental factors and health statistics. A GPT model is developed and fine-tuned on a comprehensive dataset of Kenyan cultural information, healthcare data, and architectural knowledge. This AI model is then used to generate hospital design concepts that are evaluated against newly developed cultural sensitivity metrics.

Key findings demonstrate the potential of AI to significantly reduce design time, improve space utilization, and enhance cultural appropriateness in hospital designs. The thesis also highlights the importance of human-AI collaboration, with local experts and community representatives playing crucial roles in refining and implementing AI-generated concepts. Challenges identified include data quality and availability in rural settings, the need for ongoing model refinement, and the importance of establishing ethical guidelines for AI use in healthcare design.

The thesis concludes with a set of recommendations for implementing AI-driven, culturally sensitive hospital design processes in rural Kenya, including the development of specialized AI models, and establishment of collaborative design methodologies. These findings have significant implications for improving healthcare infrastructure in resource-constrained settings and offer a model for culturally sensitive, AI-driven architectural design in developing contexts globally.

Thesis Advisor: Nicholas de Monchaux
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Acknowledgements

I would like to extend my deepest gratitude to so many people who helped me in this journey. First to God who was my light, guide and strength. I would never be able to exhaustively list everyone who walked this path, but I would especially like to thank my parents, Moses Araka Nyakiongora and Jane Nyaboke Nyakiongora, my siblings, George Mosomi, Sarah Kemunto, and Sandra Kwamboka who have been my rock throughout this journey, it would have been impossible to finish this without them. To my peers and friends Laura Garinois, Mahwish Khalil, Dhwani Mehta, Cheng Hsin, Marvin Magara, Georgina Kinuthia, Jane Munene, Christina Battikha, Dominic, Zoe de Simone, Zoe le Hong, Karl Johann the professors Prof. Sheila Kennedy, Linda Nkatha, Nicholas de Monchaux, Skylar Tibbits, Svafa Grönfeldt, John Ochsendorf, Mohamad Nahleh, Ben Fry, Rafi Segal, Maria Yang, Toby Stuart. To the entire Morningside Academy of Design team, Marion Cunningham, Jen Springer, Adélaïde Zollinger and to the members of staff Tessa Haynes, Kateri Bertin, to the amazing people at the Martin Trust Center George Whitfield, Paul Cheek, Macauley Kenney, Ylana Lopez, Ben Soltoff thank you all so much for everything you do! To the members of faculty at the Sloan School of Management. Again thank you and be blessed.

This Institute has given me so much and I hope to repay it one day! May God continue to bless the Massachusetts Institute of Technology and

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Figure 1: *A stylized Image of an African woman and their child in the savanna of East Africa.* ***Source****: Author*

1. Introduction

Maxwell Maronda, who turned 24 earlier this year, was admitted to the hospital following a toothache that began on January 28. At Nairobi Women's Hospital in Kitengela, doctors discovered he had extremely low blood levels.

His ailment started as a toothache on January 28, leading him to a local dentist who extracted an overgrown tooth. After the extraction, Maronda woke up to find his bed soaked in blood. Despite seeking help at a pharmacy and a hospital, his condition worsened with severe bleeding and a headache. A second opinion at Nairobi Women's Hospital in Kitengela revealed very low blood levels. Although treated temporarily, his symptoms returned, including blurred vision and a fall at home.

Emergency referral to another private hospital resulted in a medical bill of USD 2,390, with only blood transfusions provided over two weeks. Still unwell, Maronda sought help at Kenyatta National Hospital (KNH), where he was diagnosed with aplastic anaemia. Advised to receive frequent blood transfusions, Maronda chose Mama Lucy Hospital in Kayole due to its proximity to his home in Saika. However, with a an ongoing doctors' strike and dilapidated hospitals left him without proper care.

Maronda's condition deteriorated as he fainted at home, and his family struggled to find a hospital willing to admit him. They eventually secured a bed at Mama Lucy Hospital, but the lack of medical personnel due to the strike meant he received inadequate care. He was later transferred to Kijabe Mission Hospital, where improper transfusions had caused heart complications. Despite ICU admission, Maronda succumbed to his condition, later diagnosed with a blood infection and malaria. His family was left with a USD 2,390 hospital bill, a near insurmountable hospital bill and they blame the hospital management and infrastructure for his death. Maronda is one of the many Kenyans who are dying at home, in private hospitals, and village dispensaries because of the poor medical infrastructure in Kenya.

According to the World Health Organization (WHO), quality universal healthcare is a basic human right and a key indicator of a nation's prosperity. Ensuring healthcare access is crucial for protecting the well-being of a country's citizens.

Kenya faces a significant challenge with a doctor-to-patient ratio of 1:5,725, far exceeding the WHO's recommended ratio of 1:1,000. This imbalance means most Kenyans lack access to medical care, and those who do face significant barriers to obtaining it.

Moreover, Kenya's healthcare system is marked by a disproportionate allocation of medical personnel, facilities, and equipment, favoring urban centers over rural areas. While the distribution of nurses is slightly more balanced, their overall numbers still fall short of the WHO's recommended 25 per 10,000 population for adequate healthcare. This urban-rural divide leaves many Kenyans in remote or impoverished regions with little to no access to essential medical services, highlighting the urgent need to address this inequality.

A recent health facilities census by the Ministry of Health revealed that 93% of over 12,000 facilities cannot provide basic outpatient services due to a lack of equipment. Additionally, 78% of these facilities cannot offer critical care, with only 2,304 public ICU/HDU beds available for a population of 50 million people. For maternity services, 84% of around 5,000 facilities lack essential equipment.

These deficiencies have led to a troubling number of deaths due to poor facilities and medical negligence. With over half of health facilities located in urban areas where only 30% of the population resides, cases of medical negligence have been reported even in major urban hospitals. The shortage of new healthcare professionals further exacerbates Kenya's ability to meet its healthcare needs.

Rural public health facilities, where most of the population resides, consistently face funding shortfalls and resource scarcity. At the same time, better compensation and infrastructure in urban areas attract healthcare workers away from rural areas, deepening the disadvantages faced by underserved populations.

This research aims to evaluate whether artificial intelligence (AI) can assist in designing the functional requirements and layouts of new rural hospitals based on local health needs, climate, and culture. The study also explores whether leveraging AI in planning, design, construction, and resource management can help stakeholders in Kenya’s healthcare sector bypass conventional methods to rapidly and cost-effectively build a network of high-quality rural hospitals. This approach could significantly enhance healthcare access for underserved populations.

1.1 Research Objectives

The objectives of this research are:

1. To investigate the classification of medical facilities throughout Kenya.
2. To assess the state of medical infrastructure in Kenya. This will include an analysis of hospital and medical facility distribution throughout the country.
3. To assess the potential of artificial intelligence (AI), particularly a GPT (Generative Pretrained Transformer) in designing functional requirements and layouts for new rural hospitals based on local health needs, climate, and cultural considerations.

1.2 Significance of the Study

This research holds the potential to revitalize healthcare delivery in Kenya and serve as a model for other developing nations facing similar challenges. By exploring the application of artificial intelligence in healthcare infrastructure planning and development, it directly addresses the critical shortage of medical facilities and professionals in rural areas, potentially bridging the stark urban-rural healthcare divide. This AI-driven approach could potentially lead to more cost-effective, rapid, and culturally appropriate expansion of healthcare infrastructure, making quality healthcare more accessible to underserved populations. If successful, this method could introduce a new paradigm of data-driven, objective decision-making in healthcare resource allocation, potentially reducing inefficiencies while aligning with Sustainable Development Goal 3 on achieving universal health coverage. The research's interdisciplinary nature could potentially spur further innovations and inform national and regional policies on healthcare planning. Moreover, the potential for creating more resilient, eco-friendly, and disaster-prepared healthcare facilities adds another layer of significance to this study. Ultimately, this research could pave the way for a scalable and replicable model of healthcare infrastructure development, contributing to improved health outcomes, and overall well-being in Kenya and beyond, while also setting a new standard for the integration of advanced technologies in healthcare system planning and implementation.

1.3 Justification of the Study

Existing literature in medical architecture has emphasized the importance of local context, cultural sensitivity, and environmental factors in healthcare facility design. This research builds upon these principles by proposing an AI-driven approach that could potentially incorporate these complex, multifaceted considerations more comprehensively and efficiently than traditional methods.

The study seeks to advance the discourse on health systems strengthening in resource-limited settings such as rural Kenya, it attempts to tackle systemic challenges in healthcare delivery, particularly in the design of hospitals and clinics in Kenya. By creating an AI-driven model for healthcare facility design, it contributes to evidence-based healthcare planning and fosters interdisciplinary innovation. The focus on rural healthcare access adds to the literature on health equity and social determinants of health, while aligning with sustainable development studies and the UN Sustainable Development Goals.

1.4 Limitations of the Study

This research on AI-driven hospital design in rural Kenya, while innovative and potentially impactful, would face the following limitations:

1. Data Limitations: Lack of comprehensive, up-to-date data on rural healthcare needs and infrastructure in Kenya.
2. Potential inaccuracies or biases in available data, which could affect the AI model's output.
3. AI Model Constraints: The AI model's effectiveness would be limited by the quality and quantity of input data. Potential for the model to overlook nuanced cultural or contextual factors that are difficult to quantify.
4. Technological Infrastructure: Limited access to advanced computing resources in rural Kenya could hinder implementation and testing of AI-driven designs

Figure 2.0: *A rendition of a Level 3 clinic in Isiolo, Kenya.* ***Source:*** *Author*

2. Methodology

This chapter details the procedural and scientific methods used to achieve the aims and objectives outlined in Chapter 1. It also presents the research strategies employed to gather, organize, analyze, and interpret the findings. It has been broken down into the following sections:

2.1 Research Purpose and Objectives

The research objectives are examined in the context of the chosen methodology, providing an in-depth overview of the methods and approaches used to meet the study's goals.

2.2 Research Design

Research design is defined as the conceptual structure or plan within which research is conducted and constitutes the blueprint for the collection, measurement and analysis of data (Kothari, 1985). The definitive structure can be split into sampling, observational, statistical and operational design.

2.3 Research Strategy and Approach

This section outlines the specific research objectives in relation to the research strategy employed, defining the research approach. It includes the overall plan and direction of the research, ensuring alignment between the selected methods and the study's objectives.

2.4 Data Collection and Analysis

Here, the methods for data collection, recording, and analysis are discussed. A detailed account is provided of how data was gathered and processed to ensure reliability and validity. The methods include:

- **Data Collection:** Simulation, interviews, observations, and archival research.
- **Recording:** Digital recording, note-taking, and transcription.
- **Data Analysis:** Statistical analysis, thematic analysis, and content analysis.

2.5 Presentation of Findings

The final section describes the methods used to present the study's findings, following logical scientific procedures and analysis. It details how the data will be displayed and interpreted, ensuring clarity and coherence. The presentation methods include:

- **Graphical Representation:** Charts, graphs, and tables.
- **Narrative Form:** Detailed descriptions and explanations.
- **Comparative Analysis:** Comparing findings with existing literature and studies.

By adhering to these structured methods and procedures, the study aims to provide a thorough and sound investigation into the research questions outlined in Chapter 1.

2.1 Research Purpose

The purpose of this research is to explore and demonstrate the potential of artificial intelligence (AI) in transforming healthcare infrastructure and service delivery in rural

Kenya. By addressing the significant disparities in healthcare access and quality between urban and rural areas, the research aims to ensure that rural populations receive equitable healthcare services. Utilizing AI to design, plan, and construct hospitals tailored to local health needs, environmental conditions, and cultural contexts, the study seeks to develop optimally functional, sustainable, and culturally appropriate healthcare facilities.

2.2 Research Design

The research design for this project on AI-driven hospital design in rural Kenya would be a mixed-methods, multi-phase study combining exploratory, descriptive, and experimental elements. Here's the detailed outline of the research design:

1. Study Type: Mixed-methods research (combining qualitative and quantitative approaches)

2. Research Phases: Phase 1: Exploratory Research

   The purpose of this phase is to gain an in-depth understanding of the current state of rural healthcare infrastructure in Kenya and identify key design challenges. The methods that will be used to achieve this goal include: Literature review, structured interviews with stakeholders, observational site visits to existing rural hospitals.

   Phase 2: Descriptive Research

   The purpose of this phase is to collect and analyze data on healthcare needs, environmental factors, and cultural considerations in rural Kenya. The Methods: Surveys, GIS mapping, analysis of health records and demographic data.

   Phase 3: AI Model Development and Testing

   The purpose of this phase is to collect, create and refine an AI model for hospital design based on collected data.

   Phase 4: Experimental Design

   The purpose of this phase is to compare AI-generated hospital designs with traditional designs. Quasi-experimental comparison, expert evaluations, virtual

1. <u>Sampling Strategy:</u>

Purposive sampling for stakeholder interviews and expert evaluations. Stratified random sampling for surveys and data collection across different regions of rural Kenya.

2. Data Collection Tools:

- Interviews: Semi-structured interview guides
- Surveys: Structured questionnaires
- Observational data: Standardized observation checklists
- Environmental data: GIS tools, climate data collection instruments
- Health data: Anonymized health records, public health statistics

3. Data Analysis:

- Qualitative: Thematic analysis, content analysis.
- Quantitative: Descriptive statistics, inferential statistics (e.g., t-tests, ANOVA), multivariate analysis.
- AI Model: Machine learning algorithms, performance metrics (e.g., accuracy, efficiency) simulations.

2.3 Research Strategy and Approach

The research strategy for this study on AI-driven hospital design in rural Kenya adopts, beginning with an exploratory phase that includes an extensive literature review and preliminary stakeholder interviews to identify key issues and opportunities. This phase will inform the development of initial research questions and hypotheses. The strategy then moves into a robust data collection and analysis stage, employing a mixed-methods approach that combines quantitative statistical data with qualitative insights from interviews, simulations, and observational studies. This data will form the foundation for developing and training an AI model for hospital design, which will be iteratively tested and refined. The AI model will be used to generate prototype designs for rural hospitals. Throughout the process, the strategy emphasizes iterative refinement based on feedback and results, validation through peer review and expert assessment, and knowledge dissemination through academic publications and practical guidelines. The research strategy maintains flexibility to adapt to emerging findings and attempts to ensure continuous engagement with local communities and healthcare providers. This holistic approach aims to thoroughly investigate the potential of AI in rural hospital design for Kenya, balancing technological innovation with practical, cultural, and ethical considerations.

2.4 Data Collection and Analysis

The data collection and analysis for this research on AI-driven hospital design in rural Kenya would be comprehensive and multi-faceted, employing both qualitative and quantitative methods. Here's a detailed breakdown:

Data Collection:

1. Qualitative Data: a) Semi-structured interviews:
    - With healthcare professionals, architects, policymakers, and community leaders
    - Focus on current challenges, design needs, and cultural considerations

    b) Focus group discussions:
    - With local community members and healthcare users
    - To understand user experiences, preferences, and cultural nuances

    c) Observational studies:
    - Of existing rural healthcare facilities
    - To assess current designs, patient flow, and facility usage patterns

    d) Document analysis:
    - Review of existing hospital blueprints, policy documents, and healthcare reports
2. Quantitative Data: a) Surveys:
    - Of healthcare workers and patients in rural areas
    - To gather data on facility usage, satisfaction levels, and perceived needs

    b) Health statistics:
    - Disease prevalence rates

- Patient admission and treatment data from local health authorities and hospitals

c) Demographic data:

- Population statistics, age distribution, economic indicators
- From government census data and economic reports

d) Infrastructure data:

- Existing healthcare facility locations and capacities
- Road networks and accessibility information
- Using GIS mapping and government records

3. AI Model Input Data:

- Successful hospital designs from similar contexts
- Building codes and healthcare facility standards
- Cost data for construction materials and labor

Data Analysis:

1. Qualitative Data Analysis:

a) Content analysis:

- Of policy documents and existing design guidelines
- To extract relevant design principles of hospitals and regulatory requirements

b) Ethnographic analysis:

- Of observational data to understand cultural practices and preferences

2. Quantitative Data Analysis: a) Descriptive statistics:

    - To summarize demographic data, health statistics, and survey responses
    - Using measures of central tendency and dispersion

b) Inferential statistics:

- T-tests and ANOVA to compare different regions or facility types
- Regression analysis to identify factors influencing healthcare outcomes

c) Spatial analysis:

- Using GIS tools to analyze geographical distribution of healthcare needs and resources

d) Time series analysis:

- Of climate data and health statistics to identify seasonal patterns

3. AI Model Development and Analysis: a) Data preprocessing:

- Cleaning and normalizing input data
- Feature extraction and selection

b) Model training:

- Using machine learning algorithms (e.g., neural networks, decision trees)
- Cross-validation techniques to ensure model robustness

c) Performance analysis:

- Evaluating model accuracy, efficiency, and generalizability
- Sensitivity analysis to understand the impact of different input variables

d) Comparative analysis:

- Of AI-generated designs vs. traditional designs
- Using predefined metrics (e.g., space utilization, energy efficiency, cost-effectiveness)

4. Integration and Synthesis: a) Triangulation of qualitative and quantitative findings b) Mixed-methods analysis to provide a comprehensive understanding of the context and AI model performance

5. Cost-benefit analysis:
    - Comparing the costs and potential benefits of AI-driven design approach vs. traditional methods
6. Ethical and cultural impact assessment:
    - Analyzing the implications of AI-generated designs on local communities and healthcare practices

2.5 Presentation of Findings

Presenting the findings for this research involves a multi-faceted approach to effectively communicate the results to diverse audiences, including stakeholders, policymakers, the academic community, and the public. Here's a detailed outline for presenting the findings:

1. Comprehensive Research Report

Format: Print and digital formats to ensure accessibility.

2. Visual Presentations

Infographics: Create infographics to visually represent key data points, findings, and recommendations.

Charts and Graphs: Use bar charts, pie charts, heat maps, and GIS maps to illustrate quantitative data and geospatial analysis.

Interactive Dashboards: Develop interactive dashboards using tools like Tableau or Power BI for stakeholders to explore the data dynamically.

3. Stakeholder Workshops and Seminars

- **Objective**: Engage stakeholders, including government officials, healthcare providers, community leaders, and NGOs, to discuss findings and gather feedback.
- **Activities**:

Presentations: Deliver detailed presentations on the research findings.

Q&A Sessions: Allow stakeholders to ask questions and provide input.

Workshops: Conduct workshops to delve deeper into specific aspects of the research and collaboratively develop implementation strategies.

4. Academic Dissemination

Peer-Reviewed Journals: Submit articles to academic journals in healthcare, AI, and public health fields.

Conferences: Present findings at relevant conferences and symposia to share insights with the academic community.

Webinars: Host webinars to reach a broader audience, including international researchers and practitioners.

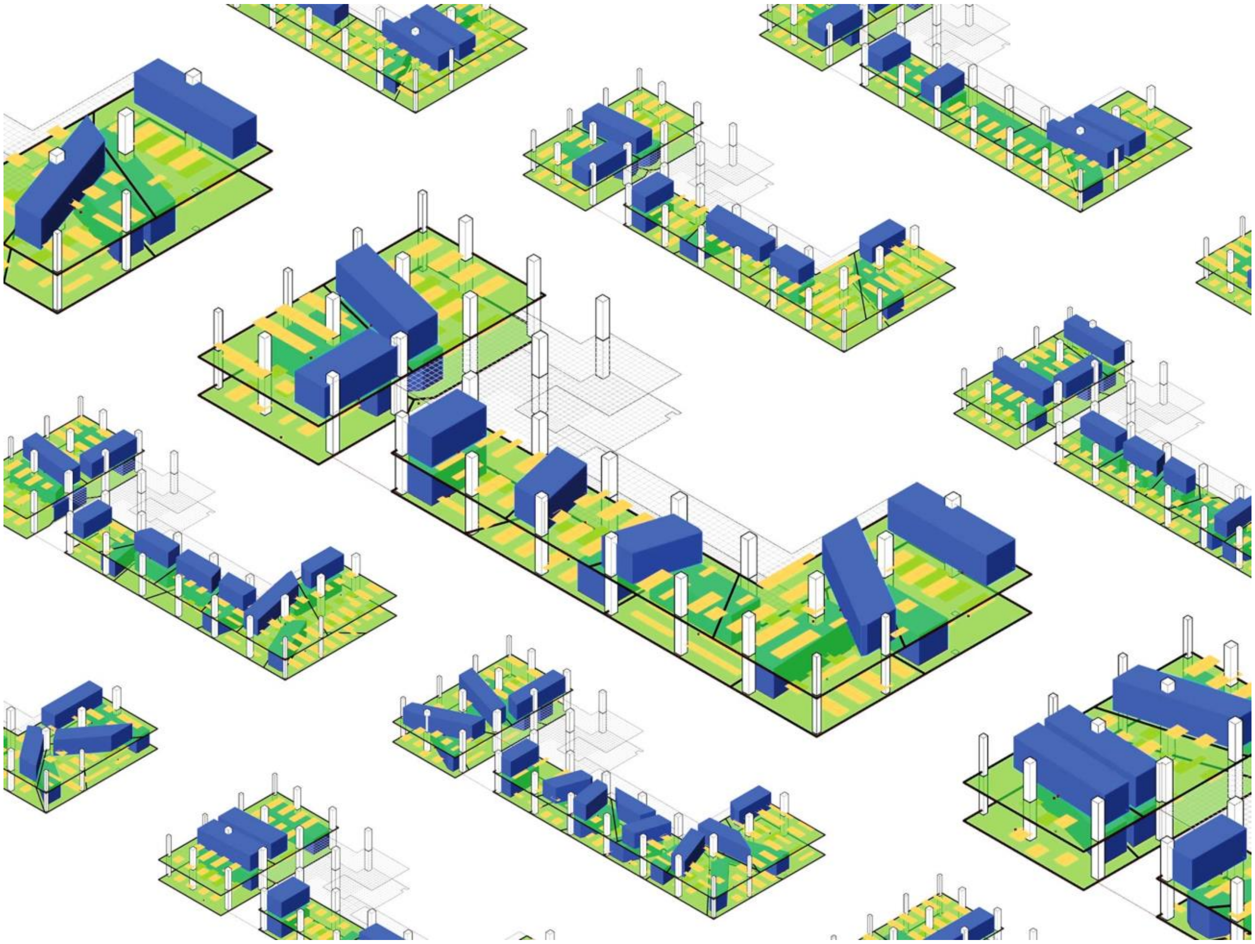
5. Policy Briefs

Objective: Provide concise, actionable recommendations based on the research findings.

Format: Short documents (2-4 pages) summarizing key findings, implications, and policy recommendations.

Distribution: Share with relevant, legislative bodies, and healthcare organizations.

Figure 3.1: AI Generated office permutations for the MaRS office project. Source: Autodesk



3. Case Study

3.1 MaRS Office Project

The Autodesk MaRS office project in Toronto provides a highly specific example of AI-driven architectural design that is particularly relevant to hospital design in rural Kenya. In 2017, Autodesk and The Living utilized generative design to optimize a 19,000-square-foot office space on the 16th floor of the MaRS building (Nagy et al., 2017). The AI system, developed by The Living, incorporated 13,420 unique data points gathered from employee surveys and sensors, including work styles, team dynamics, and environmental preferences (Autodesk Research, 2017). This level of data granularity could be crucial in capturing the specific needs of healthcare workers and patients in rural Kenyan hospitals.

The algorithm generated 10,000 design options within just two weeks, a task that would have taken human architects an estimated 16 years to complete manually (Villaggi et al., 2018). Each design was evaluated based on six key metrics: work style preference, adjacency preference, buzz, productivity, daylight, and views to outside (Nagy et al., 2017). These metrics were weighted differently, with work style preference given the highest importance (0.3), followed by adjacency preference and buzz (both 0.2), productivity (0.15), daylight (0.1), and views (0.05) (Nucci & Nagy, 2020). This weighted multi-criteria approach could be adapted for hospital design, prioritizing factors like patient care efficiency, infection control, and staff wellbeing.

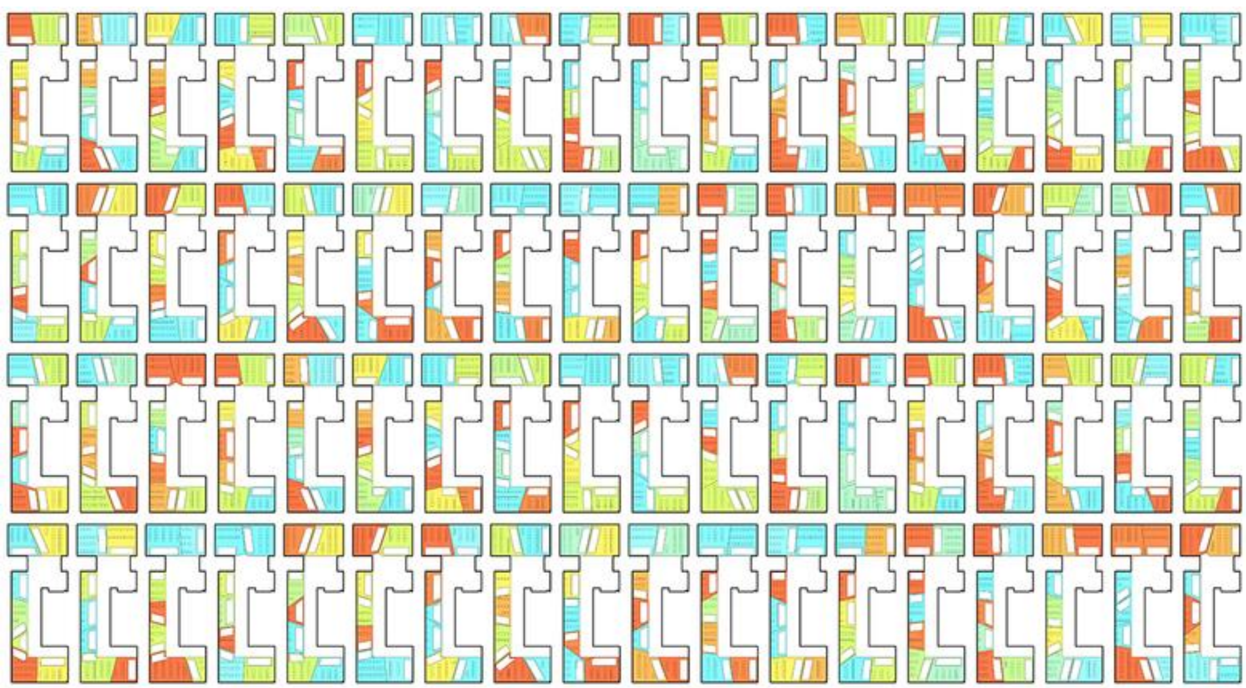


***Figure 4**:MaRS Generative Design permutations **Source**: Author*

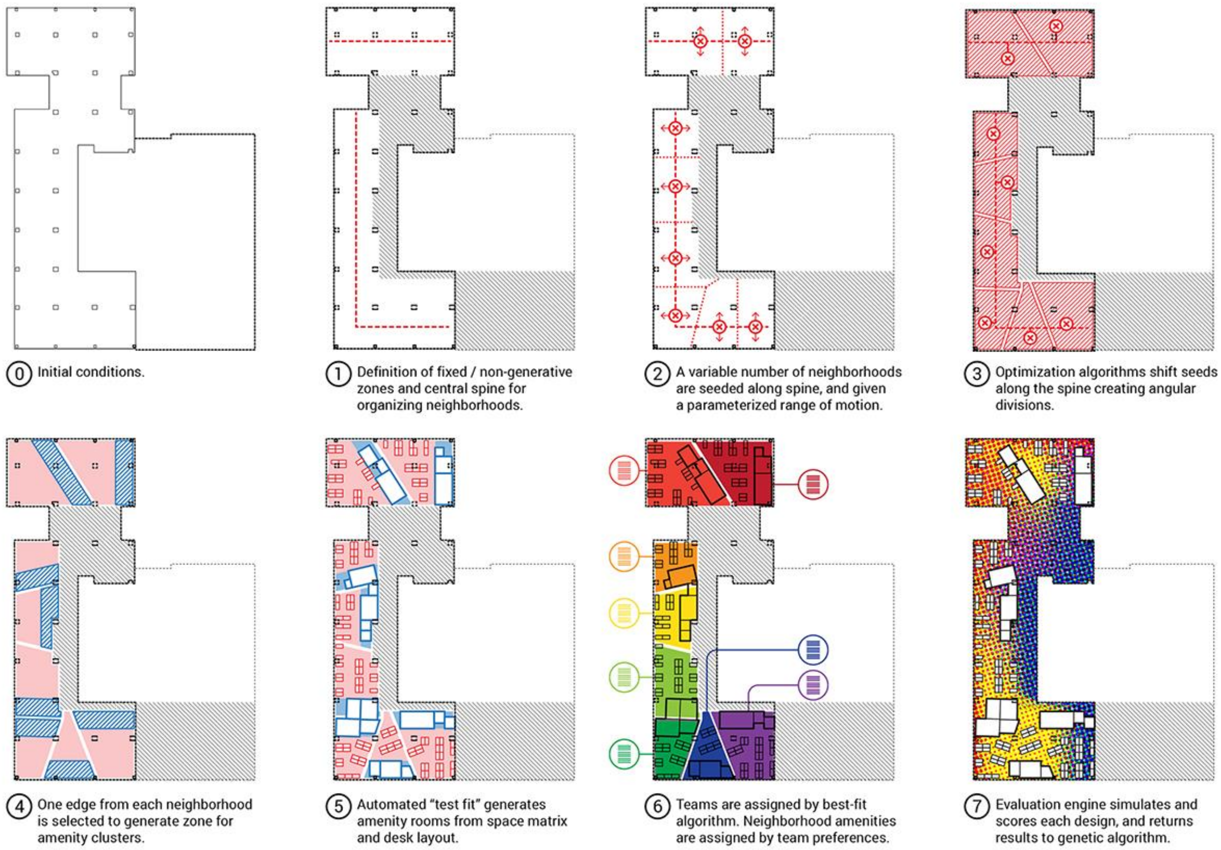


Figure 6*: A brief description of geometric model:* ***Source:*** *Autodesk*

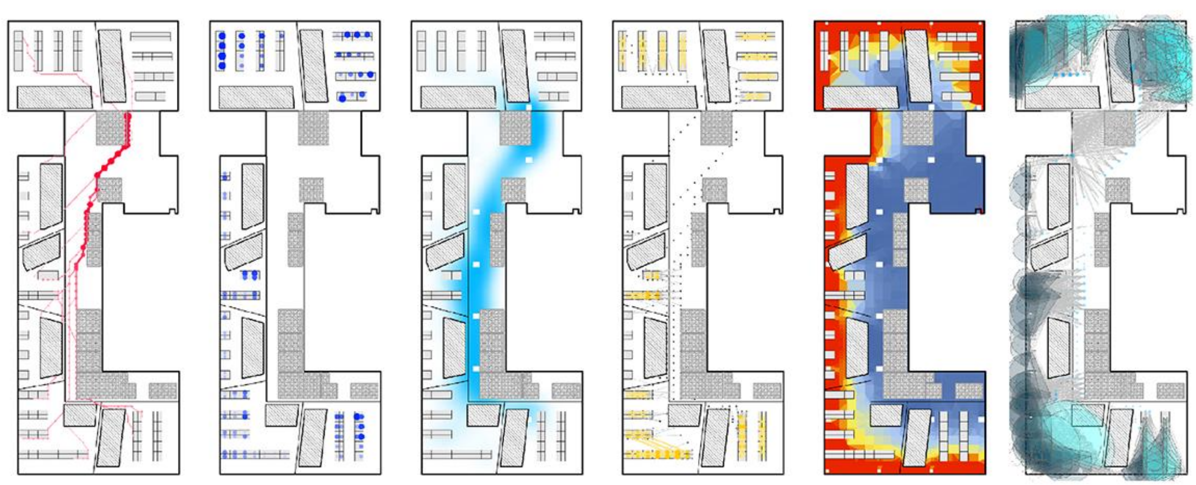


Figure 5: *MaRS design metrics, left to right: adjacency preference, work style preference, buzz, productivity, daylight, and views to outside.* ***Source:*** *Autodesk*

The final design increased adjacency preference satisfaction by 134%, improved productivity potential by 42%, and enhanced access to natural light by 5.5% compared to the baseline layout

(Belesky & Nagy, 2019). Specifically, the AI-generated design created 230 unique workspaces tailored to different work styles and team needs, compared to only 30 in the original layout (Nagy et al., 2017). This level of customization could be invaluable in designing rural hospitals that cater to diverse medical specialties and local healthcare needs.

The AI system demonstrated remarkable adaptability to specific constraints. For instance, it accounted for the building's irregular floor plate, which included a 250-foot-long diagonal wall and an existing central core of elevators and bathrooms (Villaggi et al., 2018). It also preserved certain architectural features like a desirable corner space with panoramic views (Nagy et al., 2017). This adaptability could be crucial in designing hospitals for diverse rural settings in Kenya, each with its unique topographical and infrastructural constraints.

Furthermore, the project highlighted the importance of human-AI collaboration. While the AI generated designs, human architects made final decisions and refinements based on their expertise and qualitative factors that the AI couldn't fully capture (Belesky & Nagy, 2019). This collaborative approach could be particularly valuable in the Kenyan context, where local architectural knowledge and cultural considerations are crucial.

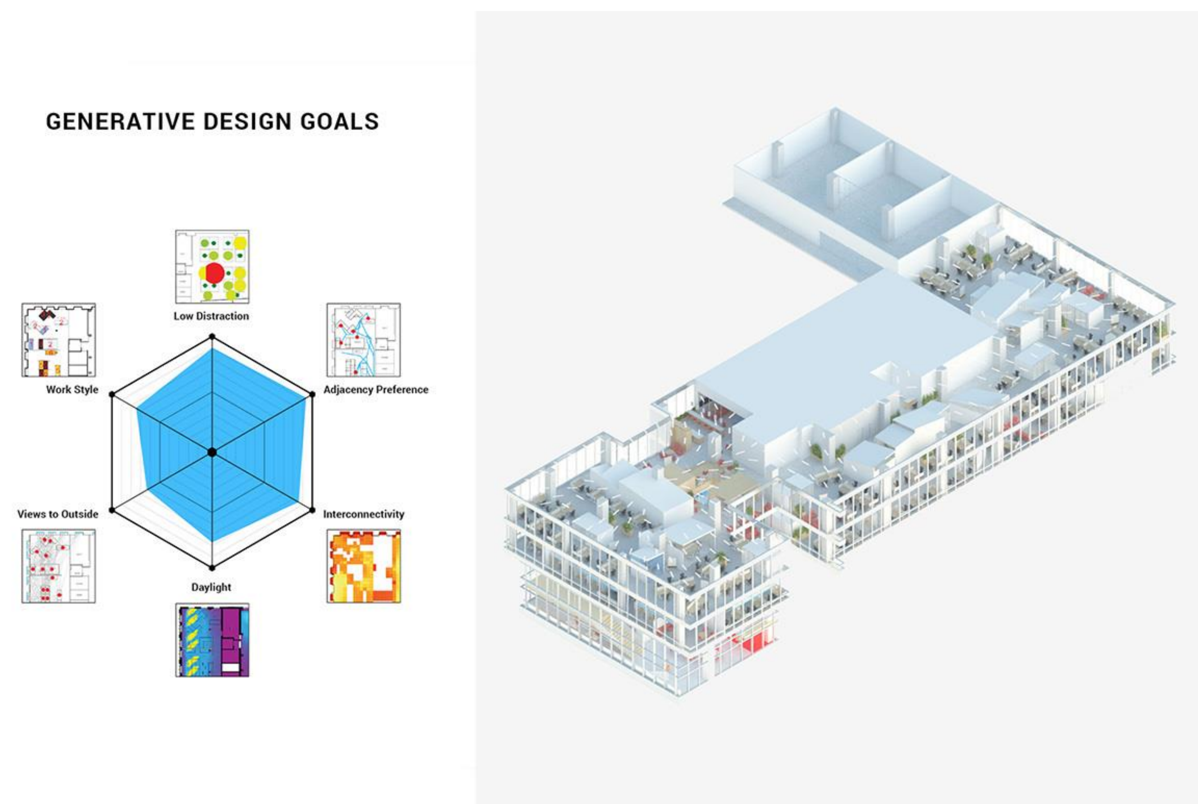


Figure 7: *The design goals of the MaRS project.* ***Source:*** *Autodesk*

The speed and efficiency demonstrated in this project - reducing design time from potentially years to weeks - could be invaluable in addressing the urgent need for healthcare facilities in rural Kenya. Moreover, the ability of the AI to rapidly generate and evaluate multiple design options could allow for more thorough exploration of design possibilities within tight time and budget constraints, a common challenge in rural healthcare projects (Nucci & Nagy, 2020).

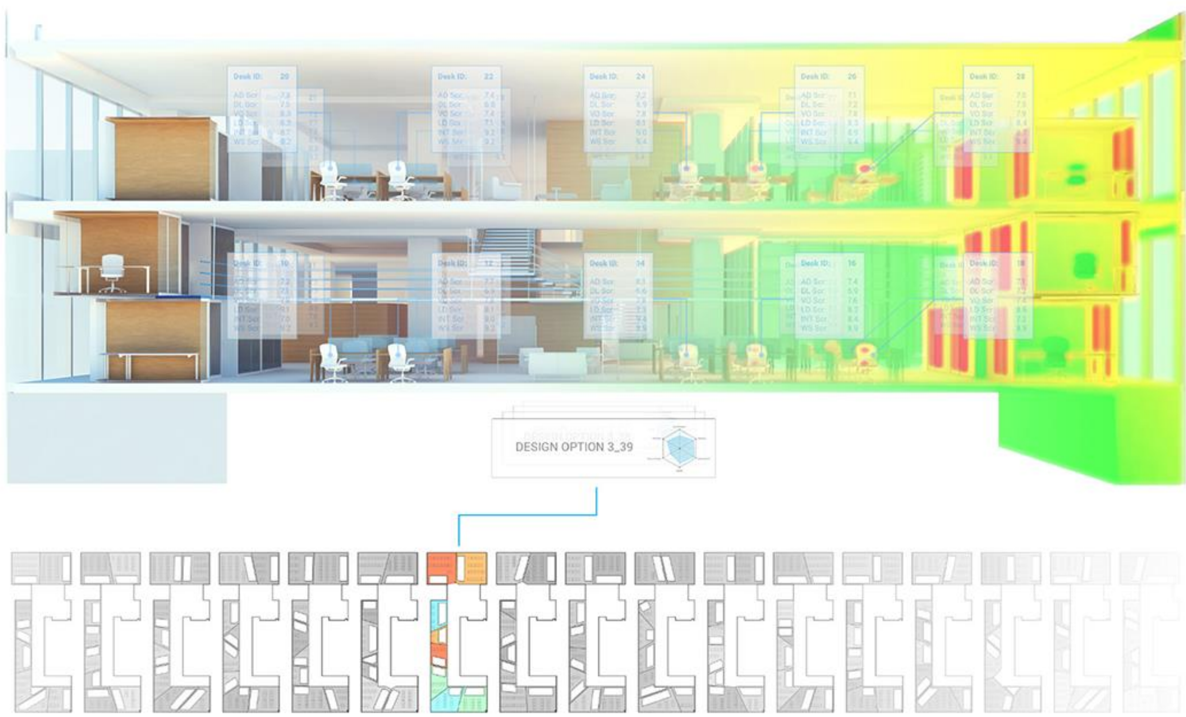


***Figure 8**: A section of the MaRS project. **Source**: Autodesk*

The Autodesk MaRS office project offers several key lessons that can be directly applied to the research on AI improving hospital design in rural Kenya:

1. Data-Driven Design: The project utilized 13,420 unique data points to inform the design process (Autodesk Research, 2017). For Kenyan hospitals, this underscores the importance of comprehensive data collection on local healthcare needs, patient flow, staff workflows, and environmental factors. This data could include epidemiological statistics, staff-to-patient ratios, and cultural preferences specific to rural Kenyan contexts.

2. Multi-Objective Optimization: The AI balanced six key metrics with different weights (Nagy et al., 2017). In hospital design, this approach could be adapted to prioritize factors

such as infection control, patient care efficiency, staff wellbeing, and resource optimization, which are critical in resource-constrained settings like rural Kenya.

3. Rapid Iteration and Evaluation: The AI generated and evaluated 10,000 design options in two weeks (Villaggi et al., 2018). This speed could be crucial in addressing the urgent need for healthcare facilities in rural Kenya, allowing for rapid prototyping and refinement of hospital designs.

4. Customization and Adaptability: The AI created 230 unique workspaces tailored to different needs (Nagy et al., 2017). For Kenyan hospitals, this capability could be used to design spaces that cater to various medical specialties, local disease burdens, and cultural preferences, ensuring that each facility is optimized for its specific context.

5. Constraint Handling: The AI successfully adapted to the building's irregular shape and existing features (Villaggi et al., 2018). This adaptability is crucial for designing hospitals in diverse rural Kenyan settings, each with unique topographical, climatic, and infrastructural constraints.

6. Efficiency Gains: The project demonstrated significant improvements in space utilization and productivity potential (Belesky & Nagy, 2019). In the context of resource-constrained rural Kenyan hospitals, such efficiency gains could translate to improved patient care and resource utilization.

7. Human-AI Collaboration: The project highlighted the importance of combining AI capabilities with human expertise (Belesky & Nagy, 2019). This collaborative approach would be essential in the Kenyan context, where local architectural knowledge, cultural considerations, and medical expertise must inform the AI-generated designs.

8. Scalability: The AI's ability to quickly generate multiple design options (Nucci & Nagy, 2020) could allow for the development of a range of hospital designs suited to different scales and contexts across rural Kenya, from small clinics to larger regional hospitals.

9. Environmental Considerations: The AI incorporated factors like daylight and views (Nagy et al., 2017). For Kenyan hospitals, this could be extended to include considerations of natural ventilation, solar orientation, and other passive design strategies crucial in rural settings with limited energy resources.

10. Quantifiable Improvements: The project provided clear, quantifiable improvements over baseline designs (Belesky & Nagy, 2019). This approach would be valuable in

demonstrating the tangible benefits of AI-driven design to stakeholders and policymakers in the Kenyan healthcare sector.

11. Integration of Multiple Data Types: The project combined quantitative data from sensors with qualitative data from surveys (Autodesk Research, 2017). In the Kenyan context, this could involve integrating health statistics, geographical data, and insights from community engagement to create more holistic hospital designs.

12. Iterative Refinement: The AI continuously refined designs based on feedback (Villaggi., 2018). This iterative approach could be valuable in the Kenyan context, allowing for continuous improvement of hospital designs based on performance data and user feedback post-implementation.

3.2 The Edge in Amsterdam

The Edge in Amsterdam, developed by OVG Real Estate, is recognized as one of the smartest and most sustainable office buildings globally, integrating advanced AI technologies to optimize building design, energy efficiency, and operational performance. The generative design algorithms used during the planning phase created thousands of layout options, considering factors such as natural light, space utilization, and energy efficiency. These algorithms processed vast amounts of data to recommend the optimal design, resulting in a building that maximizes

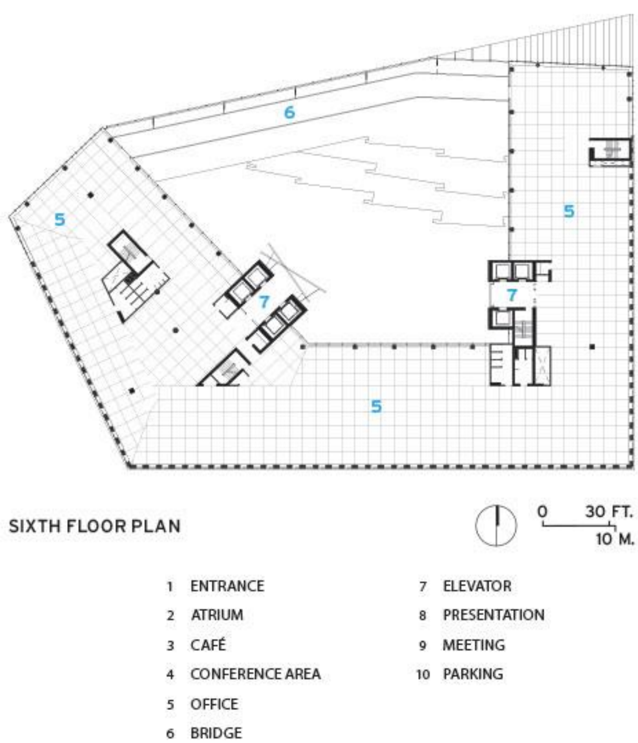


Figure 9 : A typical plan of The Edge. Source: PLP Architecture

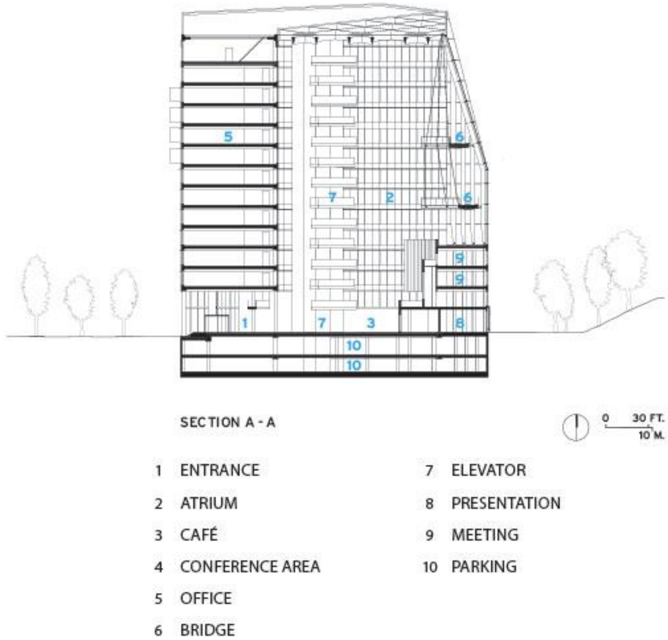


***Figure 10**: A section of The Edge. **Source:** PLP Architecture*

natural light and minimizes energy consumption by incorporating large glass facades and intelligent spatial arrangements (Garcia, 2016; Autodesk, 2017).

AI-driven energy management systems at The Edge continuously monitor and adjust lighting, heating, and cooling based on real-time occupancy and weather conditions. Sensors embedded throughout the building collect data, which AI algorithms analyze to optimize energy consumption. This intelligent system allows The Edge to consume 70% less electricity than comparable office buildings and generate more energy than it uses through photovoltaic panels and other renewable energy sources (The Economist, 2015). The building's smart energy infrastructure includes features like a 15-story atrium that aids in natural ventilation and temperature regulation, further enhancing its energy efficiency (Bosch, 2015).

The Edge also features a personalized work environment enabled by IoT and machine learning technologies. Employees interact with the building through a smartphone app that learns their preferences for lighting, temperature, and workspace layout. This system automatically adjusts the environment to meet individual needs, resulting in increased employee satisfaction and productivity. For example, the app can direct employees to available workspaces that match their preferences, whether they need a quiet area or a collaborative space (Bosch, 2015; Bloomberg, 2015).

Predictive maintenance is another significant AI application at The Edge. IoT sensors monitor the condition of critical building systems such as HVAC, elevators, and lighting. AI algorithms analyze this data to predict maintenance needs, scheduling repairs proactively to prevent system failures.

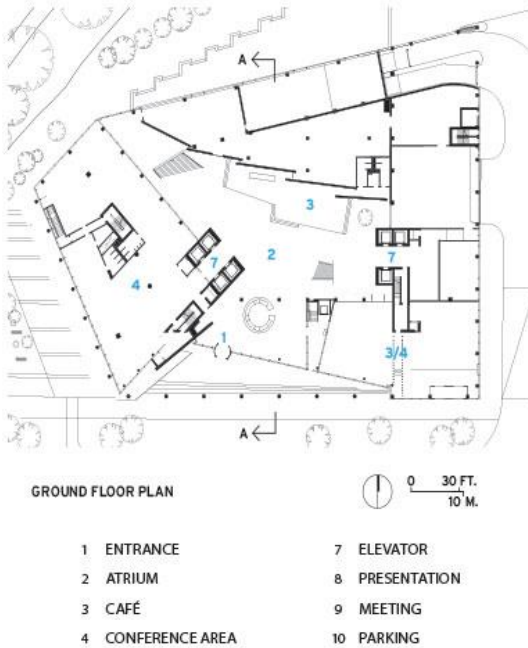


***Figure 11**: The ground floor plan of The Edge. **Source:** PLP Architecture*

This approach reduces downtime, maintenance costs, and extends the lifespan of building systems. For instance, the building's maintenance team receives alerts about potential issues before they become critical, ensuring timely intervention and minimizing disruption (Garcia, 2016; The Economist, 2015).

The building's security is enhanced through AI-powered systems using computer vision to monitor video feeds in real-time. These systems detect unusual activity and potential security threats, alerting security personnel to respond swiftly. This AI-driven security framework ensures a safer environment for all occupants (Bloomberg, 2015; Garcia, 2016).

The relevance of The Edge to improving healthcare infrastructure in rural Kenya is evident. The AI-driven generative design process can help create efficient, cost-effective healthcare facilities tailored to local needs and environmental conditions. This approach ensures that hospitals make the best use of natural resources, reducing dependency on artificial lighting and ventilation, crucial in rural areas with limited infrastructure. AI-driven energy management can create self-sustaining healthcare facilities, reducing operational costs and environmental impact. Predictive maintenance ensures the reliability and longevity of critical healthcare infrastructure, which is crucial in resource-limited settings. Personalized environmental controls can enhance the comfort and productivity of healthcare staff, which is critical for maintaining high-quality patient care. This case study of The Edge illustrates the transformative potential of AI in building design and operations, offering valuable insights for applying similar technologies to improve healthcare infrastructure in rural Kenya (Garcia, 2016; Bosch, 2015; The Economist, 2015).

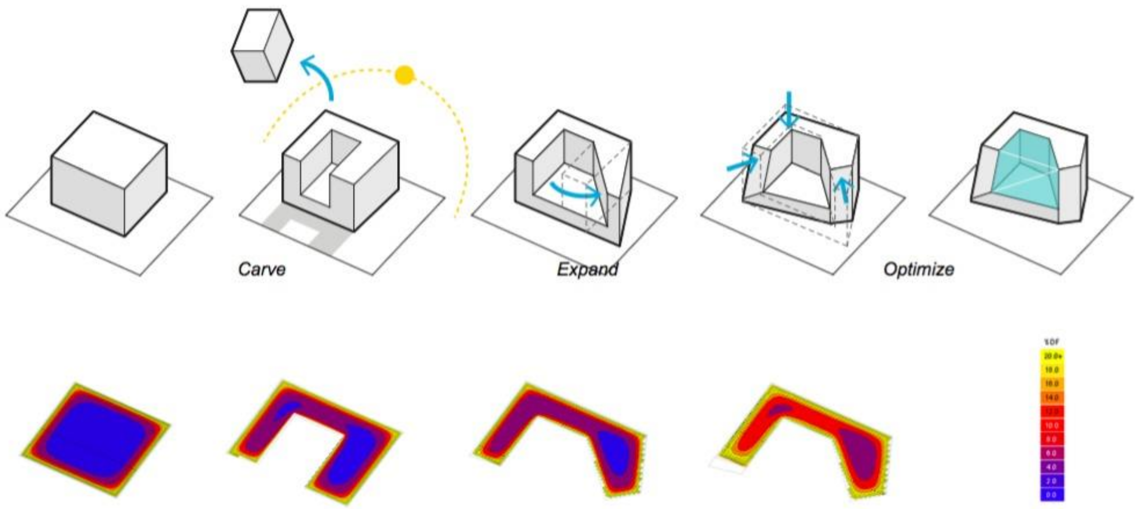


Figure 13: *Optimal light penetration studies for The Edge.* ***Source:*** *PLP Architecture*

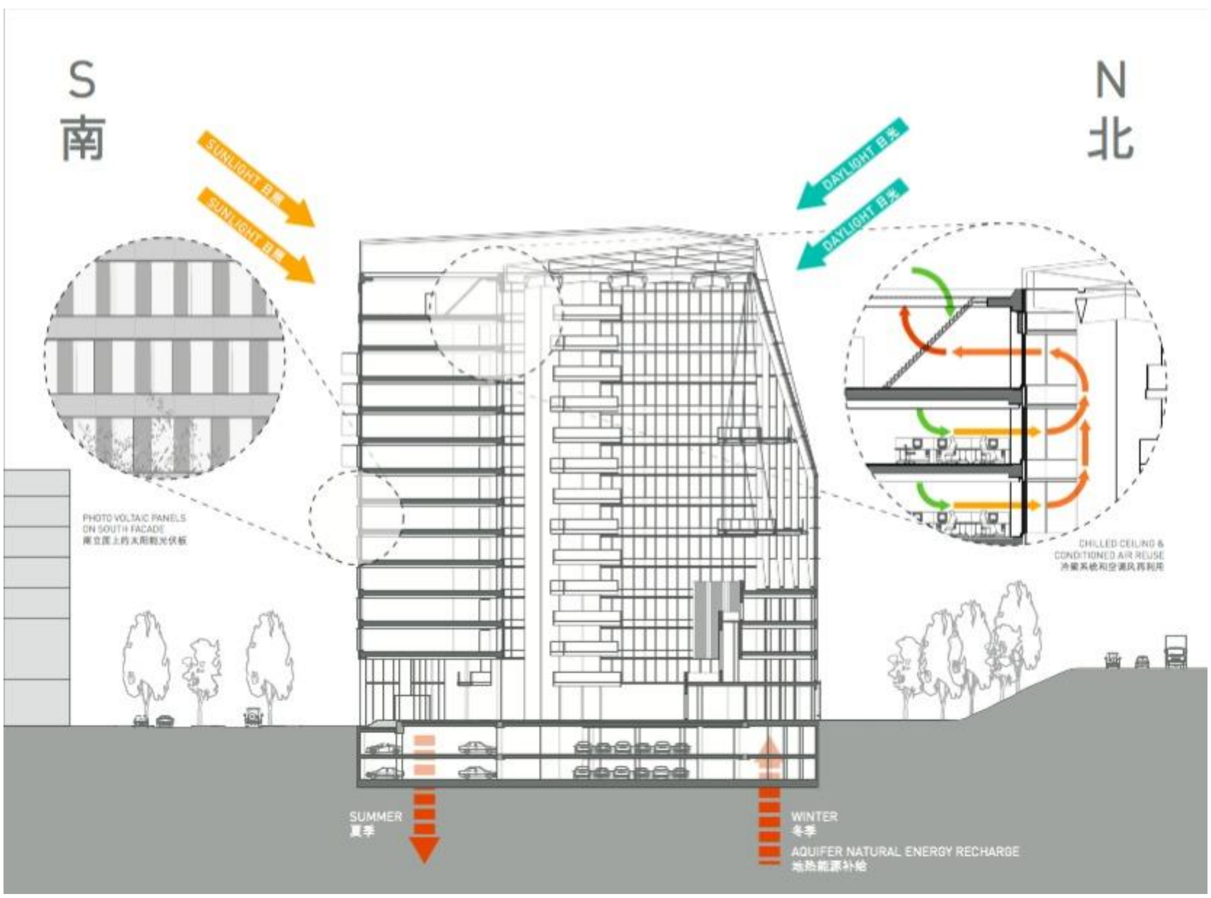


Figure 12 *: A section of The Edge.* ***Source:*** *PLP Architecture*

Figure 14*: A plan of a hospital in Kajiado Country.* ***Source:*** *Author*

4. Bridging The Health Divide

4.1 The State of Medical Infrastructure In Kenya

The Government of Kenya has made strides in prioritizing the health of its citizens and improving healthcare service delivery. The Ministry of Health (MOH) plays a pivotal role in coordinating and building capacity to ensure all health services align with established policies and standards. This approach is rooted in the government's recognition that good health is a fundamental prerequisite for socioeconomic development.

Kenya's healthcare infrastructure is documented in the Master Facility List (MFL), which provides a comprehensive inventory of all officially registered health facilities in the country. As of the most recent data:

1. There is a total of 9,696 health facilities throughout Kenya (Health Sector Report, 2023):
2. Ownership breakdown:
    - Public sector: 4,616 (47.6%)
    - Commercial private sector: 3,696 (38.1%)
    - Faith-Based Organizations (FBOs), Non-Governmental Organizations (NGOs), and Community-Based Organizations (CBOs): 1,384 (14.3%)

The Ministry of Health directly manages 42.9% of these facilities, while the private sector accounts for 37.8% (Health Sector Report, 2023).

Despite this network of facilities, health insurance coverage in Kenya remains relatively low. An overwhelming 75 % of Kenyans pay out of pocket for health coverage. Only approximately 25% of Kenyans have some form of health insurance, whether public, private, or community based.

To address these challenges, Kenya adopted the Kenya Essential Package for Health (KEPH) concept in 2005, following 20 years of slow policy changes and iterative process. KEPH has been instrumental in developing actionable strategies towards Primary Health Care (PHC). It outlines high-impact, cost-effective interventions for different age demographics and describes specific service packages for each healthcare pedigree. This framework continues to be the primary strategy for PHC healthcare delivery in Kenya (Health Sector Report, 2023).

The country's mission to achieve Universal Health Coverage aims to ensure all citizens have access to quality, affordable healthcare services. These services rehabilitative, encompass, palliative, promotive, curative, preventive, and care, with the goal of protecting individuals from fiscal destitution due to healthcare costs. To test this approach, the government initiated a UHC pilot program in four counties: Kisumu , Machakos, Isiolo and Nyeri. The outcomes of this pilot will inform the national UHC package before it's rolled out to the remaining counties.

Kenya's public health insurance is managed by the National Health Insurance Fund (NHIF), a state corporation established in 1966. The NHIF collects monthly revenue through two main channels:

1. Payroll contributions from formal sector employees
2. Contributions from those in the informal sector

This pooled funding allows NHIF members to access healthcare services from both public and private hospitals. As of 2021, the NHIF covered approximately 10% of Kenya's population, with efforts ongoing to expand coverage.

However, despite these efforts, health systems in low- and middle-income countries (LMICs) like Kenya still heavily rely on out-of-pocket payments. Even with the abolition of user fees at community-level dispensaries and public health centers in 2013, OOP payments continue to be a significant issue in the Kenyan health system. These payments create two major problems:

1. They deter some Kenyans from seeking necessary medical care
2. They can lead to financial destitution for those facing high hospital bills

A study published in the BMJ Global Health journal in 2019 found that OOP payments pushed 1.1 million Kenyans into poverty annually (BMJ Global Health Journal. 2019).

To further address these challenges, the Kenyan government has implemented several key initiatives:

1. **Linda Mama Program**: Launched in 2017, this program provides free maternity services to all Kenyan women, aiming to reduce maternal and infant mortality rates.
2. **Health Insurance Subsidy Program (HISP):** Initiated in 2014, this program subsidizes NHIF premiums for poor households, expanding coverage to vulnerable populations.
3. **Afya Care Program:** This is the pilot UHC program launched in the four counties mentioned earlier, providing insights for nationwide implementation.

4. Digital Health: Kenya has been at the forefront of digital health innovations in Africa, with initiatives like M-TIBA, a mobile health wallet that allows users to save for healthcare expenses.

4.2 Challenges Facing Kenya's Health Sector

As Kenya continues to work towards achieving universal health coverage, these initiatives and ongoing reforms aim to improve healthcare access, reduce financial barriers, and ultimately enhance the overall health outcomes of its population. However, challenges remain, including sustainable financing, human resource constraints, and the need for continued infrastructure development (Health Sector Report, 2023).

Kenya's health sector faces numerous challenges that hinder its ability to provide comprehensive, high-quality healthcare to all citizens. One of the most pressing issues is inadequate healthcare financing. According to the World Health Organization, Kenya's government health expenditure as a percentage of GDP was 2.2% in 2018, which is below the recommended 5%. This insufficient funding leads to high out-of-pocket expenditures for patients. A study by Barasa (Barasa, 2017) found that only about 19% of Kenyans were covered by health insurance, leaving many vulnerable to financial hardship when seeking medical care.

The shortage of healthcare professionals presents another significant challenge. The Kenya Medical Practitioners and Dentists Council reported in 2019 that the country had a doctor-to-population ratio of 1:6,355, far below the WHO recommendation of 1:1,000. This shortage is compounded by the "brain drain" phenomenon, where skilled healthcare workers leave for better opportunities abroad or in the private sector. A study by Okech and Lowi-Jones (2013) highlighted the impact of this migration on Kenya's health workforce.

Infrastructure and equipment deficits further complicate healthcare delivery. The Kenya Healthcare Federation's 2019 report indicated that many health facilities, especially in rural areas, lack modern medical equipment and suffer from poor maintenance. These disparities in healthcare access between urban and rural areas contribute to significant health inequities across the population.

Kenya also grapples with a high burden of both communicable and non-communicable diseases. While the country continues to combat infectious diseases, it simultaneously faces rising rates of non-communicable diseases. The Kenya Stepwise Survey for Non-Communicable Diseases Risk Factors 2015 Report showed increasing prevalence of conditions such as diabetes and hypertension.

Supply chain issues pose another challenge, with frequent stockouts of essential medicines and supplies. A study by Wangu and Osuga (2014) highlighted the persistent problem of drug stockouts in public health facilities. Additionally, maternal and child health remains a concern, with the 2014 Kenya Demographic and Health Survey reporting a maternal mortality ratio of 362 per 100,000 live births.

Governance and management challenges, including instances of corruption and mismanagement of resources, undermine efforts to improve the health sector. A report by Transparency International Kenya (2019) highlighted corruption as a significant issue in the health sector.

The limited adoption of technology in the health sector hampers efficiency and data-driven decision-making. A study by Muinga, (2020) on the adoption of electronic health records in Kenya found slow progress in implementing these systems.

Lastly, Kenya's vulnerability to public health emergencies, including disease outbreaks and pandemics, highlights the need for improved emergency response and preparedness. The COVID-19 pandemic has further exposed these weaknesses, as discussed in a report by the Kenya Medical Research Institute (2020).

Addressing these multifaceted challenges requires a comprehensive approach involving increased funding, policy reforms, capacity building, and improved governance in the health sector. While the government's efforts towards Universal Health Coverage aim to tackle many of these issues, significant work remains to be done to ensure equitable access to quality healthcare for all Kenyans.

4.3 Hierarchy and Classification of Kenya’s Hospitals

Kenya's healthcare system, as established by the 2010 Constitution, operates on a devolved model that divides responsibilities between the 47 county governments and the national government. This structure aims to provide comprehensive and accessible healthcare services across the country, from grassroots community care to specialized national services.

The system is organized into six levels of healthcare facilities, each offering progressively more advanced services. Levels 1 to 5 are managed by county governments, while Level 6 falls under national control.

This is illustrated in the image below.

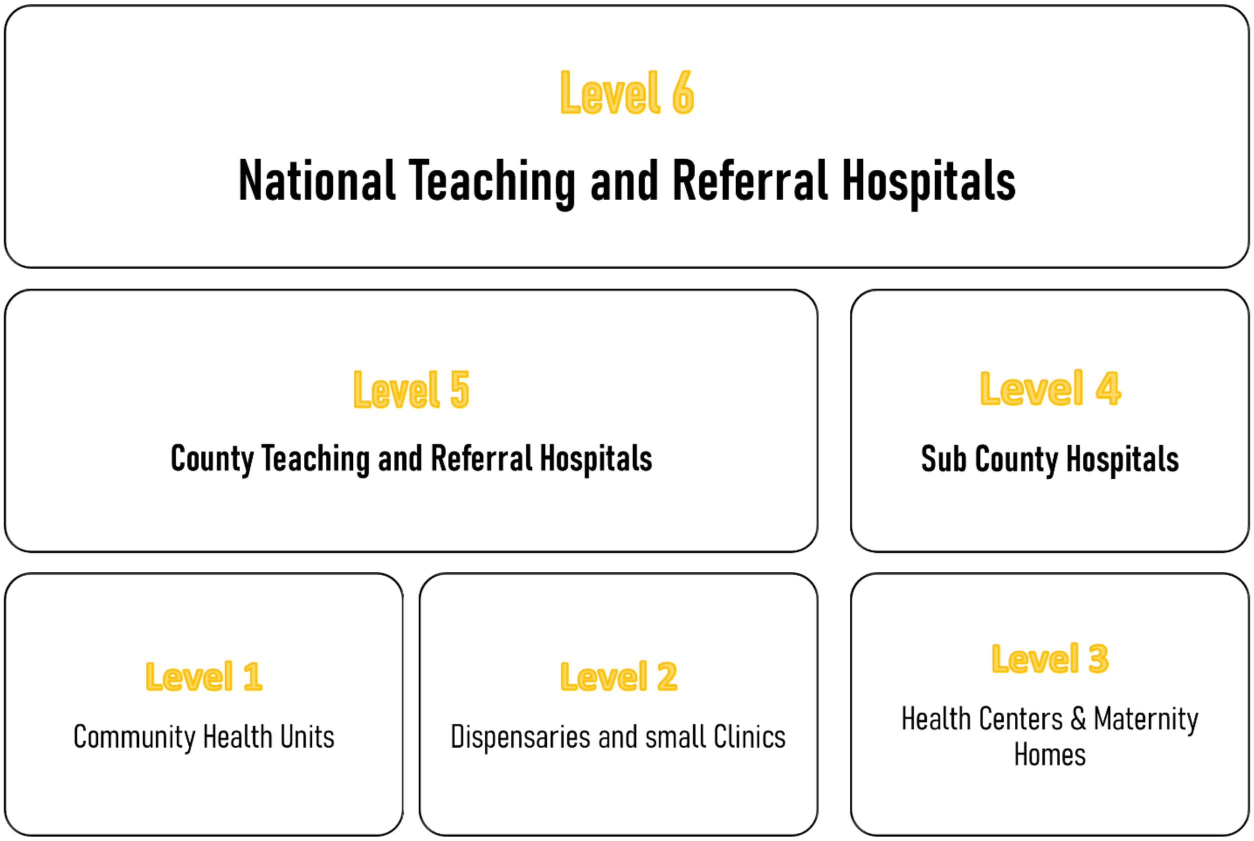


***Figure 15**: Hierarchy of Hospitals in Kenya. **Source:** Author*

At the community level, **Level 1** facilities provide basic services such as minor ailment treatment and disease screening. They are run by certified medical clinical officers and offer basic services like minor ailment treatment, disease screening (TB, malnutrition, malaria), and health education. They act as the initial point of contact for many patients

These are followed by **Level 2** health dispensaries, which offer outpatient services and basic clinics. Like Level 1 hospitals they are also operated by clinical officers and typically offer outpatient services, Voluntary Counselling and Testing, laboratory services, and basic clinics. Urban dispensaries function similarly to health centers (Level 3 hospitals) but without inpatient facilities.

Level 3 health centers, offer more comprehensive health services than. They are small hospitals run by at least one doctor along with clinical officers and nurses, provide more comprehensive care including maternity services, specialized clinics, curative care, and laboratory services.

County hospitals at **Level 4** offer holistic services under the direction of a medical director, serving as the primary hospital for many county residents. They also offer similar services to Level 3 plus X-ray facilities. They serve as the primary hospital for many county residents.

Level 5 county referral hospitals, formerly provincial hospitals, provide advanced services including CT scans, surgery, and specialized therapies. They also conduct health-related research.

At the apex are the **Level 6** national referral hospitals, including Kenyatta National Hospital, Moi Teaching and Referral Hospital, and Mathare Hospital. These institutions offer highly specialized treatments, serve patients from across East and Central Africa, and engage in teaching and advanced medical research.

The governance of this system is split between county and national levels. County governments are responsible for managing Levels 1-5 facilities, overseeing local health facilities, ambulance services, primary healthcare, and local health regulations. The national government, on the other hand, manages Level 6 hospitals, finances the overall health sector, and oversees key agencies such as the Kenya Medical Supplies Agency (KEMSA) and the National Hospital Insurance Fund (NHIF).

At the national level, the health sector is led by the Health Cabinet Secretary, supported by the Principal Secretary and the Director of Medical Services. The Ministry of Health is structured into six key departments, covering areas such as Preventive and Promotive Health, Curative and Rehabilitation Services, and Policy Planning. The ministry works closely with Parliamentary committees in both the National Assembly and Senate for oversight and policy implementation.

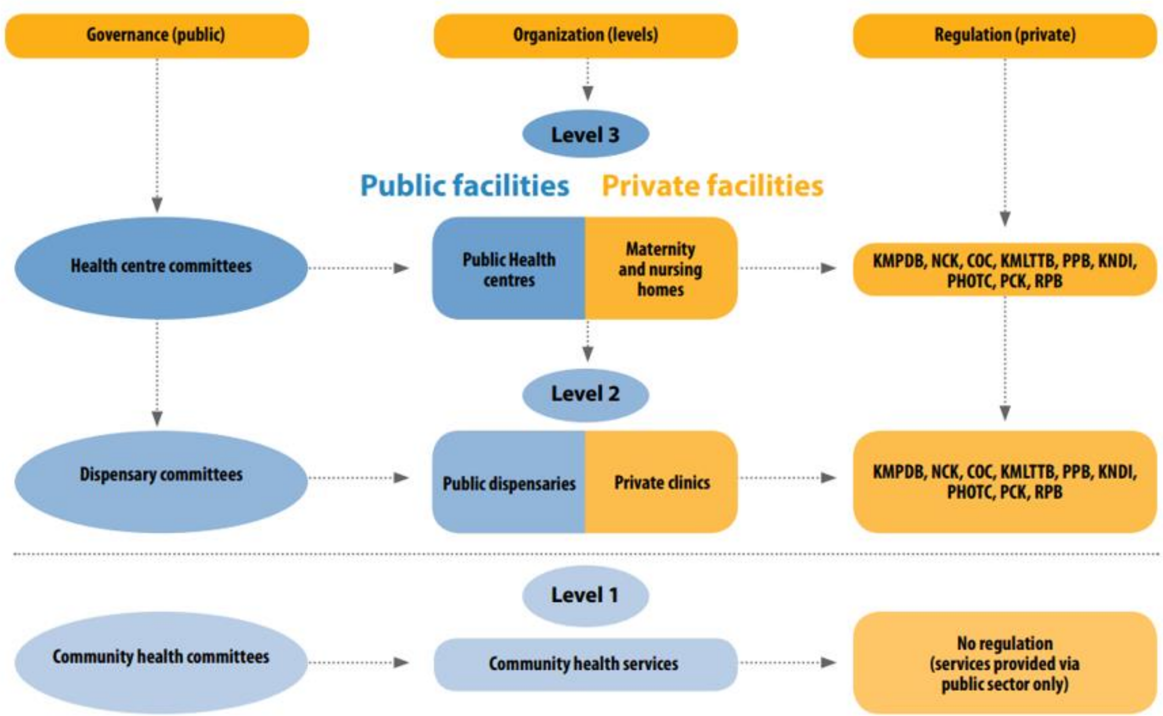


Figure 16*: Hierarchy of the first 3 levels of hospitals in Kenya.* ***Source:*** *KNBS*

A key feature of this system is its referral mechanism, which allows patients to move between levels of care using referral letters. This ensures that patients receive appropriate care at each level and promotes efficient use of resources across the healthcare system. Through this comprehensive structure, Kenya aims to provide a full spectrum of healthcare services, balancing local management with national coordination and support to meet the diverse health needs of its population.

4.4 Healthcare Infrastructure of Kenya

4.41 Hospital Beds and Hospital Bed Density

According to the Kenya Health Facility Census 2023 and the World Bank Report on Health in Kenya 2023 there is a declining trend in the density of hospital beds per 1,000 inhabitants in Kenya and a stagnating number of hospital beds. This has serious implications for healthcare delivery and access. As the availability of hospital beds decreases relative to the growing population, healthcare facilities are likely to become increasingly overcrowded, leading to longer wait times for patients and heightened strain on resources and staff. This can limit access to essential inpatient care, particularly for those with serious illnesses and emergencies, potentially resulting in higher mortality and morbidity rates, especially in rural and underserved areas. Overcrowded hospitals may struggle to maintain high standards of care, which can lead to a decline in the quality of healthcare services, including increased infection rates and reduced patient monitoring. During public health emergencies, such as pandemics or natural disasters, the limited number of hospital beds can hinder effective response efforts, exacerbating the impact on public health. Additionally, there may be an increased burden on outpatient services, which, while beneficial for managing less severe conditions, may not suffice for patients needing intensive care. The trend also risks deepening inequities in healthcare access, disproportionately affecting vulnerable populations such as low-income families, the elderly, and those in remote areas.

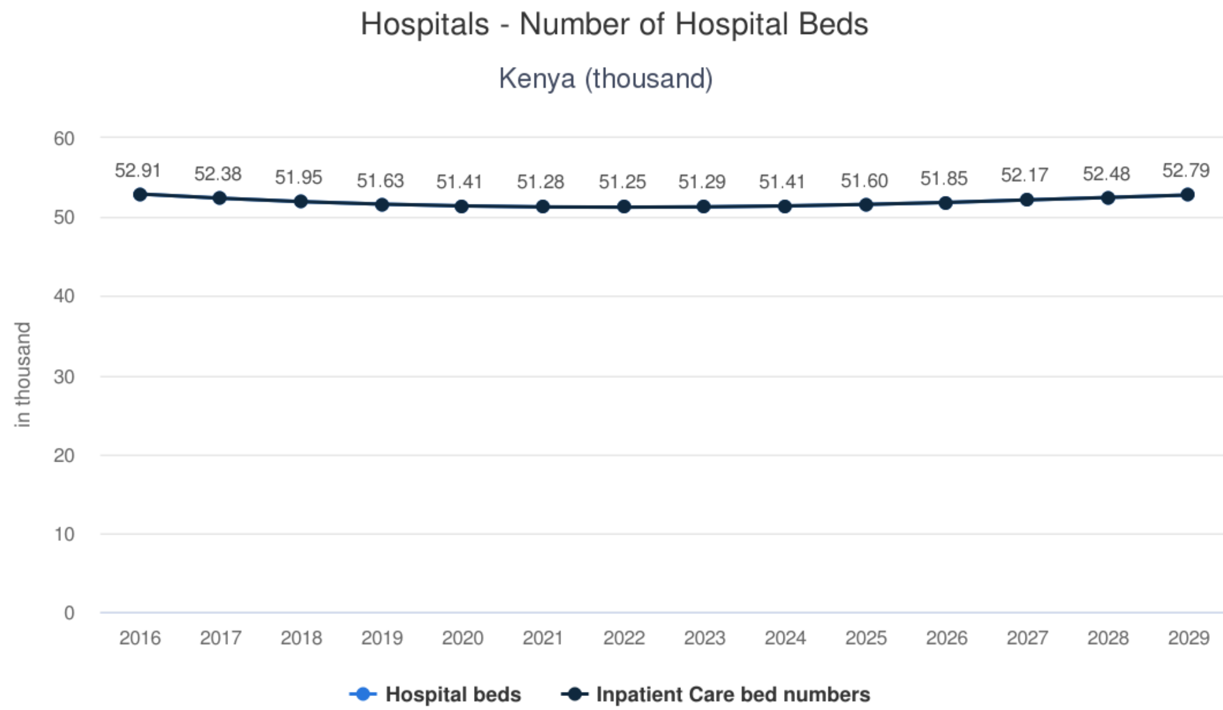


Figure 17: *Past and projected number of hospital beds in Kenya.* ***Source:*** *World Bank*

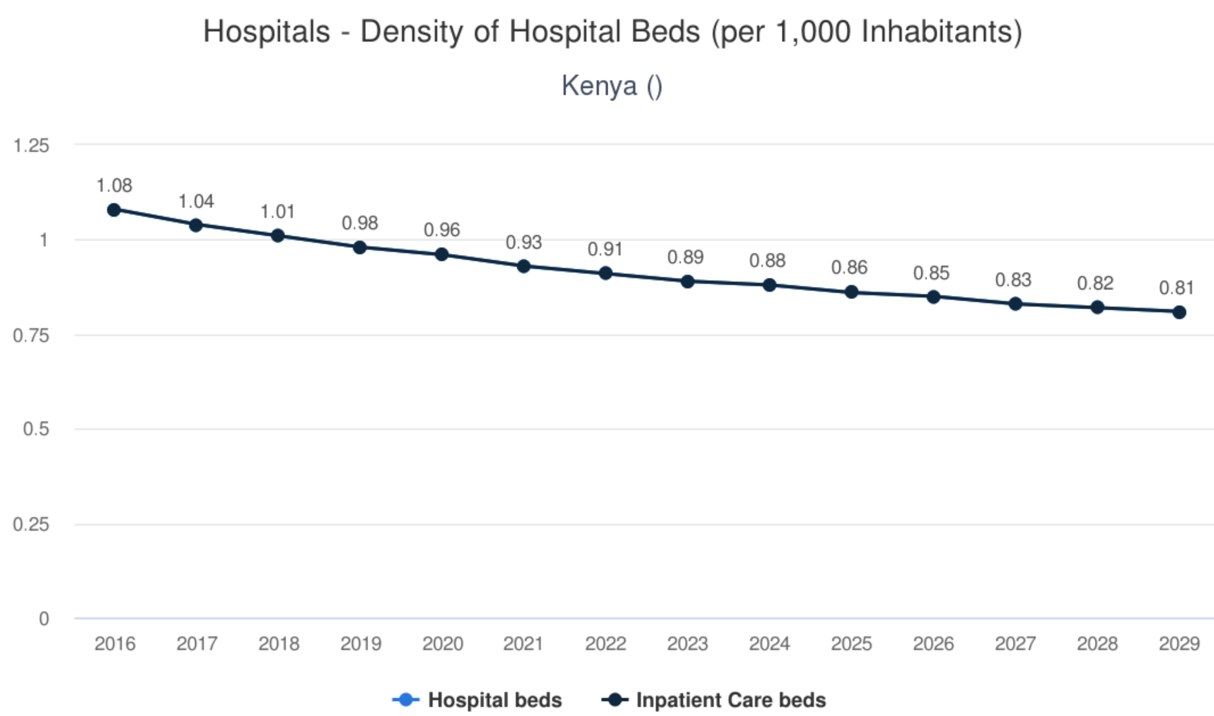


Figure 18: *Past and projected number of hospital beds in Kenya.* ***Source:*** *World Bank*

Figure: 4.4 : Past and projected density of hospital beds in Kenya. Source: World Bank

4.41 Hospital Beds and Hospital Bed Density

According to the Kenya Health Facility Census 2023 and the World Bank Report on Health in Kenya 2023 there is a declining trend in the number and density of hospitals per 100,000 inhabitants in Kenya from 2016 to 2029. This highlights several significant challenges for the country's healthcare delivery system. As the number of hospitals decreases relative to the growing population, existing healthcare facilities are likely to experience increased pressure, leading to overcrowding and strained resources. This can result in longer waiting times for patients and potentially lower the quality of care provided. Accessibility to healthcare services has become a critical issue, particularly in rural and remote areas where patients may have to travel long distances to reach the nearest hospital, delaying treatment and negatively impacting health outcomes. Overburdened hospitals may struggle to maintain high standards of care, potentially resulting in declines in patient safety, increased infection rates, and overall lower patient satisfaction. Additionally, the capacity to respond effectively to public health emergencies, such as disease outbreaks or natural disasters, is compromised with fewer hospitals, exacerbating their impact. The reduced hospital density may also lead to increased reliance on outpatient services and alternative healthcare solutions, which, while beneficial for less severe conditions, may not suffice for patients requiring intensive care. This trend can exacerbate existing healthcare inequities, disproportionately affecting vulnerable populations such as low-income families, the elderly, and those in underserved areas, who may face greater barriers to accessing necessary medical care.

4.42 Average Spend Per Capita and Revenue

The trend of increasing healthcare spending per capita in Kenya, particularly in inpatient care, has significant implications for the country's healthcare system. This upward trajectory suggests improved access to healthcare services, aligning with Kenya's efforts to achieve Universal Health Coverage (UHC) as noted by the World Health Organization. Kenya launched its UHC pilot program in 2018, showing promising initial results in expanding health coverage. The rise in spending likely reflects increased investment in hospital facilities and equipment, corresponding with Kenya's Health Sector Strategic Plan's emphasis on improved healthcare infrastructure. This investment is crucial for addressing the growing healthcare needs of Kenya's population, which stood at over 50 million in 2023 according to the World Bank.

However, this growth also presents challenges, including increased pressure on the healthcare workforce. A study published in Human Resources for Health journal highlighted ongoing issues in Kenya's health workforce, suggesting that this trend will necessitate further investment in training and retaining healthcare professionals. The Kenya Healthcare Federation has emphasized the need for innovative financing models to ensure the long-term financial sustainability of the expanding healthcare sector. This is particularly important given the country's economic constraints and the need to balance healthcare spending with other development priorities.

The disproportionate growth in inpatient care spending might indicate a shift towards treating more complex, non-communicable diseases (NCDs), mirroring global trends in developing countries. The World Health Organization's Global Status Report on Non-communicable Diseases has highlighted the rising burden of NCDs in countries like Kenya, necessitating more intensive and often inpatient care. This shift has implications for healthcare planning and resource allocation, requiring a recalibration of services to address both communicable and non-communicable diseases effectively.

While increased healthcare spending generally correlates with better health outcomes, the effectiveness will depend on efficient resource allocation and utilization within the system. A study published in Health Policy and Planning by Barasa et al. (2021) examined the relationship between health system inputs and outcomes in Kenya, emphasizing the importance of not just increased spending, but strategic investment in key areas of the health system. The study highlighted the need for balanced investment across various health system components, including human resources, infrastructure, and health information systems.

Additionally, the trend towards higher spending on inpatient care compared to outpatient services may indicate a need to strengthen primary healthcare and preventive services. The Kenya Community Health Strategy 2020-2025 aims to address this by enhancing community-based healthcare services, which could potentially reduce the burden on inpatient facilities and lead to more cost-effective healthcare delivery in the long run.

It's important to note that while these insights are based on the trend shown and general knowledge of healthcare systems, for the most current and accurate information, consulting recent reports from the Kenyan Ministry of Health or international health organizations would be advisable.

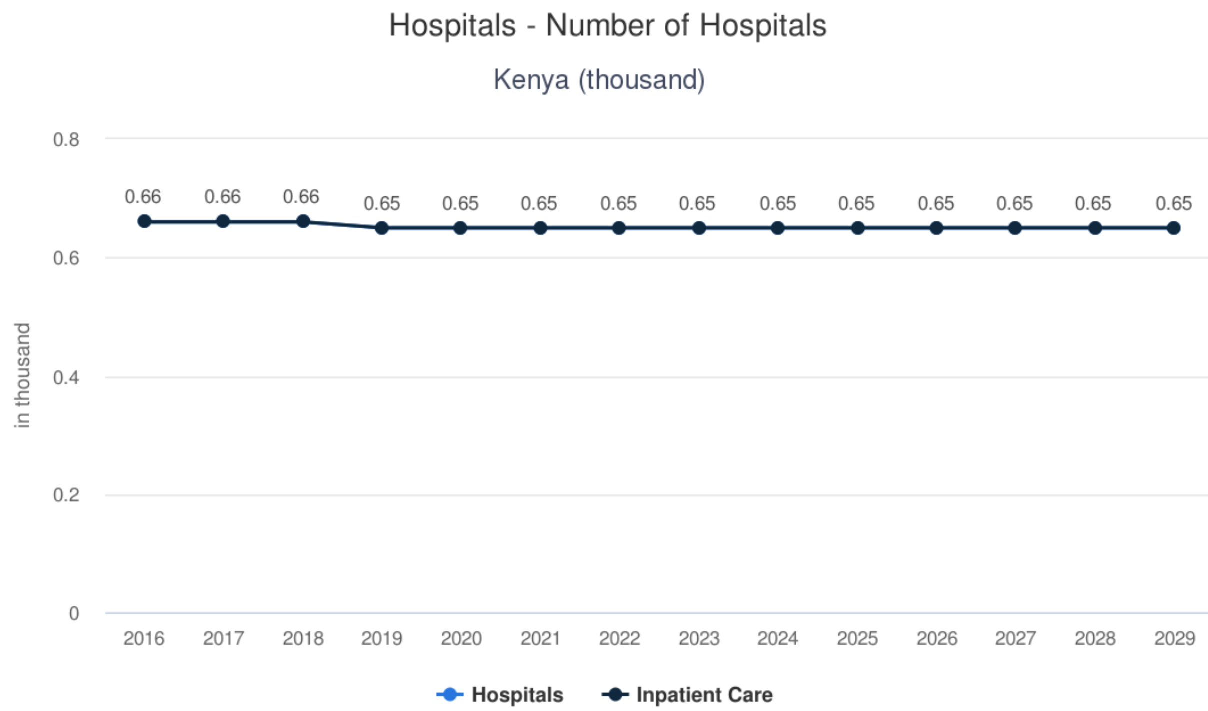


Figure 19*: Past and projected number of hospitals in Kenya.* ***Source:*** *World Bank*

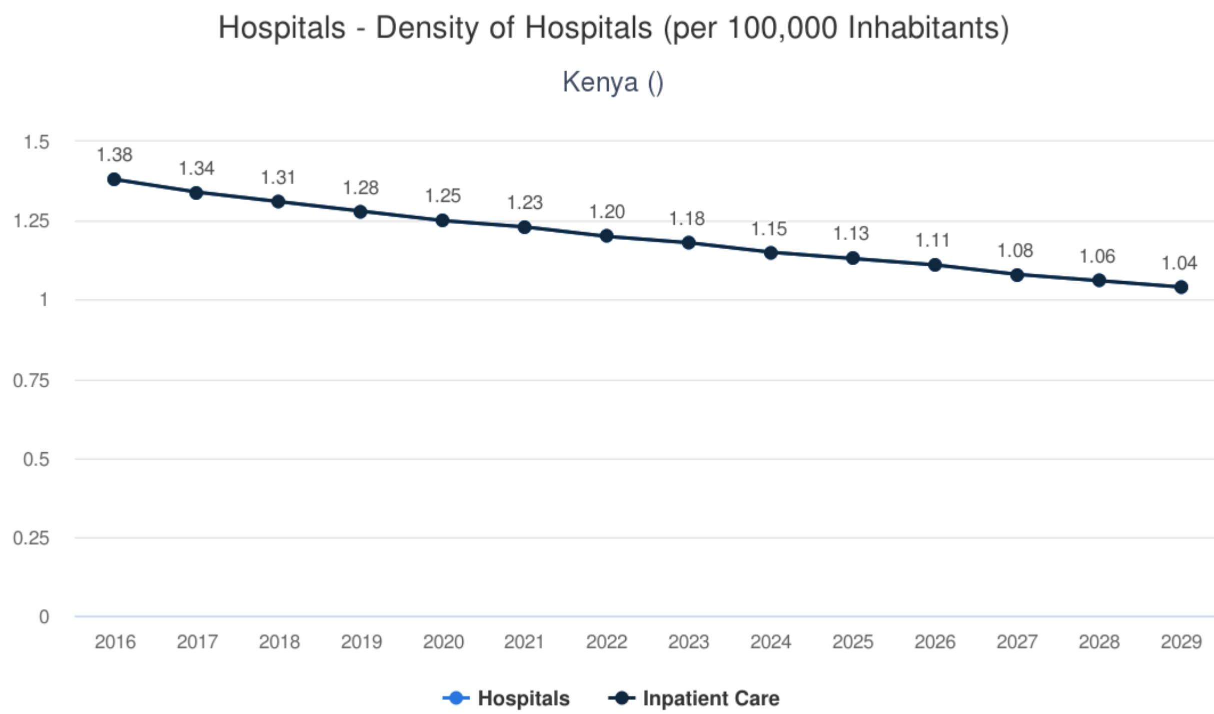


Figure 20*:Past and projected density of hospitals in Kenya.* ***Source:*** *World Bank*

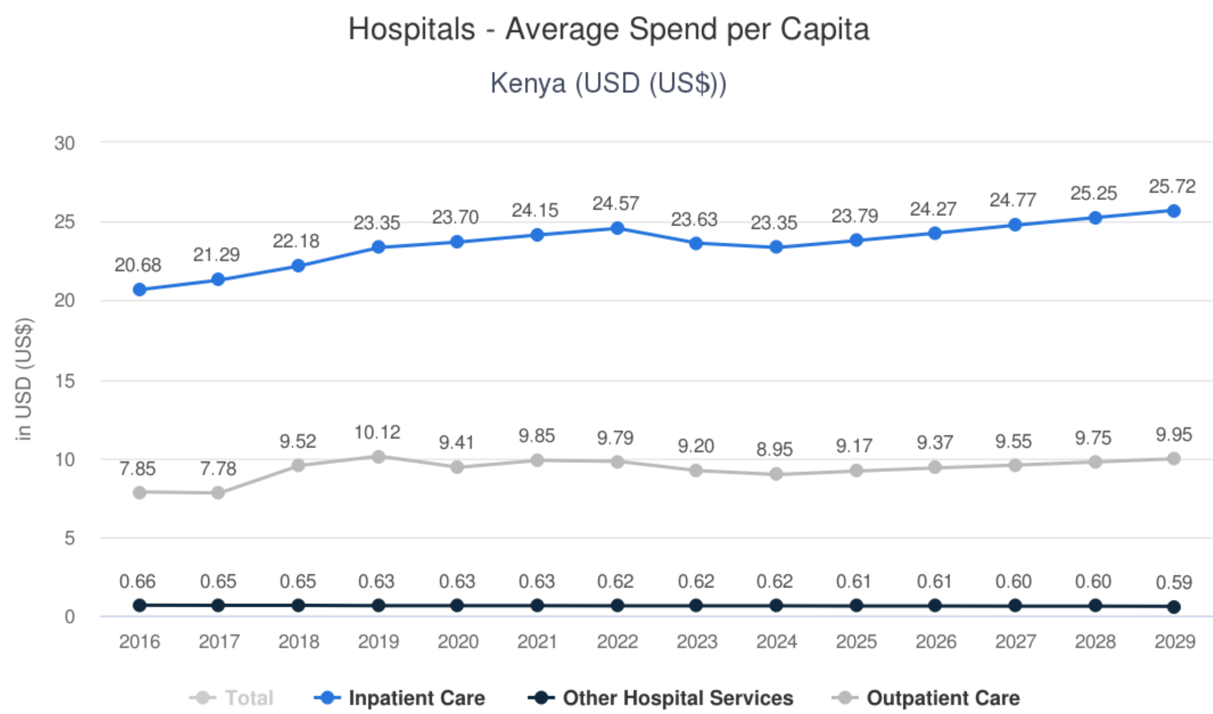


***Figure 22**: Average spend per capita of hospitals in Kenya. **Source:** World Bank*

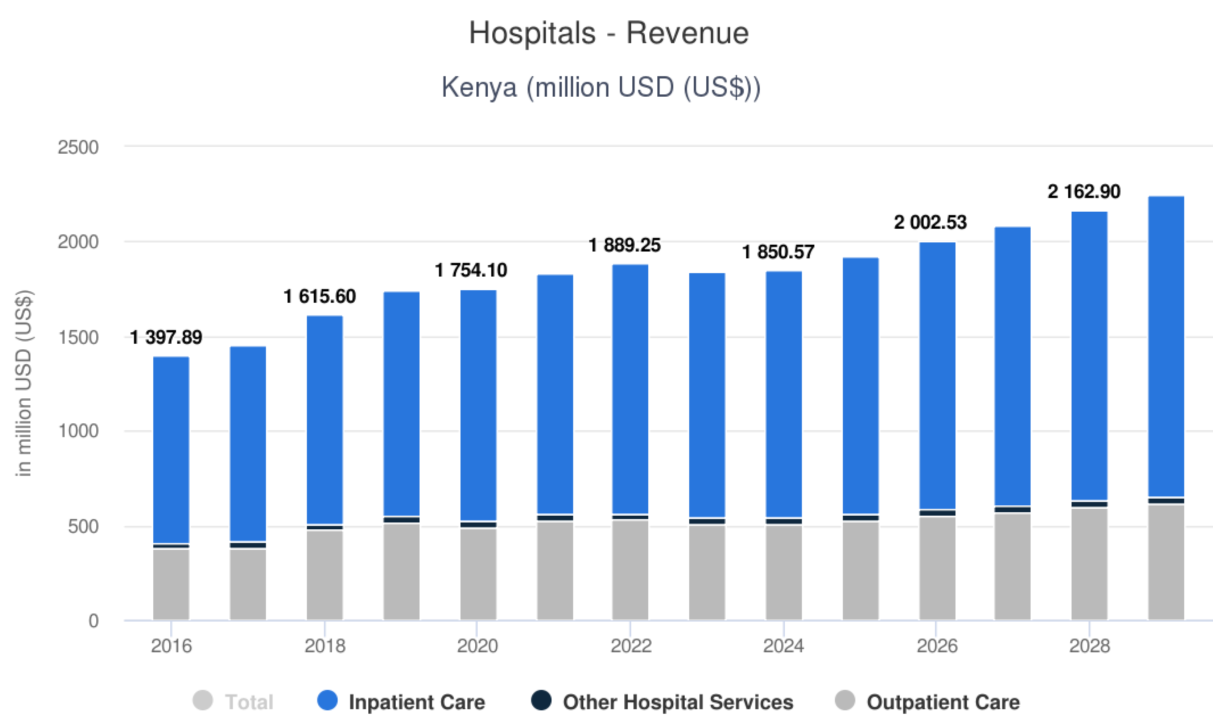


***Figure 21**: Past and projected revenue of hospitals in Kenya. **Source:** World Bank*

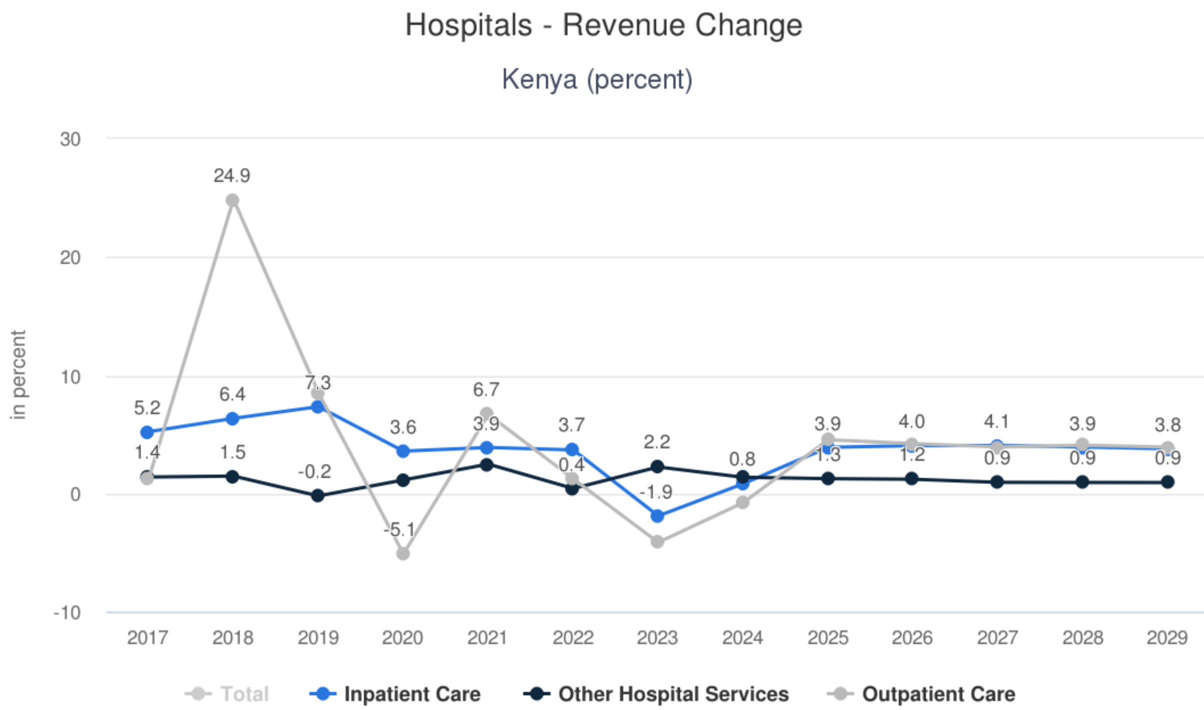


Figure 23: *Past and projected revenue change of hospitals in Kenya.* ***Source:*** *World Bank*

4.43 Distribution of Medical Infrastructure In Kenya

The distribution of healthcare facilities in Kenya is heavily skewed towards urban areas, particularly major cities like Nairobi, Mombasa, and Kisumu. Historically, about 60-70% of doctors have been concentrated in urban areas, serving only about 30-40% of the population. In contrast, rural areas, home to most of the Kenya's population, have been left with a disproportionately small share of healthcare resources. Several factors contribute to this disparity. Rapid urban growth has led to a concentration of resources in cities, and urban areas generally offer better economic opportunities, attracting more healthcare professionals. Additionally, rural areas often lack basic infrastructure such as roads, electricity, and water, which are necessary for modern healthcare facilities. Most medical training institutions are in urban areas, leading to the retention of graduates in those areas. Historically, there has also been inadequate policy focus on the equitable distribution of healthcare resources, and many healthcare professionals prefer to work in urban areas or abroad, leaving rural areas understaffed.

This imbalance has significant implications. Rural populations often have poorer health outcomes due to limited access to quality healthcare, and urban hospitals are often overcrowded as people travel from rural areas seeking better care. Poor health in rural areas can affect agricultural productivity, a key sector of Kenya's economy. Maternal and infant mortality rates are often higher in rural areas due to the lack of specialized care. Additionally, limited rural healthcare infrastructure can hamper efforts to control communicable diseases. Rural residents may face higher out-of-pocket expenses due to travel costs for accessing healthcare, exacerbating social and economic inequalities. Some healthcare professionals in rural areas may be underutilized due to a lack of proper facilities and equipment.

Addressing this imbalance is crucial for Kenya to achieve its healthcare goals and ensure equitable access to quality healthcare for all citizens. Efforts have been made to improve rural healthcare through initiatives like the Beyond Zero campaign and increased focus on primary healthcare, but significant challenges remain.

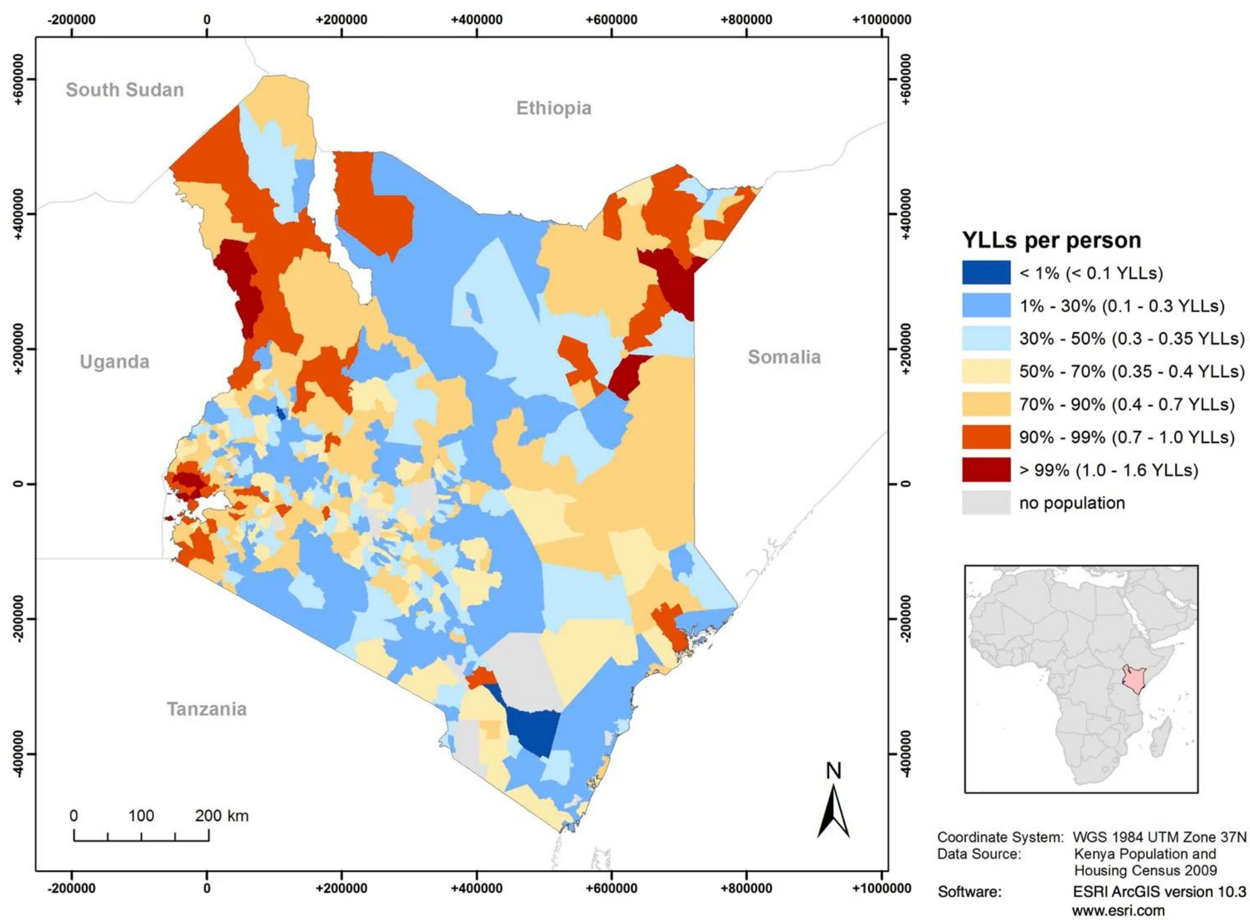


Figure 24*: Years of Lives Lost Per Person.* ***Source****: Kenya Population and Housing Census*

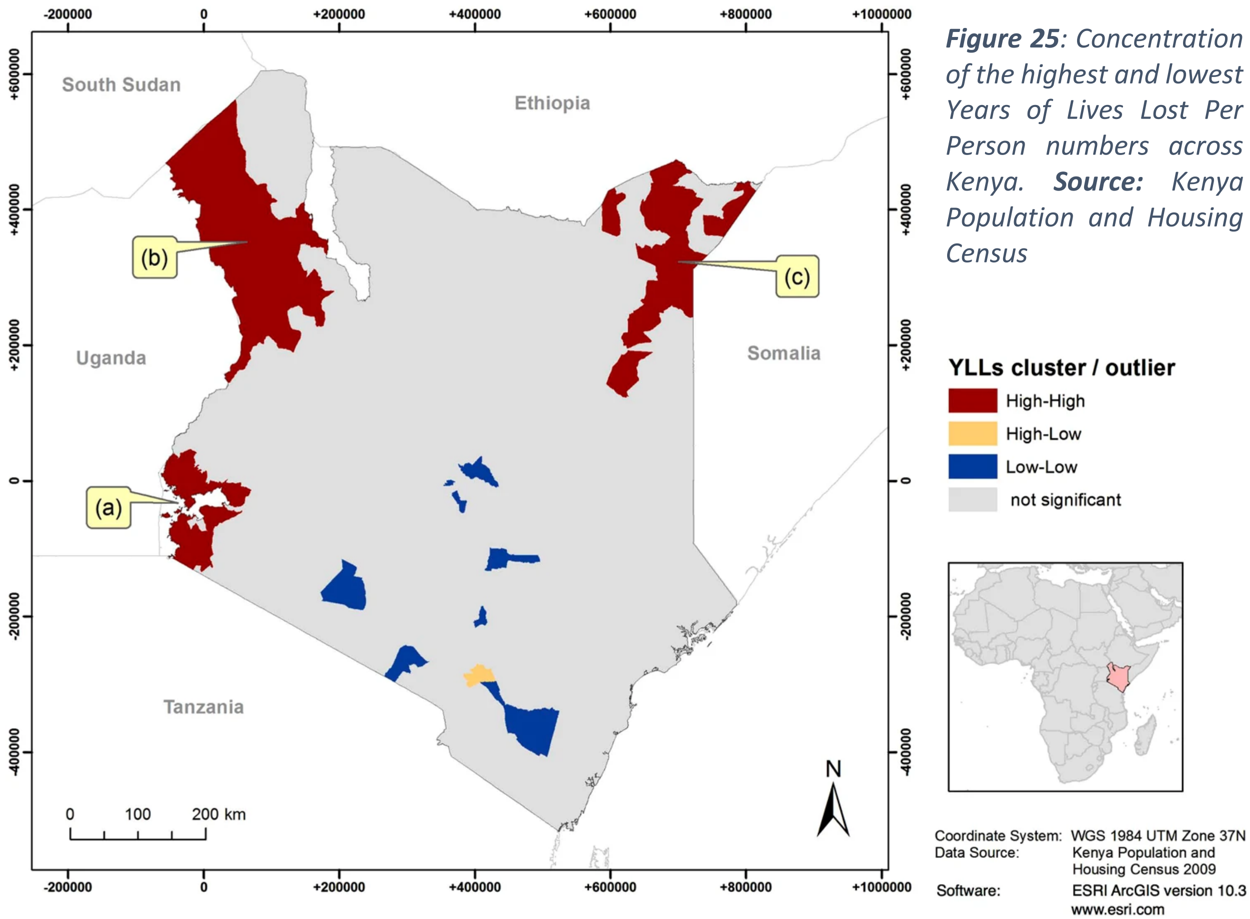


***Figure 25**: Concentration of the highest and lowest Years of Lives Lost Per Person numbers across Kenya. **Source:** Kenya Population and Housing Census*

As shown in the maps above and below, 4.11, 4.12 and 4.13 wealth and income distribution play a significant role in the disparity of healthcare facilities and services in Kenya. Wealthier individuals and families can afford better healthcare services, which are predominantly available in urban areas, leaving those in rural areas, who typically have lower income levels, facing significant barriers to accessing quality healthcare. The concentration of private healthcare facilities in cities exacerbates this disparity, as rural areas, reliant on under-resourced public healthcare, remain underserved. Access to health insurance is also correlated with income, with higher-income individuals more likely to have comprehensive coverage, enabling them to afford better and more frequent healthcare. In contrast, lower-income populations often lack adequate insurance, leading to prohibitively high out-of-pocket expenses. Additionally, government and private investments in healthcare infrastructure are often directed towards urban areas due to higher returns on investment from the wealthier population base, resulting in better-equipped and staffed healthcare facilities in cities compared to rural areas .

Higher levels of education and health literacy among wealthier individuals enable them to seek timely and appropriate medical care, whereas lower-income populations might lack the knowledge or resources to do so, leading to poorer health outcomes. Furthermore, healthcare professionals are drawn to urban areas by better pay, working conditions, and career opportunities, leaving rural areas, which offer lower salaries and fewer opportunities, struggling to attract and retain qualified healthcare workers. Economic opportunities and infrastructure development are also concentrated in urban areas, benefiting from concentrated wealth and leading to better roads, electricity, water, and telecommunications, all essential for establishing and sustaining healthcare facilities. In contrast, rural areas often lag in these developments, making it challenging to set up and maintain healthcare services.

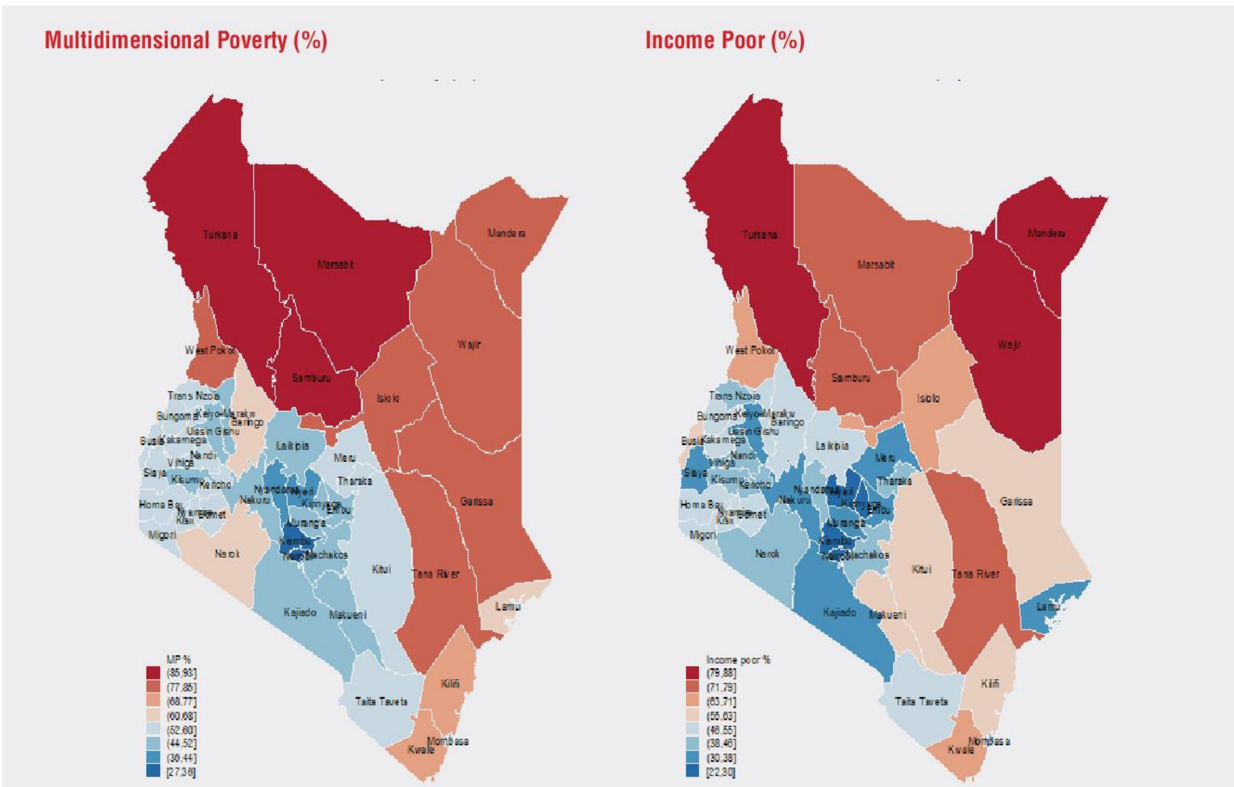


Figure 26: *Concentration of the highest and lowest Years of Lives Lost Per Person numbers across Kenya.*
Source: *Kenya Population and Housing Census*

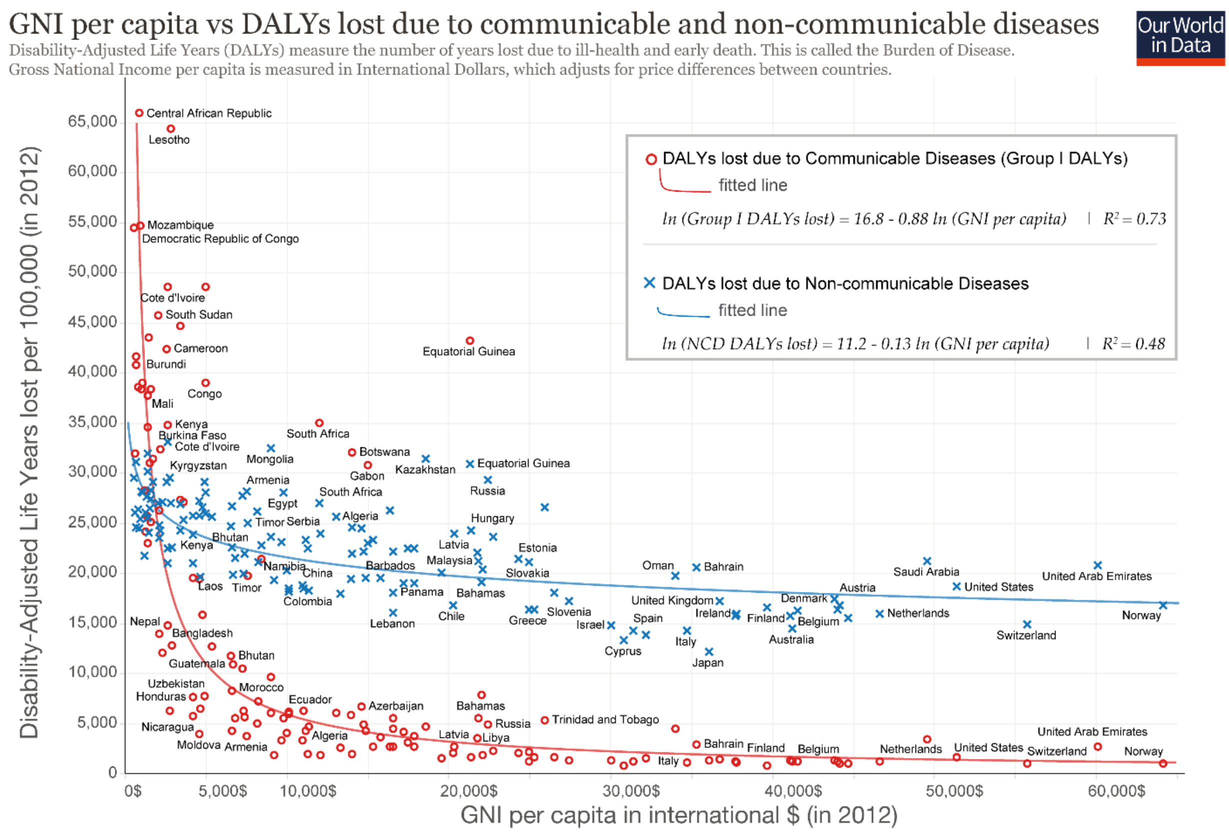


Figure 27 : *GNI per capita vs DALYs lost due to communicable and non-communicable diseases.* ***Source:*** *Our World in Data*

4.44 Disease Burden of Kenya

Communicable diseases continue to account for the highest proportion of disease burden in Kenya, with leading causes being HIV/AIDS, malaria, and tuberculosis (TB). Despite a significant reduction in malaria morbidity from 14% to 8%, it remains a serious health problem, with prevalence varying by season and geographic region. Approximately 70% of the population lives in malaria risk areas, with the Lake Region having the highest prevalence at 27%. Kenya has made strides in TB control; however, the 2016 TB prevalence survey indicated that up to 40% of cases are still missed. The emergence of drug-resistant tuberculosis has further complicated the fight against TB in Kenya. Significant progress has been made in combating HIV/AIDS, yet HIV remains the leading cause of disease burden, accounting for 24% of the total disease burden and over 29% of all hospital mortality. The HIV prevalence stood at 5.9% in 2015.

Infant mortality and under-5 mortality rates have decreased from 52 to 39 deaths per 1,000 live births and from 74 to 52 deaths per 1,000 live births between 2008/09 and 2014, respectively (KDHS, 2014). Exclusive breastfeeding among infants under six months has improved from 61.4%

in 2013/14 to 77% in 2016/17. However, immunization services have been adversely affected by frequent industrial actions by health workers since the advent of devolution. Immunization coverage in Kenya has declined over the years, with 78% of children under one year fully immunized in 2016/17 compared to 89% in 2013/14. Since 2012, the Ministry of Health and its partners, through the Neglected Tropical Diseases (NTDs) Unit, have implemented control strategies including NTDs mapping and the Kenya National School-Based Deworming Programme (NSBDP). The NTDs strategic plan has been reviewed to align with the global goal for accelerated control, elimination, and eradication of NTDs by 2020. Kenya was declared Guinea Worm free by the World Health Organization in 2017.

Cases of cardiovascular diseases, diabetes, and mental disorders are on the rise in Kenya and currently rank among the leading causes of death. In 2015, the country conducted its first ever STEPwise survey, providing baseline data on the prevalence of non-communicable diseases (NCDs). The survey revealed that 27% of Kenyan adults are either overweight or obese, 23.8% are hypertensive, and the prevalence of diabetes among adults aged 15-69 years is 1.9%. Only 41% of those with diabetes had been diagnosed, and effective treatment coverage was just 7%.

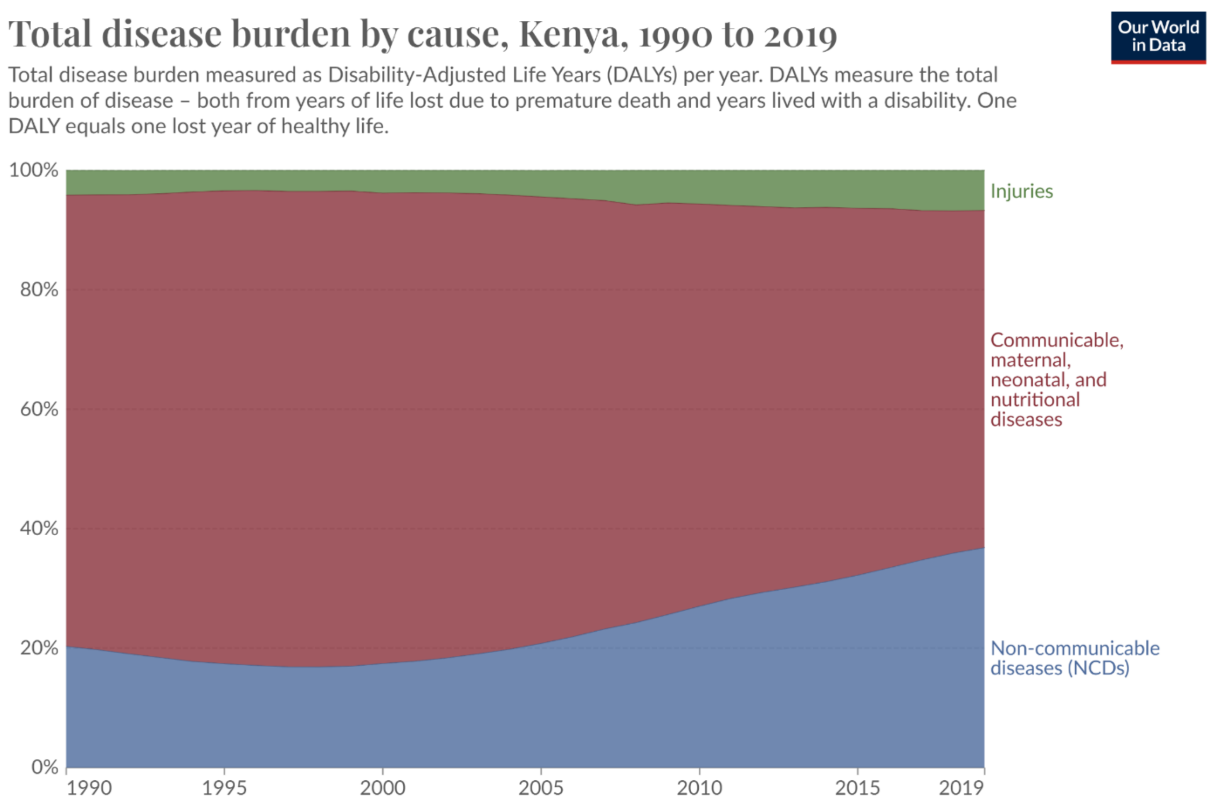


***Figure 28**: Total Disease Burden by Cause. **Source:** IHME, Global Burden of Disease (2019)*

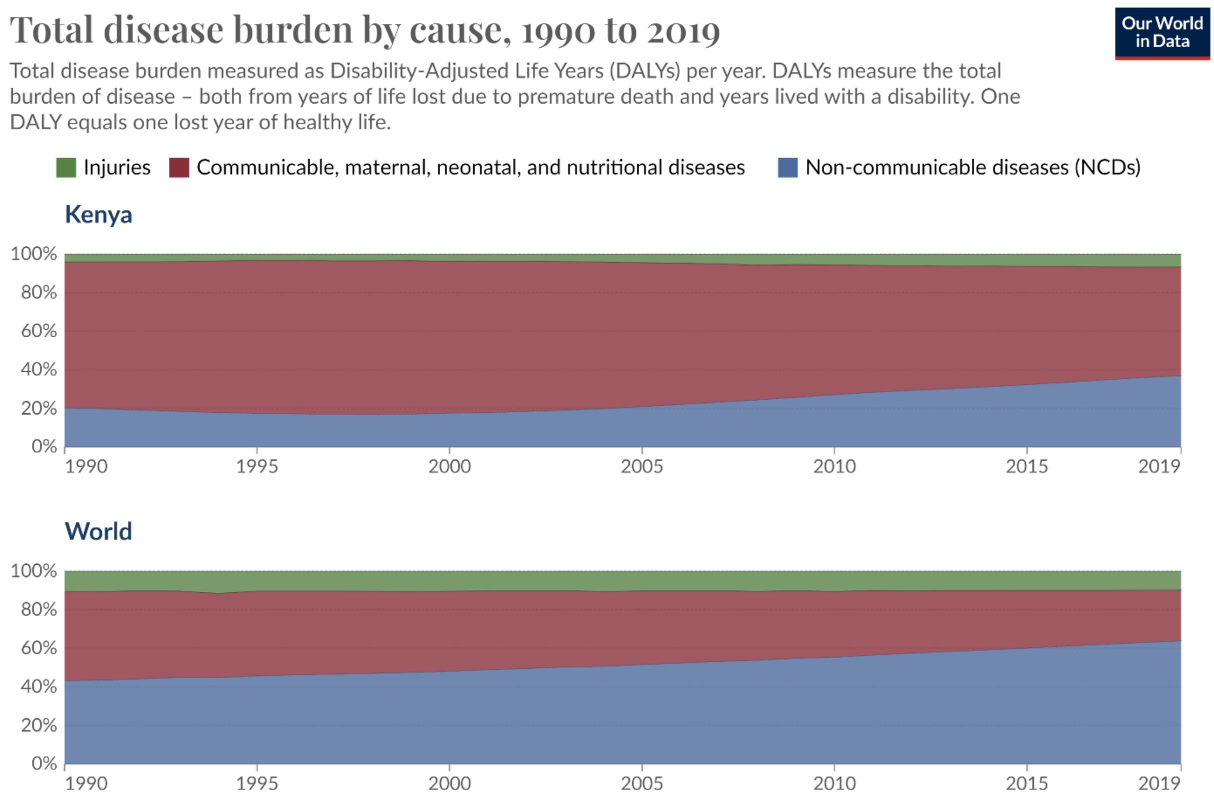


***Figure 29**: Total disease burden by cause comparison between Kenya and the world. **Source:** IHME, Global Burden of Disease (2019)*

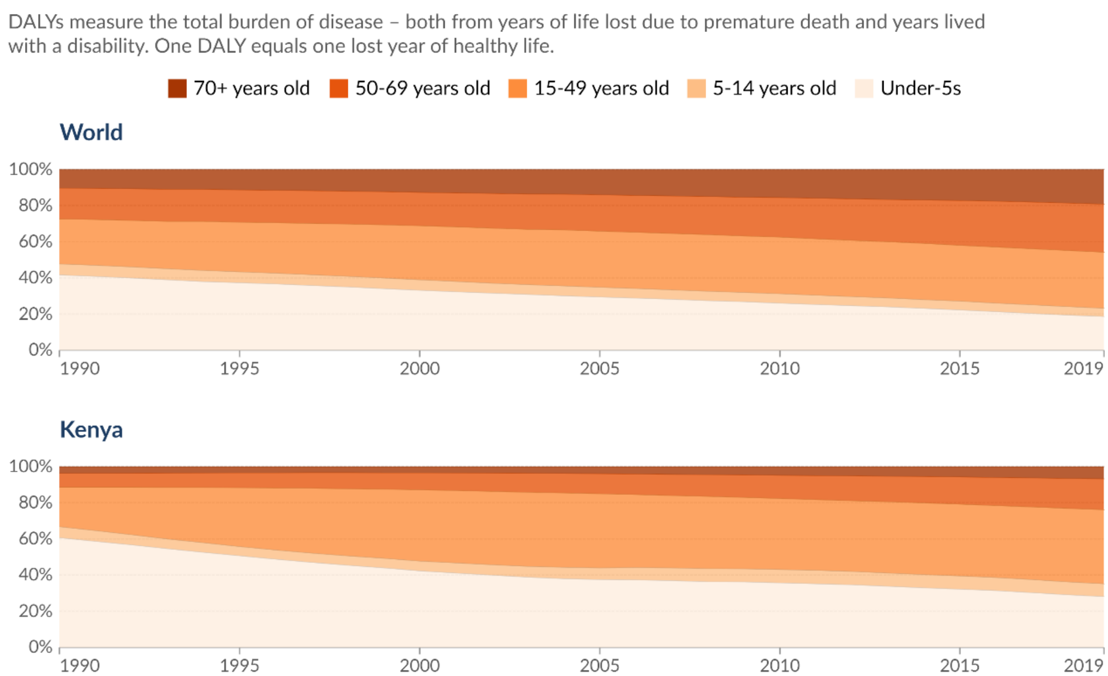


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***Figure 30**: Total disease burden by age in Kenya. **Source**: IHME, Global Burden of Disease (2019)*

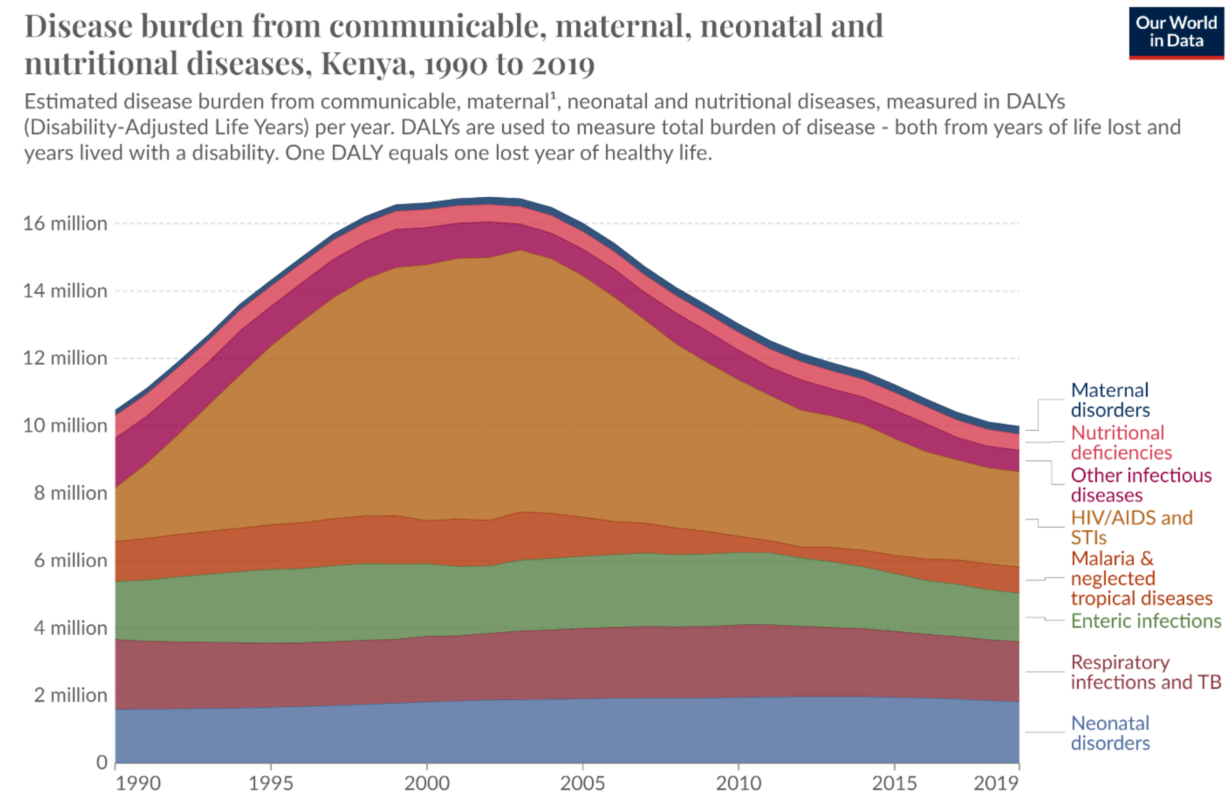

***Figure 31**: Disease burden from communicable, maternal, neonatal and nutritional diseases, Kenya, 1990 to 2019. **Source:** IHME, Global Burden of Disease (2019).*

data on the burden of disease in Kenya reveals several critical insights about the country's healthcare system. The significant burden of communicable diseases such as HIV/AIDS, respiratory infections, TB, and malaria indicates that Kenya's healthcare system faces substantial challenges in managing and controlling infectious diseases. Despite progress, these diseases continue to cause high morbidity and mortality, reflecting gaps in prevention, early detection, and treatment. The substantial contribution of neonatal disorders to the disease burden highlights ongoing issues in maternal and child health services, suggesting deficiencies in prenatal, perinatal, and postnatal care, as well as in addressing conditions that affect newborns. Additionally, the rising burden of non-communicable diseases, including cardiovascular diseases, cancers, mental disorders, and diabetes, signifies a transition in the health landscape that the healthcare system may not be fully equipped to handle, requiring enhancements in chronic disease management, lifestyle interventions, and specialized care.

The high disease burden across various conditions points to potential issues in resource allocation and healthcare infrastructure. There may be an imbalance in the distribution of healthcare facilities, personnel, and services, particularly between urban and rural areas, affecting the system's overall efficiency and equity. The data underscores the need for stronger preventive and primary care services. Effective immunization programs, health education, and early intervention strategies are essential to reduce the incidence of both communicable and non-communicable diseases. However, declining immunization rates suggest that preventive measures may be compromised, potentially due to disruptions like industrial actions by health workers.

The healthcare system's ability to manage both traditional communicable diseases and the rising tide of NCDs speaks to its resilience and adaptability. However, the current data suggests that there is still considerable room for improvement in building a more robust and responsive health system. The disease burden data also reflects underlying health inequities, with rural and lower-income populations likely bearing a disproportionate share of the burden. This inequity points to the need for targeted policies and interventions to ensure more equitable access to quality healthcare services across all regions and populations. Overall, the data indicates that while Kenya has made progress in some areas, there remain significant challenges in managing the dual burden of communicable and non-communicable diseases, addressing health inequities, and strengthening the overall healthcare infrastructure and service delivery systems.

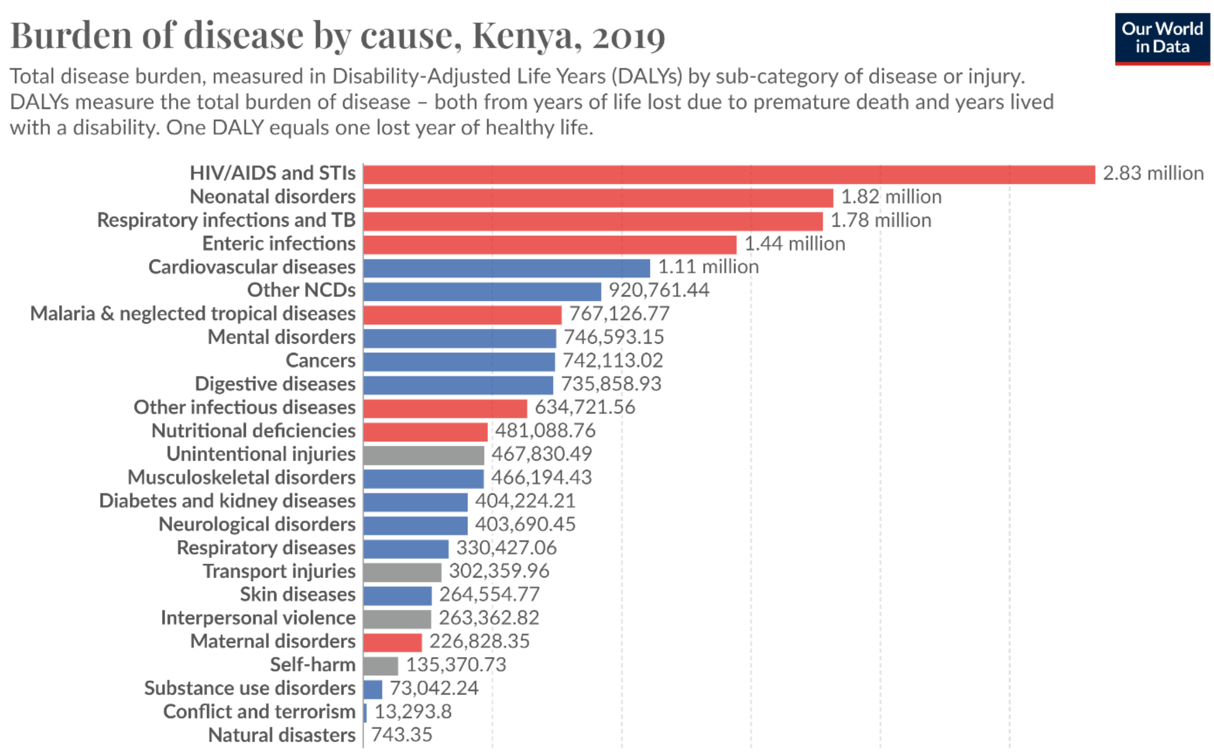

Figure 32: *Burden of disease by cause, Kenya 2019.* ***Source:*** *IHME, Global Burden of Disease (2019).*

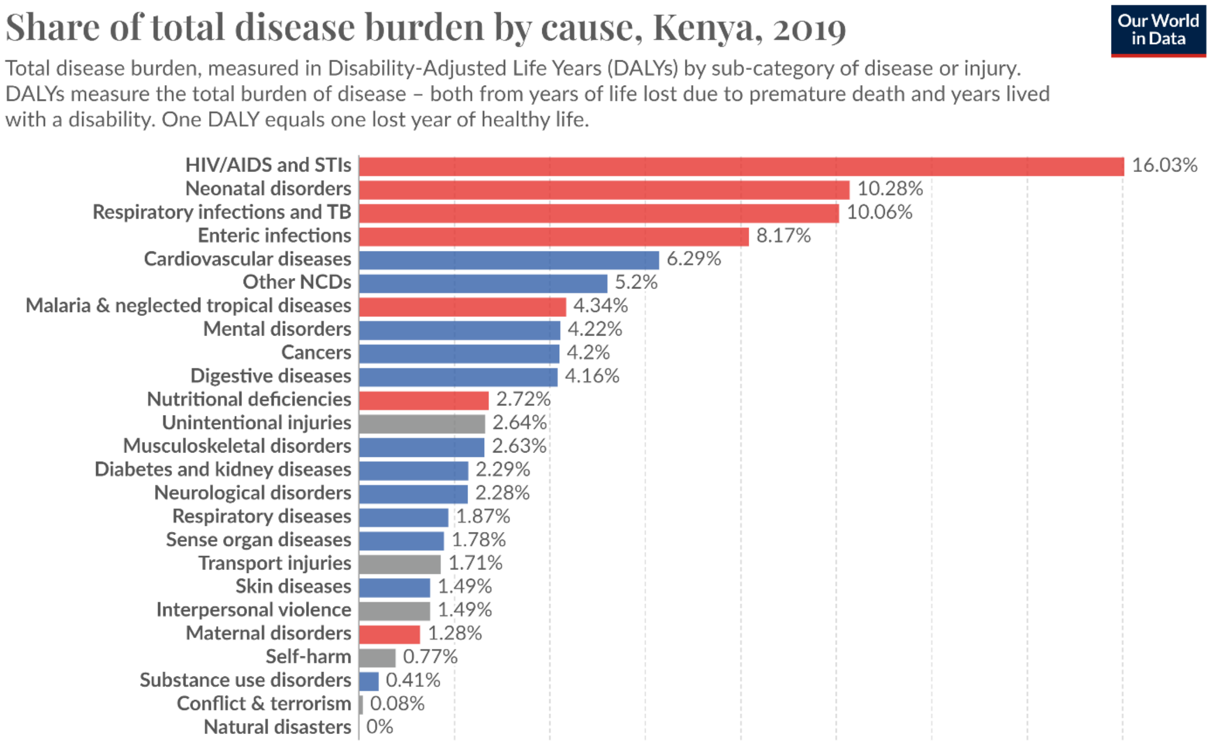

***Figure 33:** Share of total disease burden by cause, Kenya 2019. **Source:** IHME, Global Burden of Disease*

4.5 Generative Pre- Trained Transformer Architecture

A Generative Pre-trained Transformer (GPT) is a type of artificial intelligence model developed by OpenAI, designed for natural language processing tasks such as text generation, translation, summarization, and question answering. Here's a detailed explanation of what GPT is and how it works:

What is GPT?

Generative: GPT models can generate coherent and contextually relevant text based on the input they receive. They can produce new content rather than merely performing classification or regression tasks.

Pre-trained: The model is pre-trained on a vast corpus of text from the internet. This pre-training phase involves learning the statistical properties of language, such as grammar, facts about the world, and some reasoning abilities.

Transformer: GPT uses a transformer architecture, which was introduced by Vaswani et al. in the paper "Attention is All You Need". The transformer architecture relies on self-attention mechanisms to process input text in parallel, which improves efficiency and performance compared to earlier models like RNNs (Recurrent Neural Networks).

How Does GPT Work?

1. **Architecture:**

   Transformer Blocks: The GPT model is composed of multiple transformer blocks. Each block has a self-attention layer followed by a feed-forward neural network. The self-attention mechanism allows the model to weigh the importance of different words in a sentence relative to each other.

   Positional Encoding: Since transformers process the entire input simultaneously, they use positional encodings to keep track of the word order in the input sequence.

2. **Training:**

   Pre-training: During pre-training, the model learns to predict the next word in a sentence by being exposed to a large and diverse dataset. This phase allows the model to understand language patterns, grammar, and facts about the world.

   Fine-tuning: After pre-training, the model can be fine-tuned on a specific dataset tailored to a particular task. This helps the model to adjust to specific domain knowledge and improve performance on specialized tasks.

3. **Generation:**

   Input Processing: When generating text, GPT takes an input prompt and processes it through its layers.

   Token Prediction: The model predicts the next token (word or piece of a word) in the sequence based on the input and the learned probabilities from pre-training.

   Iterative Generation: This process is repeated iteratively, where the newly generated token is added to the input sequence, and the model predicts the next token until the desired length or stopping criteria are met.

4.6 Application Programming Interface (API)

An API (Application Programming Interface) is a set of rules and protocols that allows different software applications to communicate with each other. APIs enable the integration of various services and functionalities into applications, facilitating the sharing of data and functionality between different systems. Here's how APIs work in general and how they interact with Chat GPT specifically:

What are APIs?

APIs in General:

Endpoints: APIs expose certain endpoints, which are specific URLs or URIs through which applications can request services or data. Each endpoint corresponds to a particular functionality or resource.

Requests and Responses: Communication via APIs typically involves sending a request to an endpoint and receiving a response. Requests include methods like GET (retrieve data), POST (send data), PUT (update data), and DELETE (remove data).

Data Format: The data exchanged is usually in a standardized format such as JSON (JavaScript Object Notation) or XML (eXtensible Markup Language).

Authentication: Many APIs require authentication, often using API keys, tokens, or other mechanisms to ensure that the request comes from a legitimate source.

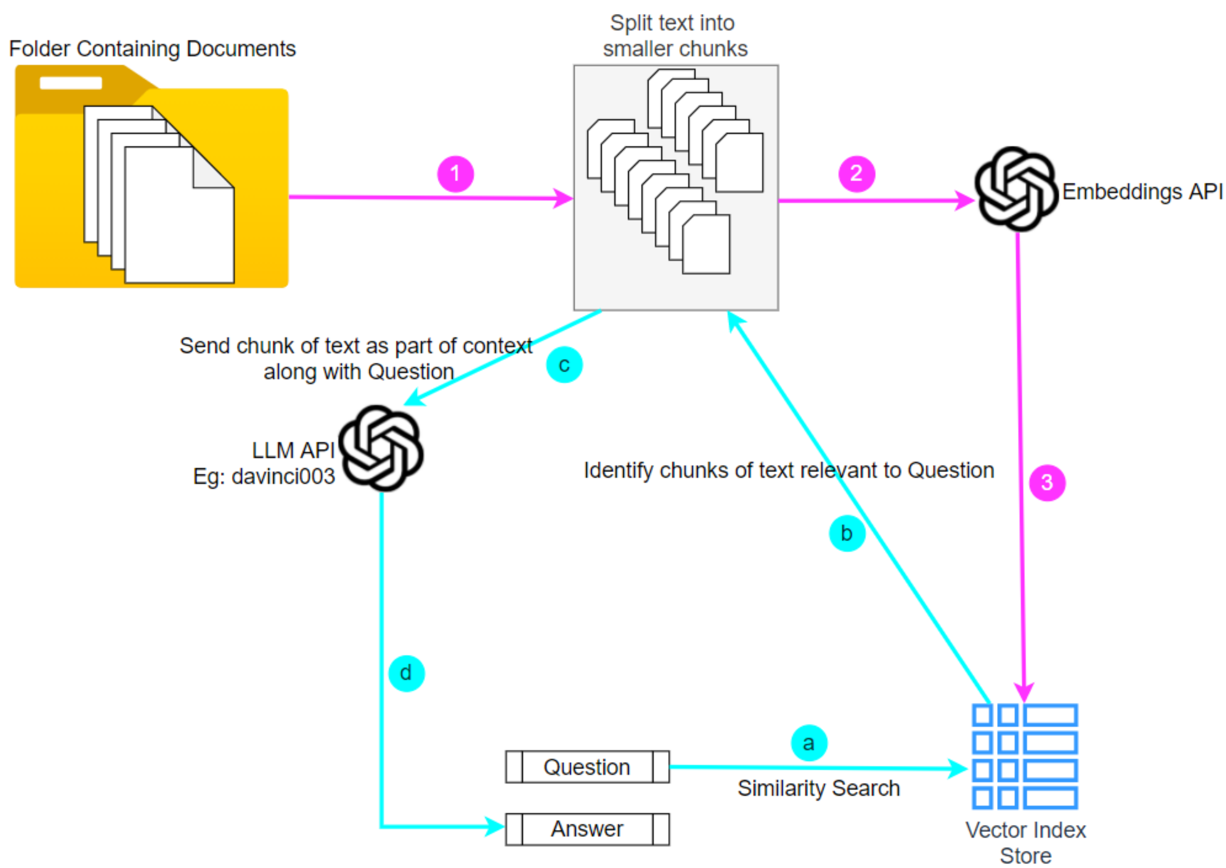

Figure 34: *API Workflow.* ***Source****: Paragh Shah*

How APIs Work with Chat GPT:

Integration with Chat GPT:

Accessing the API: To interact with Chat GPT, developers use OpenAI's API. They send HTTP requests to specific endpoints provided by OpenAI's API service.

API Key: Developers need an API key from OpenAI, which is used to authenticate requests. This key is unique to each user and must be included in the request headers.

Sending Requests: When using the API, developers send a POST request to the endpoint with the input text they want the model to process. This request includes the input text and any parameters that specify how the model should generate the response (e.g., maximum length, temperature, etc.).

Receiving Responses: The API responds with generated text from the Chat GPT model. This response can be integrated into the application, providing users with AI-driven conversational capabilities.

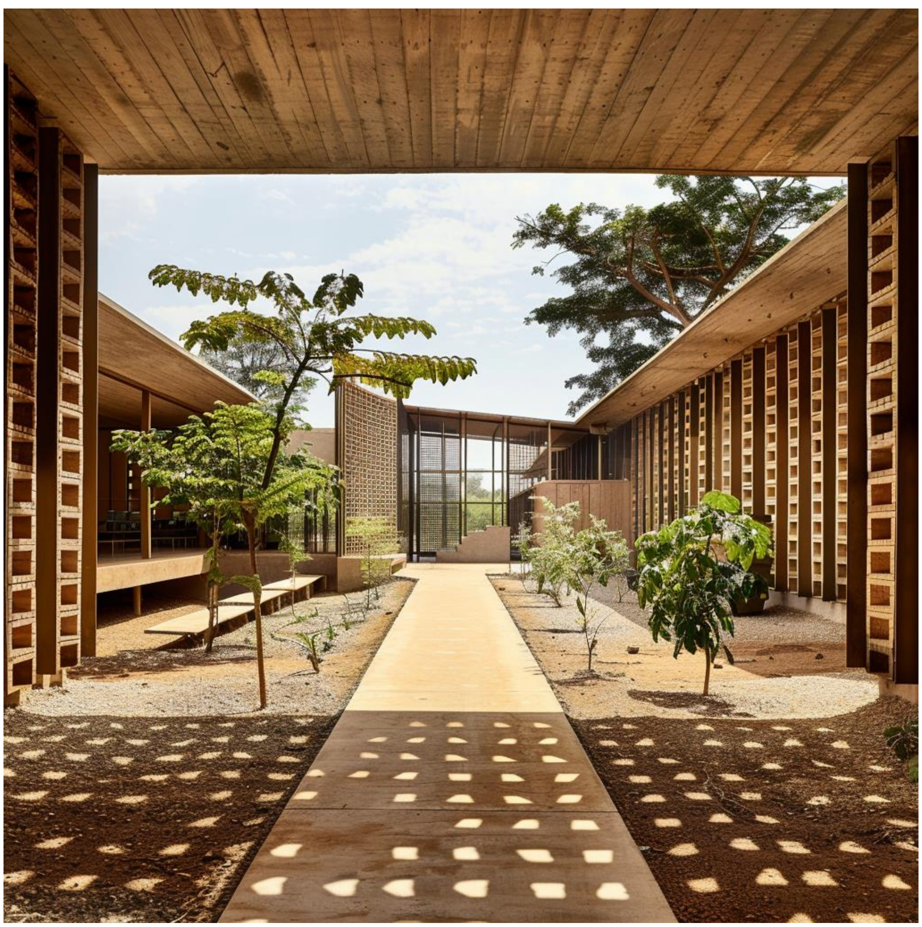

Figure 35: *A rendition of a level 3 hospital in Mandera County, Kenya.* ***Source:*** *Author*

```json
POST https://api.openai.com/v1/engines/davinci-codex/completions
Headers: {
  "Authorization": "Bearer YOUR_API_KEY",
  "Content-Type": "application/json"
}
Body: {
  "prompt": "What are APIs and how do they work with Chat GPT?",
  "max_tokens": 100,
  "temperature": 0.7
}
```

Figure 37*: API Workflow request.* ***Source:*** *Author*

```json
{
  "id": "cmpl-5hV7mYyExdFz9XxOQZg3S4bx",
  "object": "text_completion",
  "created": 1618323451,
  "model": "davinci-codex",
  "choices": [
    {
      "text": "An API (Application Programming Interface) is a set of rules and protoc
      "index": 0,
      "logprobs": null,
      "finish_reason": "length"
    }
  ],
  "usage": {
    "prompt_tokens": 9,
    "completion_tokens": 100,
    "total_tokens": 109
  }
}
```

Figure 36 *: API Workflow request.* ***Source:*** *Author*

A GPT (Generative Pre-trained Transformer) could be leveraged in multiple ways to address the challenge of improving hospital design in rural Kenya using AI. The model's advanced natural language processing capabilities, based on the transformer architecture (Vaswani, 2017), could be used to interpret complex design briefs, local building codes, and healthcare regulations, translating them into actionable design parameters. This process could involve parsing through thousands of pages of regulatory documents and extracting key requirements, a task that would be time-consuming for human designers but efficiently handled by a GPT (Brown, 2020).

GPTs excel at analyzing and synthesizing large amounts of textual data, making them ideal for processing research papers, case studies, and reports on hospital design and rural healthcare challenges in Kenya. For instance, a GPT could be trained on a corpus of medical journals, architectural design papers, and Kenyan health policy documents to identify best practices and innovative solutions applicable to the Kenyan context. This could include analyzing successful hospital designs from similar resource-constrained environments and extracting principles that could be applied to rural Kenya (Radford, 2019).

The model could generate initial design concepts in natural language, serving as starting points for more detailed development. For example, it might produce descriptions like: "A circular ward layout with a central nursing station to maximize patient visibility and minimize staff walking distances, incorporating natural ventilation through strategically placed windows to reduce infection spread in the tropical climate" (Brown, 2020). These concepts could then be translated into more detailed architectural plans by human designers or other AI systems.

GPTs could also facilitate stakeholder engagement by creating and analyzing surveys, interpreting responses to extract insights about local needs and preferences. This could involve processing thousands of survey responses from healthcare workers, patients, and community members, identifying common themes and unique insights that might be overlooked in manual analysis (Zhang, 2022). For instance, it might uncover a preference for outdoor waiting areas in certain communities, informing the design process.

In the design evaluation phase, a GPT could assess designs against extracted requirements and best practices, suggesting improvements in natural language. It could potentially identify conflicts between different design elements or highlight areas where a design falls short of regulatory requirements or best practices in healthcare design (Brown, 2020).

The model's ability to generate comprehensive reports could aid in documenting the design process and explaining the rationale behind decisions. This could be particularly valuable in communicating complex design choices to stakeholders who may not have a background in architecture or healthcare design (Radford, 2019).

Furthermore, by training on locale-specific data, a GPT could ensure that design solutions are culturally appropriate and contextually relevant to rural Kenya. This might involve incorporating traditional healing spaces, considering local building materials and techniques, or adapting designs to specific climatic conditions in different regions of rural Kenya (Raffel, 2020).

However, it's crucial to note that a GPT would be most effective when used in conjunction with other AI technologies and human expertise. For example, while a GPT might generate design concepts and evaluate them in natural language, a generative adversarial network (GAN) could be used to create visual representations of these designs. Human architects and healthcare professionals would still play a crucial role in overseeing the process, making final decisions, and ensuring that the AI-generated designs meet practical and ethical standards.

Moreover, to be truly effective for this specific application, the GPT would require fine-tuning on domain-specific data related to hospital design, Kenyan healthcare, and local cultural contexts. This fine-tuning process would involve training the model on a carefully curated dataset of relevant documents, potentially including Kenyan hospital records, local architectural guidelines, and transcripts of interviews with healthcare workers in rural Kenya. This would ensure that its outputs are accurate, relevant, and tailored to the specific challenges of designing hospitals for rural Kenya (Zhang, 2022).

A GPT (Generative Pre-trained Transformer) could be instrumental in creating more culturally sensitive hospitals in rural Kenya by leveraging its natural language processing capabilities to understand, interpret, and incorporate local cultural nuances into the design process. Here are several specific ways a GPT could be used, along with examples:

> Analysis of Local Narratives and Traditions: A GPT could be trained on a corpus of Kenyan folklore, traditional stories, and cultural practices. It could then suggest design elements that resonate with local cultural narratives.

Example: After analyzing stories about the significance of the baobab tree in certain Kenyan communities, the GPT might suggest incorporating baobab-inspired elements in the hospital design, such as a central courtyard with a large shade tree or circular waiting areas reminiscent of gatherings under a baobab.

> Interpretation of Community Feedback: The GPT could process and analyze large volumes of community feedback collected through surveys, interviews, or public meetings, identifying cultural preferences that might be overlooked in manual analysis.

Example: After processing hundreds of community interviews, the GPT might identify a recurring theme of discomfort with direct eye contact in certain medical examinations. It could then suggest design elements like privacy screens or seating arrangements in examination rooms that allow for more indirect interaction between patients and healthcare providers.

> Integration of Traditional Healing Practices: By analyzing texts on traditional Kenyan medicine and healing practices, the GPT could suggest ways to incorporate these elements into the hospital design.

Example: The GPT might recommend designing spaces for traditional healers to practice alongside modern medical professionals, or creating gardens with local medicinal plants that could be used in conjunction with modern treatments.

Customization of Wayfinding Systems: The GPT could help design culturally appropriate wayfinding systems by analyzing local language use, symbolism, and color associations.

Example: Instead of using written signs, the GPT might suggest a color-coded system based on local textiles' patterns or a symbol-based system using locally significant animals or plants to designate different hospital areas.

Adaptation of Spatial Layouts: By processing information about local social structures and family dynamics, the GPT could suggest spatial layouts that accommodate cultural norms.

Example: In communities where extended family support is crucial, the GPT might suggest larger patient rooms or adjacent family waiting areas to accommodate family members staying with patients.

Incorporation of Local Architectural Styles: The GPT could analyze traditional Kenyan architectural styles and suggest ways to incorporate these elements into modern hospital design.

Example: For a hospital in a Maasai area, the GPT might suggest a layout inspired by the circular arrangement of traditional Maasai villages, with patient wards arranged in a circle around a central treatment area.

Consideration of Cultural Taboos and Sensitivities: By processing information about local cultural taboos and sensitivities, the GPT could help avoid design elements that might be culturally inappropriate.

Example: If the GPT identifies a cultural aversion to certain animals or symbols in a particular community, it could flag these for exclusion from any decorative or design elements in the hospital.

Adaptation to Local Climate Practices: The GPT could analyze local traditional architecture and suggest ways to incorporate climate-adaptive strategies that align with cultural practices.

Example: In hot, arid regions, the GPT might suggest incorporating outdoor waiting areas with shade structures like traditional gathering spaces, rather than enclosed air-conditioned waiting rooms.

Integration of Ritual Spaces: By understanding the importance of certain rituals in Kenyan cultures, the GPT could suggest the integration of spaces for these practices within the hospital setting.

Example: The GPT might recommend including a dedicated space for prayer or meditation, designed in a way that respects local spiritual practices.

Language and Communication Considerations: The GPT could analyze local language use and communication styles to suggest ways to make the hospital environment more linguistically inclusive.

Example: In a multilingual area, the GPT might suggest a system of universal symbols for important hospital areas, supplemented by information in multiple local languages.

To implement these culturally sensitive design elements effectively, the GPT would need to be fine-tuned on a diverse dataset of Kenyan cultural information, including ethnographic studies, local literature, and community feedback. It's also crucial to note that while a GPT can provide valuable insights and suggestions, the final design decisions should always involve human oversight, particularly from local cultural experts and community representatives, to ensure cultural sensitivity and appropriateness.

Figure 38*: A rendition of a level 3 hospital in Marsabit County.* ***Source:*** *Author*

5.0 Conclusion and Recommendations

Conclusions and Recommendations for AI-Driven Culturally Sensitive Hospital Design in Rural Kenya

Conclusions:

1. Advanced AI technologies, particularly GPT models, demonstrate significant potential in enhancing the design process for culturally sensitive hospitals in rural Kenya. The ability of these models to process and synthesize vast amounts of diverse data offers a unique opportunity to create hospital designs that are both efficient and deeply rooted in local contexts.
2. AI-driven design processes can significantly reduce the time and resources required for generating and evaluating multiple design options. This efficiency is crucial in the resource-constrained setting of rural Kenya, where rapid deployment of healthcare infrastructure is needed. The adaptability of AI models allows for quick iterations and customizations based on specific local needs.
3. The use of AI in hospital design allows for the incorporation of multifaceted data, including cultural nuances, local healthcare needs, environmental factors, and traditional architectural practices. This comprehensive data integration leads to more holistic and tailored designs that are likely to be both functionally efficient and culturally appropriate.
4. GPT models, when properly trained on local cultural data, can significantly enhance the cultural sensitivity of hospital designs. They can identify and incorporate subtle cultural elements that might be overlooked in traditional design processes, leading to hospitals that resonate more deeply with local communities.
5. While AI offers powerful capabilities, the research underscores that human expertise and local knowledge remain crucial in the design process. The most effective approach is a synergy between AI-generated insights and human judgment, particularly for ensuring cultural appropriateness and practical feasibility.
6. AI-driven design processes offer the potential for developing standardized yet customizable design templates. This could facilitate faster deployment of hospitals across different regions of rural Kenya while still allowing for local adaptations.
7. The effectiveness of AI models is heavily dependent on the quality and comprehensiveness of input data. In the context of rural Kenya, gathering extensive, accurate, and up-to-date data on healthcare needs, cultural practices, and local architectural traditions remains a significant challenge.

Recommendations:

1. Create and fine-tune a GPT model specifically for the rural counties of Kenya and hospital design. This model should be trained on a comprehensive dataset including:

   Kenyan medical literature and health statistics

Ethnographic studies of various Kenyan communities

Local climate and geographical data

Kenyan building codes and healthcare regulations. The model should be continuously updated with new data to improve its relevance and accuracy. Consider partnering with Kenyan universities and research institutions for ongoing model development and maintenance.

2. Establish a Collaborative Design Process that implements a design methodology that combines AI-generated insights with input from various stakeholders such as, local architects familiar with Kenyan design traditions, healthcare professionals with experience in rural Kenyan settings, community representatives from diverse ethnic backgrounds, cultural anthropologists specializing in Kenyan cultures, environmental experts familiar with local ecosystems. Develop a structured process for integrating AI recommendations with human expertise, possibly using a Delphi method or similar consensus-building approach.

3. Conduct Comprehensive Data Collection: Prioritize the collection of high-quality, diverse data:

    I. Conduct extensive surveys and interviews in rural communities
    II. Gather detailed health statistics from existing rural facilities
    III. Document traditional healing practices and their spatial requirements
    IV. Map local resources and building materials
    V. Record climatic data across different regions of rural Kenya Establish partnerships with local universities and NGOs to assist in data collection and ensure cultural sensitivity in the process.

4. Implement Diverse Pilot Projects: Select 3-5 diverse rural locations in Kenya for pilot projects:

    Choose sites representing different ethnic groups, climates, and healthcare needs. Implement full-scale AI-driven design processes for these pilot hospitals and then conduct rigorous pre- and post-implementation studies to assess impact. And finally use these pilots as case studies to refine the AI approach and demonstrate its effectiveness. Consider a phased implementation, starting with smaller healthcare facilities before scaling to larger hospitals.

5. Develop Cultural Sensitivity Metrics: Create a set of quantifiable metrics to assess the cultural appropriateness of hospital designs:

Collaborate with cultural anthropologists and local communities to identify key cultural elements and then potentially develop a scoring system for cultural sensitivity in areas such as spatial layout, aesthetics, and functionality. And finally incorporate these metrics into the AI model's evaluation criteria. Regularly review and update these metrics based on community feedback

6. Integrate with Existing Healthcare Systems: Ensure AI-driven hospital designs are compatible with existing Kenyan healthcare systems. This could be achieved in a number of different ways such as by analyzing current referral networks and patient flow patterns. Design interfaces between new AI-designed facilities and existing healthcare infrastructure. Develop training programs for healthcare workers to effectively utilize new facility designs. Create digital systems for seamless information flow between AI-designed hospitals and other healthcare facilities.

7. Prioritize Sustainability and Scalability: Design AI models and processes for long-term sustainability. Develop open-source AI tools that can be maintained and updated by Kenyan institutions. Create modular design components that can be easily replicated and adapted. Incorporate sustainable building practices and materials into the AI design criteria and finally establish a framework for knowledge transfer to ensure long-term local management of the AI system.

8. Invest in Local AI Capacity: Develop programs to build local expertise in AI and architectural design. Collaborate with Kenyan universities to create specialized courses in AI-driven architectural design. Organize workshops and training sessions for practicing architects and healthcare planners.

9. Establish Ethical Guidelines: Develop a comprehensive ethical framework for AI use in hospital design. Address issues of data privacy and consent in data collection. Establish protocols for avoiding and mitigating algorithmic bias

    I. Create guidelines for respectful integration of traditional practices in modern healthcare settings.
    II. Develop transparency measures to explain AI-driven design decisions to communities.
    III. Establish an ethics review board including local representatives to oversee AI applications.

10. Conduct Longitudinal Studies: Implement long-term studies to assess impact:

I. Design 5-10 year studies tracking health outcomes in AI-designed vs. traditionally designed hospitals.
II. Measure patient satisfaction, staff efficiency, and community acceptance over time.
III. Analyze the adaptability of AI-designed facilities to changing healthcare needs.
IV. Assess the economic impact of AI-designed hospitals on local communities.

By implementing these detailed recommendations, this research has the potential to revolutionize hospital design in rural Kenya, creating healthcare facilities that are not only efficient and effective but also deeply resonant with local cultures and traditions. This approach could serve as a model for culturally sensitive, AI-driven architectural design in other developing contexts, ultimately contributing to improved healthcare access and outcomes on a global scale.

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