DIGITAL TWIN

وزارة الصحة
Ministry of Health

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Lean

رقيم
Raqeem

أناة
Anat

صحة
Seha

صحتي
Sehhaty

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EXECUTIVE SUMMARY

Saudi Arabia's healthcare sector is undergoing a significant transformation, driven by the Saudi Vision 2030 and the Health Sector Transformation Program. The program aims to improve the sector by prioritizing prevention, quality, and efficiency. At the heart of this transformation is the adoption of digital technologies. One of them is the digital twin, a cutting-edge technology that is set to transform healthcare service delivery.

The digital twin is a virtual representation of an individual, implemented through the Sehhaty app, that manages and monitors their health status by leveraging various health data inputs. This enables the digital twin to provide insights for preventative measures and early interventions.

The digital twin enhances both the model of care and value-based healthcare by facilitating healthcare service delivery, precise cost predictions, and outcome measurements. It also has the potential to improve patient experience and population health outcomes, while optimizing resource utilization.

The digital twin provides multiple innovative elements to optimize personalized healthcare. It currently includes health status visualization, body mass index assessment, biological age calculation, step tracking, vaccination guidance, and chronic disease risk prediction, with more promising elements to be added in the future.

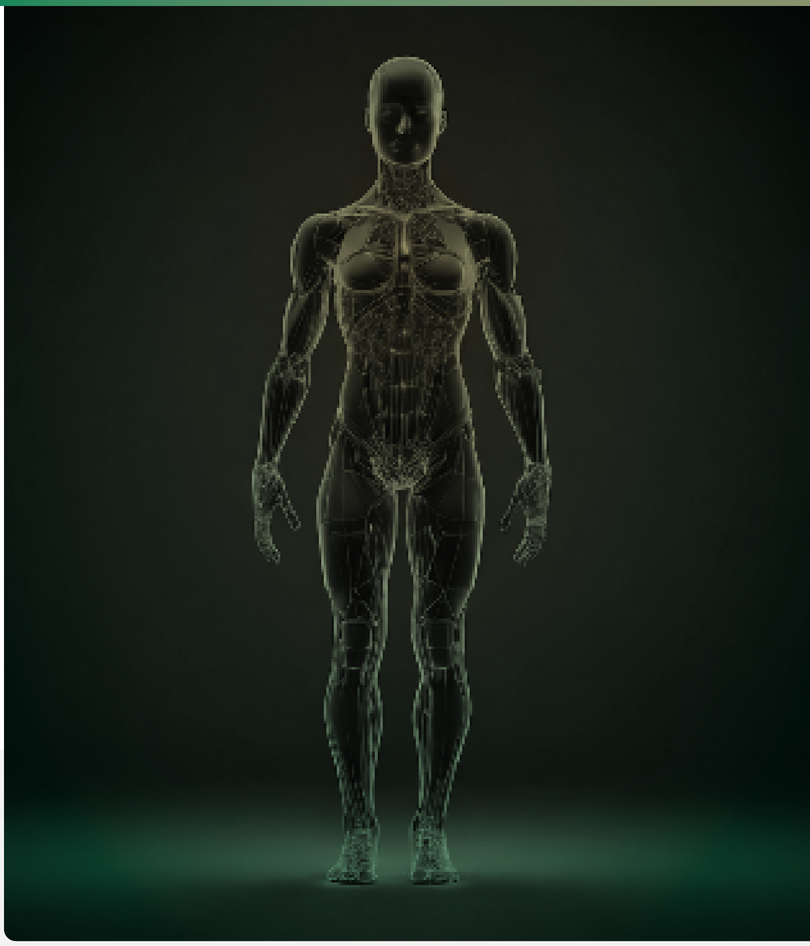
The adoption of digital twin technology marks an important moment in the healthcare transformation journey of Saudi Arabia. The era of personalized healthcare has begun.

INTRODUCTION

Advances in the Saudi healthcare system have significantly increased the population's life expectancy. This success comes with new challenges. A longer lifespan is associated with a rise in chronic conditions, putting mounting pressure on the Kingdom's healthcare system. To help mitigate this, there's a clear need for innovative solutions that can effectively prevent and manage these health issues. One promising approach is the digital twin.

DIGITAL TWIN

Digital twin technology is revolutionizing our understanding and management of complex systems. A digital twin is defined as a virtual replica or copy of a physical object, process, or system that is continuously updated with real-time data. This digital counterpart enables accurate monitoring, analysis, and prediction. By bridging the physical and digital worlds, digital twins make it possible to optimize performance, anticipate issues, and simulate scenarios in a risk-free environment.



Evolution of Digital Twins

200,000 Miles

Imagine being in space, 200,000 miles from Earth, with limited oxygen and a damaged spacecraft. This was the reality for the Apollo 13 astronauts in 1970 after an explosion occurred in their spacecraft. To save their lives, NASA engineers had to act fast: They tested different scenarios using physical simulators and mathematical models, which helped them develop a plan that successfully saved the astronauts.[1]

In 2002, Dr. Michael Grieves revisited the idea and introduced the modern digital twin concept.[1] Since then, this innovation has revolutionized how we approach complex problems across various sectors.

The Digital Twin Market

The digital twin market is set to expand dramatically, growing from $10.1 billion in 2023 to $110.1 billion by 2028, with a remarkable 61% growth rate yearly,[2] as companies worldwide rush to enter this fast-growing field **(Figure 1).**

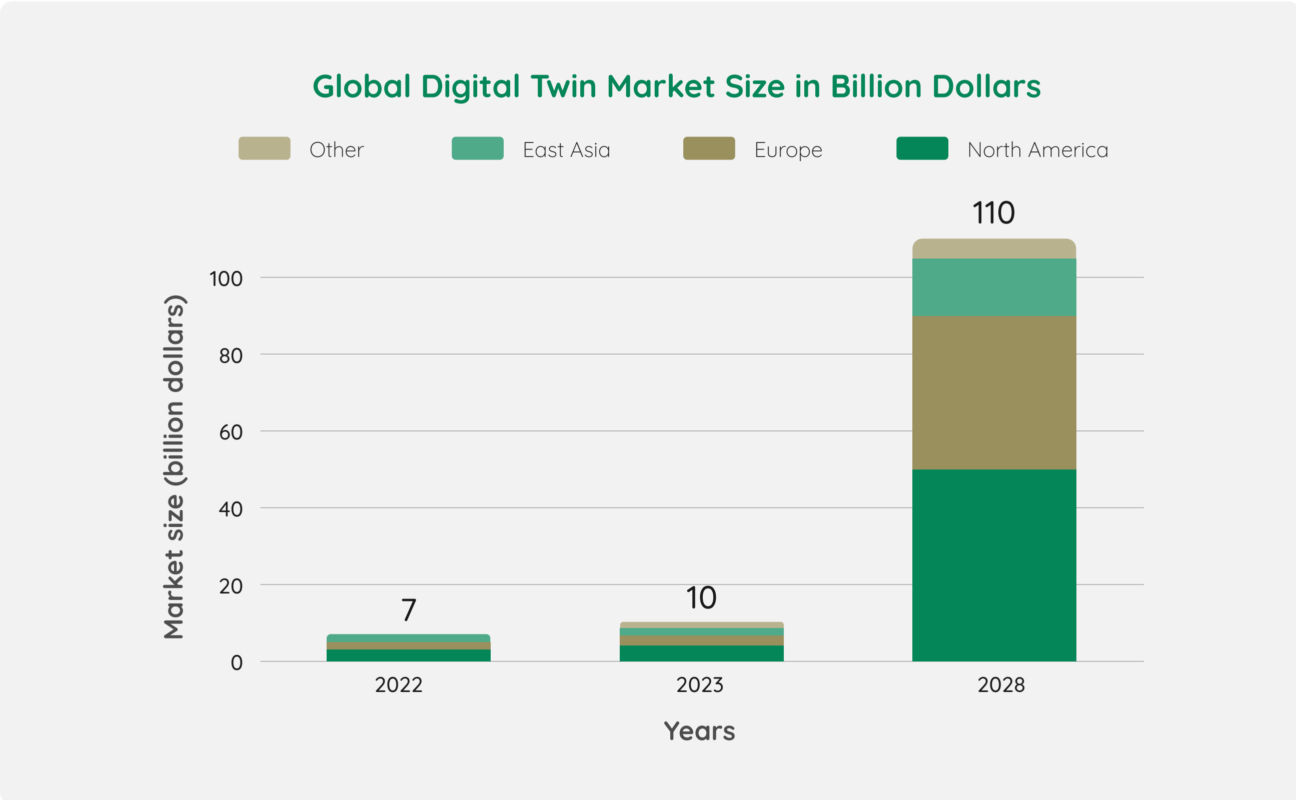


Figure 1. Global Digital Twin Market Size Projection (2022-2028). The stacked bar chart displays the projected size of the global digital twin market in billion dollars for the years 2022, 2023, and 2028. The market is segmented into four geographical categories, each represented by a different color in the stacked bars. The chart includes a compound annual growth rate (CAGR) indicator between 2023 and 2028, and the total market size values are labeled for each year shown.

Digital Twin Components

A digital twin is a complex system that consists of five core components. These components work together to create an interactive system that simulates, analyzes, and optimizes the behavior of the beneficiary **(Figure 2).**[3]

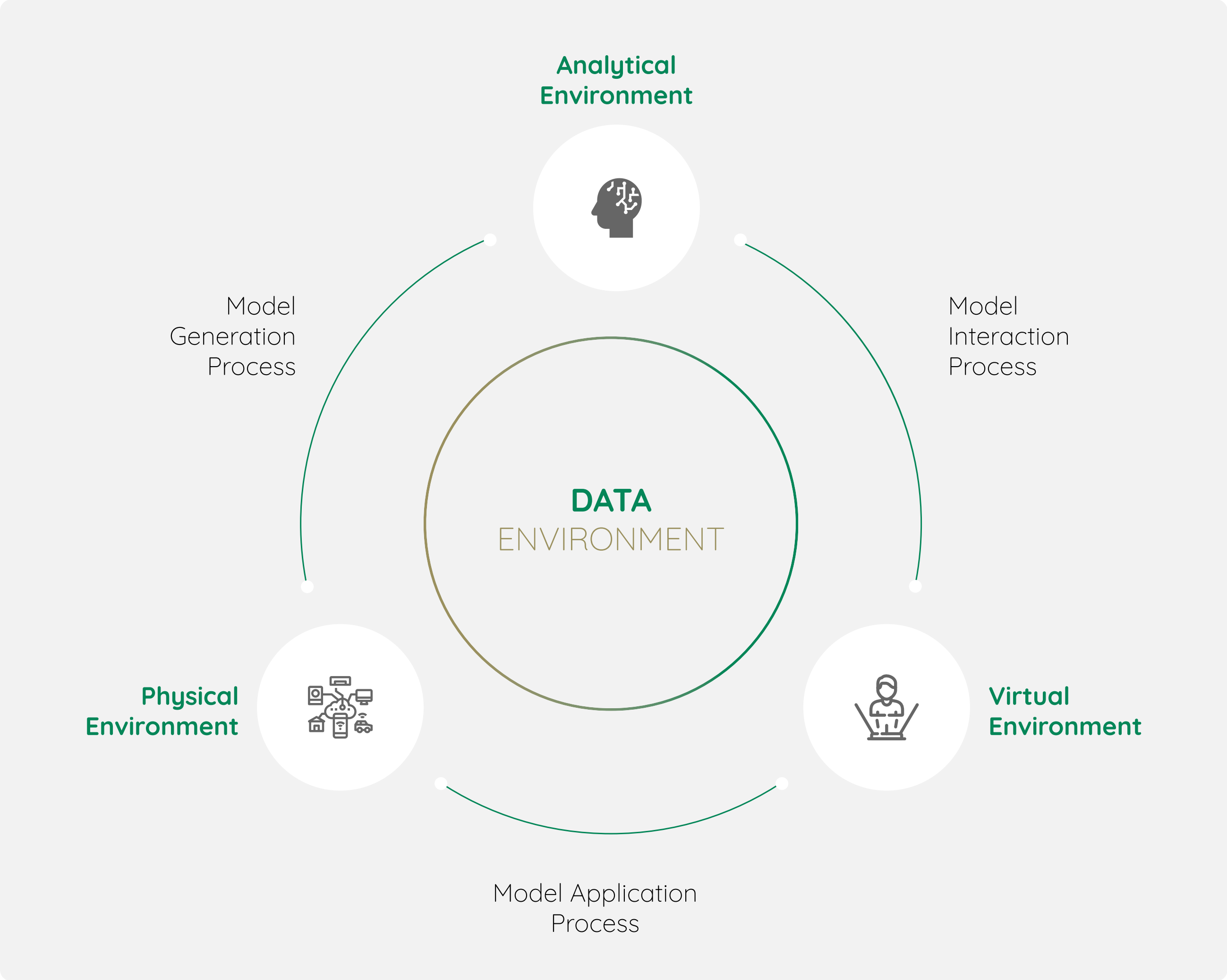


Figure 2. Architecture of a digital twin. A schematic of the core components and processes of a digital twin. At the center is the Data Environment, which stores the data. It is interconnected with three primary environments: the Physical Enviroment, which measures the physical system providing data for the digital twin; the Analytical Enviroment, which involves simulations and artificial intelligence; and the Virtual Enviroment, which visualizes the digital twin. The Connection Environment functions as the invisible structure that integrates the various components together. Bidirectional arrows indicate data flow and interactions between these components. The diagram also depicts three key processes: Model generation, Model interaction, and Model application which link the various environments.

The first component is the Physical Environment, where the physical object, process, or system exists and is measured. It is the source of the data that feeds into the digital twin, which enables the creation of the virtual replica. The second component is the Data Environment, where the raw data from the Physical Environment is stored. Third is the Analytical Environment, where simulations, artificial intelligence, and automation occurs. Fourth is the Virtual Environment, where the digital twin is visualized. This is often the only part that users interact with. Lastly, the Connection Environment, where all the environments are connected and integrated, and it includes access channels.[3]

What is a “Digital Twin” in personalized healthcare?

It is a virtual representation of an individual that visualizes and monitors their health status in an easy-to-understand format by leveraging various health data inputs such as step count, body weight, and medical history.

In a step towards transforming its healthcare system, Saudi Arabia is embracing the digital twin by integrating this technology into the Sehhaty app. Sehhaty is an application that offers a variety of health services to individuals in Saudi Arabia, enabling users to access healthcare needs, including health information and medical e-services provided by various health organizations across the Kingdom.

Digital Twin Components within the Saudi Healthcare System

The digital twin environments are integrated within the Saudi healthcare system and designed to facilitate seamless data exchange. The process begins with the physical and data environments which utilize the Internet of Things (IoT), the Sehhaty app, and the Unified Health Record (nphies) platform to collect and transmit data. The analytical environment then analyzes the data and extracts insights. These insights are visualized in the virtual environment along with health recommendations. Finally, the connection environment, which includes access channels, allows seamless integration with various Saudi healthcare platforms, including Anat, Seha, Sehhaty, and Raqeem **(Figure 3).**

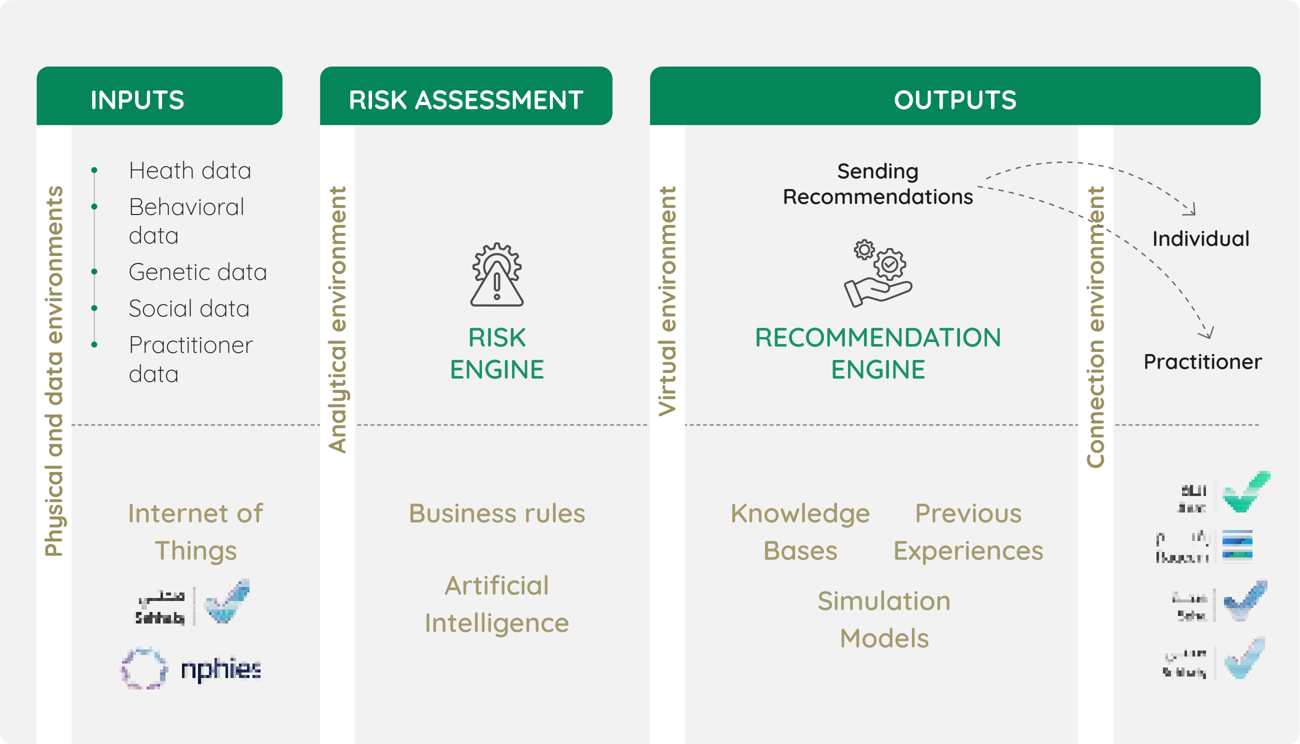


Figure 3. Digital twin components within the Saudi healthcare system. This diagram illustrates the application of digital twin architecture within the Saudi healthcare context.

FUTURE VISION OF THE DIGITAL TWIN
WITHIN THE SAUDI HEALTHCARE SYSTEM

In the future, we aim to develop the digital twin further by integrating various additional elements that provide a virtual overview of health. Digital twin solutions hold great potential to transform several aspects of personal health management and optimization as they continue to evolve. Examples of these elements include but are not limited to health status visualization, physical activity and diet tracking, genetic data integration, personalized health recommendations, mental health screening, vaccination guidance, chronic disease simulation and risk prediction **(Figure 4).**

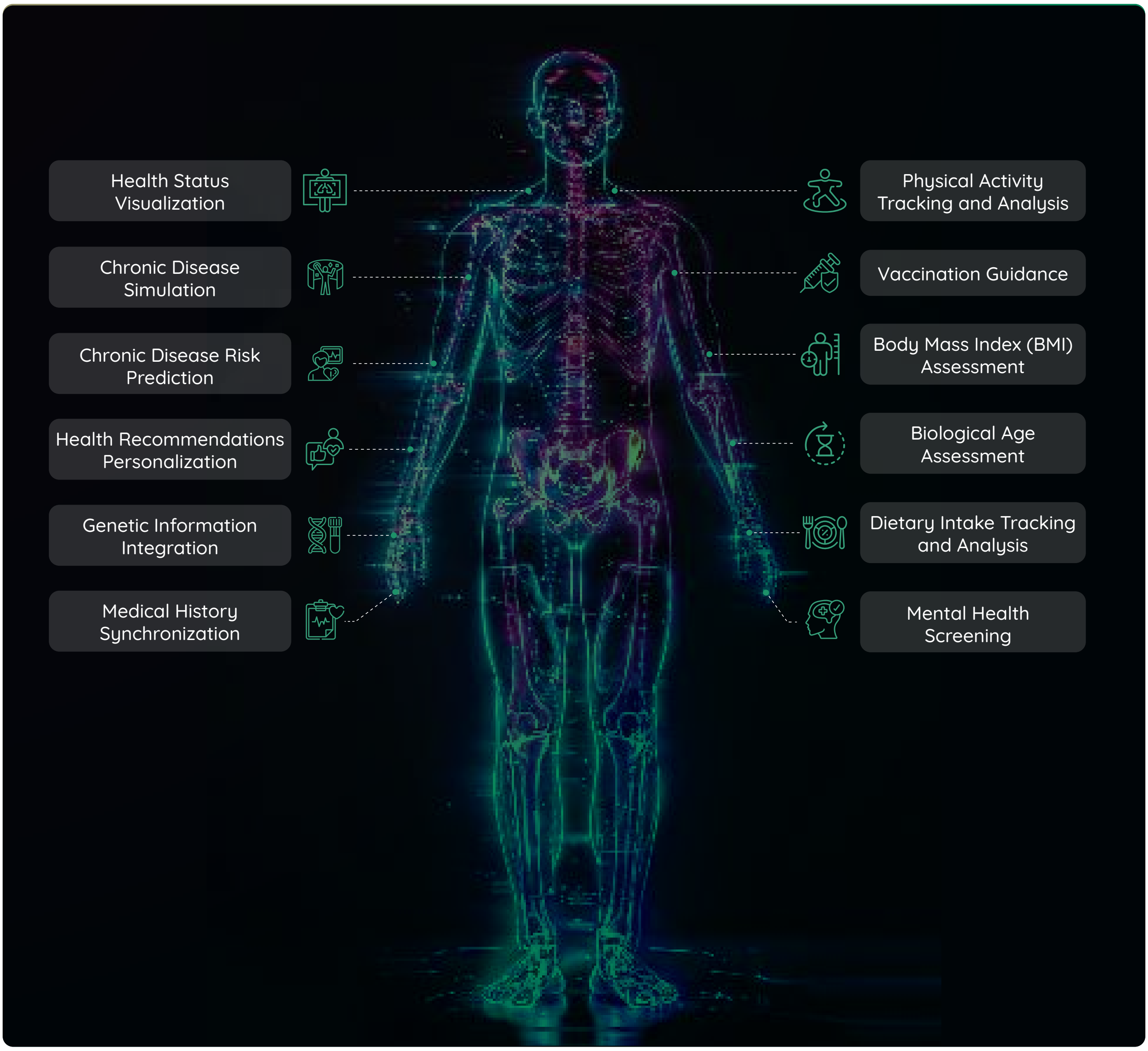


Figure 4. Current and upcoming digital twin elements to support personalized healthcare. The digital twin elements for personalized healthcare include tools for health status visualization, activity tracking, vaccination guidance, Body Mass Index (BMI) and biological age assessments, dietary and mental health monitoring, medical history synchronization, genetic data integration, personalized health recommendations, chronic disease simulation and risk prediction.

PROMOTING INNOVATION IN SAUDI HEALTHCARE WITH THE DIGITAL TWIN

Powering Vision 2030 with Digital Twins

The digital twin is an enabler of Saudi Arabia's Vision 2030. By leveraging the power of digital technologies, the digital twin can help achieve the first pillar of Vision 2030 "A Vibrant Society with Fulfilling Lives" and the following strategic objectives:[5]

Strategic Alignment:

Digital Twins and Vision 2030's Healthcare Objectives:

01 Improve healthcare service (2.1):

- **Ease access to healthcare services (2.1.1):** The digital twin can provide remote access to personalized health information.
- **Improve value of healthcare services (2.1.2):** The digital twin can enhance the efficiency of healthcare delivery.
- **Strengthen prevention against health threats (2.1.3):** The digital twin can use prediction models to predict disease risk.

02 Promote a healthy lifestyle (2.2):

- **Increase public participation in sports and athletic activities (2.2.1):** The digital twin can track and encourage physical activity.

03 Improve performance of government apparatus (5.2):

- **Enhance the performance of government entities (5.2.2):** The digital twin can optimize healthcare system performance.
- **Improve the productivity of government employees (5.2.3):** The digital twin can help healthcare workers manage patient care more efficiently.
- **Develop the e-Government (5.2.4):** The digital twin can be integrated into e-government health services.

Enabling Value-Based Healthcare and the New Model of Care

The digital twin is poised to be a transformative force in healthcare, enabling both value-based healthcare[6] and the model of care[7] **(Figures 5 and 6).** It can support the healthcare system by offering unique benefits to multiple stakeholders, including:

PATIENTS

- Personalizes health interventions
- Makes individuals active participants in their care

HEALTHCARE PROVIDERS

- Enables daily engagement with patients
- Facilitates early and cost-effective interventions

HEALTHCARE DECISION-MAKERS

- Provides data-driven insights
- Enables value-based agreements

A Digital Twin-Enabled Framework for Value-Based Healthcare

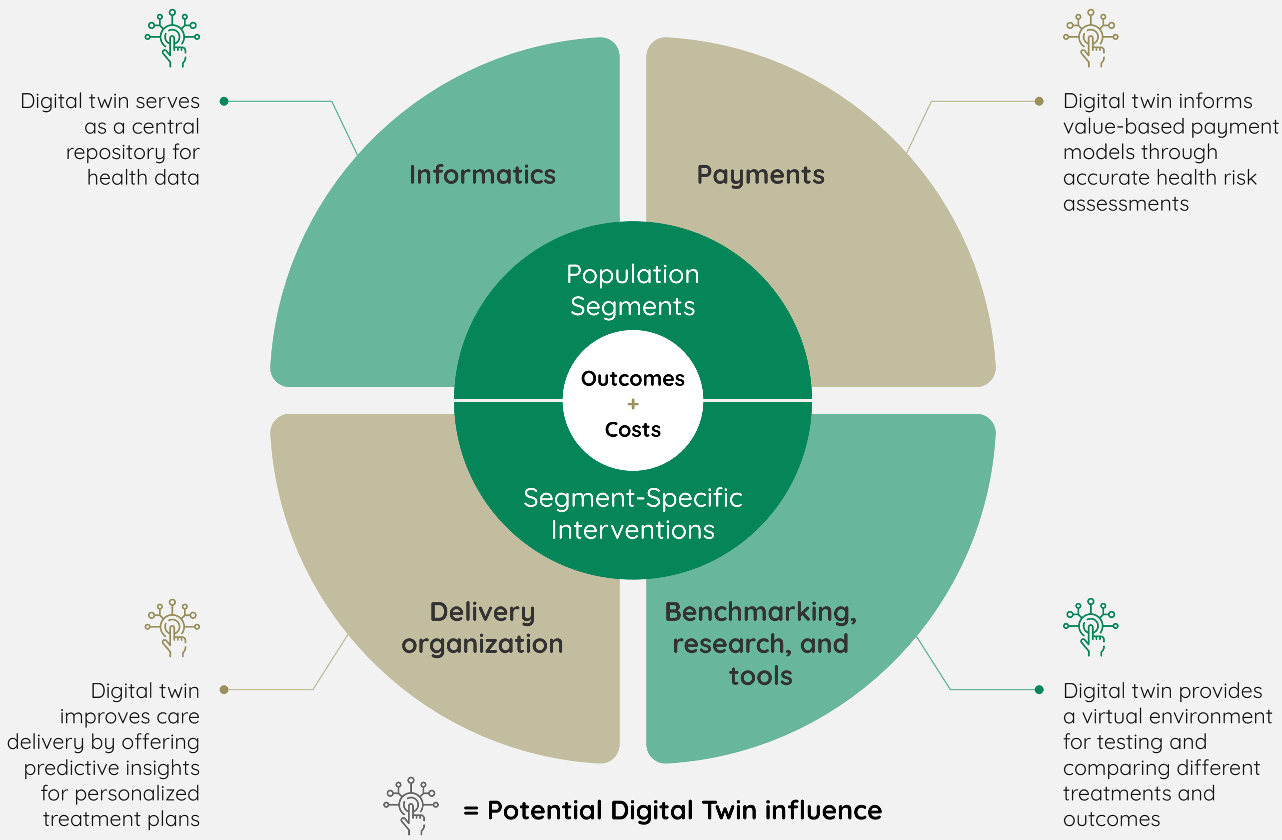


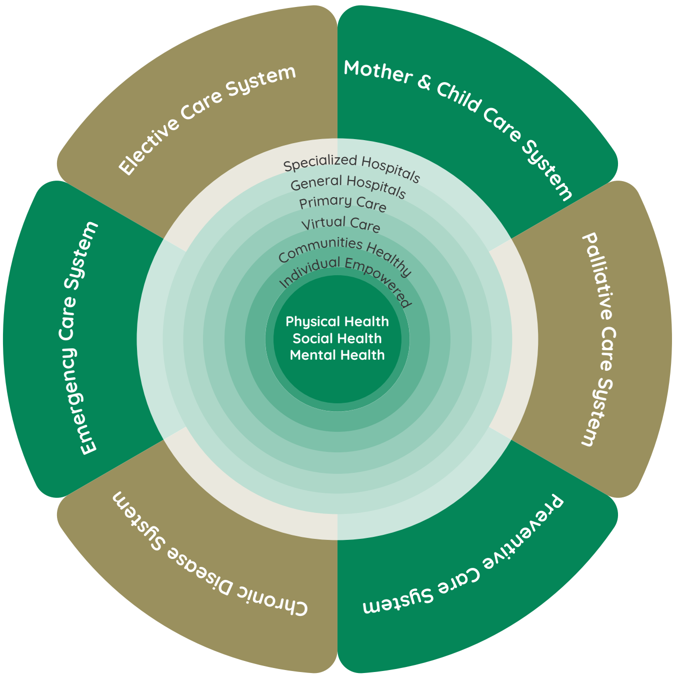
Figure 5. Integration of the digital twin into value-based healthcare framework. The integration of the digital twin into a value-based healthcare framework can enhace healthcare by optimizing informatics as a central data repository, facilitating value-based payments through accurate disease risk assessments, providing a virtual environment for benchmarking and research to compare treatments and outcomes, and supporting care delivery through personalized health management to improve outcomes and reduce costs.

A Digital Twin-Enabled Model of Care

Mother and Child Care System:
The digital twin can monitor health status and vaccination schedules for pregnant women and children, supporting optimal family health management

Primary Care:
Digital twin optimizes primary care by predicting individual health risks to enable targeted preventive measures

Virtual Care:
Digital twin enhances telehealth by supporting virtual consultations with the user's data



Healthy Communities:
Digital twin can show community health trends to optimize interventions and predict impacts on the population-level

Empowered Individual:
The digital twin can empower individuals with personalized health insights

Chronic Disease Care System
The digital twin can monitor and present patient information to give a clear picture of ongoing chronic conditions, supporting better chronic disease management

Preventive Care System
The digital twin can monitor health information to help identify potential health risks, supporting preventive care

= Potential Digital Twin influence

Figure 6. Integration of the digital twin into the model of care. Integration of the digital twin into the model of care can be beneficial across the layers of service, including primary care, virtual care, healthy communities, and empowered individuals. And the systems of care, such as mother and child care, preventive care, and, chronic disease care.

THE FIRST PHASE OF THE DIGITAL TWIN

The journey towards personalized medicine in Saudi Arabia has just begun. The digital twin is at the forefront of this promising field.

Digital Twin Elements

The first phase of the digital twin introduces six key elements that work together to provide a comprehensive view of the user's health, which are:

01
HEALTH STATUS VISUALIZATION

Visualizes the user's health condition with a digital model of the human body by highlighting any affected anatomical areas.

- **Functional Highlights:**

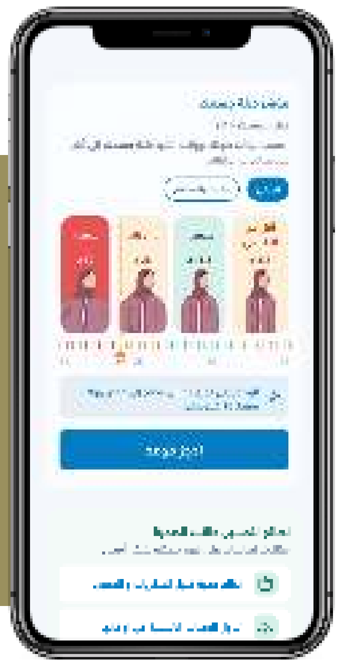
i) **Comprehensive Visualization:** Provides a visual of impacted organs on the 3D human body model.
ii) **Comparative Analysis:** Allows users to assess their model and health conditions against percentile rankings derived from aggregated data of peers with similar profiles.
iii) **Educational Content:** Presents personalized insights based on the user's health status.

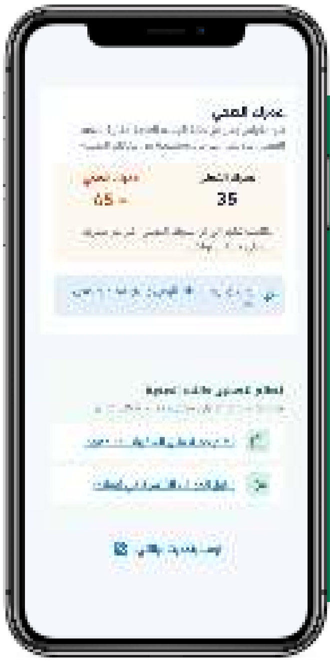
02
BODY MASS INDEX (BMI) ASSESSMENT

Provides an assessment of the user's BMI.

- **Functional Highlights:**

i) **Comparative Analysis:** Allows users to assess their BMI result against percentile rankings derived from aggregated data of peers with similar profiles.
ii) **Educational Content:** Presents personalized insights to improve the user's health based on their BMI results.





03

BIOLOGICAL AGE CALCULATION

Calculates a prediction of the user's biological age, which is known as the estimated age of the body's health and functioning, by evaluating a range of health metrics.

- **Functional Highlights:**

i) **Age Comparison:** Compares the user's chronological and biological ages.
ii) **Personalized Insights:** Delivers insights into the effects of lifestyle habits on aging.

04

PHYSICAL ACTIVITY

Monitors and reports on the user's steps activity.

- **Functional Highlights:**

i) **Activity Tracking:** Monitors daily steps count and calculates weekly averages.
ii) **Comparative Analysis:** Compares the user's activity levels with peers who have similar profiles and nudges for improvements.
iii) **Goal Setting:** Facilitates personalized goal setting based on activity data.
iv) **Educational Content:** Presents personalized insights to enhance physical activity and overall health.

05

VACCINATION GUIDANCE

Employs a risk-based evaluation approach considering age, health status, and vaccination history to determine the user's vaccination needs.

- **Functional Highlights:**

i) **Personalized Recommendations:** Suggests future vaccinations based on related risk factors.

ii) **Appointment Booking:** Allows the user to book vaccination appointments directly.

iii) **Educational Content:** Provides vaccination insights to inform and educate users.

06

CHRONIC DISEASE RISK PREDICTION

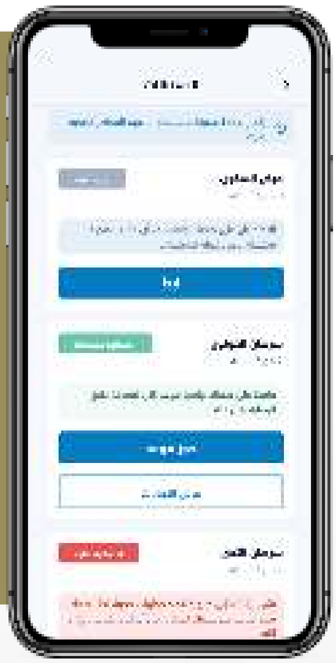
Employs a risk engine that utilizes a machine learning approach to analyze user data, predict potential disease risk, and facilitate proactive prevention.

- **Functional Highlights:**

i) **Risk Prediction:** Identifies potential disease risk based on the user's health data.

ii) **Healthcare Network:** Facilitates connections between users and healthcare practitioners for further consultations and examinations.

iii) **Educational Content:** Presents personalized insights to help users understand and avoid disease risk.



TECHNICAL FRAMEWORK
OF THE DIGITAL TWIN

A technical infrastructure is required to bring these digital twin elements to life within the Saudi healthcare system **(Figure 7).** The process flows through various decision points and engines to provide data-driven insights. The process involves both Sehhaty users and healthcare practitioners utilizing other Saudi healthcare apps and platforms, including Sehhaty, Anat, and Raqeem. As well as population health officers who operate the Yamamah platform. It contains a feedback loop, where responses are monitored and reminders are sent when necessary.

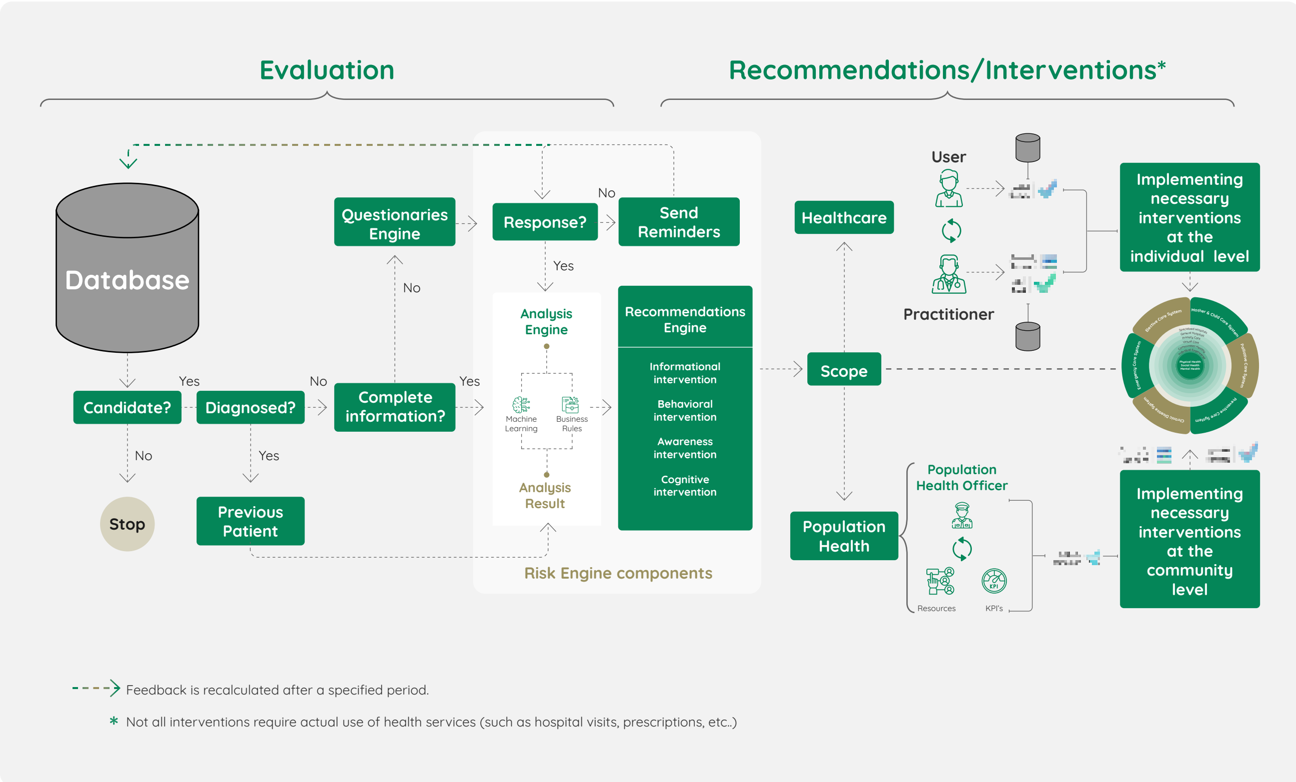


Figure 7. The standard technical infrastructure for implementing the digital twin in Saudi healthcare. The technical infrastructure of the digital twin in Saudi healthcare includes multiple decision points with a risk engine, analysis engine, and recommendations engine at its core. These components evaluate patient data, process responses, and generate personalized recommendations or interventions at both individual and community levels through platforms like Sehhaty, Raqeem, Yamamah, and Anat.

As we explore the digital twin more, it's essential to highlight the risk engine which offers the greatest value to users.

THE RISK ENGINE

Patients are often diagnosed with diseases at a late stage, leading to poorer conditions and complicated treatment journeys. Early disease detection often results in better health outcomes. However, many individuals remain unaware of their disease risk until it's too late and their disease has progressed. Numerous risk factors, such as poor diet, smoking, low physical activity, family history, and high BMI, are known to contribute to the development of chronic diseases.

To address this challenge, the risk engine has been developed as an AI-based solution comprising five machine learning models, that are designed to predict the likelihood of a user developing specific diseases based on their individual risk factors.

The targeted diseases in these models include:

- Diabetes and Prediabetes
- Arteriosclerotic Cardiovascular Disease
- Colorectal Cancer
- Breast Cancer
- Stroke

The main objective of the risk engine is to detect high-risk users early and nudge them toward addressing their health risks before disease onset or progression.

Machine Learning Methods for Risk Engine Development

The following sections outline the development process of the five machine learning models, starting from data collection **(Figure 8).**

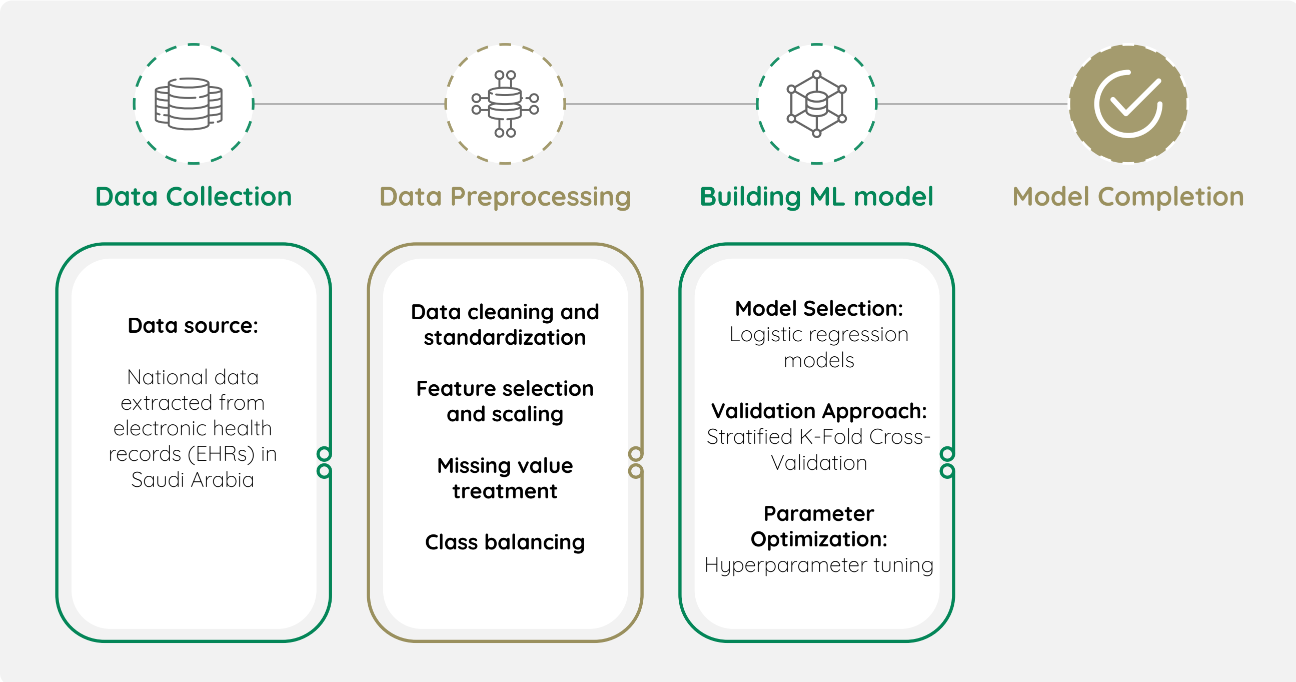


Figure 8. Risk engine development process. The development process for the risk engine includes data collection from national Electronic Health Records (EHRs) in Saudi Arabia, data preprocessing (cleaning, feature selection, missing value treatment, and class balancing), and building machine learning models with logistic regression, cross-validation, and hyperparameter tuning.

Data Collection

National data extracted from electronic health records (EHRs) in Saudi Arabia was used to comprehensively represent the population. The dataset had various types of information, including:

Demographics
Including gender, age, and marital status

Diagnoses
Coded using ICD-10 (International Classification of Diseases, Tenth Revision) codes

Procedures
Documented with ACHI (Australian Classification of Health Interventions)

Medications
Identified using codes like ATC (Anatomical Therapeutic Chemical Classification System), GTIN (Global Trade Item Number), and others

Laboratory Results
Recorded using LOINC (Logical Observation Identifiers Names and Codes)

Family History
Information on familial medical conditions

Habits and Lifestyle Factors
Data on smoking status, physical activity levels, diet, and other lifestyle aspects

This broad dataset was crucial for developing accurate and effective machine learning models within the risk engine. By accounting for a wide range of health-related information, the models can better predict the likelihood of users developing specific diseases based on their distinct risk factors.

Data Preprocessing

Several preprocessing steps were undertaken to prepare the dataset for modeling, including standardizing medication and laboratory test names with natural language processing, scaling numerical features, and handling missing values. Feature selection was based on risk factors through exploratory data analysis (EDA), and class imbalance was addressed with down-sampling.

Modeling

We employed logistic regression models to predict disease occurrence using individuals' features to estimate risk probabilities for developing diabetes, prediabetes, arteriosclerotic cardiovascular disease, stroke, colorectal cancer, and breast cancer. We identified factors that may increase disease risk to create personalized interventions. Next, we conducted an association analysis to determine the relationships between these risk factors and disease outcomes, assessing whether our data accurately reflected these connections.

Model Training

To optimize our models, we conducted multiple experiments during the training phase. In each experiment, we fine-tuned the models' hyperparameters and evaluated their performance.

Evaluation and Testing

To accurately evaluate our models, we obtained a representative test sample using the stratification method. Stratification factors varied between models based on the features included in each. We then applied stratified k-fold cross-validation to assess the performance of our models.

Resulting models

The purpose of these models is to screen for diseases and help predict the likelihood of their occurrence at early stages. To achieve this goal, the resulting models focus on identifying as many high-risk individuals as possible, capturing those with a high potential of developing the disease in the future. Each model categorizes users into defined risk groups—low risk, medium risk, and high risk—which contributes to more accurate and meaningful results and supports the recommendation engine in generating the most appropriate outputs.

THE RECOMMENDATIONS ENGINE

The recommendations engine is a supporting component of the risk engine. It translates complex risk analyses into personalized nudges. These notifications form a communication strategy designed to inform users and encourage specific responses. The engine generates different types of notifications, including informational notifications, awareness notifications, and behavioral notifications, each serving a specific purpose.

The recommendations engine determines the most suitable notification type for each scenario. A team of specialists has carefully crafted the wording of the notifications to ensure that all communications adhere to four key principles:

01 **Clarity**

Easy to understand for the general public

02 **Accuracy**

Reflecting accurate, updated medical knowledge

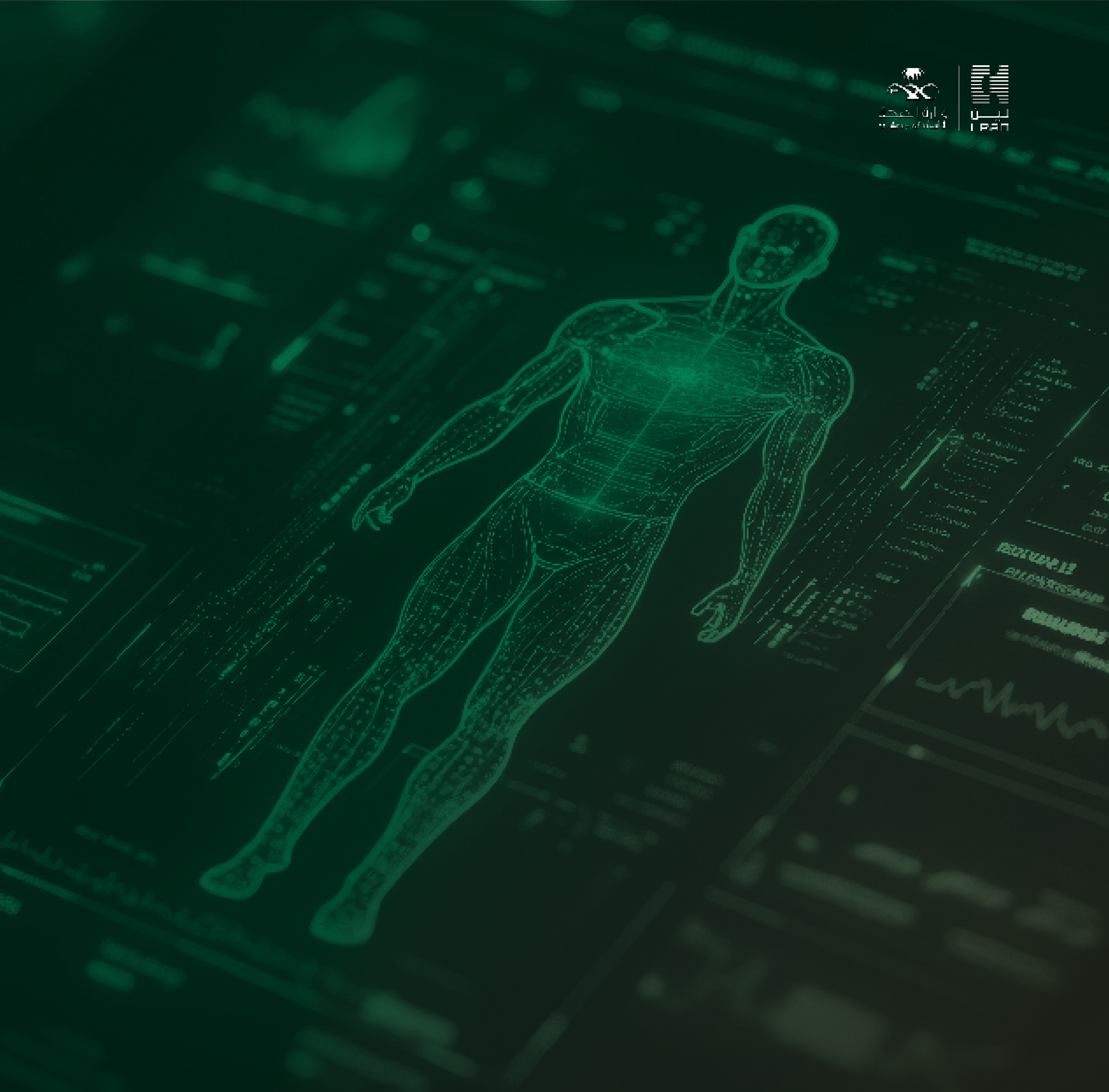
03 **Sensitivity**

Avoiding language that may scare or stigmatize users

04 **Empowerment**

Providing information that supports informed decision-making

By adhering to these principles, the engine ensures that users receive appropriate, relevant, and timely guidance. This empowers users to make well-informed decisions and take appropriate actions to manage their disease risk effectively.



CONCLUSION

The integration of digital twin technology into Saudi Arabia's healthcare system represents a transformative leap toward realizing Vision 2030. This cutting-edge approach not only aligns with but supports the Health Sector Transformation Program's core objectives of prevention, quality, and efficiency. By harnessing the power of digital twins, Saudi Arabia stands poised to revolutionize personalized healthcare, enabling a paradigm shift towards truly patient-centered, value-based care models.

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