

Review

Designing a Human-Centered National Digital Health Ecosystem: Structure, Value, and Implementation Challenges

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The global shift towards digital transformation in healthcare systems is essential for improving efficiency, accessibility, and patient outcomes. An effectively designed digital health ecosystem weaves together diverse technological elements to facilitate integrated healthcare delivery. This article examines the critical architecture, infrastructure, functional areas, advantages, drawbacks, and obstacles associated with establishing a national digital health ecosystem. Special attention is given to the human-centered benefits for patients and the overarching healthcare system. The analysis is based on an extensive review of existing literature and case studies.

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Introduction

Digital health encompasses the use of information and communication technologies to manage health and wellness. The integration of digital solutions into national health systems has the potential to revolutionize healthcare delivery, making it more patient-centered, efficient, and accessible. However, the successful implementation of a digital health ecosystem requires careful planning, robust infrastructure, and consideration of ethical, legal, and social implications.

Discussion

A. Building a Robust Digital Health Ecosystem: Structural Components and Their Value

The incorporation of digital technologies within healthcare systems has transformed the way health services are delivered, managed, and accessed. An effective digital health ecosystem consists of multiple elements that collaborate to improve patient care, enhance health outcomes, and maximize system efficiency. This article explores the structural components of this ecosystem, examining their roles and impacts on a country's healthcare framework.

Electronic Health Records (EHRs). EHRs are fundamental to digital health ecosystems, offering an organized collection of patients'

health data in electronic form. They allow for real-time, patient-focused records that can be accessed securely and instantly by authorized personnel. EHR systems can be either centralized, storing data in one location, or federated, allowing institutions to keep data on-site while being interconnected through a network. Centralized systems streamline data management and enhance consistency, while federated systems prioritize privacy and autonomy for individual organizations. The interoperability of EHRs promotes smooth information sharing among healthcare providers, minimizing duplication and enhancing care coordination. [1]

Health Information Exchanges (HIEs). HIEs provide platforms for securely sharing health information across various healthcare organizations. They facilitate the electronic exchange of health data among facilities within a community or healthcare system. By improving access to clinical data, HIEs increase the speed, quality, safety, and cost-effectiveness of patient care. They are crucial for public health initiatives as they consolidate data for population health management, assisting clinicians in making informed decisions and enabling health agencies to track disease trends, manage chronic conditions, and optimize resource allocation. [2]

Telemedicine Services. Telemedicine involves

remote patient diagnosis and treatment using telecommunications technology. It broadens access to healthcare, especially in rural or underserved areas with limited resources. Telemedicine decreases travel requirements, shortens wait times, and fosters timely consultations. During the COVID-19 pandemic, telemedicine became essential in maintaining care continuity while adhering to social distancing protocols. Its implementation has been linked to better patient outcomes and satisfaction, facilitating quicker interventions and providing access to specialists who might be unavailable locally. [3]

Mobile Health (mHealth) Applications. mHealth apps are mobile-based programs that assist in health monitoring, patient education, and chronic disease management. They empower individuals by offering tools for tracking health metrics, medication reminders, and information access. These applications support proactive health management and have demonstrated improvements in treatment adherence and patient engagement. For instance, diabetes management apps allow users to monitor blood sugar levels, medication timing, and dietary habits, leading to improved disease control and reduced complications. Moreover, mHealth applications effectively promote healthy lifestyle choices by delivering personalized health advice and encouraging exercise while enhancing medication compliance.[4]

Wearable Devices. Wearable health technologies, such as fitness bands and smartwatches, capture real-time health data, including heart rate, activity levels, and sleep patterns. These devices support continuous health monitoring, permitting the early identification of potential health issues and facilitating timely interventions. Integrating data from wearables into EHRs and health applications enhances tailored care and aids chronic disease management. For example, heart rate monitors can alert individuals and healthcare providers to abnormalities, allowing early response to prevent serious health incidents. Moreover, wearables incentivize users to adopt healthier behaviors,

which is crucial for managing conditions like obesity and diabetes.[5]

Artificial Intelligence (AI) and Analytics. AI and sophisticated analytics are pivotal in digital health ecosystems, helping analyze extensive datasets to enhance clinical decision-making and public health monitoring. AI algorithms can uncover patterns, forecast health trends, and support diagnoses, thereby increasing efficiency and precision in healthcare service delivery. The capability of AI to process large datasets enables the detection of nuanced patterns that may elude human practitioners, facilitating earlier diagnoses and better-prepared treatment approaches. In the context of public health, AI aids in the swift identification of potential outbreaks and monitoring population health metrics, equipping health authorities with the insights needed for prompt and effective responses.[6]

Cloud Computing. Cloud computing supplies scalable storage and processing resources vital for handling the immense volumes of data produced within digital health ecosystems. It offers flexible data access, bolsters system interoperability, and diminishes the need for extensive local infrastructure. Cloud solutions also enhance disaster recovery plans and secure data availability, crucial for uninterrupted healthcare services. For instance, healthcare providers can utilize cloud platforms to safely store and access patient information, medical images, and other health-related data from any location with internet connectivity. This adaptability ensures that healthcare services maintain resilience during disruptions like natural disasters, allowing them to remain operational with minimal downtime. Additionally, cloud computing fosters collaboration among healthcare providers, improving care coordination and quality. The capability to store vast amounts of data in the cloud also allows AI and analytics tools to operate more efficiently, analyzing large and diverse datasets in real-time.[7]

B. Infrastructure Requirements for a Robust

Digital Health Ecosystem

The creation of a comprehensive digital health ecosystem requires a diverse infrastructure that guarantees the efficient, secure, and equitable provision of healthcare services. This infrastructure includes several essential components: fast internet connectivity, data centers and cloud solutions, interoperability standards, cybersecurity protocols, and regulatory guidelines. Each element is vital in enhancing the capabilities of electronic health records (EHRs), telehealth services, mobile health technologies, wearable gadgets, artificial intelligence (AI) analytics, and various digital health instruments [8].

High-Speed Internet Connectivity. Dependable and high-speed internet connectivity is fundamental to any digital health ecosystem. It allows for real-time data transfer, fostering smooth communication between healthcare providers and patients, especially in remote or underserved regions. Telehealth services, which have gained immense traction, depend significantly on a strong internet backbone to perform virtual consultations, share medical imaging, and monitor patient health from a distance [9-10]. Furthermore, the integration of Internet of Medical Things (IoMT) devices, including wearable sensors and remote monitoring systems, highlights the urgent need for high-speed internet. These devices produce vast amounts of data that must be swiftly relayed to healthcare professionals for prompt action [11-13].

Data Centers and Cloud Solutions. Data centers and cloud computing provide scalable and secure storage options essential for handling the vast volumes of health data produced daily. Cloud services deliver flexibility, affordability, and scalability according to demand, making them suitable for healthcare organizations of all sizes [14]. Furthermore, cloud solutions facilitate the integration of a variety of digital health tools and systems, ensuring that data from electronic health records, mobile health apps, and wearable devices can be combined and accessed seamlessly. This integration is vital for delivering

holistic patient care and enabling data-driven decision-making [11].

Interoperability Standards. Interoperability refers to the capacity of various health information systems and devices to effectively exchange and interpret shared data. Establishing and adhering to interoperability standards, like Fast Healthcare Interoperability Resources (FHIR) and Digital Imaging and Communications in Medicine (DICOM), is crucial for ensuring smooth data sharing across different healthcare platforms [12]. These standards permit healthcare providers to access complete patient information, irrespective of the initial system, thus enhancing care coordination and minimizing redundancies. In addition, interoperability fosters the integration of AI and analytics tools dependent on varied data sources for generating insights for clinical decisions and public health monitoring [9].

Cybersecurity Measures. Safeguarding sensitive health information from unauthorized access and breaches is critical in a digital health landscape. The implementation of strong cybersecurity measures, such as encryption, multi-factor authentication, and regular security audits, is vital for protecting patient data [8]. The growing incidence of cyber threats in healthcare highlights the necessity for ongoing vigilance and the adoption of best security practices. Cultivating a culture of cybersecurity awareness among healthcare providers and patients can further strengthen the protection of health information [7].

Regulatory Frameworks. Thorough regulatory frameworks are essential to govern the use, sharing, and safeguarding of health data. Legislation like the General Data Protection Regulation (GDPR) in the European Union establishes standards for data privacy and security, ensuring responsible handling of individuals' health information [5]. These regulations also outline guidelines for securing patient consent, managing data access, and ensuring transparency in data utilization. Moreover, regulatory frameworks facilitate the ethical integration of AI and analytics tools in

healthcare by providing guidelines for their development and implementation.

C. Functional Domains of a Digital Health Ecosystem

A well-designed and thorough digital health ecosystem involves various functional areas, each enhancing the overall effectiveness, accessibility, and quality of healthcare services. Key components of this ecosystem include clinical care, public health, health administration, research and innovation, and patient engagement. These areas elevate the healthcare experience by incorporating digital technologies at all stages of service delivery, from diagnosis and treatment to health advocacy and policy formulation.

Clinical Care: Improving Diagnosis, Treatment, and Patient Oversight. A standout feature of digital health ecosystems is their ability to revolutionize clinical care. Digital health instruments like electronic health records (EHRs), telemedicine platforms, wearable tech, and remote monitoring solutions are pivotal in refining diagnosis, treatment, and management of patients. EHRs provide healthcare professionals with immediate access to comprehensive patient data, which bolsters decision-making precision and minimizes the risk of mishaps.[1] Telemedicine enhances clinical care by facilitating remote consultations, which decrease wait times, boost accessibility, and eliminate geographical barriers to treatment.[15] In addition, wearables and mobile health (mHealth) applications offer ongoing monitoring of chronic conditions such as diabetes and hypertension, delivering timely insights for patients and clinicians to modify treatment strategies. [2] Furthermore, the integration of artificial intelligence (AI) into clinical practices facilitates diagnosis and therapeutic planning by examining extensive datasets and uncovering trends that might elude human clinicians.[6] AI tools have shown success in areas like radiology, oncology, and cardiology by aiding in the interpretation of medical images, spotting irregularities, and proposing potential treatment

routes.

Public Health: Enabling Disease Surveillance, Outbreak Management, and Health Promotion Efforts. The digital health ecosystem is essential to public health, notably in disease surveillance, outbreak management, and health promotion. Digital resources allow health authorities to track disease trends, monitor infection spread, and respond swiftly to health threats. Real-time data gathering and analysis enhance the management of health crises, as demonstrated during the COVID-19 pandemic, when digital systems were used to track cases, administer vaccines, and furnish public health recommendations.[16] Health Information Exchanges (HIEs) promote the exchange of crucial health data among public health agencies, creating a holistic view of epidemiological patterns and patient demographics. This information is pivotal for outbreak tracking, predicting health trends, and designing appropriate health interventions.[17] Utilizing AI and machine learning to analyze public health data also aids in identifying at-risk populations, forecasting disease spread, and deploying preventive strategies. In addition to responding to outbreaks, digital health technologies support ongoing health promotion initiatives. Mobile apps that offer health information, vaccination alerts, and wellness resources engage communities in preventive health behaviors. Social media and digital health campaigns provide scalable platforms for health education, increasing awareness about crucial health concerns like smoking cessation and vaccination.[18]

Health Administration: Optimizing Administrative Workflow, Resource Distribution, and Policy Formulation. Within health administration, digital health systems streamline workflow, boost resource distribution, and contribute to policy development grounded in evidence. Electronic health records lessen administrative burdens on providers by centralizing patient information and enabling swift access to medical histories, prescriptions, and lab results, leading to greater operational efficiency and reduced errors.[1] Additionally,

health data from EHRs and HIEs can be utilized to enhance resource allocation, optimize staffing, and pinpoint service gaps. Predictive analytics can anticipate patient volume trends, allowing healthcare facilities to prepare effectively for peak times and manage resources efficiently.[19] Additionally, data-driven insights empower health administrators to make strategic decisions regarding funding, staffing, and medical supply allocation, ensuring optimal and equitable resource use. On a larger scale, the incorporation of digital health solutions aids in developing policies based on real-time data, enabling policymakers to assess healthcare outcomes and evaluate intervention effectiveness.[20]

Research and Innovation: Promoting Clinical Research, Data Insights, and Healthcare Technology Advancement. Digital health ecosystems encourage innovation by offering avenues for clinical research, data analysis, and the creation of novel healthcare technologies. Data harvested from a variety of digital tools, including EHRs, telemedicine, and wearable devices, provide researchers with unique opportunities to investigate healthcare trends, discover new therapeutic strategies, and enhance clinical practices.[21] The application of AI and big data analytics in clinical research accelerates the identification of new treatments, drug development, and disease prevention approaches. By examining large datasets from diverse patient populations, researchers can discern trends that inform the creation of personalized medicine and targeted therapies, thus improving treatment precision and effectiveness.[22] Additionally, digital health ecosystems foster an environment ripe for innovation within healthcare technology. Advances in medical devices, software applications, and telemedicine platforms are frequently inspired by insights obtained from the deployment of digital health tools in clinical environments, allowing researchers to pilot new concepts and technologies extensively.

Patient Engagement: Empowering Individuals in Health Management. Patient engagement constitutes a vital aspect of any digital health

ecosystem, empowering individuals to actively participate in managing their health. Digital resources like mobile health apps, telemedicine services, and wearable technology afford patients continuous access to their health data to track vital signs, monitor symptoms, and make informed care decisions.[23] mHealth applications facilitate the management of chronic conditions by allowing patients to log their symptoms, monitor medication adherence, and receive tailored recommendations. This ongoing engagement enhances self-management, promoting healthier lifestyle choices such as regular exercise, improved diet, and smoking cessation. Wearable devices further boost patient engagement by providing real-time health metrics, empowering patients to assess their progress and adjust behaviors as needed.[24] Moreover, digital health solutions enhance communication between patients and providers, enabling patients to seek advice, pose queries, and receive prompt feedback on their health status. This collaborative dynamic fosters better outcomes and cultivates a more patient-centered approach to care.

D. Advantages of a Digital Health Ecosystem

The emergence of digital health technologies has revolutionized healthcare delivery, positively impacting patients and the overall health system. A comprehensive digital health ecosystem includes a variety of tools, including telehealth services, mobile health (mHealth) apps, electronic health records (EHRs), wearable technology, and artificial intelligence (AI), among others. These advancements have led to notable enhancements in healthcare accessibility, efficiency, and quality. This section examines the benefits of a digital health ecosystem for both patients and the healthcare system.

1. Advantages For Patients. The main advantages for the patient are following.

Improved Access to Care. One of the most significant advantages of digital health technologies for patients is the enhanced access to healthcare, particularly for individuals living in remote, rural, or underserved regions.

Telemedicine and mobile health (mHealth) applications have effectively removed geographical obstacles that once restricted access to medical services. Telemedicine platforms allow patients to interact with healthcare providers without the necessity of traveling, which decreases both the time and financial burdens associated with face-to-face appointments. This is especially crucial in rural and economically disadvantaged areas, where specialist care and healthcare facilities are scarce.[25] Additionally, mHealth applications empower patients to engage with healthcare services from the comfort of their own homes, promoting a more proactive stance on health management. These applications offer a variety of services, including appointment scheduling, medication reminders, health monitoring, and teleconsultations. This enhanced access alleviates pressure on healthcare systems and enables more timely interventions, ultimately improving the patient experience and satisfaction.[3]

Personalised Medicine. Tailored medicine is another essential benefit of a digital health ecosystem. By collecting, storing, and analyzing extensive patient data, healthcare providers are able to create customized treatment plans that consider an individual's unique genetic profile, medical background, lifestyle, and preferences. Electronic Health Records (EHRs) and mHealth applications give clinicians real-time access to comprehensive patient information, permitting informed, evidence-based choices concerning treatments, medications, and preventative strategies. [26] Furthermore, artificial intelligence (AI) and machine learning algorithms facilitate the analysis of complex data sets, uncovering trends and predicting outcomes to enhance personalized patient care. For instance, AI-based platforms can recommend the most effective treatment protocols specific to a patient's condition, potentially minimizing the trial-and-error approach historically associated with medical care. [6] Tailored medicine not only boosts the likelihood of successful outcomes but also reduces the chances of adverse drug reactions while improving patient satisfaction by

aligning care with individual needs.

Enhanced Health Literacy. Digital health platforms significantly contribute to improving health literacy among patients. By offering access to educational resources, interactive tools, and trustworthy health information, digital health ecosystems empower individuals to become more informed about their conditions and the healthcare system. For example, mHealth apps can provide educational materials like videos, articles, and tutorials covering topics from chronic disease management to preventive health practices.[17] This enhancement of patients' understanding of their health enables them to make informed choices and promotes healthier lifestyle decisions. Moreover, these platforms frequently incorporate features that allow patients to track their symptoms, monitor vital signs, and establish health goals. This increased engagement with health data fosters a sense of ownership and responsibility, resulting in better adherence to treatment plans and preventive measures. Over time, this improved health literacy contributes to overall health outcome enhancements. [16,17,24]

2. Advantages for the Health System. A digital health ecosystem does not offer advantages only for the patients but increases the efficacy and the functionality of the health system.

Operational Efficiency. A digital health ecosystem significantly enhances operational efficiency within healthcare organizations. The integration of digital solutions such as electronic health records (EHRs), telehealth services, and automated administrative systems alleviates the strain of manual data entry, decreases paperwork, and speeds up workflows. For example, EHRs enable providers to swiftly access patient data, which curtails the necessity for repeated tests and diminishes errors stemming from miscommunication or incomplete documentation [1]. Moreover, digital health technologies can streamline numerous administrative tasks, encompassing appointment scheduling, billing, and claims processing, allowing healthcare professionals to dedicate more time to patient care. This optimization of

administrative duties not only boosts healthcare delivery efficiency but also cuts down on operational costs, thereby benefiting the entire healthcare network. Telemedicine, for instance, lowers the need for physical infrastructure and transportation expenses while permitting a greater number of consultations within a condensed timeframe [27].

Data-Driven Decision-Making. One of the key strengths of a digital health ecosystem is its capability to facilitate data-driven decision-making at multiple levels within the health system. Real-time data harvested from EHRs, health information exchanges (HIEs), wearable devices, and telemedicine platforms can be analyzed to enhance clinical decisions, improve operational processes, and influence policy development. Predictive analytics tools, for example, utilize patient data to anticipate healthcare demand, pinpoint potential outbreaks, and optimize resource distribution [27]. On a broader scale, big data analytics empowers policymakers to make informed decisions that bolster health system efficiency and equity. By examining patterns in patient outcomes, health behaviors, and disease incidence, health authorities can enact policies that tackle urgent public health issues, allocate resources effectively, and optimize service delivery [23]. This capacity for data-driven decision-making also fosters transparency, accountability, and improved management of healthcare funding.

Enhanced Health Outcomes. Digital health solutions play a crucial role in advancing health outcomes by facilitating early detection, ongoing monitoring, and more tailored care. Wearable devices, for instance, generate real-time insights into various health metrics like heart rate, physical activity, and sleep quality. This continuous monitoring enables patients and healthcare providers to identify shifts in health status early on, allowing for timely interventions and the prevention of complications [5]. Similarly, telehealth and mobile health (mHealth) applications support the effective management of chronic issues such as diabetes, hypertension,

and asthma. These platforms empower patients to monitor their symptoms, receive advice from healthcare professionals, and modify their treatment plans as needed, leading to improved disease management and reduced hospital admissions [3]. Over time, the proactive healthcare approach promoted by digital health ecosystems results in better patient outcomes, lower mortality rates, and decreased strain on healthcare facilities.

Conclusion

A digital health ecosystem offers significant benefits for patients as well as the overall healthcare system. It improves access to medical care, allows for customized treatment plans, and enhances health literacy among patients. For the healthcare system, it boosts operational efficiency, enables informed, data-driven decisions, and results in improved health outcomes. As digital health innovations advance, these advantages will likely become more apparent, fostering a healthcare system that is more efficient, accessible, and focused on patients.

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