DIGITAL HEALTH FRAMEWORK TO COMBATING NEGLECTED TROPICAL DISEASES

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FRAMEWORK DE SAÚDE DIGITAL PARA O COMBATE DE DOENÇAS TROPICAIS NEGLIGENCIADAS

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Programa: Engenharia de Produção

As tecnologias digitais estão dominando muitos mercados, e não é diferente com o mercado da saúde. Quando falamos de saúde, neste trabalho, foi explorado o universo das doenças tropicais negligenciadas. São doenças comumente comunicáveis, e que na maioria das vezes, pode ser prevenida com o aumento de informação sobre higiene ou cuidados previnindo a infecção. Como são doenças que afetam muitos países pelo mundo, o impacto global é significativo, demandando esforços para combater tais doenças. Diante desta problemática, as ferramentas de transformação digital, conhecidas como digital health, têm sido utilizadas no enfrentamento de surtos em países endêmicos.

Muitas tecnologias digitais são aplicadas a doenças em geral, no entanto, algumas são aplicadas diretamente para as doenças tropicais negligenciadas. Na literatura, a maior incidência de aplicações digitais recai sobre esquistomose, dengue, chikungunya e leishmaniose. Existe uma vastidão de tecnologias empregadas para classificação, diagnóstico, descoberta de novas drogas ou novas aplicações para medicamentos já

conhecidos e a descoberta de novos conhecimentos acerca das doenças. Essa gama de tecnologias envolve Inteligencia Artificial e suas variações como Machine Learning e Deep Learning e outros algoritmos de redes neurais, técnicas de Dada Mining, sistemas de Geoprocessamento e Sensoriamento Remoto e monitoramento através de tecnologias de Internet das Coisas.

Entender como estas tecnologias são empregadas em determinado país pode ser útil para compreender como a ferramenta digital que ajuda um país pode ser replicada em outro que sofre do mesmo problema seja com a mesma doença ou uma doença parecida. Portanto, mapear a utilização destas tecnologias é crucial para promover o desenvolvimento no ambito do combate às doenças tropicais negligenciadas. É importante ressaltar que não apenas países de baixa e média renda produzem conhecimento sobre as doenças negligenciadas. Países como Inglaterra e Estados Unidos produzem bastante conhecimento científico sobre as doenças negligenciadas, principalmente no que tange a utilização de tecnologia endereçada a mitigação de efeitos nocivos destas doenças. O conhecimento mapeado gerou informações que, quando organizadas, resultaram em um framework baseado em tecnologia Blockchain e Marketing Digital, desenvolvido nesta tese. Correlacionaram-se as tecnologias necessárias para a criação de um sistema que combina a segurança das redes Blockchain com o engajamento promovido pelo Marketing Digital. Embora este framework seja direcionado para doenças tropicais negligenciadas, ele pode ser amplamente aplicado a outras doenças infecciosas, sendo um fator crucial na mitigação ou até mesmo eliminação dessas doenças nos países que o adotarem.

Abstract of Thesis presented to COPPE/UFRJ as a partial fulfillment of the requirements for the degree of Doctor of Science (D.Sc.)

DIGITAL HEALTH FRAMEWORK TO COMBATING NEGLECTED TROPICAL DISEASES

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August/2024

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Digital technologies dominate many markets, including healthcare. This work explores the universe of neglected tropical diseases (NTDs), which are often communicable and preventable through improved hygiene and infection prevention measures. NTDs have a significant global impact, affecting many countries and necessitating concerted efforts for their control. In response, digital health tools have been employed to combat outbreaks in endemic regions. Many digital technologies are applied to various diseases, with some specifically targeting NTDs. In the literature, the highest incidence of digital applications is observed in schistosomiasis, dengue, chikungunya, and leishmaniasis. These technologies are used for classification, diagnosis, drug discovery, repurposing existing medications, and gaining new insights into diseases. The technologies include Artificial Intelligence (AI) and its subsets such as Machine Learning (ML) and Deep Learning (DL), other neural network algorithms, Data Mining techniques, Geoprocessing and Remote Sensing systems, and monitoring through Internet of Things (IoT) technologies. Understanding how these technologies are employed in specific countries can reveal how a digital tool successful in one nation can be replicated in another facing similar challenges. Mapping the use of these technologies is crucial for promoting advancements

in the fight against NTDs. It's important to note that not only low- and middle-income countries contribute to the knowledge about NTDs. Countries like England and the United States produce significant scientific knowledge, particularly regarding the use of technology to mitigate the harmful effects of these diseases. The mapped knowledge generated information that, when organized, resulted in a framework based on Blockchain technology and Digital Marketing, developed in this thesis. The necessary technologies were correlated to create a system that combines the security of Blockchain networks with the engagement promoted by Digital Marketing. Although this framework is directed towards neglected tropical diseases, it can be widely applied to other infectious diseases, potentially becoming a crucial factor in the mitigation or even elimination of these diseases in the countries that adopt it.

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LISTA DE ABREVIATURAS

AI - Artificial Intelligence
AR - Augmented Reality
BRICS - Brazil, Russian Republic, India, China, and South Africa
CPF - National Insurance Number
DALYs - Disability-Adjusted Life Years
DH - Digital Health
DT - Digital Transformation
EHS - Electronic Health Systems
GPT - Generating Pre-trained Transformation
GIS - Geographic Information System
GLDP - General Law of Data Protection
ICT - Information and Communications Technology
IoT - Internet of Things
IoMT - Internet of Medical Things
IPFS - InterPlanetary File System
LMIC - Low and Middle-Income Countries
MCP - Multiple Country Publications
NTD - Neglected Tropical Diseases
OI - Open Innovation
OWL - Ontology Web Language
P2P - Peer-to-peer
PIHS - Private Initiative Healthcare System
POC - Point of Care
PoW - Proof of Work
R&D - Research and Development
SCP - Single Country Publications
SDG - Sustainable Development Goals
SHA - Secure Hash Algorithm
SUS - Brazilian Unified Health System
TC - Times Cited
VR - Virtual Reality
W3 - Web 3.0
WWW - World Wide Web

1 INTRODUCTION

Digital transformation (DT) is a crucial area for production engineering, driving the progress of Industry 4.0. In healthcare, DT is referred to as digital health. Within this context, Neglected Tropical Diseases (NTDs) are so named because they are often overlooked by the pharmaceutical industry, leaving their management primarily to the governments of affected countries.

Neglected Tropical Diseases (NTDs) remain a major source of illness and death in endemic countries, perpetuating a vicious cycle of poverty for vulnerable populations worldwide (MARTINS-MELO *et al.*, 2016, 2018). Each country faces its own set of NTDs, and Brazil prioritizes those diseases that contribute to inequality and hinder development (FONSECA; ALBUQUERQUE; ZICKER, 2020). Many NTDs are preventable with low-cost medications, but logistical and economic challenges in affected areas complicate their control. Increased attention to the impact of NTDs has led to significant progress in eliminating some of these infections (BERGQUIST et al., 2015).

NTDs negatively impact health, education, agriculture, and the economy. Unfortunately, pharmaceutical companies often lack interest in these diseases, leaving affected countries to develop their own public policies for combating them. Ackley et al. (2021) noted that the initial impetus to group NTDs together was their suitability for mass drug administration (MDA) and the support from pharmaceutical partners through drug donations. Consequently, information management and digital transformation (DT) have become essential tools in the fight against NTDs.

Digital transformation (DT) aims to improve an entity by significantly altering its characteristics through the integration of information, computing, communication, and connectivity technologies. Digital health refers to the development and use of digital technologies to enhance health outcomes (WORLD HEALTH ORGANIZATION, 2021). It encompasses digital consumers with smart devices, as well as applications of IoT, artificial intelligence, big data, and robotics in healthcare (WORLD HEALTH ORGANIZATION, 2020a, 2021). The necessary steps for adopting DT technologies in health include: i) creating credible health content; ii) using digital health interventions to facilitate the delivery or availability of this content; iii) developing digital applications (WORLD HEALTH ORGANIZATION, 2019). Digital health interventions encompass telemedicine between patients and providers to complement health service delivery,

telemedicine between providers, targeted delivery of tailored health information, decision support for health professionals, digitized health information tracking, and education (LI et al., 2021).

This comprehensive work is presented in three peer-reviewed articles submitted to prestigious international journals and conferences. The articles explore detailed aspects of digital health, primarily applied to NTDs, and demonstrate analytical rigor. The ongoing research promises to further advance knowledge in these dynamic areas. The papers developed in this thesis are:

i. de Souza Rodrigues, D., de Paula Fonseca, B. & Fernandes, E. Digital Transformation in the Control of Neglected Tropical Diseases: A Scoping Review. Curr Trop Med Rep 11, 78–91 (2024). https://doi.org/10.1007/s40475-024-00319-x

ii. RODRIGUES, Douglas de Souza; Feitoza Bassi Costa, Marcelle; de Paula Fonseca, Bruna; Fernandes, Elton. **Blockchain-based framework and open innovation to improve healthcare services in Brazil**. (Presented at The BRICS Postgraduate Forum, 2023)

iii. RODRIGUES, Douglas de Souza; Mncedisi Willie, Michael; Mbongwe, Nokonwaba Andiswa; de Paula Fonseca, Bruna; Fernnades, Elton. **Health tech's patient engagement through marketing strategies**. (To be submitted)

The three articles form the core of this thesis. The first article reviews the global use of digital technologies, known as digital health, to mitigate the negative effects of neglected diseases in Low and Middle-Income Countries (LMICs). This study examines publications from various countries and institutions. The second article proposes a blockchain-based framework to enhance quality in healthcare systems by preventing data duplication and ensuring immutability. This approach aims to reduce errors in diagnostics, prescriptions, and emergency care. The third article analyzes the conditions required for a digital application to achieve sufficient patient engagement to remain operational. It identifies factors influencing patient engagement and suggests marketing strategies to maintain this engagement.

Both the blockchain and patient engagement sections are addressed broadly in this thesis due to the lack of comprehensive literature on these topics. The thesis includes an introduction to DH in the context of NTDs and patient engagement through marketing strategies, followed by the rationale, objectives, and structure of the thesis.

1.1 Digital Health for Neglected Tropical Diseases

Digital health has garnered significant interest in medicine and public health, particularly in LMICs, where mobile communications offer a new means to overcome geographic barriers to healthcare (WORLD HEALTH ORGANISATION, 2019). In LMICs, digital health is rapidly evolving, with new technologies and tools being developed to address the health needs of these populations. A notable impact of digital health is its role in controlling and eliminating NTDs. NTDs, a group of parasitic and bacterial infections affecting over 1 billion people globally, predominantly impact LMICs. Despite being frequently overlooked by the global health community, these diseases cause significant morbidity, mortality, and hinder economic development in affected countries (HOLST et al., 2021, 2022; LABRIQUE et al., 2018).

Digital health tools are being employed in various ways to tackle NTDs in LMICs. Mobile apps and messaging services assist community health workers and patients by providing information on NTD prevention, diagnosis, and treatment. These tools also help track disease outbreaks and monitor the effectiveness of treatment programs. Additionally, telemedicine and remote healthcare services are making a significant impact by addressing the shortage of healthcare workers and reducing the need for patients to travel long distances for medical care. These services enhance access to care and alleviate pressure on healthcare systems (KRAUS et al., 2021; MASSARO, 2021; SIBUYI; DE LA HARPE; NYASULU, 2022).

Digital health has the potential to transform healthcare in LMICs, including the control and elimination of NTDs. However, challenges such as infrastructure limitations, funding constraints, and regulatory issues must be addressed. Despite these challenges, the increasing adoption of digital health in LMICs is a promising development that could significantly enhance the health and well-being of millions globally (FORD et al., 2017; WOULFE et al., 2021). While implementing digital health interventions can be difficult, they have been shown to improve healthcare quality by reducing mortality and medical

errors and enhancing patient safety and satisfaction (AGARWAL et al., 2010). Body-worn sensors and social networking platforms are crucial in advancing data collection and health monitoring (ALI et al., 2021).

A blockchain-based framework offers several benefits for healthcare services. It can enhance data precision by providing a secure, transparent, and decentralized platform for managing healthcare information. Open Innovation (OI) can add value to healthcare operations by fostering collaborative partnerships, patient-centered approaches, co-creation, rapid prototyping, knowledge sharing, and leveraging emerging technologies. The proposed framework serves as an initial model to promote the development of Information and Communications Technology (ICT), advancing both government and private sector initiatives.

Blockchain technology enables healthcare providers to maintain accurate and up-to-date records of patient health, treatment history, and medication administration, thereby reducing errors, enhancing care quality, and preventing medical malpractice. Its distributed, peer-to-peer structure addresses transaction order and double-spending issues (CASINO; DASAKLIS; PATSAKIS, 2019). Blockchain-based solutions are crucial for improving healthcare services (KUMARI; GUPTA; VED, 2021; NAMASUDRA; DEKA, [s. d.]; VARADHARAJAN et al., 2021) and promoting effective management practices in hospitals and clinics (SHARMA et al., 2021). lockchain networks underpin the decentralized web, referred to in this paper as Web 3.0 (W3). W3, driven by technologies like the InterPlanetary File System (IPFS), represents a significant innovation in data sharing and networking (ALABDULWAHHAB, 2018). IPFS is the evolution of database and storage systems, being an important way to provide broad information data networking. W3 is known as the intelligent web, provided for structuring all the content available on the World Wide Web (WWW) protocol within the concepts of the Semantic Web. With the development of languages such as Ontology Web Language (OWL), W3 has the ability to use the information on the Web more wisely, formulating meaning from the context in which the information is published IPFS enhances database and storage systems, supporting extensive information data networking. W3, known as the intelligent web, leverages the Semantic Web to structure content on the World Wide Web (WWW), utilizing languages such as Ontology Web Language (OWL) to interpret and contextualize web information more effectively (RUDMAN; BRUWER, 2016).

Open Innovation (OI) is a concept that emphasizes shared growth through collaborative efforts. It involves relinquishing part of the inbound development and adopting outbound research and development (R&D) processes, which is often a top-down exercise linked to strategic planning (CHESBROUGH; CROWTHER, 2006). Open Innovation (OI) is a paradigm that posits firms should leverage both external and internal ideas, as well as multiple pathways to market (LEYDESDORFF; IVANOVA, 2016)

1.2 Patient engagement by marketing strategies

The use of technology to enhance healthcare delivery and treatment efficiency must be coupled with efforts to engage patients in digital health services. This is especially crucial for NTDs, which require comprehensive and efficient public health interventions. Alongside the development and implementation of digital health solutions, a patient engagement strategy is essential to improve care efficiency (BLASIAK et al., 2022). Clear communication is key to effective patient engagement (SINGH et al., 2018). NTDs are particularly problematic due to their lack of visibility and communication. Digital health plays a vital role in preventing the loss of over 25 million disability-adjusted life years (DALYs) globally (MITRA; MAWSON, 2017; UNITING TO COMBAT NTDS, 2019).

The world is currently witnessing a new era where novel disruptive technologies are gaining prominence in healthcare. A key technology is Artificial Intelligence (AI), which is applied in diagnosis, treatment, and clinical research. Although AI was developed in the 1950s (Turing, 1950), its widespread adoption began with the advent of generative AI (gAI) in 2020, following the launch of OpenAI's GPT-3 beta testing. Generative Pre-trained Transformers (GPT) use deep learning to generate human-like text (FLORIDI; CHIRIATTI, 2020). This marks a significant paradigm shift, akin to a fourth revolution, where Information and Communications Technologies have become pervasive forces that shape and redefine realities (FLORIDI, 2014).

Another significant technology is 3D printing, which can be used to educate patients, students, trainees, and surgeons. It is applied in orthopedic procedures and implants, as well as in surgical planning to reduce costs and customize patient needs (MULFORD; BABAZADEH; MACKAY, 2016; SINGH et al., 2020; THOMAS; SINGH, 2020). echnologies like mHealth and apps are revolutionizing the treatment of

many diseases, including NTDs, at a low cost. Additionally, big data and data integration enable predictive analysis for numerous infectious diseases, drug discovery research, and public health insights (DIMITROV, 2016; EKINS et al., 2014; EKINS; CLARK; WILLIAMS, 2012).

Among these technologies, mHealth has been transformative by facilitating the exchange of patient information with caregivers and health professionals. The significance of mHealth apps lies in their ability to improve patient care, quality of life, and information access, while also addressing challenges such as lack of clinical effectiveness evidence, integration with healthcare systems, and concerns about safety and privacy (NJOROGE et al., 2017; WANG et al., 2020). However, these benefits depend on strong patient commitment to using mHealth tools. Therefore, the main objective of this study is to emphasize the importance of patient engagement in health technologies through mHealth tools.

1.3 Background and motivation

The initial phase of this research aimed to understand and enhance the application of DT tools in addressing NTDs. NTDs predominantly affect LMIC and are often overlooked in global health priorities, resulting in insufficient research, funding, and healthcare interventions. This research addresses the pressing need to bridge this gap through innovative technological solutions.

The motivation for exploring digital health solutions in this context stems from the transformative potential of these technologies to improve healthcare delivery, patient engagement, and disease management. The rapid evolution of digital tools presents a unique opportunity to revolutionize the approach to NTDs, which have long lacked effective and scalable interventions. By harnessing the power of digital technologies, there is an opportunity to explore Blockchain Technology to improve health outcomes and democratize healthcare access in underserved regions affected by NTDs.

The second phase of this research focuses on a critical yet often overlooked aspect of digital health solutions: user engagement. The motivation here arises from the recognition that the success of digital health applications depends not only on technological innovation but also on sustained user engagement and robust data privacy

protocols. Patient engagement is an underexplored subject in the literature, presenting a gap that this thesis aims to address.

This focus is underscored by the challenges in ensuring continued patient involvement with digital health tools. Engagement is a multifaceted issue influenced by factors such as user interface design, cultural relevance, accessibility, and perceived value of the technology. The hypothesis driving this research is that higher engagement with digital health tools can lead to better health outcomes, particularly in the management and treatment of NTDs. Therefore, understanding and enhancing factors that promote patient engagement is crucial.

1.4 Rationale and objectives

The global landscape of digital health technologies offers a diverse and rich source of data and insights. The first part of this research focuses on a comprehensive review of the current state of digital health applications, particularly concerning NTDs. This involves analyzing studies and initiatives from various countries and institutions to understand the utilization of digital tools and identify best practices and gaps.

The integration of digital technologies in healthcare raises significant concerns about the privacy and security of sensitive patient data. With the increasing prevalence of data breaches and privacy violations, establishing trust in digital health systems is paramount. This concern is especially relevant for NTDs, where patients often belong to vulnerable groups in LMIC, and mishandling data could lead to severe consequences.

The second part of the research identifies and analyzes key factors influencing patient engagement with digital health tools and creates a digital health framework for combating NTDs. This involves exploring various engagement strategies, including healthcare-specific marketing approaches, as the literature lacks significant papers on this subject.

This understanding is crucial for developing strategies that are technologically sound and aligned with the unique needs and constraints of LMICs. The overarching motivation is to contribute to the fight against NTDs through innovative, sustainable, and scalable digital health solutions, ultimately improving the quality of life for affected populations and contributing to the global effort against these diseases. A comprehensive

understanding of this scenario will establish the initial premises and concepts for addressing the issues faced by countries suffering from NTDs, which will be used to create the framework resulting from this thesis.

The goal is to establish a clear understanding of the digital health landscape in the realm of NTDs, identifying successes, challenges, and unexplored opportunities, and ensuring that digital health solutions are sustainable, trusted, and embraced by users. By addressing both engagement and blockchain technology, this research aims to develop a holistic and responsible digital health framework, enhancing efficacy and acceptance in the fight against NTDs.

1.5 Structure

Chapter 1: Introduction

This chapter introduces the application of digital health tools to address NTDs in LMICs. It provides initial considerations, an overview of the investigated matter, research motivation, rationale, and specific objectives.

Chapter 2: Literature Review

This chapter comprises a targeted review of the most pertinent studies in this area of investigation.

Chapter 3: Research Methodology

This chapter describes the methods adopted to achieve the results in the scoping review and other papers. It is divided into four sections explaining the methodological framework for studying the application of digital tools to address NTDs.

Chapter 4: Results

This chapter presents the research findings on how digital health improves the management of NTDs. It provides an overview of the main findings on patient engagement through marketing strategies and features a framework guiding developers in creating blockchain solutions for NTDs.

Chapter 5: Conclusions

This chapter consolidates and integrates the main conclusions of the research, pointing to potential further studies, additions, and other possibilities for future research related to the topic.

At the end, all references used in the development of the thesis are cited.

2 LITERATURE REVIEW

The literature review in this thesis represents a foundational element, offering a comprehensive and critical examination of existing work related to digital health technologies, particularly within the context of NTDs. This review encompasses a broad spectrum of literature, addressing the technological intricacies of digital health solutions, their application in LMICs, and the unique challenges posed by NTDs. While the primary focus is on NTDs, the review also includes relevant content from broader digital health literature due to the limited number of publications specifically addressing NTDs.

2.1 Neglected Tropical Diseases

Neglected tropical diseases (NTDs) are a diverse group of communicable diseases that prevail in tropical and subtropical regions, primarily affecting impoverished communities with limited access to healthcare. These diseases are characterized by their association with poverty, inadequate sanitation, and limited medical infrastructure, which complicates prevention, diagnosis, and treatment.

The World Health Organization (WHO) identifies several key characteristics of NTDs WORLD HEALTH ORGANIZATION, (2024):

i) NTDs predominantly affect people living in poverty, with poor housing and inadequate sanitation and hygiene.

ii) These diseases often lead to chronic conditions and long-term disabilities, significantly impacting the quality of life, productivity, and social standing of affected individuals.

iii) NTDs receive less attention and funding compared to other diseases such as HIV/AIDS, tuberculosis, and malaria.

iv) They are caused by a variety of pathogens, including viruses, bacteria, protozoa, and helminths (worms).

v) Transmission can involve vectors such as mosquitoes, flies, and snails, or direct contact with contaminated water and soil.

vi) NTDs can be prevented through improved sanitation, hygiene, and vector control.

vii) Effective treatments are available for most NTDs, although access to these treatments is often limited in affected regions.

This overview highlights the complexity and challenges associated with NTDs, underscoring the need for targeted efforts to improve health outcomes in affected communities.

NTDs continue to be a major cause of morbidity and mortality in endemic countries, perpetuating a vicious cycle of poverty among vulnerable populations worldwide (MARTINS-MELO et al., 2016, 2018). The direct impact of NTDs is evident not only in health but also in education, agriculture, and overall economic stability. They contribute to poverty and hinder economic development due to their effects on child health and development, pregnancies, and labor productivity, as well as their stigmatizing nature (HOTEZ et al., 2020). NTDs are estimated to be responsible for over 25 million disability-adjusted life years (DALYs) lost worldwide (MITRA; MAWSON, 2017a) and affect over 1.6 billion people (UNITING TO COMBAT NTDS, 2019).

The burden of NTDs varies by country, and although the WHO has identified a group of priority NTDs to be eradicated by 2030 (WORLD HEALTH ORGANIZATION, 2020b), eradication is challenging due to each country's specific context. This context reflects a country's health profile, disease epidemiology, and shifting government priorities. Each affected country requires tailored public policies to address NTDs, and information management and digital transformation have become crucial tools in this effort, accelerating and promoting interaction among public health stakeholders (SIBUYI; DE LA HARPE; NYASULU, 2022). Despite some shared similarities among these countries, digital transformation could serve as a crucial link connecting all nations burdened by NTDs.

2.2 Health Tech Evolution and Digital Health

From the late 19th to the early 20th centuries, significant advancements in medical equipment began with the development of basic tools such as stethoscopes, thermometers, surgical instruments, and X-rays. Post World War II, the advent of electronic devices

transformed medical practice, introducing electrocardiographs, defibrillators, pacemakers, and other monitoring equipment. The 1970s marked the emergence of information technology in medical imaging, leading to the establishment of the first hospital information systems for patient management and medical records, as well as the development of portable medical devices. With the turn of the millennium, telemedicine gained traction, wearable devices became prevalent for monitoring health indicators, and Electronic Health Systems (EHS) began with the digitization of medical records and integration across health networks (BATES et al., 2001; ECCHER et al., 2020; NEUMAN et al., 2012; PROTAS et al., 2018). This evolution has culminated in what is now known as digital health, characterized by the integration of digital tools to enhance public health.

Digital health is a discipline that leverages digital technologies to improve health outcomes and optimize healthcare delivery. It encompasses a broad spectrum of technologies, including smart devices, connected equipment, the Internet of Things (IoT), artificial intelligence (AI), big data, and robotics. The increasing importance of digital health is particularly evident in LMIC, where mobile communication technologies are overcoming geographical barriers to healthcare (WORLD HEALTH ORGANIZATION, 2020a, 2021).

The application of digital transformation (DT) tools in healthcare is crucial for achieving the Sustainable Development Goals (SDGs), especially Goal 3: “Ensure healthy lives and promote well-being for all at all ages.” This includes target 3.3, which aims to end the epidemics of AIDS, tuberculosis, malaria, and neglected tropical diseases by 2030, as well as combat hepatitis, water-borne diseases, and other communicable diseases. Therefore, digital health interventions tailored to NTDs are essential for promoting digital applications through information and communication technologies (ICTs) to improve the fight against these diseases.

2.3 Marketing in Healthcare

Marketing in healthcare involves the promotion and sale of medical products and services to both patients and healthcare providers. It uses various strategies and tactics to attract and retain customers, increase brand awareness, and enhance the reputation of healthcare organizations. Effective healthcare marketing requires a deep understanding

of patient needs and preferences while adhering to legal and ethical standards in the industry.

Key aspects of healthcare marketing include service quality, consumer satisfaction, service branding, patient participation, and service recovery. Ensuring high service quality and consumer satisfaction is crucial as these factors significantly influence patient loyalty and the overall reputation of healthcare providers. Service branding involves creating a strong and recognizable brand that resonates with patients and distinguishes the provider in the marketplace. Patient participation is increasingly important, involving patients in their healthcare decisions to enhance satisfaction and outcomes (CORBIN; KELLEY; SCHWARTZ, 2001).

Healthcare marketing faces unique challenges such as managing diverse markets, effectively segmenting customers, and maintaining high performance standards at every patient interaction point. Balancing patient care experience with achieving business objectives is a significant challenge, compounded by the need to navigate a highly regulated environment (MACSTRAVIC, 1989).

In BRICS nations, healthcare marketing is influenced by factors such as rapid changes in disposable income, wealth accumulation, and distinct social and cultural characteristics, all of which impact consumer behavior and preferences (KIVENZOR; TOFFOLI, 2015). These countries face challenges in achieving universal health coverage, including increasing public spending, managing mixed private and public health systems, ensuring equity, and addressing changing demographics and disease burdens (MARTEN et al., 2014). Marketing strategies must address these broader health system challenges. .

Healthcare marketing in BRICS countries must balance promoting public health, controlling noncommunicable diseases, and improving overall population health while also encouraging physical activity and healthy lifestyles (JAKOVLJEVIC et al., 2019). The rising share of global medical spending in these countries comes with challenges such as increasing out-of-pocket expenses and healthcare accessibility, particularly in rural areas (JAKOVLJEVIC, 2016).

The integration of sophisticated information and communication technologies (ICTs) in healthcare presents managerial and policy-making challenges and opportunities. ICTs are shifting the focus towards more patient-centric systems and necessitate an integrated approach to ensure effective and relevant marketing strategies. Healthcare

marketers are increasingly using data analytics and digital platforms to better understand patient needs and tailor their marketing efforts (LYTRAS; PAPADOPOULOU; SARIRETE, 2020). BRICS countries are encouraging innovation and applying new technologies in healthcare, though they face challenges such as lower rates of certain medical procedures compared to G7 countries, indicating a gap in healthcare delivery and potential for targeted marketing strategies (GOMES, 2013).

Healthcare marketers operate in a complex and regulated environment, necessitating strict compliance with laws and regulations (CAIRNS; YARKER, 2008). This is particularly challenging in the digital health space, where innovative eHealth solutions must comply with traditional health laws (PURTOVA; KOSTA; KOOPS, 2015). Compliance with security and privacy regulations is crucial, requiring organizations to implement specific procedures and training (LUTES, 2000). To navigate this landscape, healthcare organizations must foster a culture that supports their mission while addressing operational and financial objectives (SIMON, 2018).

Looking forward, the evolving health technology landscape suggests promising implications for the future. Integrating artificial intelligence (AI) and machine learning into marketing strategies can enhance personalization, emphasize the value of AI in analyzing unstructured data, and optimize content personalization (KHRUPOVYCH; BORYSOVA, 2021; NIKOLAJEVA, 2021). Immersive technologies such as virtual reality (VR) and augmented reality (AR) present opportunities for creating engaging and interactive marketing campaigns. VR can provide realistic depictions of medical procedures and outcomes, while AR can overlay digital information onto real-world environments, enhancing user engagement with health information. The application of VR and AR in healthcare marketing is growing, offering innovative ways to engage with health information (EKMEIL et al., 2021). Additionally, exploring collaborations with influencers in the healthcare space can extend marketing efforts' reach (LUCCA; CANDELIERI; PIGNOLO, 2010). This literature review explores these opportunities and the impact of immersive technologies and influencer collaborations in healthcare marketing.

2.4 Patient Engagement

Patient engagement in healthcare is a multifaceted concept influenced by a variety of factors. These factors can be broadly categorized into patient-related, healthcare system-related, and external environmental factors. Key elements that drive patient engagement include patients' motivation, persistence, skills, and understanding of the benefits of participating in their own healthcare. Behavioral, cognitive, and emotional commitment are crucial for patients to actively participate in their care, especially with the advent of new technologies (TRIBERTI; BARELLO, 2016). Additionally, factors such as age, race, educational level, and employment status play a significant role in determining a patient's capacity to engage in different healthcare activities (SUN *et al.*, 2019).

The engagement of patients is significantly influenced by the healthcare environment, including the relationship and communication with healthcare providers. Aspects such as the reputation of physicians and healthcare organizations, contractual and logistical factors, and appointment availability also play a role (ABRAHAM *et al.*, 2011). Furthermore, the implementation of patient engagement strategies, such as personalized care, access to providers, and self-management support, is essential (HUDON *et al.*, 2017). The adoption of technologies in healthcare, such as personal electronic health records, influences patient engagement by providing patients with access to their clinical data and empowering them to be more involved in their care (CRAMERI *et al.*, 2020). Moreover, external factors like societal attitudes towards healthcare, the availability of resources, and socio-economic conditions also affect patient engagement.

Patient engagement, coupled with the strategic integration of technology, has become a transformative force in healthcare (BOMBARD *et al.*, 2018). We expand on the concept of patient engagement, emphasizing the pivotal role of technology in improving healthcare delivery and treatment efficiency. The integration of technology into healthcare delivery enables patients to access personalized health information, monitor their health status, and actively participate in decision-making (DOLAN; FRAENKEL, 2017). Wearable devices, mobile applications, and telehealth platforms facilitate real-time data exchange, contributing to better management of chronic conditions and overall improved health outcomes (SINGH *et al.*, 2018).

Technological advancements also play a crucial role in addressing challenges such as medication non-adherence. Medication reminder apps and smart pill dispensers offer solutions that provide timely reminders, educational resources, and tracking mechanisms, enhancing patient adherence to treatment plans (BLASIAK *et al.*, 2022). Moreover, telehealth has emerged as a game-changer, offering remote consultations, monitoring, and follow-up care. Virtual platforms not only enhance accessibility but also allow patients to engage actively with healthcare providers from the comfort of their homes, reducing barriers to care (HALEEM *et al.*, 2021; HUAYNATE *et al.*, 2015; LUXFORD; SAFRAN; DELBANCO, 2011; STEINBROOK *et al.*, 2020).

The adoption of Health Information Technology, including Electronic Health Records and patient portals, facilitates seamless information exchange between patients and healthcare providers, empowering patients to be more informed participants in their care (DENDERE *et al.*, 2019; KRYZANOWSKI *et al.*, 2019). However, critical analysis reveals challenges and gaps in the implementation of technology for patient engagement. Data security concerns, such as breaches and unauthorized access, pose a significant challenge to the widespread adoption of digital health solutions (HALE; KVEDAR, 2014).

Disparities in technology access, particularly among underserved populations, create a digital divide that hinders equitable engagement opportunities (AFZAL *et al.*, 2023). Despite the potential benefits, resistance to change within healthcare systems remains a formidable barrier. The transition from traditional models to technology-enabled care requires organizational restructuring, staff training, and overcoming institutional inertia (HUANG *et al.*, 2013). Additionally, the effectiveness of certain technological interventions in diverse patient populations, especially those with varying levels of health literacy or cultural backgrounds, presents a notable gap in current research. Opportunities for improvement lie in addressing these challenges through interdisciplinary collaboration, robust cybersecurity measures, and tailored interventions for diverse patient groups (JALALI; SIEGEL; MADNICK, 2019). Future research should focus on developing inclusive and user-friendly technological solutions while considering the unique needs of diverse patient populations. By addressing these challenges and leveraging opportunities, the integration of technology in patient engagement has the potential to revolutionize healthcare delivery and contribute to better health outcomes on a global scale.

2.4.1 Challenges faced by rural communities

Integrating technology into patient engagement in rural communities faces challenges such as access, literacy, healthcare provider shortages, cultural considerations, financial constraints, regulatory barriers, and infrastructure limitations (WOLDAREGAY *et al.*, 2018). Limited access to technology in rural areas, due to remote locations and inadequate infrastructure, hampers the implementation of digital health solutions (AFZAL *et al.*, 2023; HALE; KVEDAR, 2014).

Health and digital literacy disparities in rural populations pose challenges in effectively utilizing technology for healthcare engagement (HUAYNATE *et al.*, 2015). Healthcare provider shortages in rural areas hinder in-person support for patients adopting technology-driven solutions (GUMEDE; TAYLOR; KVALSVIG, 2021). The unique cultural contexts and community dynamics in rural settings necessitate careful consideration to ensure the cultural relevance and acceptance of technology solutions. Financial constraints and limited budgets in rural healthcare facilities impede investments in necessary technology resources. Regulatory complexities and infrastructure limitations, such as inadequate broadband connectivity, further hinder the adoption of technology (GKRIMPIZI; PERISTERAS; MAGNISALIS, 2023).

To overcome these challenges, future efforts should focus on expanding broadband infrastructure, tailoring education programs, incentivizing telehealth adoption, engaging communities in technology development, and advocating for regulatory reforms. Sustainable funding models, streamlined policies, and investments in rural healthcare infrastructure are critical for fostering successful technology integration, ultimately enhancing patient engagement and health outcomes in rural communities (GIZAW; ASTALE; KASSIE, 2022).

While patient-centric marketing approaches have proven effective, a challenge lies in understanding the diverse needs and preferences of individual patients. To address this, advanced analytics and data-driven insights can be incorporated into marketing strategies, ensuring precision and relevance across diverse demographics. Collaboration with patient advocacy groups also holds promise in aligning strategies with the lived experiences of the patient community (BATKO; ŚLĘZAK, 2022). Digital literacy challenges present obstacles to effective patient engagement. Marketing strategies can mitigate this by

incorporating user-friendly educational content, such as video tutorials and interactive guides, to make health technologies more accessible.

Effective collaboration with healthcare providers is crucial for success, yet challenges may arise due to differences in communication styles and priorities. Marketing strategies should involve targeted outreach and education programs for healthcare professionals, showcasing the benefits of health technologies in improving patient outcomes. Establishing collaborative forums and feedback mechanisms can facilitate ongoing communication, ensuring alignment between marketing efforts and healthcare provider recommendations.

2.5 Digital Marketing

This section discusses the role of digital marketing in patient engagement and the associated data security concerns, as sensitive patient information may be stored and shared by health tech companies. It synthesizes research findings on this topic to complement the framework, introducing a new perspective.

2.5.1 The Convergence of Health Tech and Marketing

The convergence of health technology and marketing is a dynamic and multifaceted development, increasingly recognized for its potential to drive innovation and growth in the healthcare sector. This convergence is notably evident in various fields including health IT, educational technology, and marketing services, where it fosters new avenues for innovation (FOSTER, 2014). In regions like China, the integration of economic growth, market development, technology investment, and capital input is significantly influencing the health tourism industry, illustrating how economic and technological factors interplay in this convergence (QIAN; SHANG, 2022). Global healthcare landscape is experiencing a convergence trend, propelled by increasing income levels, advancements in medical technologies, and a rising demand for high-quality, yet affordable foreign medical services (WON; LEE; JUNG, 2016).

In the life sciences and healthcare industries, convergence is creating new opportunities for business growth and product differentiation. This phenomenon, however, comes with its own set of risks and uncertainties that need to be managed (ESELIUS *et al.*, 2008). The concept of convergence technology in healthcare, which

integrates multiple devices or functionalities within a single platform, adds significant functional, operational, and economic synergies (MACKLIS; SHARMA, 2011). Additionally, the convergence of engineering, physical, computational, and mathematical sciences with biomedical science holds promising potential for advancements in healthcare, reflecting a broader trend of interdisciplinary integration (SHARP; JACKS; HOCKFIELD, 2016).

Smart Health, emerging as a next-generation growth engine, exemplifies the potential of information and communication technology convergence in healthcare. it is driven by the growing demand for high-quality health and medical services that are also cost-effective (PARK; KIM, 2013). Furthermore, the convergence of information technology and medical devices is enabling the ubiquitous measurement of health-related information and facilitating anytime, anywhere access to medical care (NAM *et al.*, 2012). This convergence is not only reshaping the healthcare landscape but also presenting new challenges and opportunities that necessitate strategic and innovative approaches.

Collaborations with educational institutions and community organizations can further enhance digital literacy programs, empowering patients to confidently navigate and utilize health technologies (BUSSE *et al.*, 2022). Social media and online platforms offer real-time interaction opportunities but concerns about misinformation and data privacy persist as significant challenges (GIUSTINI *et al.*, 2018). Marketing strategies should prioritize transparency in data handling, utilize secure communication channels, and actively debunk myths through credible sources. Building a supportive online community around health technologies, where users can share experiences and insights, can help mitigate these challenges. Figure 1 expands on the seven fundamental ways in which social media is actively employed in the healthcare domain, based on the seven categories proposed by Moorhead et al. (MOORHEAD *et al.*, 2013).

Figure 1 - Fundamental ways in which social media is actively employed in the healthcare domain. Source: adapted from Moorhead et al. (2013).

The rise of digital platforms in health technology has significantly transformed patient engagement, becoming a pivotal element in modern healthcare delivery. Digital health platforms have enhanced physician loyalty by fostering online engagement and enabling the co-creation of value between physicians and patients (LO PRESTI *et al.*, 2019). They have proved particularly effective in specific areas like cancer care, where social media platforms and wearable technologies facilitate interaction, communication, and data sharing, thus enhancing the quality of medical care (FISCH; CHUNG;

ACCORDINO, 2016). Moreover, these platforms connect patients, families, and health systems, enabling integrated research, outcomes management, and seamless communication between medical entities (SEYFERT-MARGOLIS, 2018).

Digital health technologies are not only reshaping patient engagement but also encouraging patients to engage in self-monitoring and self-care, albeit with complexities such as surveillance and emotional impact (LUPTON, 2013). In addition, they help in monitoring health behaviors and physiological parameters, though accessibility barriers remain for certain populations (LIU *et al.*, 2020). Platforms like Digilego have shown promise in specific applications like peripartum depression screening and management, demonstrating the versatility of digital health in various medical contexts (ZINGG *et al.*, 2020). The emergence of these platforms represents a significant shift in patient-centered healthcare, enhancing patient satisfaction and sustainability while reducing costs and promoting value co-creation patterns (MORO VISCONTI; MOREA, 2020).

Marketing strategies in healthcare are increasingly leveraging personalized content to enhance patient engagement, as evidenced by recent research. Personalizing healthcare through digital technologies, with a focus on individual health and wellness, is shown to significantly enhance patient engagement and empowerment. This approach involves democratizing healthcare information, which is key to personalizing the patient's experience (SNOWDON *et al.*, 2015a). Additionally, the use of personalized inpatient portals has been identified as an effective means to improve patient engagement in clinical care settings, indicating the potential benefits of such digital tools across various healthcare delivery contexts (MASTERSON CREBER *et al.*, 2016).

The effectiveness of customization and personalization in marketing strategies is also highlighted in fostering customer engagement. This approach is context-dependent and relies on various business factors and circumstances (BLEIER; DE KEYSER; VERLEYE, 2018). Moreover, a patient-centered toolkit prototype for web-based platforms has been found effective in engaging hospitalized patients and caregivers in their care plans, thus improving access to health information and enhancing patient outcomes (DYKES *et al.*, 2014).

2.5.2 Marketing Strategies for Enhanced Patient Engagement

Enhanced patient engagement in healthcare is increasingly achieved through targeted marketing strategies that focus on customer needs and challenges, emphasizing the benefits of healthcare services (UDAYAI; KUMAR, 2013). information and communication technology strategies, including websites, portals, social networks, and synchronous and asynchronous communication, are instrumental in improving patient engagement and promoting healthy living (MARIN; DELANEY; DELANEY, 2017). Personalizing health services by focusing on individual health and wellness and democratizing healthcare information is pivotal for enhancing patient experience and engagement (SNOWDON *et al.*, 2015b).

Shifts in the care delivery process that focus on patient strengths and consider all entities as equal partners are crucial for patient engagement (SWARTWOUT *et al.*, 2016). Doctors play a key role in patient engagement by ensuring patients' understanding of medical information, addressing psychological concerns, and employing effective communication strategies (YU; PUN, 2021). New patient engagement strategies, including the use of social and consumer technologies, improve communication and participation between patients and healthcare providers (GREAVES; ROZENBLUM, 2017). Some strategies detailed as follows, illustrate a concerted effort to create a more patient-centered, participative, and personalized healthcare system.

2.5.2.1 Content Marketing

Informative and educational content plays a crucial role in engaging patients in healthcare. It encompasses a range of strategies, from providing necessary information to enhancing patients' understanding and participation in their healthcare journey. Information quality, along with physician behavior and education, has a significant impact on patient interactions and satisfaction (KHODADADI *et al.*, 2021). Social media platforms have shown high engagement levels for patient support and information, suggesting their potential role in enhancing healthcare research and delivery (DELLA ROSA; SEN, 2019).

Educational content should be tailored to patients' individual needs, with a focus on empathy and emotional support, especially for older patients (POSMA *et al.*, 2009). Health education interventions have been found to improve self-efficacy, patient satisfaction, coping skills, and perceptions of social support, leading to significant clinical

benefits (ADAMS, 2010). Moreover, the design of information architecture in patient education websites can improve satisfaction and knowledge gain, although not all approaches lead to significant knowledge gain (DEKKERS *et al.*, 2021).

Patient engagement in the development of mobile health applications, for instance, can integrate a vast range of information and resources, enhancing involvement in recovery planning (CHUDYK *et al.*, 2021). This engagement is pivotal in developing patient-centered health technologies, empowering patients and caregivers with information throughout their healthcare journey.

2.5.2.2 Social Media Engagement

Social media platforms have become integral in reaching and engaging patients, offering new avenues for digital interaction and enhancing patient engagement and understanding of healthcare delivery. These platforms are not only pivotal in communicating research and encouraging participation in clinical studies but also in fostering patient support and awareness (GIUSTINI, 2014; ROZENBLUM; GREAVES; BATES, 2017). They enable activities such as participating in tweet chats and improve health-related outcomes, facilitating a more interactive and engaging approach to patient care (MARKHAM; GENTILE; GRAHAM, 2017).

Social media's impact extends to influencing patient ratings of healthcare providers, with higher ratings associated with providers' active social media presence (LAMANO *et al.*, 2021). In the UK, healthcare professionals increasingly use social media platforms like Twitter and LinkedIn for medical education and interaction with patients and colleagues, demonstrating its growing importance in professional healthcare communication (MCDONALD *et al.*, 2015). Furthermore, engaging in social eHealth activities on these platforms is linked to increased electronic communication with healthcare providers, reducing health inequality (RYAN; KUSHALNAGAR, 2018).

2.5.2.3 Email Marketing

Newsletters, updates, and personalized emails play a significant role in maintaining patient engagement in healthcare. They serve as effective tools for engaging with patients and promoting health-related topics, leading to increased awareness and improved well-being (ANAND; CHEEMA, 2022). These communication methods help patients play an effective role in their own health care by improving health literacy, shared decision making, and contributing to quality improvement (COULTER, 2012). Additionally, they

help build patient trust and promote a strong patient-provider relationship in the evolving healthcare system (PETERSEN, 2016).

Newsletters have been successful in communicating with patients, developing an identity for healthcare practices, and introducing new staff or announcing changes (Thomas, 1991). They facilitate communication, provide accurate health information, and allow direct communication with patients and family members (PITMAN; TENNANT, 2000). Furthermore, patient-initiated emails may improve patient engagement and health outcomes, potentially leading to overall survival benefits among cancer patients undergoing chemotherapy (COQUET *et al.*, 2020).

Personalized emails and active personal health records with personalized alerts promote better communication and partnership with healthcare providers, enhancing patients' sense of self-management (RIEF *et al.*, 2017). Personalization in email newsletters increases evaluation and interest, particularly among individuals with a high need for uniqueness (MASLOWSKA; PUTTE; SMIT, 2011). In summary, newsletters, updates, and personalized emails are essential tools in healthcare communication strategies, effectively engaging patients and enhancing their involvement in healthcare management.

2.5.2.4 Telehealth and Virtual Consultations

Recent trends and strategies in marketing telehealth services (2018-2023) emphasize a multifaceted approach to ensure effective implementation and broad acceptance. Central to these strategies is understanding and aligning with the expectations of both patients and providers. Moving away from traditional healthcare revenue models, these strategies focus on deconstructing standard healthcare encounters and embracing innovative, visionary approaches. This shift is pivotal for the long-term sustainability and integration of telehealth into routine care, especially post-COVID-19. Telehealth is not only seen as a supplement to existing healthcare practices but also as a key component in managing specific health issues, such as musculoskeletal illnesses, in a post-pandemic world (MINER; KOENIG; BOZIC, 2020).

The successful implementation of telehealth services hinges on strategic adoption and patient engagement. It requires involvement from clinicians, patients, and administrative personnel to maximize utilization and achieve significant benefits. Furthermore, focusing on financial strategies and business models is crucial for telehealth

services to increase their return on investment and investment value, thereby ensuring their viability and growth (BRYAN, 2022). In addition to these aspects, telehealth plays a vital role in emergency responses, such as reducing cross-contamination during pandemics, suggesting its critical function in crisis management and routine healthcare systems (SMITH *et al.*, 2020; THOMAS *et al.*, 2020).

Moreover, telehealth services are being strategically implemented in specialized settings such as schools, particularly in rural areas, to augment clinical capacity. This approach requires comprehensive planning involving technology training, reimbursement, and community engagement (FOX *et al.*, 2021). In the realm of maternal health, telehealth strategies have shown positive impacts on breastfeeding support, indicating their role in diverse healthcare areas (DOS SANTOS; BORGES; ZOCCHE, 2020).

2.6 Blockchain Technology

Blockchain technology offers a promising avenue for improving healthcare systems, particularly in addressing NTDs. These diseases, widespread in many developing countries, have long been overlooked in global health priorities. Blockchain can revolutionize the management and treatment of NTDs through several key approaches.

A blockchain network provides a secure and transparent way to manage patient data, which is crucial for managing NTDs. Effective disease management requires tracking patient history and treatment outcomes, ensuring the integrity of the pharmaceutical supply chain, and combating counterfeit drugs— a significant issue in NTD treatment. Blockchain technology can also accelerate research and development of new drugs for NTDs by enabling secure and efficient sharing of research data among stakeholders (PATNAIK *et al.*, 2020; TILAHUN *et al.*, 2021; WINKLER, 2021).

Blockchain technology can significantly enhance the quality of health systems through its unique features. It facilitates interoperability among various health systems, allowing for seamless data exchange—an essential aspect for comprehensive care in NTD treatment, which often involves coordinated efforts across different healthcare sectors. Additionally, blockchain applications empower patients by giving them control over their medical records, which can enhance patient engagement and improve health outcomes

for those with NTDs. By providing a secure platform for sharing clinical data, blockchain can accelerate research into NTDs, leading to the development of new treatments and better disease management strategies (DURNEVA; COUSINS; CHEN, 2020; GÖKALP *et al.*, 2018; NAGARATHNA; ARALIMARD, 2023; ZHUANG *et al.*, 2020).

According to the WHO (WORLD HEALTH ORGANIZATION, 2007), effective health services are those that deliver personal and non-personal health interventions efficiently, safely, and with high quality, when and where needed, while minimizing resource wastage. Improving healthcare services involves influencing health determinants as well as implementing direct health-improving activities. The WHO document identifies six key system building blocks essential for achieving these goals: i) service delivery; ii) health workforce; iii) information; iv) medical products, vaccines, and technology; v) financing; vi) leadership and governance. These building blocks contribute to enhancing access coverage, quality, and safety of healthcare services by focusing on health, efficiency, and responsiveness. Achieving these objectives requires employing an integrated health system (CIAMPI *et al.*, 2021; HASSELGREN *et al.*, 2020; JIANG *et al.*, 2018).

The integration of ICT systems in healthcare organizations has often been limited to specific sectors, departments, treatments, or processes (TORTORELLA *et al.*, 2019). Due to the high complexity of operations, many initiatives have failed to deliver the expected results, discouraging further ICT implementation (TORTORELLA *et al.*, 2021). In response to this issue, the concept of a new and integrated system that consolidates health data could significantly improve healthcare services. This system is not limited to isolated private initiatives healthcare systems (PIHS) or universal systems like the Brazilian Unified Health System (SUS) but is instead envisioned as an open individual-based health archive.

2.6.1 Open innovation, Blockchain and Web 3.0 for healthcare improvement

Blockchain works like a ledger that stores a huge and immutable amount of data such as timestamp and information about events, in a digital medium (HABER; STORNETTA, 1991). According to (MEYLAN; BAUCE, 2019) a blockchain is a chain of information blocks (Figure 2) that provides synchronism among blocks, ensuring invariability of these data and guaranteeing its chronological sequence. Blockchain (AGBO; MAHMOUD; EKLUND, 2019) plays a key role as the technology allows the

creation of blocks for the transit of data chains in a secure, anonymous and independent way. Commonly associated with cryptocurrencies, considered as the successors of physical money, blockchain will play a key role in the futuristic web. The revolutionary power of such technology compares with the revolution unleashed by the WWW and the Internet in general.

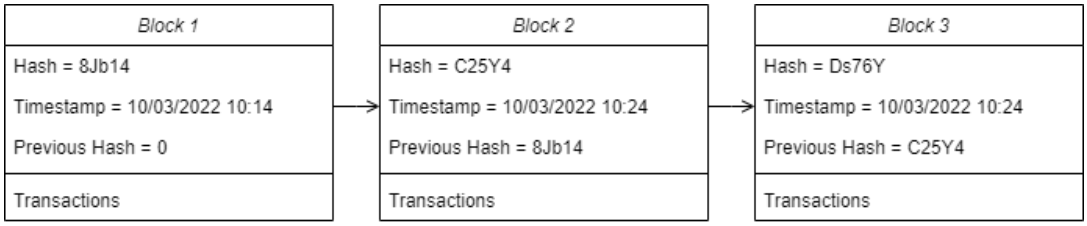

Figure 2 - A simplified example of how blocks are chained to form a blockchain. Notice that previous hash is part of the next hash in order to bring reliability and security to the chain.

On the way to guarantee security, a hash, a unidirectional cryptography function is employed. Secure Hash Algorithm (SHA) is a set of hash functions developed to enable authenticity of blocks throughout cryptography. In this concern, SHA256 is a special subset of SHA once it has hash functions containing 32-bit words (MENDEL; NAD; SCHLÄFFER, 2013). Proof-of-Work (PoW) was developed to eliminate cyber-attack effects to the hash functions, making blockchain secure. PoW works to reduce the velocity that new blocks are generated or modified, in case of network attacks (GERVAIS *et al.*, 2016). This indicates once again the strong security level provided by blockchains. Additionally, Peer-to-Peer (P2P), is a computer network architecture which allows sharing information in a decentralized approach. Unlike centralized systems, the control of information is done by all the individual network actors, guaranteeing the overall knowledge of blocks content; and once a new block surges, all users must confirm block authenticity and only if the block is confirmed it is added in the blockchain (SINGHAL; DHAMEJA; PANDA, 2018). P2P also allows communication among all healthcare systems throughout its network and warranty that access to all patients' information is trustworthy.

Blockchain can serve as a decentralized repository for patient information. In Brazil, where high unemployment and frequent job changes mean that individuals may lose access to employer-sponsored health plans, a blockchain-based decentralized healthcare management system could address the gaps that confine patient information

within distinct healthcare systems. Such a system is critical for the effective collection, analysis, and seamless exchange of clinical data across organizational boundaries (BOSE, 2003). In Brazil, it is mandatory to integrate these different systems and subsystems, which are nationally based on SUS and PIHS, across all municipalities (CUNHA; VARGENS, 2017; SAÚDE, 2020). This integration is essential for the organization and operation of the Healthcare Network. Additionally, the use of ICT is becoming increasingly vital for managing SUS operations.

W3 technologies can facilitate this decentralization by moving from traditional cloud storage to blockchain networks for file storage. For example, NFTs are used to store tokens, items, and assets in individual wallets. This framework utilizes National Identification Numbers (NIN) as a wallet address and functions as the primary key for patient identification. In a decentralized network, there is a single ledger, but all nodes maintain a copy of the ledger and have varying levels of access to its contents (AGBO; MAHMOUD; EKLUND, 2019).

To operationalize this system, a file system model is necessary. IPFS, a distributed file system, builds on successful ideas from peer-to-peer sharing systems like BitTorrent and Git (BENET, 2014). IPFS offers a new approach to distributing and versioning large datasets and has recently garnered significant interest (LAJAM; HELMY, 2021). To ensure the quality of the healthcare management system, a blockchain schema is proposed (Figure 3).

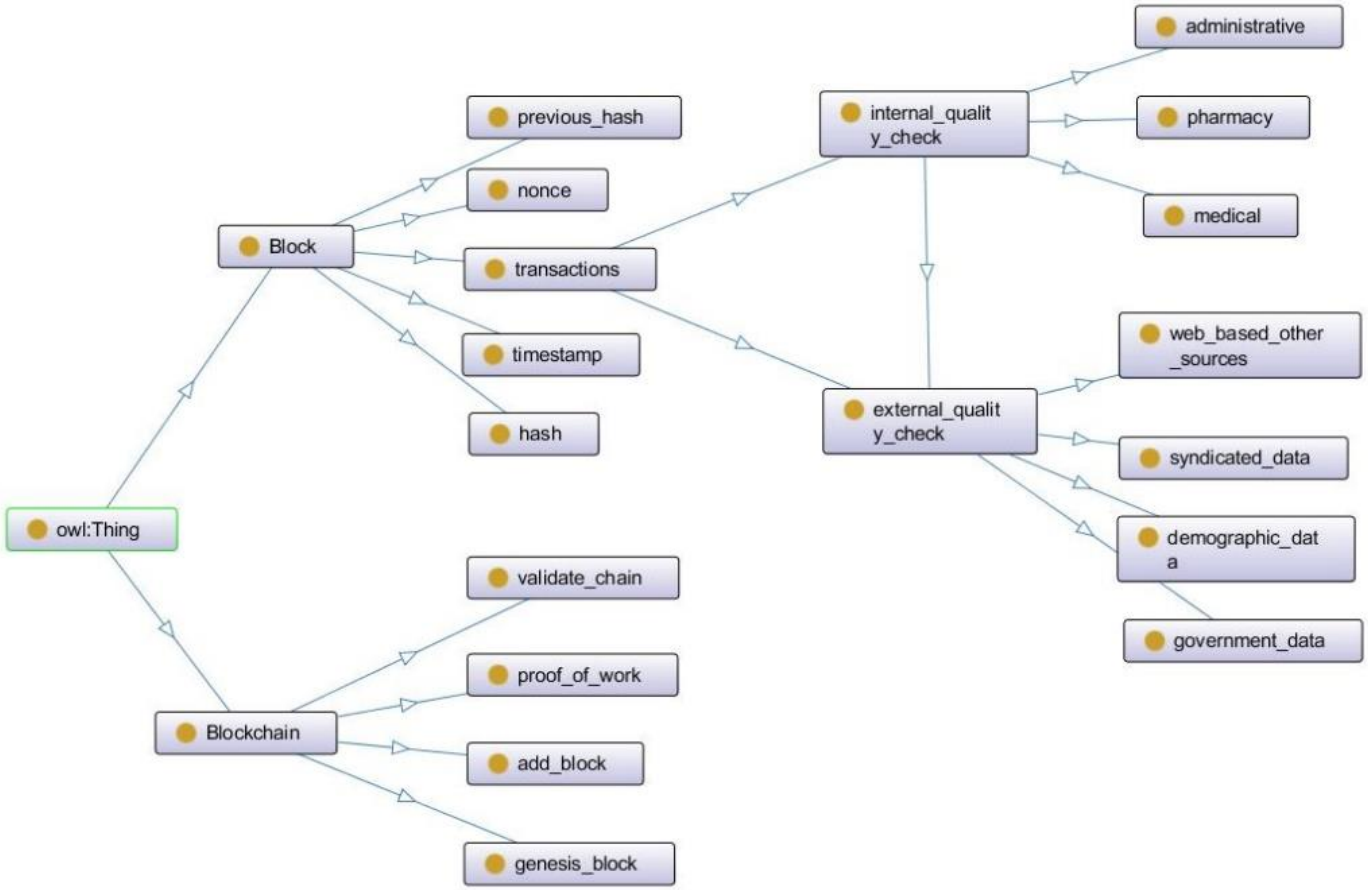

Figure 3 - Blockchain schema proposed to improve healthcare management system quality.

3 METHODOLOGY

This chapter details a review of global literature and digital health applications, providing insights into trends, patterns, and the impact of digital technologies on NTDs. The methodology involves a comprehensive literature review of books, scientific papers, technical reports, and industry studies. Based on this analysis, research processes were developed, and frameworks and diagrams were created to synthesize the content.

3.1 Scoping Review

Scientific publications were considered herein as evidence of research in digital transformation applied to NTDs. Three dimensions, as follows, oriented the analysis: a bibliometric review, a content analysis, and an ontological model. Before the analysis, a data collection and search strategy were defined.

3.1.1 Data collection and search strategy

Scientific publications on NTDs containing DT approaches were retrieved from the Scopus, WoS and PubMed databases in December 2023, and manual searching engines. The search was carried out in the title, abstract and keywords of publications. Only articles were included. The search string included terms specific for NTDS (WORLD HEALTH ORGANIZATION, 2020b) (Table 1) and terms associated with DT ("Digital transformation" OR "Blockchain" OR "Data mining" OR "Mobile phone" OR "Internet of things" OR "Software as a service" OR "Information management" OR "Big data" OR "Deep learning" OR "Metaverse" OR "Information systems" OR "Web platform" OR "Mobile platform" OR "Cloud computing" OR "Digital health" OR "Open health").

Table 1 - Search terms for NTDs, based on Machado-Silva et al. 2023 (unpublished)

Disease	Search terms
Chagas disease	chagas OR "Trypanosoma cruzi" OR "T cruzi" OR "American Trypanosomiasis"
Buruli ulcer	buruli OR "Mycobacterium ulcerans" OR "M ulcerans"
Chikungunya	chikungunya OR CHIKV
Dengue	dengue OR DENV OR DENF
Dracunculiasis	dracunculiasis OR dracunculosiasis OR "Guinea worm" OR "Dracunculus medinensis" OR "D medinensis"
Echinococcosis	echinococcosis OR echinococcoses OR hydatidosis OR "Echinococcus granulosus" OR "Echinococcus multilocularis" OR "Echinococcus vogeli" OR "Echinococcus oligarthrus" OR (hydatid pre/1 disease)

Foodborne trematodiases	clonorchiasis OR clonorchisis OR "Clonorchis sinensis" OR "Chinese liver fluke" OR "Oriental liver fluke" OR opisthorchiasis OR "Opisthorchis viverrini" OR "O viverrini" OR fascioliasis OR fasciolosis OR "Fasciola hepatica" OR "Fasciola gigantica" OR "F gigantica" OR paragonimiasis OR "Paragonimus westermani" OR "P westermani" OR "Oriental Lung Fluke" OR "Endemic Hemoptysis"
Human african trypanosomiasis	"Trypanosoma brucei" OR "T brucei" OR "African Trypanosomiasis" OR "Sleeping sickness"
Leishmaniasis	*Leishmania*
Leprosy	lepra OR leprae OR leprosy OR leprose OR leprosis OR Hanseniasis OR Hansenosis OR "Hansen disease" OR "Hansens disease" OR "Mycobacterium leprae" OR "M leprae" OR "Mycobacterium lepromatosis" OR "M lepromatosis" OR antileprotic OR antileprosy
Lymphatic filariasis	filariasis OR filariases OR filariosis OR filarioses OR elephantiasis OR elephantiases OR Bancroftian OR brugian OR "Wuchereria bancrofti" OR "W bancrofti" OR "Brugia malayi" OR "B malayi" OR "Brugia timori" OR "B timori"
Mycetoma	mycetoma OR actinomycetoma OR eumycetoma OR mycetomata OR maduromycosis OR "Madura foot"
Chromoblastomycosis (CBM) and other deep mycoses	chromomycosis OR chromoblastomycosis OR "Dermatitis verrucosa" OR "Fonsecaea pedrosoi" OR "F pedrosoi" OR "Fonsecaea monophora" OR "F monophora" OR "Fonsecaea nubica" OR "F nubica" OR "Fonsecaea pugnaciosa" OR "F pugnaciosa" OR "Cladophialophora carrionii" OR "C carrionii" OR "Cladophialophora amoensis" OR "C amoensis" OR "Phialophora verrucosa" OR "P verrucosa" OR "Rhinocladiella aquaspersa" OR "R aquaspersa" OR "Exophiala jeanselmei" OR "E jeanselmei" OR "Exophiala dermatitidis" OR "E dermatitidis" OR "Exophiala spinifera" OR "E spinifera"
Onchocerciasis	onchocerciasis OR Onchocerca volvulus OR "River blindness"
Rabies	rabies OR antirabies OR antirabic OR lyssa OR lyssavirus
Scabies and other ectoparasitoses	scabies OR scabietic OR "Sarcoptes scabiei" OR "Sarcoptic mange"
Schistosomiasis	*schistosomiasis* OR *bilharzia* OR "S mansoni" OR "S japonicum" OR "S mekongi" OR "S guineensis" OR "S intercalatum" OR "S haematobium"
Soil-transmitted helminthiases	ancylostomiasis OR ankylostomiasis OR anchylostomiasis OR "Necator americanus" OR "N americanus" OR "Ancylostoma duodenale" OR "A duodenale" OR trichuriasis OR trichocephaliasis OR "Trichuris trichiura" OR "T trichiura" OR strongyloidiasis OR strongyloidosis OR anguilluliasis OR "Strongyloides stercoralis" OR "S stercoralis"
Taeniasis	teniasis OR taeniasis OR taeniid OR *cysticercosis* OR "Taenia solium" OR "T solium" OR "Taenia saginata" OR "T saginata" OR "Taenia asiatica" OR "T asiatica"
Trachoma	trachoma OR "Egyptian ophthalmia" OR "Granular conjunctivitis" OR "Chlamydia trachomatis" OR "C trachomatis"
Yaws and other endemic treponematoses	yaws OR "Treponema pallidum" OR "Treponema carateum"

3.1.2 Relevance screening

Titles and abstracts were screened for relevance to DT on NTDs based on the following criteria: i) use of DT tools in health interventions; ii) use of digital applications for disease communication and/or monitoring; iii) database building purposes with information that can be used to create dashboards and used for decision making.

3.1.3 Bibliometric analysis

RStudio Bibliometrix (ARIA; CUCCURULLO, 2017) was used for descriptive analysis of data, identification of most scientifically productive countries, most relevant journals, and most relevant publications. Results were plotted on a two-dimensional map. The VOSViewer software (ECK; WALTMAN, 2010) was used to map the relationships among author keywords in publications and identify research clusters. Similar keywords were grouped to improve visualization, (e.g., “neglected diseases”, “neglected tropical diseases”, “neglected disease”). The size of the circles is proportional to the number of co-occurrences of keywords. Each colour represents a cluster of closely related keywords.

3.1.4 Content analysis

A content analysis of the included studies was conducted to explore the role of digital health technologies in reducing or eliminating NTDs in the context of LMICs. The analysis followed established guidelines for qualitative data analysis (ELO; KYNGÄS, 2008). Selected articles were meticulously reviewed to identify relevant information on the application of digital health technologies in combating neglected tropical diseases in LMICs. Data were categorized based on emerging themes and categories (VAISMORADI; TURUNEN; BONDAS, 2013).

The main categories identified during the analysis included: (1) types of digital health technologies used, (2) specific mobile applications and digital health solutions mentioned, (3) digital diagnosis and screening methods, (4) disease surveillance and monitoring approaches, (5) access to information and health education through digital platforms, (6) digital interventions for disease treatment and control, (7) challenges and barriers in implementing digital health technologies for NTDs, and (8) reported outcomes and impacts of digital health interventions in the reviewed studies (FLODGREN *et al.*, 2013).

Following the categorization of data, we conducted a comprehensive analysis of the included studies using thematic analysis to identify common patterns and trends regarding the use of digital health technologies for addressing NTDs in LMICs (BRAUN; CLARKE, 2006; DOS SANTOS; LOPES, 2019; SUNDLER *et al.*, 2019). he synthesized findings were presented through a narrative description, supported by relevant citations from the reviewed studies. This content analysis aimed to address the diversity of contexts across LMICs and highlight successful initiatives and experiences in utilizing digital

health technologies for NTDs. We also considered the limitations of the included studies, such as methodological heterogeneity and variability in outcome measurements (MUNN *et al.*, 2015).

The analysis provided a comprehensive overview of the role of digital health technologies in managing NTDs within LMICs. These findings enhance the understanding of the potential of digital health solutions to reduce the burden of NTDs and offer valuable insights for policymakers and healthcare professionals in developing effective strategies (ACKLEY; ELSHEIKH; ZAMAN, 2021a, 2021b; ACKLEY ID; ELSHEIKH ID; ZAMAN, 2021).

3.1.5 Ontological model

The Protégé software (Stanford University) was utilized to build an ontological model that illustrates the relationships between technologies and diseases. Ontologies can be categorized into several types, including lightweight and dense (or heavy) ontologies (GUARINO, 1997). Lightweight ontologies focus on creating a hierarchical taxonomy of concepts rather than detailing each concept extensively. In contrast, dense or heavy ontologies aim to precisely represent the meanings and relationships between concepts by defining and organizing them according to well-defined principles. This approach involves formally defining the semantics and relationships between concepts.

To facilitate the creation of reusable and shareable knowledge bases, heavy ontologies are generally preferred. However, this thesis will employ a hybrid approach, combining elements of both lightweight and heavy ontologies. This approach will include a hierarchical taxonomy of concepts while also defining the semantics of their relationships.

3.2 Blockchain-based Framework

To explain the development of this framework, the methodology applied in this paper is divided into two parts: the research method and the working method (Figure 4). The research method details the conduct of the research, including the objectives and its temporal context. In contrast, the working method describes the elaboration of the

research, outlining the methods used and the process of creating the proposed blockchain framework to enhance healthcare operations.

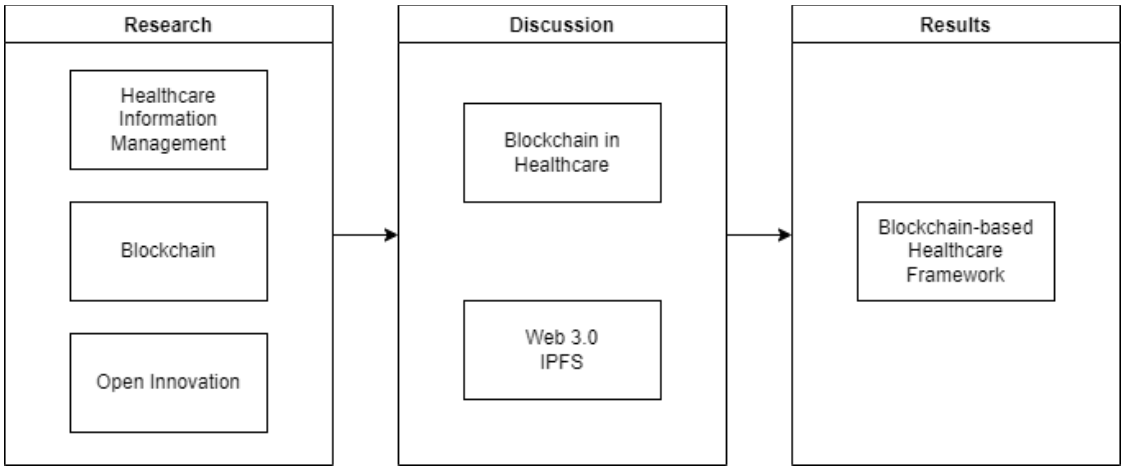

Figure 4 - Working method to reach expected results

3.2.1 Research method

This study is classified as applied research, as it utilizes previously studied concepts to address real-life problems (VERGARA; PECI, 2003). It is categorized as qualitative, as it uses literature data to develop a blockchain system aimed at improving healthcare services.

The primary objective of this research is exploratory, involving bibliographic research on Blockchain, Open Innovation (OI), Brazilian Healthcare Systems, and Web 3.0 (W3) to capture and interpret relevant concepts for a deeper understanding of the subject (GIL, 2008); It is also explanatory, as it seeks to investigate and elucidate the characteristics and interrelations of the phenomenon under study.

The research string used to search for Blockchain in Brazilian healthcare operations in the Compendex and Scopus databases was (“healthcare operations” OR “Health Care operations”) AND (“Blockchain” OR “cryptography”). Identified articles were analyzed and selected based on their relevance to the paper’s subject. Additional databases, including Google Scholar, Portal CAPES, and Mendeley, were also explored to find papers on healthcare information management, blockchain in healthcare, and W3.

3.2.2 Working method

A literature review was conducted focusing on the following areas: blockchain architecture to explore its potential applications in healthcare (JIANG et al., 2018; NAMASUDRA; DEKA, [s. d.]; VARADHARAJAN et al., 2021); open innovation to understand how a decentralized network can facilitate shared growth among healthcare organizations; and Web 3.0 concepts to examine how technological advancements can drive disruptions and improvements in the healthcare system (ALABDULWAHHAB, 2018; ÇEKANI, 2021).

A survey of Brazilian government databases was conducted to identify the existing healthcare information systems. This survey aimed to pinpoint the main Brazilian healthcare systems and assess the feasibility of implementing blockchain technology for potential improvements. Additionally, articles were reviewed to determine which types of information are crucial for the study and to understand the limitations associated with implementing Blockchain in complex healthcare systems.

For the development of the blockchain framework, research was conducted on blockchain architecture and its potential applications in healthcare information management. This research focused on understanding the information flow required for a blockchain-based healthcare solution. To illustrate and visualize the framework, Stanford's Protégé software was utilized. Additionally, patient engagement concepts will be integrated into the framework, as detailed in Section 3.2.3.

3.2.3 Patient Engagement

This research examines key domains that collectively underpin the framework of contemporary healthcare delivery, with a focus on engaging patients through mHealth tools to achieve better treatment outcomes. We explore the concept of patient engagement, analyzing strategies that promote active patient participation in their own healthcare management—an essential factor for improving health outcomes and enhancing patient autonomy. Additionally, it will evaluate the role of digital marketing in the healthcare sector, outlining strategies that effectively communicate the value of health interventions to affected populations. This examination will provide a comprehensive understanding of how technological innovation, patient-centered care, and market dynamics interact to shape the health landscape for NTDs.

3.2.4 Search Sources and Keywords

A comprehensive search was conducted across electronic databases, including PubMed, Web of Science, and Scopus, for studies published up to the current year. Keywords related to NTDs (see Table 1) and to digital marketing and patient engagement were used in various combinations. The search terms included: ("patient engagement" OR "patient participation" OR "patient involvement" OR "patient empowerment" OR "patient-centered care") AND ("health education" OR "community engagement" OR "health communication" OR "self-management" OR "digital health" OR "telemedicine" OR "mobile health" OR mHealth OR "social support" OR "support groups").

3.2.5 Inclusion and Exclusion Criteria

The scope of the research was delineated by stringent inclusion and exclusion criteria to ensure the relevance and quality of the data. Studies considered for inclusion must be primary research articles focusing on digital marketing and patient engagement specifically for NTDs and must evaluate patient engagement through qualitative measures. Articles were excluded if they were not written in English, did not focus on healthcare, or did not address NTDs. These criteria streamlined the selection process, ensuring that the studies reviewed were both relevant and substantial.

3.2.6 Data Analysis

The approach to qualitative data analysis began with meticulous data preparation, involving an immersive reading of selected articles to distill information pertinent to our research themes: patient engagement and digital marketing within healthcare. Subsequently, theme development was conducted through rigorous thematic analysis, where data were refined and categorized. This process ensured that a robust narrative emerged, both insightful and grounded in literature evidence for applications in NTDs.

The synthesis of the data culminated in a cohesive narrative that integrated our thematic findings, providing a nuanced understanding of the interface between technological advancements in healthcare and patient engagement strategies, underpinned by digital marketing imperatives. While mindful of the inherent limitations of this methodology, significant steps were taken to fortify the integrity of our findings. We believe these contributions meaningfully advance the discourse on digital

transformation in healthcare. Since this study relies on published data, ethical approval was not required.

4 RESULTS AND DISCUSSION

4.1 Mapping the literature on Digital Health for Neglected Tropical Diseases

This section consolidates the literature review on the application of digital technologies in the context of NTDs, linking each type of technology to its intended purpose. A research gap was identified, revealing no existing technology addressing NTDs using blockchain networks. In response, a framework focusing on quality and information security in health systems was proposed. The initial search for digital technologies (DT) related to NTDs retrieved 3,645 articles, which were screened down to 28 papers. The PRISMA flowchart (MOHER *et al.*, 2009) is illustrating this process in the Figure 5.

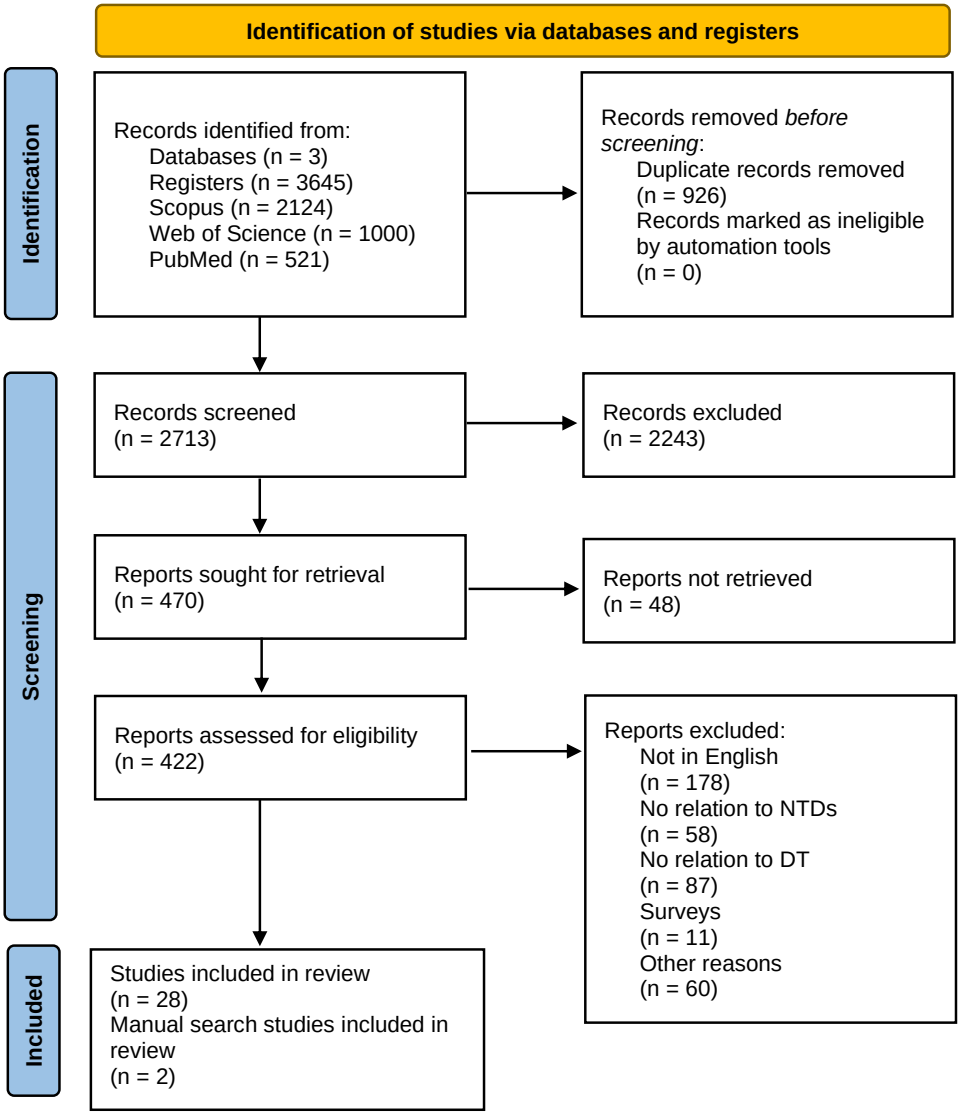

Figure 5 - PRISMA flowchart

An increase in annual article citations is observed in Figure 6, with notable peaks in 2014, 2018, and 2022. Another rising peak is seen in 2021, continuing into 2022. This graphic illustrates the trends in scientific production over the years. The data in Figure 6 indicates a growing interest within the scientific community in Digital Tools for NTDs, significantly intensified during the COVID-19 pandemic.

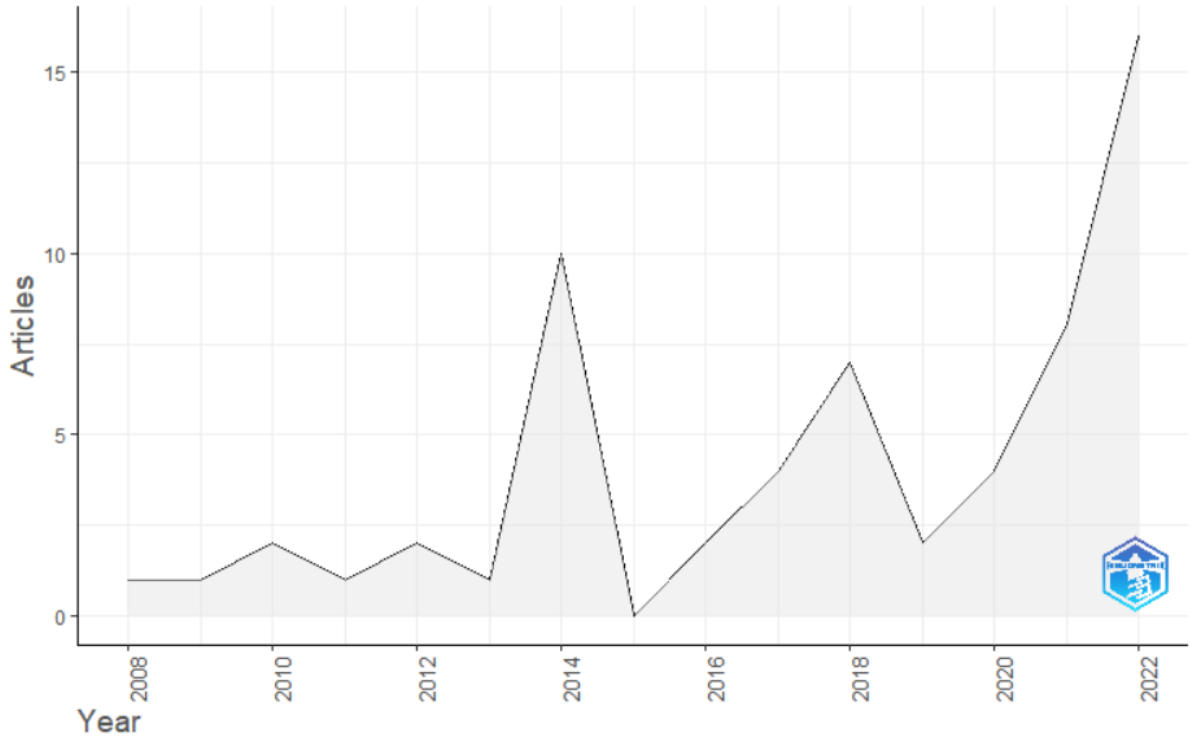

Figure 6 - Annual scientific production growth

The selected dataset presented 154 authors' keywords, clustered according to their co-occurrence in publications. The four clusters shown in Figure 7 illustrate the structure of the digital health research field for NTDs. Diseases such as dengue, malaria, cysticercosis, rabies, and schistosomiasis were the main NTDs identified in the dataset.

Dengue showed the strongest relationship with digital technologies, as seen in the yellow cluster. It is connected with decision-making tools such as IoT, big data, deep learning, and machine learning. This indicates that these digital tools significantly aid in decision-making and strategy development to combat the disease. Additionally, these tools are linked to disease diagnosis through new technologies, artificial intelligence, and the discovery of new treatments using data mining and AI applied to drug discovery.

The green cluster focuses on interventions made through mobile phones and messaging technologies for monitoring epidemics and disease surveillance, especially related to rabies. This cluster gains further relevance when health education is also emphasized. The blue cluster shows a relationship between Geographic Information System (GIS) tools and their application in risk assessment, monitoring disease vectors, and assessing environmental conditions such as seasonal variance and climate change. The red cluster demonstrates a correlation between diseases like leprosy and malaria and the use of information systems to study disease transmission and surveillance through databases and data collection. The purple cluster centers on image analysis for schistosomiasis, helminthiasis, and trichiniasis, linking cross-sectional studies to diagnostic accuracy achieved through technology. The yellow cluster is perhaps the most expressive, highlighting the use of artificial intelligence, including machine learning and deep learning, with algorithms like decision trees (random forest) and convolutional neural networks powered by big data and cloud computing solutions.

There are intersecting relationships between the clusters. For instance, analyzing the purple cluster reveals a connection between image analysis and the use of cell phones, which will be detailed later in this section. In the yellow cluster, diseases like dengue and chikungunya show that all clusters are interconnected in efforts to mitigate the impact of these diseases. This is achieved through deep learning, data mining, big data, and cloud computing; and utilizing cell phones, GIS, databases, and information systems for mosquito control interventions in strategic areas. Similarly, in the blue cluster, GIS is applied to diseases like dengue, chikungunya, and schistosomiasis, relating to the use of

cell phones, data mining, and data analysis. The most significant relationships will be further explored.

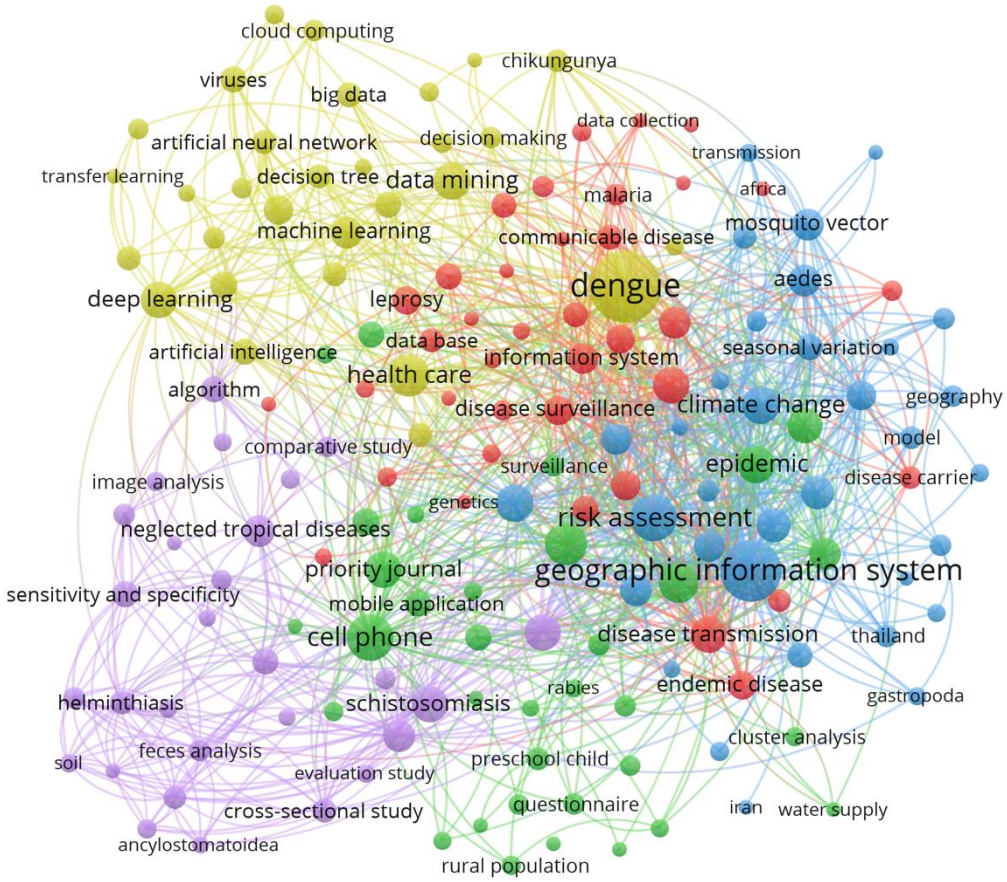

Figure 7 - NTDs' keyword graph representing the main research terms

Figure 8 shows the United States (USA) as the most scientifically active country in the field, with 33 publications. Brazil is the second country in scientific production by number of publications with 24 papers, followed by India (n=25), China (n=21) and the United Kingdom (n=12). International collaboration on DT for NTDs seems to be low, as most publications in all top 15 countries are single country publications (SCP). It was not expected to see a country as USA leading the list of most productive countries researching on NTDs but as a technological country this may represent a motivator to encounter papers on DT for NTDs.

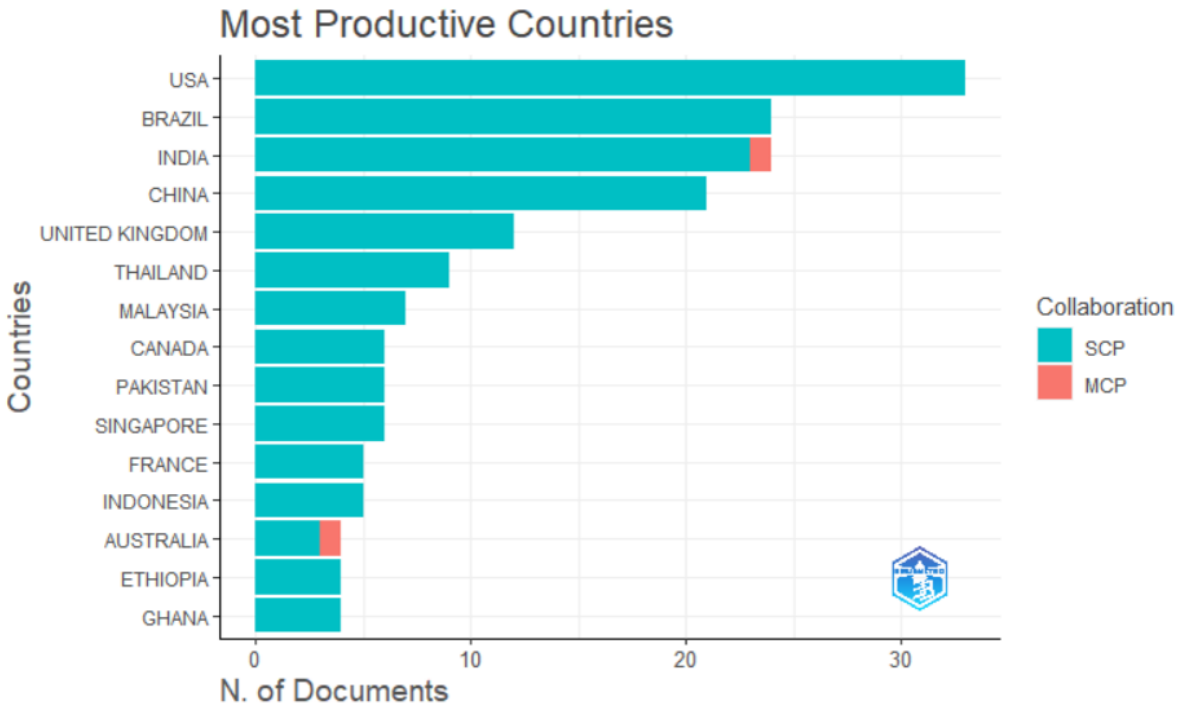

Figure 8 - Most productive countries, categorized by single country publications (SCP) and multiple country publications (MCP)

The most expressive journals according to the number of publications in the period studied are shown in Table 2. PLoS Neglected Tropical Diseases and Geospatial Health stand out by presenting 15 and 12 publications, respectively. The remaining journals had between 7 and 4 publications, most of which were between 6 and 5 publications.

Table 2 - Top 10 most relevant journals in digital transformation applied to NTDs

Journals	**Number of articles**
PLoS Neglected Tropical Diseases	15
Geospatial Health	12
Acta Tropica	7
American Journal of Tropical Medicine and Hygiene	6
BMC Public Health	6
International Journal of Environmental Research and Public Health	6
IEEE Access	5
PLoS One	5

Scientific Reports	5
Transactions of the Royal Society of Tropical Medicine and Hygiene	5

The top 15 manuscripts according to the number of citations received (times cited – TC) and the yearly average number of citations each manuscript has received TC per Year (TC/Y) is shown in Table 3. Korotcov (2017) has 178 citations and an average of 29.67 TC/Y; this paper confirms that the results of the study showed that deep learning models generally outperformed other machine learning methods on most of the datasets. However, the authors also found that the performance of deep learning models varied depending on the dataset. For example, deep learning models performed better on datasets with a large number of features, while other machine learning methods performed better on datasets with a small number of features. Jain (2021) has 101 citations and an average of 50.5 TC/Y; this paper explores the integration of Internet of Medical Things (IoMT) and biosensors for point-of-care (POC) testing of infectious diseases. It reviews advancements in POC diagnostics for diseases like malaria, dengue, influenza A, HPV, Ebola, Zika, and COVID-19. It highlights the benefits of IoMT in POC diagnostics or homecare needs if considering wearable devices tools, such as real-time data analysis, remote monitoring, and improved patient compliance.

Table 3 - Top 15 manuscripts according to citations

AUTHOR	YEAR	TITLE	TC	TC/Y
JAIN S	2021	Internet of medical things (IoMT)-integrated biosensors for point-of-care testing of infectious diseases	101	50.5
KOROTCOV A	2017	Comparison of deep learning with multiple machine learning methods and metrics using diverse drug discovery data sets	178	29.8
D'AMBROSIO MV	2015	Point-of-care quantification of blood-borne filarial parasites with a mobile phone microscope	151	18.9
SOOD SK	2017	Wearable IoT sensor-based healthcare system for identifying and controlling chikungunya virus	96	16.0

SOOD SK	2018	A fog-based healthcare framework for chikungunya	78	15.6
EISEN L	2011	Using geographic information systems and decision support systems for the prediction, prevention, and control of vector-borne diseases	132	11.0
BOGOCH II	2013	Mobile phone microscopy for the diagnosis of soil-transmitted helminth infections: a proof-of-concept study	91	9.1
KUAN G	2009	The Nicaraguan paediatric dengue cohort study: study design, methods, use of information technology, and extension to other infectious diseases	93	6.6
FLAHAULT A	2006	Virtual surveillance of communicable diseases: a 20-year experience in France	109	6.4
PAPADOPOULOS MC	2004	A novel and accurate diagnostic test for human African trypanosomiasis	116	6.1
RANDRIANASOLO L	2010	Sentinel surveillance system for early outbreak detection in Madagascar	77	5.9
YANG GJ	2005	A review of geographic information system and remote sensing with applications to the epidemiology and control of schistosomiasis in China	86	4.9
YILMA JM	1998	A geographic information system forecast model for strategic control of fasciolosis in Ethiopia	99	4.0
LWAMBO NJS	1999	Patterns of concurrent hookworm infection and schistosomiasis in schoolchildren in Tanzania	82	3.4
ROGERS DJ	1993	Monitoring trypanosomiasis in space and time	82	2.7

The ontological diagram of DT research applied to NTDs is shown in Figure 5. To better organize the instances of the diagram, the division of the application areas was divided into: diagnostic management; public health management; geographic mapping of

vectors; infection risk management; disease case monitoring; disease transmission; illness's prediction and forecasting; knowledge management; vector identification; classification of mosquitoes; image processing; drug discovery; and alert system.

The performed ontological model presented in Figure 9 is a hybrid lightweight-heavy ontology, containing taxonomy and some concept's definitions. The organization of this ontological model is detailed into Classes, Object properties, Data properties and Individuals. Classes are the application areas represented by the orange circles; Object properties are the relations between Individuals and Classes; Individuals are the digital tools to be applied and are represented by purple rhomb; The ontological model is represented by the main Class "owl: Thing" which has subclasses pointed by the blue arrows. Purple arrows indicate that a Class has an individual instanced, while orange arrows indicate the Object property "isPartOf" and "isA" is represented by yellow arrows.

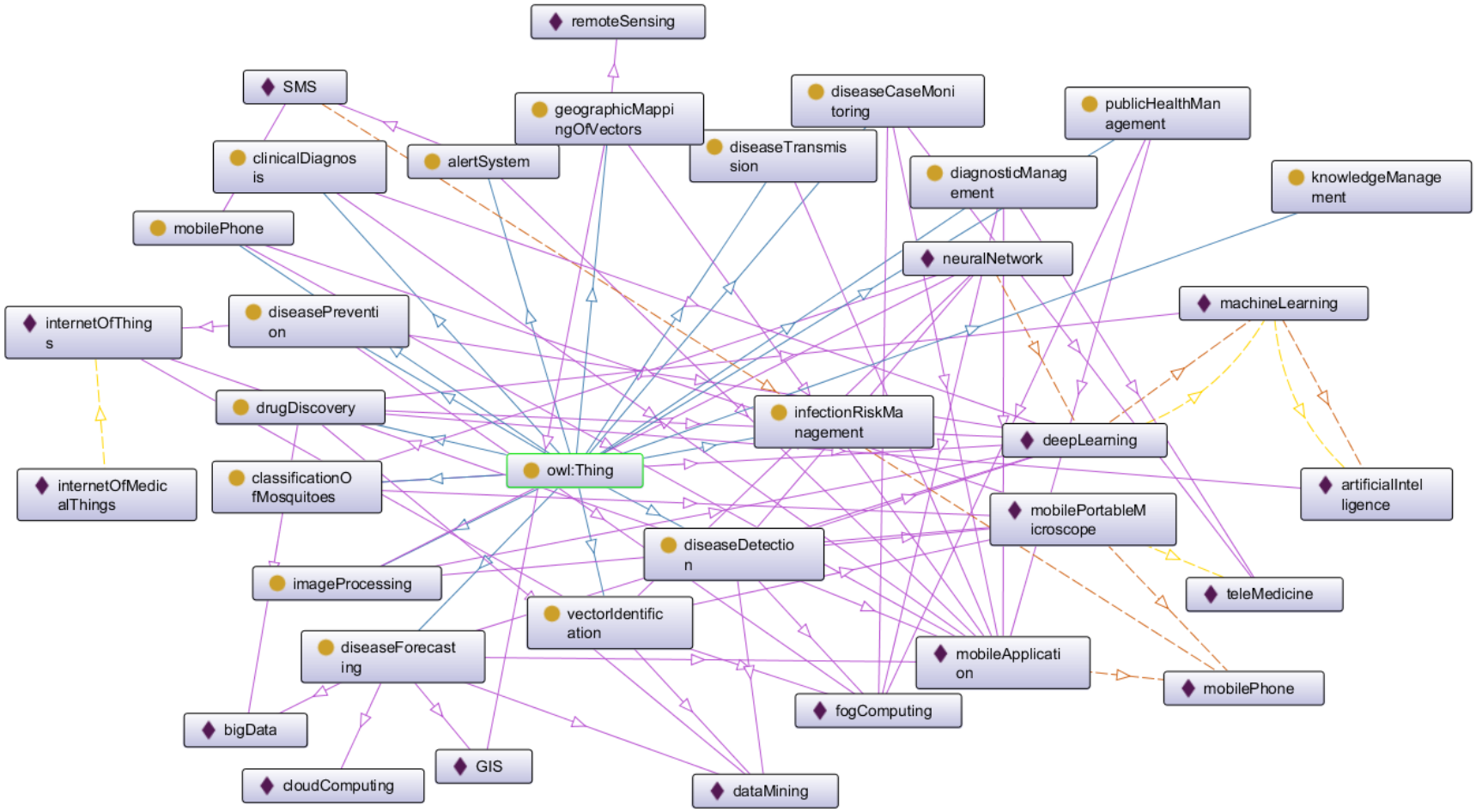

Figure 9 - Ontological model

The detection of vectors or diseases is usually done with the use of a machine learning's branch (deep learning, and more specifically neural network) combined with the use of another technology such as IoT in forecasting systems (ISMAIL *et al.*, 2022), in public health to generate response to infection diseases (RAHMAN *et al.*, 2022) automatic classification of mosquitoes (PISE; PATIL; PISE, 2022). Artificial intelligence (AI) is a broad field of computer science dedicated to creating machines capable of mimicking or replicating human-like behaviour. AI includes both machine learning and deep learning, which are two subfields of AI. Machine learning is a subset of AI that involves algorithms that can learn and improve from experience, without being programmed explicitly. It is based on the idea that systems can learn from data, identify patterns, and make decisions with minimal human intervention. Deep learning, on the other hand, is a subset of machine learning that uses multi-layered artificial neural networks to learn complex patterns in data. It is based on the idea that machines can learn to recognize patterns in data by analysing large amounts of data and making associations between them. Machine Learning algorithms are used for a variety of tasks, such as classifying data while Deep Learning algorithms can be used for tasks such as image recognition. Machine learning can be used in various ways to prevent, control, or mitigate neglected tropical diseases. Some of the ways in which machine learning can be applied to NTDs include the following topics.

- Early Detection and Diagnosis: Machine learning algorithms can be trained to identify patterns in large datasets of clinical and epidemiological data to enable early detection and diagnosis of NTDs. For example, machine learning can be used to analyse patient symptoms, environmental factors, and other risk factors to predict the likelihood of an individual contracting a particular NTD (BARDE; MISHRA; SINGH, 2018; DA SILVA NETO *et al.*, 2022; JIN; CRUZ; GONCALVES, 2020).
- Disease Surveillance: Machine learning can be used to analyse and model disease transmission dynamics, enabling more effective disease surveillance and control. For example, machine learning algorithms can be used to track the spread of NTDs in different regions and identify potential hotspots for disease transmission (LOPEZ *et al.*, 2017; PATAKI *et al.*, 2021).

- Vector Control: Machine learning can be used to optimize vector control strategies by predicting the distribution and abundance of vectors and developing targeted interventions. For example, machine learning algorithms can be used to predict the distribution of mosquito populations based on environmental factors, such as temperature and humidity, and develop targeted interventions to control vector populations (EKPO et al., 2013; GUIYAB, 2019; KUMAR; SIKAMANI, 2020).
- Drug Development: Machine learning can be used to accelerate the development of new drugs for NTDs by predicting the efficacy of different compounds and identifying potential drug targets. For example, machine learning can be used to predict the binding affinity of drug candidates to specific molecular targets and prioritize candidates for further testing (KOROTCOV et al., 2017; KWOFIE et al., 2023; ZORN et al., 2021).

The use of machine learning is applicable to mitigate impacts for various NTDs, including but not limited to: Malaria; Dengue; Chagas disease; Leishmaniasis; Schistosomiasis; Lymphatic Filariasis; Onchocerciasis (river blindness); African Trypanosomiasis (sleeping sickness); Soil-transmitted helminthiasis (intestinal worms). IoT has also been used in conjunction with Fog-Cloud Computing for the prevention and control of Dengue infections (SOOD et al., 2022; SOOD; KAUR; SOOD, 2021). Fog computing and cloud computing are similar in that they are both forms of distributed computing that involve the use of multiple computing devices to process data. The primary difference between them is that fog computing involves the use of devices that are located near the end user, while cloud computing involves devices that are located in remote data centres. Fog-cloud is a hybrid of fog computing and cloud computing, where fog computing is used for data that needs to be processed closer to the user, and cloud computing is used for data that can be processed in remote data centres. This allows for a more efficient use of resources and better performance, as data can be processed in the most appropriate location (KASHIFMUNIR; MOHAMMED, 2018; PHAM; HUH, 2016; RAMIREZ et al., 2017; SARKAR; MISRA, 2016; SINAEEPOURFARD et al., 2018).

GIS can be used to create a hierarchical taxonomy of the geographical distribution of the diseases. This involves mapping the location and prevalence of the diseases in different regions, identifying the factors that contribute to their spread, and visualizing

the data to help identify areas that are at risk. By providing a spatial context for the diseases, GIS can aid in the development of prevention and control strategies and help target interventions to areas where they are most needed (ABEYSIRIWARDANA; KODITUWAKKU, 2012; DEHGHANI et al., 2019; HOQUE et al., 2004; TRAN et al., 2013).

4.2 Blockchain-based Framework adressing Neglected Tropical Diseases

The ontological model (Figure 9) serves as a elaboration basis to the framework, consolidating key concepts and relationships pertinent to the thesis. This model is instrumental in understanding the intricate interconnections among various domains and technologies in the context of disease prevention, management, and related fields.

The framework developed in this thesis will be augmented by the integration of blockchain technology to provide a robust guide for developers on creating blockchain-based digital solutions aimed at mitigating the burden of NTDs. Blockchain's inherent features of transparency, security, and decentralization make it an ideal candidate for enhancing data integrity and trust in health information systems. By incorporating blockchain, the framework will ensure that health records, disease monitoring data, and resource allocation are managed efficiently and securely, thereby supporting more effective and accountable interventions in combating NTDs. This integration will not only streamline the development process for digital health solutions but also bolster the overall impact and reliability of these interventions in resource-constrained settings.

Health Technologies (HealthTech) are digital solutions that have been developed to address NTDs. These include mobile health (mHealth) tools, electronic data collection systems, and digital diagnostic devices. Digital solutions in Table 4 illustrate the innovative approaches across the years being employed to combat NTDs, leveraging technology to improve efficiency, accuracy, and reach in both data collection and patient care.

Table 4 - Examples for expressive digital solutions addressed specifically to neglected tropical diseases.

DIGITAL HEALTH SOLUTION	DESCRIPTION	USE CASE
Liverpool mHealth Suite (LMS); (STANTON et al., 2016).	Mobile health tools for mass drug administration, morbidity mapping, and treatment distribution	Used in Tanzania, Malawi, Ghana, Ethiopia, Bangladesh
Electronic Data Collection Systems; (KING et al., 2013)	Android-based system for large-scale surveys	Used in Ethiopia for household data collection
Digital Diagnostic Devices; (ONASANYA et al., 2023)	Optical diagnostic devices for NTDs	Evaluated in Nigeria for user efficiency and acceptability
Collaborative Use Repurposing Engine (CURE); (KOKAI-KUN et al., 2017)	Platform to capture global clinical experiences of drug repurposing	Facilitates treatment discussions and reporting for NTDs and emerging infections
Interactive Voice Response (IVR) Systems; (LEE et al., 2003)	Automated phone systems for patient follow-ups and health education	Used in areas with low literacy rates for patient engagement in NTD programs
Geographic Information Systems (GIS); (BUTT et al., 2020)	Mapping tools for tracking NTD outbreaks and treatment coverage	Used in mapping NTD prevalence and treatment distribution

Digital solutions in HealthTech are only as effective as their ability to engage patients and the broader community. While technological advancements provide innovative tools for disease prevention, diagnosis, and management, their success ultimately hinges on active participation and trust from end-users. Engaging patients and communities ensures that digital health solutions are tailored to their needs, culturally sensitive, and accessible. Furthermore, community involvement fosters a sense of ownership and empowerment, encouraging adherence to health interventions and promoting better health outcomes. Without this crucial engagement, even the most

advanced healthtech solutions risk becoming underutilized and failing to achieve their full potential in improving public health.

4.2.1 Digital Marketing for Neglected Tropical Diseases

Engaging the population affected by NTDs is crucial for the success of any intervention aimed at mitigating their impact. Involving those directly impacted by NTDs ensures that the solutions developed are culturally appropriate, contextually relevant, and responsive to the actual needs and challenges faced by the community. This engagement fosters trust and cooperation, which are essential for the effective implementation of health programs and for encouraging adherence to preventive measures and treatments. Moreover, it empowers the affected populations by giving them a voice in the decision-making process, thereby promoting a sense of ownership and responsibility towards their health outcomes. Ultimately, meaningful engagement with affected communities enhances the sustainability and effectiveness of interventions, leading to more significant and lasting improvements in the fight against NTDs.

To engage communities affected by NTDs requires an approach that prioritizes education, empowerment, and collaboration. One effective strategy is to involve local leaders and healthcare providers in the planning and implementation of health interventions. These individuals can serve as trusted intermediaries who facilitate communication and foster trust between health professionals and the community. Additionally, leveraging digital transformation tools, such as mobile health applications and social media platforms, can enhance outreach and education efforts, ensuring that accurate information reaches a wider audience. Community workshops and participatory research initiatives can also empower individuals by giving them an active role in the development and assessment of health programs. By adopting these strategies, we can create a more inclusive and effective framework for addressing the challenges posed by NTDs, ultimately leading to better health outcomes for affected populations.

mHealth applications can significantly enhance patient engagement by leveraging digital marketing strategies to reach a wider audience and promote health awareness effectively. These applications can utilize personalized marketing techniques, such as targeted notifications and reminders, to provide patients with timely information about their health conditions and necessary actions. Social media integration within mHealth apps allows for the dissemination of health campaigns and educational content, fostering

a community of informed and proactive users. Additionally, mHealth apps can employ gamification and reward systems to motivate patients to adhere to treatment plans and adopt healthier lifestyles. By offering user-friendly interfaces and interactive features, mHealth applications can create a more engaging and supportive environment for patients, ultimately improving their health outcomes and fostering a stronger connection with healthcare providers.

Social media and digital marketing strategies can significantly enhance education for populations affected by NTDs by providing wide-reaching, accessible, and engaging content. These platforms enable health organizations to disseminate vital information quickly and effectively, reaching diverse populations, including those in remote and underserved areas. Through the creation of interactive and compelling content such as infographics, videos, and animations, complex medical information about NTDs can be made more understandable and engaging. Additionally, the ability to run targeted campaigns allows for precise delivery of health education tailored to the unique needs and characteristics of different communities, ensuring that the messages resonate with and address the specific concerns of those affected.

Furthermore, social media facilitates two-way communication, enabling affected individuals to interact directly with health experts, ask questions, and share experiences, thereby enhancing understanding and trust. These platforms also help build supportive online communities where individuals can connect, share their experiences, and support each other, fostering a sense of solidarity and collective action. Real-time updates and alerts about disease outbreaks, treatment availability, and health campaigns can be disseminated quickly, ensuring timely information reaches those in need. Moreover, digital marketing strategies can drive behavioral change campaigns that leverage influencers, testimonials, and compelling narratives to encourage preventive practices and adherence to medical treatments. Through these approaches, social media and digital marketing can play a crucial role in reducing the burden of NTDs and improving health outcomes in affected populations.

4.2.2 Understanding the role of HealthTech Companies for Neglected Tropical Diseases

HealthTech companies play a crucial role in supporting the fight against NTDs by complementing public health systems rather than interfering with them. One significant

way they contribute is through mHealth solutions. These tools enable disease control programs to benefit from real-time data collection, which improves drug supply management and facilitates mass drug administration coverage. For instance, the Liverpool mHealth Suite has been successfully implemented to support NTD elimination programs in various countries, providing valuable real-time data to enhance health services (STANTON et al., 2016).

Another critical contribution of HealthTech initiatives is the integration of NTD services into primary healthcare systems. This integration improves the detection, management, and reporting of NTD cases, ensuring that interventions are both cost-effective and sustainable. For example, in Ethiopia, integrating NTD services into the primary healthcare system was well-accepted by health workers and led to improved overall service delivery (DONOVAN et al., 2023). By embedding NTD interventions within the broader healthcare framework, HealthTech solutions ensure that resources are efficiently utilized and health outcomes are maximized.

HealthTech solutions also empower local health workers through training and supportive tools. Mobile apps and SMS tools provide continuous education and support, enhancing the capacity of health workers to manage NTDs effectively. This empowerment is critical for the success of NTD programs, as well-trained health workers are better equipped to deliver high-quality care and engage communities in disease prevention efforts. Community participation is another area where HealthTech platforms make a significant impact. By involving local leaders and community members in health governance, these platforms improve the sustainability of NTD control programs. In Tanzania, for instance, community participation led to significant health benefits and a reduction in disease prevalence. This approach ensures that health interventions are culturally appropriate and have strong local support, which is essential for long-term success (MADON et al., 2018; STANTON et al., 2016).

HealthTech companies play a vital role in integrating NTD data into national health information systems. This integration enhances the tracking and reporting of NTD cases, making it easier for public health authorities to monitor disease trends and respond effectively. In Cameroon, for example, integrating NTD data into the District Health Information Software (DHIS2) improved data management and stakeholder engagement, despite initial challenges (MOUNGUI et al., 2021). By leveraging technology,

HealthTech companies ensure that public health initiatives against NTDs are more efficient, comprehensive, and community-driven.

4.2.3 Understanting the Role of Digital Technologies for Neglected Tropical Diseases

In the fight against NTDs, mHealth applications play a crucial role by providing platforms for education, disease monitoring, and communication between patients and healthcare providers. These applications can deliver personalized health information, reminders for medication adherence, and symptom tracking, making it easier for individuals in remote or underserved areas to access timely medical care and advice. Furthermore, mHealth apps can facilitate remote consultations, which are particularly beneficial for patients who cannot easily reach healthcare facilities. By empowering patients with tools for self-management and continuous monitoring, mHealth applications significantly enhance disease management and improve health outcomes in regions burdened by NTDs.

Geographic Information Systems (GIS) and point-of-care diagnostics are also essential technologies in addressing NTDs. GIS enables precise mapping and analysis of disease outbreaks, helping public health officials identify hotspots and plan targeted interventions. By visualizing spatial data, GIS supports the efficient allocation of resources and enhances the effectiveness of disease control measures. On the other hand, point-of-care diagnostics, including rapid diagnostic tests (RDTs) and portable molecular testing devices, allow for quick and accurate diagnosis of NTDs in field settings. Early and precise diagnosis is critical for effective disease management, as it enables timely treatment and reduces transmission, especially in remote and resource-limited areas.

4.2.4 Blockchain as a Management System Provider for Neglected Tropical Diseases

Blockchain technology can restructuring the management of various technologies aimed at combating NTDs by concentrating their responses into a single, secure, and integrated system. The decentralized and immutable nature of blockchain ensures that all data, whether from mHealth applications, IoT devices, or point-of-care diagnostics, is securely recorded and verifiable. This ensures data integrity and prevents unauthorized access or alterations, which is crucial for maintaining accurate health records and diagnostic results. By providing a trustworthy and tamper-proof data repository, blockchain fosters confidence among stakeholders, enhancing the overall reliability of health interventions.

Furthermore, blockchain facilitates seamless interoperability among diverse technologies, such as GIS, and telemedicine, by offering a standardized platform for data exchange. This interoperability is essential for real-time access and harmonization of data from various sources, enabling more efficient data sharing and collaboration among healthcare providers, researchers, and policymakers. A unified blockchain-based system ensures that all relevant information is accessible and actionable, thereby improving the coordination and effectiveness of NTD management efforts.

Patient engagement can be significantly improved through blockchain's capability to empower individuals with control over their health data. Patients can selectively grant access to their health records to healthcare providers, ensuring privacy and fostering trust. This patient-centered approach enhances adherence to treatment plans and encourages active participation in health management. Moreover, secure communication channels facilitated by blockchain ensure that all interactions among patients, healthcare providers, researchers, and public health officials are encrypted and protected from unauthorized access, promoting collaboration and coordinated efforts.

Blockchain's inherent transparency and immutability ensure that every action within the system is recorded and auditable. This feature is crucial for monitoring the effectiveness of interventions, tracking fund allocation and usage, and ensuring accountability in health programs. Stakeholders can audit the blockchain to verify the outcomes of disease control measures and the proper use of resources. By providing a single, secure, and integrated system for managing diverse technologies, blockchain enhances trust, accountability, and overall effectiveness in the fight against NTDs.

4.2.5 Presenting and Discussing The Framework

The proposed blockchain-based framework for addressing NTDs leverages the unique advantages of blockchain technology to enhance transparency, security, efficiency, and collaboration. By incentivizing developers, ensuring transparent data management, improving drug discovery, drug repurposing, and engaging patients, the framework aims to overcome the multifaceted challenges of NTDs. Additionally, the integration of funding transparency and collaborative research promotes trust and innovation. Overall, this comprehensive approach promises to improve health outcomes for millions affected by NTDs, making significant strides towards their management and eradication. See in Figure 10 the framework’s three macro phases.

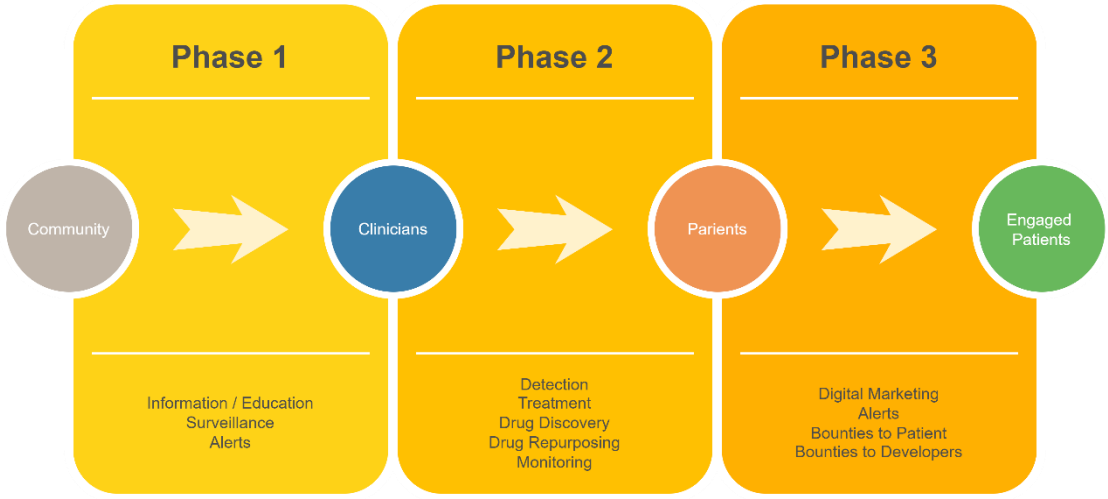

Figure 10 – General framework's macro phases addressing NTDs.

The framework for combating NTDs is a three-phase approach that strategically involves the community, clinicians, and patients to ensure comprehensive management and engagement. In the initial phase, the community plays a crucial role in the dissemination of information and acquiring education about NTDs. This phase focuses on raising awareness through public health campaigns, community workshops, and digital platforms. By educating the community, individuals become more aware of the risks and symptoms associated with NTDs, thereby fostering a proactive attitude towards prevention and early detection. Additionally, surveillance activities are essential in this phase to monitor the prevalence and spread of these diseases. Data collected through surveys, health screenings, and mobile health applications help in identifying outbreaks early and deploying necessary interventions promptly. The use of alert systems via SMS, email, or community announcements ensures that timely information is communicated, enabling communities to respond effectively to potential health threats.

The second phase involves clinicians who are pivotal in the detection, treatment, and ongoing management of NTDs. Clinicians utilize diagnostic tests, regular health check-ups, and screening programs to identify cases early. Once diagnosed, appropriate medical treatments are administered, and follow-up care is ensured. This phase also emphasizes the importance of drug discovery and drug repurposing. Collaborative research projects, clinical trials, and partnerships with pharmaceutical companies are vital for developing new treatments and finding new uses for existing drugs. The tools and

infrastructure necessary for these activities include diagnostic kits, laboratory facilities, and electronic health records (EHR) systems. Furthermore, monitoring patient progress through regular follow-ups and data analysis helps in evaluating the effectiveness of treatments and making necessary adjustments. This phase ensures that patients receive comprehensive care, from diagnosis to treatment and ongoing management.

In the final phase, patient engagement is achieved through digital marketing, alerts, and incentive-based strategies. Digital marketing campaigns on social media and other platforms are used to educate patients and keep them informed about their health status and treatment options. Automated alerts via SMS, email, and mobile applications serve as reminders for medication adherence and follow-up appointments, ensuring that patients stay on track with their treatment plans. Moreover, offering bounties to patients for participating in health surveys, adhering to treatment protocols, and engaging in health programs motivates them to remain involved in their health care. Similarly, bounties to developers for creating innovative health applications and diagnostic tools encourage the development of new solutions to combat NTDs. This phase leverages technology to maintain patient involvement, provide continuous education, and foster innovation, ultimately leading to better health outcomes and more engaged patients.

By following this structured approach, the framework effectively integrates community awareness, clinical interventions, and patient engagement to combat NTDs comprehensively. Each phase builds on the previous one, ensuring a seamless flow of information and actions. The community is educated and made aware of NTDs, clinicians provide necessary medical interventions, and patients are continuously engaged through digital tools and incentives. This holistic strategy not only addresses the immediate health needs of individuals but also fosters long-term participation and innovation, ultimately contributing to the eradication of neglected tropical diseases.

The blockchain-based framework for combating neglected tropical diseases integrates various technological components to enhance patient engagement and education. Patient information is collected and managed via web3 technology, enabling secure and transparent interactions with smart contracts. These smart contracts facilitate processes such as data privacy, governance, and fraud detection. The backend infrastructure supports machine learning for data analysis, predictive modeling, and monitoring, while also providing essential analytics and geographic information system

(GIS) capabilities. Digital marketing strategies are implemented through platforms like Instagram, Facebook, WhatsApp, and email to disseminate educational content and alerts. This cohesive system ensures a comprehensive approach to disease management by leveraging blockchain's security, machine learning's analytical power, and digital marketing's outreach as showcased in Figure 11.

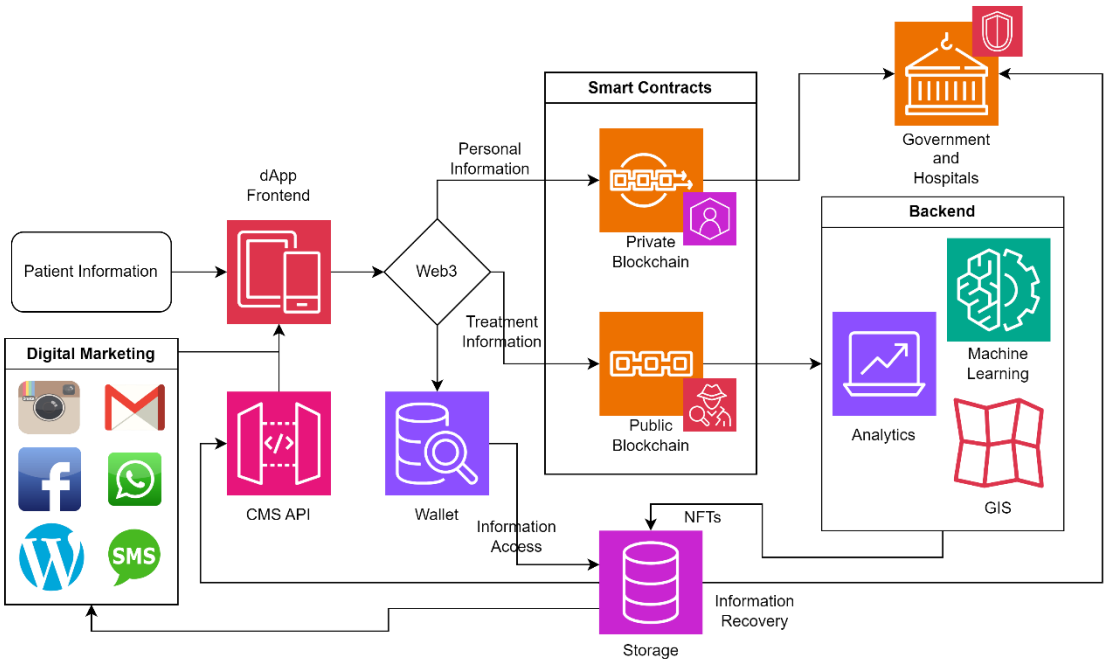

Figure 11 – General information flux for the Blockchain-based framework.

Smart contracts are self-executing digital agreements encoded in software, which automatically enforce the terms of a contract without requiring intermediaries (EENMAA-DIMITRIEVA; SCHMIDT-KESSEN, 2019). These contracts enable secure and transparent transactions on a blockchain by updating the contract's state only according to the predetermined conditions outlined in the code (TAHERDOOST, 2023). Smart contracts consist of on-chain and off-chain components. The on-chain component, known as the validator script, is used to validate that each transaction involving value locked by the script – Unspent Transaction Output (UTXO) at the script's address – adheres to the contract's rules, requiring specialized tools and languages for creation. The off-chain component is a script or application used to generate transactions that conform to the contract's rules, which can be developed in almost any programming language.

Smart contracts can be recorded on both private and public blockchains to leverage the unique benefits of each. A private blockchain allows for greater control and privacy,

ideal for handling sensitive information and internal processes, while a public blockchain offers transparency and security through decentralization, ensuring that transactions and contract executions are verifiable and immutable by anyone. This dual-blockchain approach combines the strengths of both types, enhancing both privacy and trust in the system.

Alternatively, using only a public blockchain with encrypted data can achieve similar benefits without the need for a private blockchain. By encrypting data before recording it on a public blockchain, the information remains secure and inaccessible to unauthorized parties while still benefiting from the transparency and verifiability of the public ledger. This approach simplifies the architecture by eliminating the need for managing a private blockchain, thus reducing complexity and operational overhead while maintaining high security and privacy standards.

Smart contracts on the blockchain can automate and streamline various aspects of the drug discovery process. These self-executing contracts can manage intellectual property rights, automatically enforce terms of agreements, and facilitate secure data sharing among researchers, institutions, and pharmaceutical companies. This reduces administrative overhead, minimizes delays, and ensures that all parties adhere to agreed protocols, thus speeding up the research and development cycle. Blockchain technology offers a robust solution for disease surveillance and data management. Smart contracts can automate the collection and reporting of disease incidence data, allowing health workers to input data that is immediately validated and stored on the blockchain. This real-time reporting capability provides health authorities with up-to-date information, enabling prompt and effective responses to outbreaks and other health events.

Zero-knowledge proofs (ZKPs) in the context of smart contracts for NTDs allow for the verification of sensitive health data and compliance with treatment protocols without revealing the underlying personal information, ensuring patient privacy. This enhances trust and transparency in NTD programs by enabling secure and private validation of critical health data on public blockchains (LI; PENG, 2023).

ZKPs enable verification of information without revealing the information itself. ZKPs are cryptographic protocols that enable one party to prove to another party the validity of a statement without revealing any additional information beyond its validity. There are various types of ZKPs, each with unique properties and applications, but two

types highlights: Zero-Knowledge Succinct Non-Interactive Argument of Knowledge (Zk-SNARKs) and Zero-Knowledge Scalable Transparent Arguments of Knowledge (Zk-STARKs). Zk-SNARKs enables efficient and succinct proofs that can be verified quickly, making them suitable for privacy-preserving applications and scalability solutions while unlike zk-SNARKs, zk-STARKs offer transparent and scalable proofs that do not require a trusted setup, making them suitable for applications where trustlessness is paramount (LI; PENG, 2023; PARTALA; NGUYEN; PIRTTIKANGAS, 2020; WAN; ZHOU; REN, 2023).

To spur the development of blockchain solutions for NTDs, developer bounties can be established through a Decentralized Autonomous Organization (DAO) ensuring transparent and democratic allocation of funds. Hackathons and competitions focused on blockchain applications for NTDs can further motivate developers by providing winners with funding, mentorship, and support to advance their projects. Additionally, creating an open-source GitHub repository for blockchain solutions related to NTDs encourages collaboration and knowledge sharing. Contributors can be rewarded with tokens, recognizing their efforts and contributions to the Community. DAO is an organization represented by rules encoded as a computer program that is transparent, controlled by organization members, and not influenced by a central government. DAOs operate on a blockchain, allowing for decentralized decision-making and management, where governance is achieved through voting mechanisms typically using cryptocurrency tokens (APPEL; GRENNAN, 2023; SAITO; ROSE, 2022; SUN et al., 2022).

Blockchain technology can significantly enhance the transparency and efficiency of drug discovery and repurposing in its management through several key mechanisms. Blockchain's immutable ledger provides a transparent and tamper-proof record of all transactions and data entries. This feature is particularly valuable in drug discovery, where the provenance of data, research findings, and trial results must be meticulously tracked to ensure integrity and trustworthiness. Researchers can record their findings on the blockchain, creating a verifiable timeline of discoveries that can be audited and reviewed without risk of data manipulation.

Furthermore, blockchain can enhance the efficiency of drug repurposing by providing a robust platform for data sharing and collaboration. The decentralized nature of blockchain allows for the secure and efficient exchange of vast amounts of research

data, clinical trial results, and patient outcomes across different stakeholders. This collaborative environment accelerates the identification of potential new uses for existing drugs, as researchers can access and analyze data from a wider array of sources.

In the context of the proposed blockchain-based framework, token incentives play a crucial role in engaging both patients and clinicians, enhancing participation and accuracy in healthcare practices. For patients, tokens can be awarded for activities such as attending appointments, adhering to treatment plans, and participating in educational programs. These tokens can be redeemed for health-related rewards, thus promoting better health behaviors and outcomes. For clinicians, tokens can incentivize the accurate reporting of drug dispensation data, adherence to treatment protocols, and participation in continuous professional development. These tokens, managed and tracked through smart contracts on the blockchain, ensure transparency and accountability, fostering a more reliable and effective healthcare ecosystem for managing neglected tropical diseases (DARAGHMI; DARAGHMI; YUAN, 2019; ESMAEILZADEH; MIRZAEI, 2023; JUNG et al., 2021; LITCHFIELD; KHAN, 2021).

Table 5 provides a comprehensive overview of various technologies and frameworks essential for implementing a blockchain-based healthcare system. It categorizes each technology by its specific application area, such as Web3, private and public blockchains, smart contract languages, CMS APIs, wallets, NFTs, storage solutions, machine learning, GIS, and analytics. Each entry includes a short description, links to download the technology, access documentation, and whether the technology is paid or free. This organized structure aims to assist developers, researchers, and healthcare professionals in understanding and selecting the appropriate tools for enhancing healthcare practices through blockchain technology.

Table 5 – Programming Technologies and Frameworks proposed to be used by developers.

Category	Technology	Short Description	Download
Web3 Protocol	Web3	A decentralized web protocol enabling direct interaction between users and blockchain networks	https://web3js.readthedocs.io/
Private Blockchain	Hyperledger Fabric	Blockchain network with restricted access for authorized participants to ensure privacy	https://www.hyperledger.org/projects/fabric
	Midnight	A blockchain platform designed for privacy and compliance	https://docs.midnight.network/quickstart/
Public Blockchain	Cardano	A blockchain platform for changemakers, innovators, and visionaries	https://cardano.org/
	Solana	A high-performance blockchain supporting builders around the world	https://solana.com/
	Stellar	A blockchain for payments and asset transfers	https://www.stellar.org/
Smart Contracts	Solidity	A high-level language for implementing smart contracts	https://soliditylang.org/
CMS APIs	Wordpress	Content Management System API for integrating various digital marketing platforms	https://wordpress.org/
Wallets	Metamask	Digital wallet for storing and managing cryptocurrencies and tokens	https://metamask.io/

NFTs	OpenSea	Non-Fungible Tokens for unique digital asset representation and ownership tracking	https://opensea.io/
Storage	IPFS	A peer-to-peer protocol for storing data in a decentralized file system	https://docs.ipfs.tech/install/ipfs-desktop/
Machine Learning	TensorFlow	Algorithms and models for data analysis and predictive analytics	https://www.tensorflow.org/
GIS	QGIS	Geographic Information Systems for mapping and spatial data analysis	https://www.qgis.org/
Analytics	Tableau	Tools and platforms for data analysis and business intelligence	https://www.tableau.com/

To effectively engage patients in the fight against NTDs, a complex approach is essential. This includes comprehensive education and awareness campaigns, utilizing informative materials, community workshops, and media platforms to disseminate crucial information: community participation can be enhanced by involving local leaders, forming health committees, and establishing feedback mechanisms (MADON et al., 2018); patient empowerment is achieved through self-management training, support groups, and education on patient rights (CHOWDHURY et al., 2023); ensuring access to treatment involves deploying mobile clinics, medication distribution programs, and integrating NTD services with primary healthcare (STANTON et al., 2016); technological interventions, such as telemedicine and mobile health apps, provide remote consultation and symptom reporting (STANTON et al., 2016). Implementing a blockchain-based framework for addressing Neglected Tropical Diseases offers a solution to the complex challenges faced in managing these diseases and engage patients effectively.

Leveraging social media and chat messengers to educate and engage patients involves utilizing the expansive reach and interactive capabilities of these platforms to disseminate valuable health information and foster meaningful connections. The strategies in Figure 12 can be employed to achieve this objective.

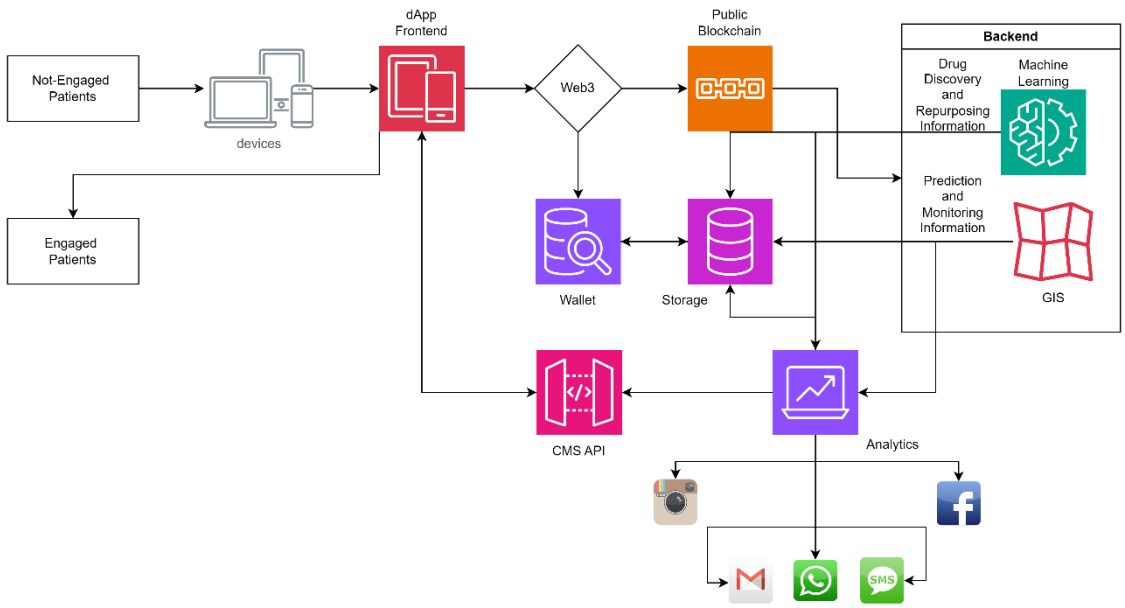

Figure 12 – Digital marketing information flux for the Blockchain-based framework.

Creating and disseminating educational content is essential. Healthcare organizations should regularly publish – mainly for those population affected by NTDs – health tips disease prevention strategies, and wellness advice on platforms such as Facebook, Instagram, and Twitter. Additionally, producing informative videos and hosting webinars on YouTube or Facebook Live can address various health topics, including chronic disease management, mental health, and the importance of vaccinations.

Direct communication through chat messengers provides a more personalized approach to patient engagement. Platforms like WhatsApp or Facebook Messenger can be utilized to send automated reminders for appointments, medication schedules, or upcoming health screenings. In Brazil, particularly, messages sent in Instagram chats are becoming usual and efficient to reach the community. Furthermore, developing chatbots capable of delivering personalized health advice based on user inputs and preferences can enhance patient interaction. Real-time support through chat messengers also offers patients a direct communication channel with healthcare professionals, thereby increasing engagement and trust.

Employing interactive content can significantly enhance patient engagement. Conducting polls and surveys on social media platforms such as Twitter, Instagram, and Facebook can gather valuable patient feedback and better understand their needs. Additionally, creating health-related quizzes and challenges can engage patients and encourage them to learn more about their health. Hosting live Q&A sessions on Instagram Live or Facebook Live allows patients to pose health-related questions and receive immediate responses from experts, fostering a more interactive and informative experience.

Building online communities is another effective strategy to foster patient engagement. Establishing private Facebook groups or using platforms like Slack or Discord to create communities where patients can share experiences and provide mutual support can be highly beneficial. Facilitating discussions on specific health topics on platforms like Reddit or specialized health forums can promote deeper engagement. Running social media campaigns around health awareness days, such as World Diabetes Day, can also enhance awareness and encourage community participation.

Leveraging influencers and partnerships can further extend the reach of health messages. Collaborating with health influencers who can share content and promote health messages to a broader audience is a valuable strategy. Additionally, partnering with other healthcare organizations to co-create content can help reach a wider audience through joint initiatives (KOTLER, 2010).

Finally, monitoring and analyzing engagement is crucial for refining strategies. Utilizing social media analytics tools to track engagement, understand which content resonates with the audience, and adjust approaches accordingly is essential. Encouraging feedback through comments, messages, and direct interactions helps continuously improve content and engagement strategies.

By strategically utilizing social media and chat messengers, healthcare organizations can effectively educate and engage patients, providing them with the necessary information and support to manage their health proactively. The engagement process within this blockchain-based framework begins by reaching out to non-engaged patients through a variety of devices, including desktops, tablets, and smartphones. Utilizing Web3 technology, the framework ensures a decentralized and secure internet environment, allowing patients to interact with healthcare providers and access health-related information securely. This initial connection is crucial, as it provides the first point of contact between patients and the healthcare system, fostering a foundation of trust and accessibility.

Central to the engagement process is the collection and analysis of patient data. This is facilitated by advanced database technologies capable of real-time data processing and long-term storage. The collected data is analyzed to provide personalized healthcare interventions, which are then communicated back to the patients through their preferred communication platforms, such as social media (Instagram, Facebook), messaging apps (WhatsApp, SMS), and email (Gmail). By leveraging these familiar and widely-used platforms, the framework ensures that health updates, appointment reminders, and educational content are delivered in a manner that is both convenient and accessible for patients.

Engagement of patients, particularly in the Global South, is crucial for addressing the challenges posed by NTDs. These diseases often affect marginalized communities with limited access to healthcare. By leveraging this blockchain-based framework,

healthcare providers can overcome barriers related to trust, data security, and personalized care. Active patient engagement leads to better disease management and prevention, as engaged patients are more likely to adhere to treatment plans, attend follow-up appointments, and adopt preventive measures. This proactive involvement results in improved health outcomes and a more resilient healthcare system capable of effectively responding to disease outbreaks.

5 CONCLUSIONS

In a world where volatility and uncertainty reign, technological innovations play a crucial role in terms of control, especially of information. In the healthcare sector, the concern with reliability leads to the need for increasingly robust, fast information systems containing as much information as possible about the patient and their health. Taking this into consideration, information and communication technologies are increasingly being used for medical purposes, whether as electronic record systems or as a means of communication between the doctor and the patient. There are also other technologies capable of assisting in diagnosis and long-distance monitoring, such as wearable devices and others, thanks to the advent of the Internet of Things.

So far, the results of the research and literature review have not yielded much about the application of Blockchain technology for NTDs, which raises the hypothesis that a health system running on this technology could be pioneering. With this in mind, the proposal of a Blockchain-based framework could be a watershed, paving the way towards a collaborative project between countries, for the development of a shared system, focused on combating neglected tropical diseases.

The literature review showed that there is considerable application of artificial intelligence technologies (including Machine Learning and Deep Learning), with algorithms being applied to large volumes of available data (Big Data). Data Mining algorithms have also been used for knowledge discovery about a disease or for Drug Discovery or Drug Repurposing. This in itself can be considered very important in relation to neglected diseases, since the pharmaceutical industry has no interest in producing new drugs for these diseases. By using drugs already available on the market to cure or alleviate NTDs (Neglected Tropical Diseases), it is possible to connect the use of these tools with the achievement of the goal proposed by the WHO, to eliminate NTDs by the year 2030.

Enhanced data analytics is another significant benefit of integrating blockchain with technologies combating NTDs. By consolidating data from various sources on a blockchain, big data analytics can leverage this comprehensive dataset to generate more accurate insights and predictions. This enables the early detection of disease outbreaks, optimization of treatment protocols, and personalization of patient care. Blockchain

ensures the accuracy and trustworthiness of the data used in these analyses, leading to more informed and effective decision-making in disease control and prevention.

Implementing a blockchain-based framework for addressing NTDs offers a solution to the complex challenges faced in managing these diseases and effectively engaging patients. By utilizing blockchain technology, this framework enhances transparency, security, and efficiency in disease surveillance, drug discovery and repurposing, and patient data management. It empowers patients through secure, decentralized access to their health records and treatment plans. Furthermore, blockchain enables the use of smart contracts and token-based incentives to promote adherence to treatment protocols and encourage community participation, ultimately fostering a more inclusive and responsive healthcare system for NTDs.

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