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REVIEW

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Designing interoperable health information systems using Enterprise Architecture approach in resource-limited countries: A literature review

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Summary

Background: Enterprise Architecture (EA) integrates business and technical processes in health information systems (HIS). Low-income and middle-income countries (LMIC) use EA to combine management components with disease tracking and health care service monitoring. Using an EA approach differs by country, addressing specific needs.

Methods: Articles in this review referenced EA, were peer-reviewed or gray literature reports published in 2010 to 2016 in English, and were identified using PubMed, Scopus, Web of Science, and Google Scholar.

Results: Fourteen articles described EA use in LMICs. India, Sierra Leone, South Africa, Mozambique, and Rwanda reported *building the system* to meet country needs and implement a cohesive HIS framework. Jordan and Taiwan focused on specific HIS aspects, ie, disease surveillance and electronic medical records. Five studies *informed the context*. The Millennium Villages Project employed a "uniform but contextualized" approach to guide systems in 10 countries; Malaysia, Indonesia, and Tanzania used interviews and mapping of existing components to improve HIS, and Namibia used of Activity Theory to identify technology-associated activities to better understand EA frameworks. South Africa, Burundi, Kenya, and Democratic Republic of Congo used EA to move *from paper-based to electronic systems*.

Conclusions: Four themes emerged: the importance of multiple sectors and data sources, the need for interoperability, the ability to incorporate system flexibility, and the desirability of open group models, data standards, and software. Themes mapped to EA frameworks and operational components and to health system building blocks and goals. Most articles focused on processes rather than outcomes, as countries are engaged in implementation.

KEYWORDS

design of health information systems, health information systems, health systems building blocks, information, interoperability

1 | INTRODUCTION

The World Health Organization (WHO) prioritizes: achieving health and well-being, coordinating service delivery, and strengthening governance and accountability.[1] Underpinning these priorities is the need for a reliable health information system (HIS) that combines national health priorities with local requirements. WHO identified HIS as one of the six health system building blocks, though data are essential to each of the other five health system components: service delivery, health workforce, access to essential medicines, financing, and leadership/governance.[2] HIS ideally integrates vital statistics registries, disease surveillance data and facility, community and program monitoring data with workforce, financial and management data to inform planning, decision-making, and resource distribution. For example, delivery of clinical services and addressing health workforce issues can both be supported by computer-based medical decision support systems.[3]

A comprehensive architecture can facilitate communication between building blocks and promote interoperability across existing components, harmonizing the country's overall strategy to include new skills, tools, and holistic systems in a manageable and sustainable manner.[4,5] One such approach, Enterprise Architecture (EA), has been used by countries and businesses to provide a governing and operating structure, as well as guidelines to optimize and integrate applications, networking, expansion capacity, and standardized processes.[6] EA offers a framework or blueprint to identify the business processes, data, and technical or technological processes for the development of an integrated HIS. Although application of EA can include adapting tools or templates available from open source software, commercial products, or certification programs, this manuscript will focus on the processes and essential artifacts that are common across its implementation.

For many low and middle income countries (LMICs), incomplete data and cumbersome systems are the byproduct of vertical and fragmented health programming, health sector reforms, nonaligned funding, and unsynchronized reporting requirements.[2] Further, incompatible data collection methods, standards, and protocols limit the integration of HIS components.[7] In the face of these limitations, some countries look to ongoing universal health coverage and health systems strengthening efforts to provide opportunities for improving HIS.[7,8] Initiatives like the Population Health Implementation and Training Partnerships, established in five sub-Saharan African countries, promote an iterative and tailored approach to strengthening health systems that focuses on existing tools, multiple data sources, theories of change, and HIS linkages to improve decision-making.[7]

Interoperability ensures that data can be readily exchanged and disseminated at multiple levels. Yet, the roll-up of data from health facilities to districts to national agencies may reveal incomplete or inaccurate data, identify areas where lack of training and time for data collection impact results, and indicate gaps between multiple platforms, eg,

District Health Information Software (DHIS), *Open MRS* (sub-Saharan Africa's open source platform for electronic medical records), and locally adapted information platforms.[3,9,10] Progress toward interoperability has been noted in South Africa's mobile health (mHealth) scale-up efforts, where enhanced government stewardship and improved organizational, technological, and financial systems were essential.[11] Progress also has been noted in Tanzania's use of information and communication technologies (ICT) to facilitate resource management and workload reduction.[12-14] Kenya used focus groups, interviews, and document review before, during, and after system implementation to identify critical policy, technical, financial, and administrative factors,[15] and Taiwan's Agile Enterprise Regulation Architecture has strengthened information security in their HIS, building security management applications into the electronic health records, and responding to clinical users according to their level of access.[16]

Technological advancements have fostered computer-based medical decision support in sub-Saharan Africa[3] and information transfer between the district/national and villages/community levels in Tanzania.[17] Ministries of Health and software development agencies in Tanzania and Mozambique have forged relationships to move HIS forward.[12]

EA's comprehensive approach to specific country adaptations and changes over time builds on a cross-sector portfolio of practices and methods applied to shared data elements, business processes, governance mechanisms, and investment strategies.[4,8,18-21] The incorporation of business/financial applications with ICT infrastructure helps countries manage diverse health sector operations and resources. EA is applied through multiple frameworks—eg, The Open Group Architecture Framework (TOGAF), Zachman framework, Enterprise Architecture Planning, Generalized Enterprise Reference Architecture and Methodology, and Extended Enterprise Architecture framework—that vary parameters to meet country or corporate needs.[22,23]

The overall goal of this literature review is to identify best practices related to EA-based HIS design, implementation, and evaluation in LMICs. Literature identified in this review present ways in which EA frameworks have been used to facilitate data collection, examine critical elements for effective health care systems, and identify framework contributions to the advancement of HIS interoperability.

2 | METHODS

The literature search was conducted in March 2017 using the PubMed, Scopus, Web of Science, Google Scholar, and two specific journals: *Electronic Journal of Information Systems in Developing Countries* and *Information Technology for Development*. Selection criteria selection included publication in English between 2006 and 2016.

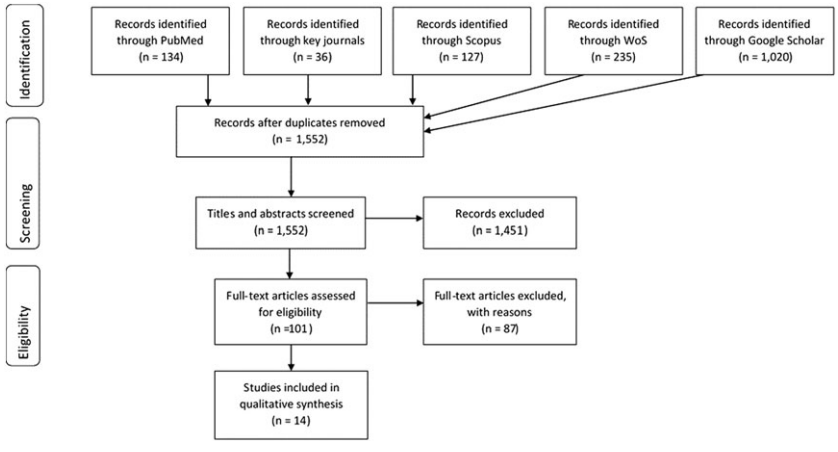

FIGURE 1 Articles identified at each stage of the literature search

TABLE 1 Characteristics of studies included in the literature review synthesis

Author (Year)	Title	Problem/Purpose	Intervention/Review	Comparison/Method	Outcome in Study	Setting
Adenuga et al[4]	eHealth integration and interoperability issues: Toward a solution through Enterprise Architecture	ICT and HIS not successful despite investment	Propose architecture for eHealth to improve health service delivery	Implemented ICT and HIS compared with eHealth model	Barriers to: Health care organization Learning Use of eHealth	South Africa
Bakar et al [6]	Investigating Enterprise Architecture implementation in public sector organization: A case study of Malaysia	Need to overcome weaknesses in system and identify critical success factors	Explore government implementation of EA system	Interviews with Ministry of Health officials and other stakeholders	Strengthen the TOGAF system initiated earlier to take the next steps in implementation	Malaysia
Braa et al [24]	Comprehensive yet scalable health information systems for low resource settings: A collaborative effort in Sierra Leone	How to integrate health information systems in low-income African countries	Introduce tools for different service areas and communities	Provision of services in various sites and levels of the health care system	Collaborative implementation approach	Sierra Leone
Crichton et al [25]	An architecture and reference implementation of an open health information mediator: Enabling interoperability in the Rwandan health information exchange	Design a system that is flexible, interoperable and scalable, while also being easy to use	Building on Rwanda Health Enterprise Architecture project to support system interoperability, flexibility, and scalability	Introduction of the Health Information Mediator (HIM) and Enterprise Service Bus (ESB) to facilitate translation of information across components	Development of HIM and ESB in response to systems analyses that indicated the need to create new components for the architecture	Rwanda
Gichoya et al [26]	Information architecture considerations in designing a comprehensive tuberculosis enterprise system in western Kenya	Need for a mobile health device for control of tuberculosis	Introduction of mHealth system to track supplies and communicate with patients and clinics	Implementing at local and scaling up to national level	Improvement of tracking supplies and patients; community engagement	Kenya
Handayani et al [27]	Integrated hospital information system architecture design in Indonesia	Need for a hospital information system to link into the TOGAF-based HIS	Implementation of updated processes for registration, medical records, billing, and patient services	Interviews with representatives from the Ministry of Health and stakeholder groups	An integrated information system architecture model	Indonesia
Kanter et al [28]	The importance of using open source technologies and common standard for interoperability within eHealth: Perspectives from	Need for an eHealth system to support increased access to health services and improve quality of care and ICT. Need to facilitate collaboration	Implementation and evaluation of the eHealth program, which used an EA-based process and generalized to use with	Across sites implementing the pilot phase	Flexibility of open source tools Human resources Bridge between information systems cost-benefit analysis that links economics	10 sub-Saharan Africa countries

(Continues)

TABLE 1 (Continued)

Author (Year)	Title	Problem/Purpose	Intervention/Review	Comparison/Method	Outcome in Study	Setting
	the Millennium Villages Project		open source software tools			
Kaushik and Raman[29]	The new data-driven Enterprise Architecture for e-health care: Lessons from the Indian public sector	Transitioning from the manual to a unified health care system in Tamil Nadu	Use of a modified EA for the Tamil Nadu HMIS	Modified EA vs. existing EA approaches and operating models	• Significant impact on delivery—useful for patient care and reporting • Routine HIS associated with better outcomes and disease tracking • Simplified processes and streamlined care • Cost-effective and potentially sustainable	India (Tamil Nadu)
Moodley et al [30]	Position paper: Researching and developing open architectures for national health information systems in developing African countries	Application of EA in low-resource settings requires new tools to integrate components, build capacity, promote interoperability	HEAL—Health EA Laboratory; HEAF—HEA Framework HEART—HEA Repository of Tools	Three initiatives in developing African countries—will be assessed at a later time	The development of these tools and ways to frame system needs will take into account limited infrastructure and resources	South Africa, Rwanda, Mozambique
Mwanyika et al [19]	Rational systems design for health information systems in LIC: An Enterprise Architecture approach	Lack of systematic documentation for health information systems	Develop SARA: Systematic, architected, and rational approach—a portfolio of methods and tools Test on TB control program	Case study of implementing SARA, which is based on EA, and guiding stakeholders to use in a TB case management example	Assessment of HIS functional domain Baseline inventory of existing systems Mapping HIS capabilities Development and application of SARA	Tanzania
Shaanika and Iyamu[31]	Development of Enterprise Architecture in the Namibian government: The use of activity theory to examine the influencing factors	To address the challenges of EA concepts, activity theory was applied to identify the non-technical factors that affect implementation of the EA model	Interviews with key respondents Application of activity theory to the EA model	Description of model and theory and how they work together	Contributes both theory-related and practical guidance to use activity theory to inform the EA approach and the interoperable system	Namibia
Sheikhali et al [32]	Design and implementation of a national public health surveillance system in Jordan	Fragmentation and siloed approach to health surveillance systems requires applying a mechanism to integrate	Application of EA approach to design, planning, and implementation of national public health surveillance	Review of the development of the new system	Innovative public health principles are being incorporated into the system, which will include clinical decision support, timely	Jordan

(Continues)

TABLE 1 (Continued)

Author (Year)	Title	Problem/Purpose	Intervention/Review	Comparison/Method	Outcome in Study	Setting
					analysis of data and cost-effectiveness reports	
Verbeke, Nyssen et al [33]	Using TOGAF for building a national implementation strategy for eHealth services and technologies in Burundi	Paper-based system predominant in health system, with lack of standardization and infrastructure. National Health Information System strategy and M&E plan developed.	Preliminary steps to develop TOGAF e-health system, based on analysis of country systems.	Analysis of regulatory documents and strategic plans Interviews	Findings of the analysis of country health information systems.	Burundi
Verbeke, Shamasanga et al [34]	Developing a national e-health strategy for DR Congo: A preliminary analysis of business needs, existing information systems, and solutions	DR Congo needed to better align ICT implementation in the health sector, per the National Plan for Health Development	Preliminary steps to develop TOGAF e-health system, based on analysis of country systems.	Analysis of regulatory documents and strategic plans Review of infrastructure Interviews	Findings from the analysis of country health information systems	DR Congo

The main search terms combined *Enterprise Architecture*, *health*, and *interoperability* using Boolean operators. Results were limited by Africa, Asia, and LMIC. Broader constructs, including HIS, HMIS, eHealth, and mHealth, were excluded. Descriptions of Enterprise Architecture and interoperability were used to provide background and context.

The phrase "Enterprise Architecture" or specific EA frameworks (eg, TOGAF or Zachman) were required for inclusion. Articles eligible for inclusion included literature reviews, peer-reviewed quantitative and qualitative studies, and gray literature reports. These criteria reflect our focus on developing and implementing an EA framework and the challenges of EA-based HIS in resource-limited settings. Qualitative information was extracted from the articles.

These restrictions may unintentionally exclude articles or reports that applied an EA approach but did not use the specific terminology. In addition, because of potential publication bias that favors quantitative results and lack of publication practice by governments or nongovernmental organizations, some advances in applying EA in LMICs may not have been available through the search process.

3 | RESULTS

The search identified 134 articles through PubMed, 36 articles from key journals, and 1020 from Google Scholar, 127 from Web of Science, and 235 from Scopus (Figure 1). Once duplicates were removed and exclusion criteria applied, the title and abstract review yielded 101 articles or reports for full-text review. Eighty-seven references were excluded for content, eg, technical systems descriptions or non-LMIC applications; 14 studies were included in the synthesis of articles (Tables 1 and 2). The studies included in the synthesis covered three steps in the process of developing an interoperable system: building an EA system, informing the context of HIS, and moving from paper-based to electronic systems.

3.1 | Building an EA system

Integrating HISs in low-income African countries often focused on scalability and comprehensiveness. In Sierra Leone, an EA approach provided tools for collecting data at multiple sites and using multiple sources.[24] Interoperability between *OpenMRS*, DHIS2, ICT development and capacity building components, along with an adaptable maturity model, were cornerstones of the approach. A second example of scalability and comprehensiveness is the Health Enterprise Architecture Laboratory which built EA-based health architectures and capacity for South Africa, Mozambique, and Rwanda.[30] Two key components were identified in the study: a framework that encompassed EA principles, methods, and models, and a repository of tools designed for low-resource settings. These countries noted different systems needs but shared common themes in identifying requirements and challenges; developing flexible and pragmatic technical innovations; bringing in implementing, academic, and funding partners; and developing training and technical literacy strategies. Rwanda's assessment and iteration approach allowed the system to adapt to changing environments and enabled the HIS support team to develop needed components, such as the Health Information Mediator and Enterprise Service Bus to facilitate interoperability, flexibility, and scalability.[25]

Jordan's use of EA in their public health surveillance system combined mobile and online tools to report data used in addressing diseases.[32] This phased-in approach included meetings between stakeholders and partners that informed the organizational architecture. The data architecture used WHO frameworks and protocols to assist with disease mapping and reporting, using case-based reporting forms that were uploaded into the HIS. The system deployed open source software on a secure network, promoting clinical decision support and epidemiological analysis. In Tamil Nadu, India, a more effective HIS initiated by the State Rural Health Mission coupled hospital and supply chain information targeted to health needs.[29] The EA-informed, computerized HIS plan and responsive training for health workers replaced manual data entry, cut across diseases, and reduced inconsistent and incomplete data. These changes led to the standardization of 276 secondary hospitals, entry of 25.2 million clinical records,100% compliance in supply chain compliance reports, and improved coordination between provider and monitoring and evaluation data.

TABLE 2 Descriptions of studies included in the literature review synthesis

Author (Year)	Descriptions
Adenuga et al [4]	• Prior efforts to invest in interoperable ICT and HIS were not successful, leading to a plan to implement an eHealth architecture; • Describes the planned approach: • Ensure a flexible and adaptable model rather than continuing with the existing disparate systems, siloed information structures, and lack of adherence to standards; • Offers an opportunity to meet growing demands and to integrate health data and components related to data collection, learning about the growth of the system, and the ease of use for health professionals who have limited time for data entry.
Bakar et al [6]	• The overall plan is to expand upon FA-based TOGAF system that was initiated in 2015 to facilitate operations; • Through interviews and observation, study identified critical success factors to ensure that the implementation of next steps takes into account the context of daily operations; • Study focused on internal governance and communication processes, learning and growth, authority support for rules and participation, cost and technology perspectives, and retention of expertise/experienced staff.
Braa et al [24]	• An EA approach to structure the provision of relevant tools and collection of data at the national, facility, and community levels, such as aggregate indicators, patient records, and mobile tools for outreach, respectively; • Interoperability between OpenMRS and DHIS2 and a collaborative approach to ICT development and capacity building, including learning from the Millennium Villages Project and building on HIV/AIDS programming; • One key component of the system is a maturity model that incorporates more elements over time.
Crichton et al [25]	• Implementation of the system and components (including HIM and ESB) is underway; • Testing of the system showed that it was able to adapt to changing environments or needs; • Use of a data center enhances responsiveness of the system, as clients may be slow to respond, but also introduces a single "point of failure" that could slow/delay/terminate communication.
Gichoya et al [26]	• Mobile devices already widely used in country, providing buy-in and comfort with the technology; • Proposed system of integrated and scalable tuberculosis control measures—tracking commodities and engaging patients and clinics; • Combined planning and feasibility with a focus on design and system requirements; • At the implementation stage.
Handayani et al [27]	• Designing and implementing the hospital components of an integrated HIS to serve as a model of coordinating activities; • A data catalog, flow charts, and schema were created to codify the processes, decisions made, and overall structure; • In-depth interviews were conducted to ensure that business and patient components were integrated into the architecture; • The goal is to design an overall architecture for the health system, with the hospital model representing one step in the process.
Kanter et al [28]	• The MVP evaluates an EA-based architecture adapted for use with open source software tools for improved interoperability; • MVG-Network's eHealth architecture brought together uniform yet contextualized approach and incorporated health service-related information tracking and economic components, such as cost-benefit analysis and expense tracking; • Model stresses the importance of a specific architecture, standards, well-trained staff for development and implementation, expense and cost-benefit tracking, stakeholder buy-in, and appropriate software applications.
Kaushik and Raman[29]	• Transition to a more effective HIS is tied to improvements in the health management system using an EA-informed process; • Prior system was largely manual and fragmented by disease-specific programming; data were inconsistent (eg, entered by multiple people), incomplete, not targeted to health system needs, and of poor quality;

(Continues)

TABLE 2 (Continued)

Author (Year)	Descriptions
	• New computerized clinical data collection and electronic health records reduced manual system errors; facilitated equipment and commodities distribution through improved supply chain management and standardized coding of supplies; allowed for timely coordination between physicians, pharmacists, and other health professionals; and improved generation of accurate and efficiently produced reports; • Standardized and streamlined 276 secondary hospitals and entered 25.2 million clinical records; 62% of patients remembered to bring their personal identification number to hospital visits.
Moodley et al [30]	• Health Enterprise Architecture Laboratory (HEAL) researched health architectures and built capacity for South Africa, Mozambique, and Rwanda with a framework that encompasses the principles, methods, and models of EA, and a repository of tools for low resource settings; • Countries have different specific needs in their systems; common threads include identifying experiences, requirements, and challenges; developing flexible and pragmatic innovations; and bringing partners in who to design and roll-out the system and providing training.
Mwanyika et al [19]	• Tanzania's methodical development of an EA-based system assesses existing systems and engaging stakeholders and maps HIS capacity to determines the current and future state, gaps, and needs of the HIS; • Systematic, architected, and rational approach (SARA) begins with an EA/TOGAF framework and incorporates stakeholder/country needs; • Country-specific system makes SARA a powerful approach that identifies practices, tools, and methods appropriated to strengthen the HIS; • Tested on the country's tuberculosis control program, used mobile technology, and identified processes to manage disease; this refined approach to real-world demands and use of non-technical language facilitated application; informed the EA approach and efforts to simplify the process of developing HIS.
Shaanika and Iyamu[31]	• Namibian used activity theory to identify and address non-technical factors that impact HIS, consider the business and ICT components, and focus on the social activities to apply the EA model to health sector and education, agriculture, transportation, and judiciary sectors; • Through interviews conducted with four ministries, key components were discussed: The use of tools and skill sets, human-to-human interactions and communications, motivations and goals of the actors, rules or policies that guide or constrain actions, the communities that exist within the government or among the actors, and the division of tasks among individuals or groups. • Examination and mapping of these components suggest points of potential stress or interconnectivity, and challenges to integration; • Activity theory: Understand the human level that intersects with business and technology provides a lens for monitoring, evaluation, and analysis across processes, skills, and knowledge parameters.
Sheikhali et al [32]	• Jordan's EA-based public health surveillance system and clinical decision system support combines mobile and online tools; • The phased-in approach allowed the organizational architecture to be informed by stakeholder and partner meetings with a range of actors who would be both involved in future scale-up and instrumental in responding to potential health needs; • The technical architecture uses case-based reporting data forms that are rapidly uploaded into a cloud-based system with open source software on a secure network, allowing for timely epidemiological analysis.
Verbeke, Nyssen et al [33] and Verbeke, Shamasanga et al [34]	• Burundi and the Democratic Republic of the Congo (DRC) have advanced eHealth strategic plans that integrated HIS, employed a TOGAF framework, and transitioned from paper-based instruments; • Using a parallel approach in the two countries, the assessment of existing resources and processes reviewed regulatory documents and strategic plans, and conducted field visits and interviews with key informants across a range of facilities; • In Burundi, the hardware and processes for its management and distribution were not coordinated, internet access was often unstable and, although ICT was used at the district level, paper-based instruments were used by many hospitals and health centers;

(Continues)

TABLE 2 (Continued)

Author (Year)	Descriptions
	• Burundi's existing system lacked data standardization and coding systems, databases were not backed up or protected from viruses, ICT infrastructure and computer equipment were inadequate, information dissemination was ineffective; • DRC assessment revealed similar themes—the need for better management in business operations related to health information systems, computer hardware and network inconsistencies/inadequacies, paper-based instruments for routine and facility-based data collection, and information management issues that are largely the result of piecemeal programming; • The TOGAF framework, training programs, DHIS2, and an information management system will enable the countries to advance.

3.2 | Informing the context

The process of developing a HIS starts with understanding the existing context: strengths and weaknesses of tools, and gaps and duplications of piecemeal systems already in place. On a multinational scale, the Millennium Villages Project (MVP), which has been implemented in 10 countries and 14 sites in sub-Saharan Africa, advanced an EA-based architecture adapted for use with open source software tools for improved interoperability.[28] The Millennium Villages Global Network (MVG-Net) brought together an eHealth approach that was uniform yet contextualized, which incorporated health service information and economic components and emphasized training and acceptance of development and implementation.

Tanzania's methodical development of an EA-based system began with assessing existing systems, engaging stakeholders, and mapping results to HIS capacity.[8] This approach determined the current and future state, gaps, and needs of the HIS and applied a systematic, architected, and rational approach (SARA) with an EA/TOGAF framework. By incorporating stakeholder needs, the model was adapted from a generic to country-specific design, making SARA a powerful approach that identifies practices, tools, and methods to both strengthen and simplify the approach to HIS. SARA was tested on the country's Tuberculosis Control Program by using mobile technology to manage the disease and developing non-technical language to encourage application.

In Malaysia, interviews with the Ministry of Health and other stakeholders were conducted to identify critical stress factors related to governance and communication processes, learning and growth, support for rules and participation, cost and technology perspectives, and retention of expertise/experienced staff.[6] Results from these interviews will inform the next steps in implementing the HIS's public sector components. Interviews were also used to inform the prioritization of Indonesia's hospital business practices (eg, registration, medical records, and billing) and information tracking for inpatient and outpatient services.[27] Experts in the Ministry of Health and other key stakeholders identified and described critical elements linking business practices and patient services in the country's TOGAF system.

Namibia's use of Activity Theory to identify and address non-technical factors that impact an HIS demonstrates the value of using additional tools to inform EA.[31] Social activities need to work with the business and ICT components of the health sector, as well as with the education, agriculture, transportation, and judiciary sectors. Interviews conducted with these Ministries identified key components including human-to-human interactions and communications, motivations and goals of the actors, rules or policies that guide or constrain actions, and communities within the government or among HIS actors. Component mapping suggested points of potential stress, interconnectivity, and nonalignment, while understanding how the human level intersects with business and technology provided a lens for monitoring and evaluation across processes, skills, and knowledge parameters.

3.3 | From paper-based systems to eHealth

For many countries, HIS efforts mark a transition from paper-based recordkeeping to computer-based data collection. An EA model for South Africa's ICT system focused on health care services, implementer and software needs,

and hardware requirements[4] Promoting interoperability through a flexible and adaptable model that integrates an eHealth architecture should enhance organizational design and decision-making. The planned approach offers a response to growing demands for integrated data, system growth, and ease of use for health professionals. In Kenya, movement from a paper-based system used an mHealth approach to target supply chain management, patient communication, and clinical support and reporting.[26] With a focus on tuberculosis control, the system highlighted connections with communities and addressed challenges that include a lack of electricity and supplies at local clinics.

For more than a decade, Burundi and the Democratic Republic of the Congo (DRC) have employed TOGAF frameworks to implement integrated HIS and facilitate transition from paper-based instruments.[33,34] Existing resources and processes in the two countries were assessed by reviewing regulatory documents and conducting field visits and interviews with key informants across a range of facilities. In Burundi, the assessment indicated that management was not coordinated with distribution hardware and processes, internet access was often unstable, and, although ICT was used at the district level, paper-based instruments were used by many hospitals and health centers.[33] Their piecemeal system resulted in a lack of data standardization, incomplete or unreliable data, databases without backup or protection from viruses, data access risks, inadequate ICT infrastructure, lack of trained staff, and ineffective dissemination strategies. The assessment in DRC revealed similar themes and the need for better business operations management, computer hardware and networks, and instruments for routine and facility-based data collection.[34] The assessments suggest that implementing the TOGAF framework, training programs, DHIS2, and an information management system will enable both countries to move forward.

4 | DISCUSSION

Several articles cited the importance of applying contributions from multiple sectors and data sources to the EA framework. Systems in South Africa, Mozambique, and Rwanda point to understanding what the existing mechanisms can and cannot do, the role of partners in moving forward, and ways to building on shared experiences.[30] In Tanzania, existing contextualized systems highlighted the need to fully understand how data management components fit together.[8] In Burundi and DRC, policy documents and input from key informants captured information on system strengths and weaknesses to transition effectively from paper-based and piecemeal data collection to a comprehensive business-technology-health system.[33,34] This articulation of the central system elements is demonstrated in Indonesia's efforts to streamline hospital administrative procedures for registration, medical records, billing, and patient tracking,[27] Malaysia's application of critical success factors in expanding EA across public sector HIS.[6]

The need to bring elements together in an interoperable manner was a second common theme in most EA articles or reports. The EA framework provides a means of viewing multiple parameters in one model, which is useful for a system with many disparate components. In South Africa, prior attempts to create an interoperable ICT/HIS system were not successful, requiring a status review and development of an EA framework that laid out an integrated HIS.[4] In Sierra Leone, the desire to aggregate indicators, consolidate patient records, and expand mobile tools to strengthen the public health surveillance system led to the use of the MVP model, *OpenMRS* and DHIS2; finding ways for these elements to work together was critical.[24] The MVP model focuses on employing contextualized uniformity, in which a model is adapted to meet the needs of individual countries by incorporating health services and financial information.[28] Jordan incorporated disease mapping and reporting, clinical decision support, and epidemiological analyses into a public health surveillance system.[32] In Tamil Nadu, India, an interoperable system was required to coordinate health professions, promote standardized medical records, strengthen supply chain management, and promote training and capacity building.[29] Namibia's interoperability needs were identified through a mapping exercise highlighting potential areas of stress and interconnectivity, and by coordinating personnel working on the system.[31] Rwanda's interoperability efforts were improved through the development of components designed to facilitate information flow between community clinics and the national data center.[25]

Flexibility within a stable system was another common element of EA-based systems. In Namibia, Activity Theory was used to account for the human element and individual needs of those using the HIS.[31] In Sierra Leone, a maturity model as part of the system framework was one way of ensuring that adaptability was built into the system.[24] In South Africa's ICT system, flexibility has been essential in combining systems and cross-cutting previously siloed programmatic and measurement efforts.[4] South Africa, Rwanda, and Mozambique all cited the importance of combining flexibility with pragmatism in developing a system that draws on research and experience to meet the needs of the system and the people using it.[25,30]

A fourth common element was the use of open group models, data standards, and source software to enable customization, ease data exchange and implementation, and assemble components to address health, economic, and social issues.[4,6,24,26,28,32] In South Africa, data exchange barriers were addressed using an open group model and evolving standards.[4] Jordan's cloud-based systems to manage public health surveillance, Kenya's android system to promote scalability of mHealth, and India's efforts to ease linkages to a larger system all used open standards or open software to accomplish goals.[26,29,32] Health Enterprise Architecture Laboratory and MVP used the Open Architectures, Standards, and Information Systems for Healthcare in Africa project (OASIS II) to evaluate these open data standards, data exchange and implementation efforts[24,25,28,30] The MVP countries identified open and international standards as important to successful implementation, with Sierra Leone incorporating open standards into its model.[24,28] MVP also is one of the largest examples of using open source software and *OpenMRS* in its eHealth efforts.[28]

These four EA characteristics or operating functions—multiple sources, interoperability, flexibility, and open standards/models/software—demonstrated congruence with both the EA framework and operational components and WHO's health system building blocks and overall goals. The building blocks interface to achieve the overall goals of improved health, responsiveness, risk protection, and efficiency.[2] The LMIC's EA frameworks contribute to these goals by using data from multiple sources in an interoperable and flexible system that makes use of existing, often open source, software. When overlaying the WHO and EA frameworks, the EA outcomes identified in the assessed articles contribute to WHO goals (see Figure 2). The inclusive "interoperable systems" component contributes to each of the WHO goals by improving efficiency, enacting protection measures, responding to needs, and, through quality data and recordkeeping, improving health. Although the other components also contribute to some degree to all the goals, some linkages were more compelling. Using data from multiple sources was linked to improving health and efficiency, while flexibility was linked to responsiveness and efficiency, and open standards and sources were linked to risk protection and responsiveness.

The limitations of this review include focusing on the explicit use of the term "Enterprise Architecture" in the health sector and in low-income and middle-income countries. Other types of architecture have been applied and could be examined. In addition, studies may use but fail to identify using an Enterprise Architecture framework in their systems development efforts. Some studies broadly identified incorporation of business components or linking

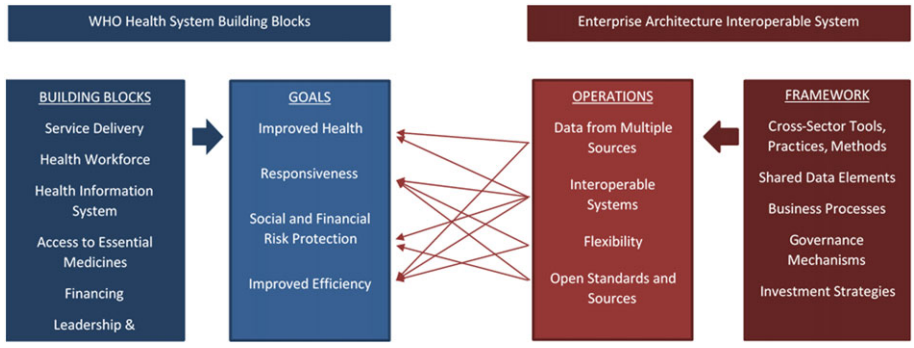

FIGURE 2 Linking EA components to WHO building blocks

across sectors but did not mention EA specifically. One article, Gichoya et al, refers to the "enterprise architecture" of the system, although it is unclear whether this is a formal EA approach or general application of the term.[26]

A second limitation of the review is that many countries are planning, introducing, or scaling up solutions for strengthening their HIS. Therefore, the articles identified here highlight the stages of development and implementation, rather than presentation of the outputs and outcomes of these systems. In addition, specific strategies and guidance of model development varied by country. It remains to be seen whether these efforts will generate effective and comprehensive HIS in the countries mentioned. Nevertheless, this review provides information about how EA is being used by LMIC governments to facilitate interoperability in HIS. A separate review of eight digital libraries found limited information related to factors associated with government adoption of EA metamodels, and limited findings related to organizational structure, use of meta-databases to house data, EA model maintenance, and use of EA to predict potential costs, risks, or success factors.[35]

5 | CONCLUSIONS

The WHO suggests that the EA approach to designing and implementing national HIS across health facilities and communities can foster better decision-making that leads to improved patient care and achievement of national goals.[1] Health care professionals and their clients benefit when interoperability is achieved, as accurate data are accessible in a timely fashion. Ideally, EA-facilitated data exchange improves data availability and accuracy by (1) providing better quality and continuity of care, referrals, and follow-up between levels of the health system (eg, community to health facility); (2) improving data quality and analysis to understand how system components work together (eg services delivered and medicines dispensed); and (3) ensuring data comparability from registries and programs for clients, facilities, and providers.

Although many LMIC systems have not been in place long enough to provide a comprehensive view of EA effectiveness in fostering data exchange, the cited studies identified key findings from the assessment and design phase of systems development. Three main gaps identified in this review are the lack of (1) systematic outcomes evaluations of EA-based systems to determine their effectiveness; (2) cost-benefit analysis for improving health services; and (3) dissemination of lessons learned to inform the development of systems in resource-limited settings. The use of methodical development phases in the countries cited are highly promising, as the attention to factors affecting the success or failure of a system will enable countries to adapt to meet challenging health sector demands.

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