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Research Paper

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ABSTRACT

e-Health solutions in low-income countries are fragmented, address institution-specific needs, and do little to address the strategic need for inter-institutional exchange of health data. Although various e-health interoperability frameworks exist, contextual factors often hinder their effective adoption in low-income countries. This underlines the need to investigate such factors and to use findings to adapt existing e-health interoperability models. Following a design science approach, this research involved conducting an exploratory survey among 90 medical and Information Technology personnel from 67 health facilities in Uganda. Findings were used to derive requirements for e-health interoperability, and to orchestrate elements of a service oriented framework for developing interoperable e-health systems in a low-income country (SOFIEH). A service-oriented approach yields reusable, flexible, robust, and interoperable services that support communication through well-defined interfaces. SOFIEH was evaluated using structured walkthroughs, and findings indicate that it scored well regarding applicability, usability, and understandability.

Keywords

E-health, E-health interoperability, service-oriented perspectives, low-income country.

INTRODUCTION

Digital technologies provide an unprecedented opportunity for implementing technological solutions that can accelerate the achievement of development goals such as poverty alleviation, healthcare improvement, and universal education. Digital technologies include block chain technologies, Internet of Things, mobile technologies, cloud computing, web technologies, social media technologies, and information and communication technologies (ICTs) (United Nations Conference on Trade and Development, 2019). The adoption of such technologies to support healthcare service delivery is commonly termed e-health (Eng, 2001; Mugo & Nzuki, 2014; Pagliari et al., 2005; Qureshi et al., 2013) or digital health interventions (World Health Organization, 2018).

E-Health solutions have strengthened health systems in various ways. Solutions exist that support patient or clinical diagnosis, testing, monitoring and treatment; billing for healthcare services; management of healthcare resources (Bock et al., 2005). Others facilitate pharmaceutical prescription record keeping (Furusa & Coleman, 2018) and health information management in general (Adebesin et al., 2013; Fichman et al., 2011). Also, e-health solutions can support storage, processing, and communication of health information to decision makers enabling better coordination of healthcare at national, provincial, and hospital levels (Kolodner et al., 2008). Furthermore, e-health solutions can help to improve care delivery (Shekelle et al., 2006), medicine distribution thereby avoiding stock-outs (Car et al., 2017) and patient monitoring (Car et al., 2017). They can also reduce medical errors (Kiberu et al., 2017) and improve physician-patient relations (Lancaster et al., 2018).

The World Health Assembly recognizes e-health as a cost-effective and secure approach to healthcare service delivery and has urged member states to devise sustainable e-health implementations (International Telecommunication Union [ITU], 2008). In response, most high-income economies have invested in acquiring robust and reliable e-health solutions. For example: Canada's Health Infoway and electronic health information systems (Protti, 2008); Denmark's universal electronic health records system (Cruickshank et al., 2012) and Germany's electronic health card (Mugo & Nzuki, 2014). Low- or middle-income countries (LMIC) have also embraced e-health in various ways. For example: the RAFT telemedicine network for Francophone countries in Africa (Bediang et al., 2014); the Babyl Rwanda solution (Babyl, 2019); and the District Health Information System (DHIS2) and mTrack (Uganda Ministry of Health [MOH], 2011). However, despite these efforts the rate of e-health adoption in LMICs is slow and they are under-utilized (Zayyad & Toycan, 2018). Challenges responsible for this have been categorized into socio-cultural (Achampong, 2012; Kaplan, 2020; Omary et al., 2010), technical (Parajuli et al., 2022; ITU, 2012), and governance issues (George et al., 2012) as shown in Table 1.

Table 1

Categories of Challenges Hindering Implementation of e-Health Solutions

Socio-cultural challenges (Kaplan, 2020; Achampong, 2012; Omary et al., 2010)	Technical challenges (Parajuli et al., 2022; ITU, 2012)	Governance challenges (George et al., 2012)
Negative perceptions of e-health lead to resistance (Cho et al. 2021; Achampong, 2012) Digital illiteracy (Ittefaq and Iqbal, 2018; Achampong, 2012) Cultural values that hinder effective implementation and adoption of e-health services (Alanezi, 2021; Omary et al., 2010)	Lack of privacy and security (Archer et al, 2021; Alunyu et al., 2021; Kiberu et al, 2019; Muhaise et al., 2019 and Okunade et al., 2019; Mugo & Nzuki, 2014; Achampong, 2012; Omary et al., 2009) Lack of, or minimal, interoperability between e-health systems (Al-Shorbaji et al., 2018; ITU, 2012). Poor internet connectivity (Archer et al., 2021; Qureshi et al., 2013) Insufficient ICT equipment (Archer et al., 2021; Alunyu et al., 2021; Kiberu et al. 2019; Qureshi et al., 2013; Achampong, 2012)	Limited financial resources for e-health projects (Archer et al., 2021; Achampong, 2012). Weak governance and leadership structures for e-health initiatives (Al-Shorbaji et al., 2018; King et al., 2012) Difficulty in establishing clear regulatory and legal policies to foster coordination between government agencies and e-health initiatives (Mburu and Oboko, 2018; Mandirola et al., 2015; Achampong, 2012)

Note. Lack of interoperability is under technical issues, yet it is an effect/cause of challenges under the other two categories. ICT = information and communication technologies.

Although the challenge of deficient e-health interoperability is included in the technical category, it can also be seen both as a symptom/effect and a cause of challenges under the socio-cultural and governance categories. Interoperable e-health solutions support data sharing within and across agencies; this eliminates unnecessary medical errors (Biltoft & Finneman, 2018; Kaushal et al., 2010) and reduces healthcare costs through a shared infrastructure for service delivery (Iroju et al., 2013; Reed et al., 2020). It provides patients with timely access to healthcare information and enables informed decisions and personalized care (Adebesin et al., 2013; Li et al., 2022). Healthcare professionals also benefit as these systems yield high-quality integrated information for evidence-based decision making (Malley et al., 2010; Rinty et al., 2022). Interoperability can improve communication of healthcare information by supporting continuity care (Halamka et al., 2005; Li et al., 2022). Consequently, interoperability leads to easy access to patient data via a single point of care shared by several institutions and the realization of better healthcare outcomes (Health Information Management System Society [HIMSS], 2023).

However, achieving interoperable e-health solutions poses a severe challenge in LMICs (Charalabidis et al., 2009; Rinty et al., 2022) despite the urgent need for e-health information exchange between institutions (Adebesin et al., 2013; ITU, 2012; Savage & Savage, 2020). e-Health solutions are usually custom built to achieve specific outcomes identified by different implementing partners, use different architectures and technologies, and give low priority to connecting, exchanging, and re-using health data across institutions (ITU, 2012; Rockefeller Foundation, 2010). This makes it difficult to seamlessly exchange and access patient healthcare data from different locations in the same city and even more difficult across a country (Gambo et al., 2011). The challenges that hinder development of interoperable and sustainable e-health solutions in LMICs can be categorized into technical, informational, and organizational issues (HIMSS, 2023; Kyalo et al., 2018; Omary et al., 2010; Shrivastava et al., 2021; Tambouris et al., 2007). This is explained in the next section.

The situation is worsened by the lack of appropriate frameworks for developing interoperable e-health solutions especially in low-income economies (Adebesin et al., 2013). Existing frameworks developed for the industrialized economies (Kuziemsky & Weber-Jahanke, 2009; National E-Health Transition Authority [NEHTA], 2005; Sadeghi et al., 2011) cannot readily be adopted for use in low-income countries because of the significant differences in design requirements related to infrastructure and resource limitations. The ITPOSMO (Information, Technology, Processes, Objectives, Staffing, Management, and Other factors) design-reality model explains that trying to introduce a system designed in and for a developed economy to a developing/transitioning economy, leads to country-context design-reality gaps which can lead to a total or partial failure of the system (Heeks, 2003).

High income economies have used various approaches to develop e-health interoperability frameworks. For example, the mashup-based framework for multilevel healthcare interoperability (Sadeghi et al., 2011) and the e-business-based framework for e-health interoperability (Kuziemsky & Jahnke, 2009). Open distribution processing, used in Australia (NEHTA, 2005), supports the development of systems which can be distributed across a computer network and can operate independent of the platform and technology used (Raymond & Armstrong, 2013). This makes it a good choice given that these systems often operate in complex, open, distributed, and heterogeneous computing environments (Fook et al., 2006).

The open distribution processing in the e-health interoperability framework is realized using the Service Oriented Architecture (SOA) model (NEHTA, 2005). SOA is a web-based approach which helps users to exchange information and share knowledge during an internet-mediated transaction (Yu et al., 2011). It uses a structural approach to create collaborative, agile, reusable, flexible, robust, and interoperable services that support communication through well-defined interfaces (Zhang et al., 2007). Due to its adaptation to the World-Wide-Web, SOA has been used in complex and heterogeneous system development projects ranging from e-government systems to environmental systems (Silveira & Guelfi, 2008; Serbanati et al*.*, 2011). Considering that development of e-health systems also takes place in complex and heteronomous settings, SOA can equally be used to achieve interoperability in those systems (Fook et al., 2006). SOA also represents a valuable option for extending the life of mission-critical legacy systems (Canfora et al., 2008). This makes it a good choice for low-income countries that already have legacy e-health systems in place as these can easily be integrated through the use of SOA.

Thus, in order to achieve a SOA-oriented mechanism for delivering interoperable e-health solutions, this research was motivated to first investigate issues that hinder e-health interoperability in a low-income country, and then identify contextual issues that can be used to adapt existing e-health interoperability frameworks with respect to the service-oriented paradigm. Accordingly, the design science approach was adopted to provide explicit answers to three research questions: *(A) What issues hinder development of interoperable e-health solutions in Uganda (as an instance of low-income countries)? (B) What are the possible solutions to hindrances of e-health interoperability? (C) To holistically realize the possible solutions, what would constitute a Service Oriented Framework for guiding the development of Interoperable E-Health systems in a low-income country (SOFIEH)?* The next section discusses the research method used, related work on e-health interoperability issues and e-health interoperability frameworks, and the research gap. Thereafter, findings from an exploratory survey on the research gap are presented. Furthermore, the design of SOFIEH as the desired solution is presented, its evaluation is discussed, and a conclusion is provided.

RESEARCH METHOD, RELATED WORK AND GAP ANALYSIS

Design science is a problem-solving paradigm that supports the creation of relevant solutions in the form of constructs, models, methods, and instantiations (Hevner et al., 2004). It involves designing innovative artifacts and analyzing their use and performance to facilitate an understanding of, and improvement of their behavioral aspects (Vaishnayi & Kuechler, 2010). Design science research yields knowledge in the form of scientifically validated design principles, which can be perceived as explicit prescriptions for how something can be done to achieve a given goal such as addressing a problem or realizing a desired solution (Gregor et al*.*, 2020). Thus, the design science research method guided the formulation of SOFIEH, which is envisioned as an approach for supporting the development of interoperable e-health systems in Uganda. Various ways of implementing design science research have been suggested (e.g., Peffers et al., 2007; Offermann et al., 2009) so as to advance the work of Hevner et al. (2004). The suggestion made by Peffers et al. (2007) provides six steps: i) specify the research problem and provide a motivation; ii) specify the purpose of the desired solution or artifact; iii) design and improve the artifact; iv) demonstrate the use of the artifact; v) evaluate and monitor the artifact's performance; and vi) communicate the results obtained to a target audience. This six-step process was adopted in this study, and the steps were executed in 3 phases as elaborated below.

Phase 1 involved specifying the problem and solution by executing steps (i) and (ii) above. This would answer research questions A (*What issues hinder development of interoperable e-health solutions in Uganda?*) and B *(What are the possible solutions to hindrances of e-health interoperability?).* This was achieved using two techniques. First, literature was reviewed on e-health interoperability issues and existing e-health interoperability frameworks or approaches, findings from which are presented in the subsequent subsections. Second, an exploratory survey was conducted among health and computing professionals to investigate hindrances impeding e-health interoperability in Uganda. Findings from the literature and from the exploratory survey were synthesized and used to derive the requirements for e-health interoperability in a low-income country, as presented in the next section.

Phase 2 involved designing SOFIEH by executing steps (iii) and (iv) above. SOFIEH was designed by adapting insights from the e-health interoperability framework for Australia (HIFA) and other service-oriented approaches, so as to address the requirements for e-health interoperability that were obtained in phase 1. Phase 2 addressed the design aspects of research question C *(What should constitute SOFIEH?).* Details are presented in the results section of this paper.

Phase 3 involved evaluating SOFIEH by executing steps (v) and (vi) above. This was done by conducting structured walkthroughs with a sample of potential end-users and experts – healthcare and computing practitioners at health facility level and programme level. Feedback was processed to address the validation aspects referred to in research question C. Evaluation findings are presented later in this paper.

Existing Work on e-Health Interoperability Issues

Interoperability is a state when at least two heterogeneous entities can communicate to achieve a common goal without the need for each entity to know detailed aspects of the other entities; each entity maintains its autonomy and heterogeneity (Soares & Amaral, 2011). In healthcare the interoperability ecosystem comprises entities such as individuals, processes and systems that need to create, share, exchange, and access health information in discrete, narrative, and multimedia formats (HIMSS, 2023). Thus, interoperability can be broadly perceived as the *"*ability of a system to exchange and make use of information from another system*"* (Granja et al., 2018, p. 6). This implies that e-health interoperability is the ability of different digital solutions to access, exchange, integrate, and use data in a synchronized way (within and across institutional boundaries) to provide timely and seamless information for optimizing the health of individuals and populations globally (HIMSS, 2023). Challenges hindering the achievement of interoperability across information systems or e-health solutions are reported by several studies (e.g., Adebesin et al., 2013; Dawes, 1996; HIMSS, 2023; Irojue et al., 2013; ITU, 2012; Lau & Shakib, 2005; Landsbergen & Wolken, 2001; Novakouski & Lewis, 2012; Ryan, 2006; Sanderson et al., 2015; Sroetmann et al., 2012; Tambouris et al., 2007; Guo et al., 2011). Some of these studies (e.g., Dawes, 1996; Novakouski & Lewis, 2012; Sandersen et al., 2015) suggest a specific way of categorizing interoperability challenges. The categorization by Tambouris et al. (2007) is adopted herein because it helps one to create linkages between challenges hindering e-health implementation in general (see Table 1), and challenges hindering e-health interoperability in particular. Thus, Table 2 provides a synthesis of views on issues hindering development of interoperable e-health solutions.

Table 2

Taxonomy of Challenges Hindering Development of Interoperable e-Health Systems

Specific category adopted from Tambouris et al. (2007)	Specific instances of challenges under each category (as reported in literature)
Technical aspects include issues associated with connecting computer systems and services for different organizations to support cooperation and data sharing (Kyalo et al., 2018; Laskaridis et al., 2007).	Use of restricted or closed technology standard interface; and incompatible hardware and software technologies (Rinty et al., 2022; Pharr et al., 2022; Landsbergen and Wolken, 2001). Privacy and security challenges – lack of standards for: data integration, open interfaces, data exchange, security, interconnection services (Pharr et al., 2022; Safi et al., 2018; Granja et al., 2018; Omary et al., 2009). Use of legacy healthcare systems (Pharr et al., 2022; Irojue et al., 2013).
Organizational aspects include issues associated with budgeting, financing, coordination of institutional stakeholders to secure their support and ensure full compliance to laws, regulations, and standards (Shrivastava et al., 2021; Soares and Amaral, 2011); and means for promoting cooperation between institutions to realize mutual goals (Whiteman and Panetto, 2006).	Resistance to change from disparate e-health systems to interoperable e-health systems (Kujala et al., 2020; Furusa and Coleman (2018); Safi et al., 2018; Global Digital Health Partnership [GDHP], 2020; Rosati & Lamar, 2005). Infrastructure challenges such as poor internet connectivity and insufficient ICT equipment (Ndlovu et al., 2021; Safi et al., 2018; GDHP, 2020; Qureshi et al., 2013). Lack of trained staff to operate interoperable e-health systems (Pharr et al., 2022; Ndlovu et al., 2021; WHO and ITU, 2012). Differences in organizational cultures, behaviors, and business processes (Reisman, 2017; Adebesin et al., 2013). Lack of awareness of opportunities to share health information (Landsbergen & Wolken, 2001). Data exchange/sharing and re-use across actors and ICT solutions in healthcare has not been prioritized, thereby fueling the proliferation of fragmented and incompatible e-health systems (Adebesin et al., 2013).
Informational aspects include issues associated with how separate systems are able to understand the format, the meaning and the quality of the information being exchanged (HIMSS, 2023).	Use of incompatible clinical ontologies/vocabularies (Heacock et al., 2022; Bock et al., 2005). Lack of unified healthcare standards (Safi et al., 2018; GDHP, 2020; Lau and Shakib, 2005). Inconsistent data structures and lack of standardized mechanisms that can facilitate data sharing (Alunyu et al., 2021; Landsbergen & Wolken, 2001).

Note. Interoperability issues in the organizational or managerial category are more than issues in the other categories. This implies the need to strengthen the development process of e-health systems.

Existing e-Health Interoperability Frameworks

Existing efforts towards implementing interoperable e-health solutions mainly include studies in four categories: A) Best practices or success factors for e-health interoperability (e.g., Bauer et al., 2020; Bestek & Stanimirovic, 2017; Hollin et al., 2010); B) Standards for e-health interoperability (e.g., Thun & Dewenter, 2018; Atalag, 2013; Hammond, 2008); C) e-Health interoperability frameworks (e.g. Sadeghi et al., 2011; Kuziemsky & Weber-Jahanke, 2009; NEHTA, 2005); and D) SOA-driven models for achieving interoperability in healthcare (Gazzarata et al., 2017; Hosseini et al., 2014; Raghupathi & Kesh, 2007; Fook et al., 2006). Since this study focuses on providing an approach or procedure for guiding implementation of interoperable e-health systems, the following discussion highlights strengths and limitations of candidate frameworks in only categories C and D that could usefully inform the design of SOFIEH.

e-Health interoperability framework for Australia (HIFA) provides a common reference point that guides business and IT experts to deliver interoperable e-health systems (NEHTA, 2005). It promotes shared understanding among stakeholders on interoperability and sustainability of e-health solutions (Milosevic, 2006). It describes three levels of interoperability and components that constitute them – organizational, informational, and technical levels; and a set of e-health interoperability principles (NEHTA, 2005). However, for this framework to directly and contextually address interoperability challenges in a low-income country like Uganda, there is need to adapt it to address contextual factors such as different healthcare workflows, different levels of maturity and use of e-health systems, different levels of technology infrastructure development, and different levels of skilled personnel.

Mashup-based framework for multi-level healthcare interoperability focuses on enhancing interoperability and the integration of healthcare services and applications at the process level through online applications and aided by mashups (Sadeghi et al., 2011). Mashups can reconcile multiple data sources or applications (Daniel & Matera, 2014) and facilitate openness, data reuse, and interoperability (Anderson, 2007). This mashup-based framework comprises four components: a) one that enables healthcare actors to openly communicate, cooperate, and customize their information management channels or solutions; b) another that disseminates information to enable collaboration among healthcare actors in order to achieve interoperability; c) an integration component which is a graphical user interface that enables users to meet their specific needs; and d) a component that considers all possible data sources that could be used across healthcare processes (Sadeghi et al., 2011). However, the interoperability requirements used to develop the mashup framework were based on a single case study and it does not holistically address contextual factors that shape the e-health interoperability gap in low-income countries.

e-Business-based framework for e-health interoperability by Kuziemsky & Weber-Jahnke (2009) enables e-health integration and interoperability by specifying 3 components: a) the healthcare integrated system, which focuses on achieving interoperability across the micro-, meso-, and macro-levels of healthcare; b) an interoperability infrastructure component, which defines the infrastructure needed to accomplish e-health interoperability; and c) the tools and applications component, which aligns interoperability concerns with the tools and applications developed in e-business and e-health. This framework is based on concepts found in e-business models (e.g., the Supply Chain Operations Reference model) and their evident success stems from the way they facilitate a thorough understanding of process levels prior to the development of ICT solutions for supporting the processes (Kuziemsky & Weber-Jahnke, 2009). However, the complexity of a business enterprise can hardly be compared to that of the national-level healthcare enterprise or setting (Avison & Young, 2007). Therefore, adopting an e-business-based approach without customizing it to accommodate contextual issues in healthcare may not yield the same results as achieved in e-business.

Existing SOA-based Solutions to e-Health Interoperability

e-Health systems vary across institutions and are typically accessed at various locations, each of which has their own systems that need to link into a shared system (Costa et al., 2011). Hence, to effectively connect the different localized systems, it is necessary to integrate data from more than one source and to maintain the integrity of data used by each of those systems (Manpaa et al., 2009; Pirnejad et al. 2008). SOA is a good choice for interoperability in healthcare considering that e-health systems are implemented in a complex, distributed, and heterogeneous computing environment (Fook et al., 2006). This is because SOA is based on network-accessible and platform-neutral software services (web services), which can encapsulate the functionality and data of existing systems and make them accessible through the internet/web (Sheng et al., 2014). Boyd et al. (2009) further argue that SOA-based systems can easily be integrated and aligned with new and existing systems with minimal impact on service consumers and at a highly reduced economic cost. This can ensure good system collaboration and integration (Raghupathi & Kesh, 2007).

According to Bridges (2007), SOA is suitable for healthcare contexts because it provides a valuable option for reuse of mission-critical legacy systems, which were financed by previous investments. The design and implementation of interoperable health information systems based on SOA has been reported in many studies. Examples all based on SOA include supporting clinical data sharing (Gazzarata et al., 2017), achieving interoperability between immunization information systems in Iran (Hosseini et al., 2014), a healthcare information system (Guo et al., 2011); the design and implementation of interoperable medical information systems (Zhang et al., 2007); and the design of interoperable electronic health records (Raghupathi & Kesh, 2007). However, the existing solutions do not address contextual issues affecting e-health interoperability in low-income countries, thus making it difficult to implement them without contextualization. Therefore, to contextualize existing SOA-based e-health interoperability solutions there was need to gain a comprehensive understanding of e-health interoperability issues in a low-income country setting.

Research Gap

Existing e-health interoperability frameworks do not holistically and contextually address e-health interoperability issues in a low-income country and cannot readily be adopted for use without adapting them to the local context. Also, existing SOA-based solutions cannot be simply implemented in a low-income country without contextualization. To achieve this there was need to conduct an exploratory survey to investigate the extent of e-health interoperability issues in a low-income country like Uganda. Those findings were used to extend and blend existing approaches into the desired solution.

EXPLORATORY SURVEY ON E-HEALTH INTEROPERABILITY ISSUES IN UGANDA

An exploratory survey was conducted among medical/healthcare and computing practitioners involved in managing e-health initiatives at the health facility level in Uganda to gain a deeper understanding of issues that hinder e-health interoperability in Uganda. Table 3 highlights the design of the survey and Table 4 summarizes the findings and the consequent requirements for e-health interoperability.

Table 3

Summary of the Design of the Exploratory Survey

No	Parameter	Details of How Each Parameter was Addressed in the Survey
1.	Aim of the survey	To investigate issues hindering the realization of e-health interoperability in Uganda (as an instance of low-income countries) to derive contextual factors that can be used to adapt existing service-oriented e-health interoperability frameworks.
2.	Target population	Personnel involved in the use of e-health initiatives at health facilities and personnel involved in implementing e-health solutions in Uganda.
3.	Sample size and response rate	• 67 health facilities that use e-health systems were selected from the central region of Uganda in the districts of Kampala and Wakiso. • Two respondents were selected from each health facility, one medical or healthcare practitioner and the other a computing practitioner. 134 respondents were approached. • Of the 134 questionnaires distributed only 90 questionnaires were returned (47 were medical practitioners and 43 were computing practitioners) – response rate of 67.1%.

No	Parameter	Details of How Each Parameter was Addressed in the Survey
4.	Sampling method	Purposive sampling was used to select: • Health facilities that had previously used or were using e-health solutions. • Two medical and computing practitioners from each selected health facility.
5.	Data collection instrument	A self-administered questionnaire was used, with the following topics of inquiry: • **Topic 1:** Ability of e-health systems to successfully exchange information within the same institution or with external institutions. • **Topic 2:** Issues hindering realization of interoperable e-health systems. • **Topic 3:** Possible solutions to address issues hindering interoperability of e-health systems.
6.	Analysis of collected data	Analysis involved deriving: • Themes from views elicited from respondents about the survey topics, using content analysis. • Descriptive statistics (frequencies and percentages) on aspects collected about the topics

Note. Findings from topic 1 confirmed the relevance of this research, while findings from topics 2 and 3 informed the design of the required solution.

Under topic 1, findings indicate that none of the 67 healthcare units that participated in the survey had achieved full interoperability of e-health solutions. There are several e-health solutions operating in those facilities, but they operate in silos and information sharing within and across facilities is not possible. Under topic 2, questions were semi-structured to allow validation of views in the context of Uganda relating to challenges reported in literature (see Table 2). Participant responses to prompts on aspects associated with topic 2 were captured using a Likert scale of 1 to 5, where 1 indicated that an issue is very unlikely to hinder e-health interoperability and 5 indicated that an issue is most likely to hinder e-health interoperability.

The mean score of each aspect on topic 2 is indicated in column 2 of Table 4. Findings from the exploratory survey on topics 2 and 3 are summarized in Table 4. To enable traceability and cross-referencing during subsequent discussions, issues reported by computing practitioners are coded T1 to T6, whereas issues from medical or healthcare practitioners are coded M1 to M6. Column 3 of Table 4 classifies each issue with respect to the taxonomy by Tambouris et al. (2007) that is adopted herein (see preceding section) to provide a holistic understanding of e-health challenges and possible interventions. Column 4 presents requirements for addressing specific issues which are coded as TR1 to TR6 and MR1 to MR6. Issues and requirements in Table 4 are discussed further in the subsequent subsections on technical, informational, and organizational issues.

Table 4

Findings on Issues Hindering Interoperability of e-Health Systems, and Requirements to Address Them

Code	Issues from computing practitioners (T1-T6) and medical practitioners (M1-M6) who participated in the survey.	Classification based on Tambouris *et al.* (2007)	Derived requirements to address issues and their corresponding codes (TR1 to TR5 and MR1 to MR5).
T1	Health facilities have old/legacy e-health systems with different data types and structures *(mean score = 4.72).*	Informational	TR1. Provide guidelines for selecting and adopting appropriate middleware platforms that can translate and interpret inputs and outputs from different systems that need to interact with each other.
T2	e-Health systems used by health facilities lack adequate measures to safeguard security, privacy, and	Technical	TR2. Provide guidelines for strengthening security capabilities of e-health systems to address privacy and confidentiality concerns of patients' electronic

Code	Issues from computing practitioners (T1-T6) and medical practitioners (M1-M6) who participated in the survey.	Classification based on Tambouris *et al.* (2007)	Derived requirements to address issues and their corresponding codes (TR1 to TR5 and MR1 to MR5).
	confidentiality of patients' medical records *(mean score = 4.83).*		medical records.
T3	There are incompatible clinical terminologies/ vocabularies used by different health facilities *(mean score = 4.76).*	Informational	TR3. Provide guidelines for unifying and standardizing interoperable interfaces that can help in unifying the different data types and formats used by the different health facilities.
T4	Lack of unified healthcare standards for the different health facilities *(mean score = 4.71).*	informational	TR4. Provide guidelines for developing universal and open e-health standards across e-health systems.
T5	Some existing e-health systems are complex to use *(mean score = 3.95).*	Technical	TR5. Provide guidelines for developing simple, robust, and scalable e-health systems to minimize complexity.
T6	Some existing e-health systems use restricted or closed technology standard interfaces *(mean score = 3.62).*	Technical	TR4 addresses this.
M1	Lack of top management support and willingness to share information *(mean score = 4.67)*	Organizational	MR1. Provide guidelines for creating awareness among top management to secure their commitment to information sharing.
M2	Lack of a coherent e-health strategy at both national and institutional level to guide the coordination of e-health initiatives *(mean score = 4.27).*	Organizational	MR2. Provide guidelines for developing a coherent e-health strategy to guide coordination of e-health efforts at national and institutional levels.
M3	Lack of adequate funds to acquire physical infrastructure that enables secure exchange of healthcare information *(mean score = 4.73).*	Organizational	MR3. Provide guidelines for developing a value proposition for establishing shared physical infrastructure to facilitate information sharing.
M4	There are no policies and guidelines for sharing information among different health facilities *(mean score = 3.98).*	Organizational	MR4. Provide guidelines for developing policies and principles on information sharing across health facilities.
M5	There is resistance to change from existing, traditional, disparate systems to interoperable e-health systems *(mean score = 3.72).*	Organizational	MR5. Provide guidelines for the contextualized adoption of change management approaches in the development of interoperable e-health systems.
M6	Lack of trained staff to operate interoperable e-health systems *(mean score = 4.76).*	Organizational	MR6. Provide guidelines for training technical staff on how to implement, operate, and maintain and interoperable e-health systems.

Note. The challenges and requirements are coded to allow traceability regarding which of the elements of the solution address which of the requirements and solve which challenges/issues.

Technical Level Issues and Requirements – Issues T2, T5 and T6

e-Health systems at facilities lack adequate measures for safeguarding the security, privacy, and confidentiality of patient's medical data (T2): This poses a big threat to the goal of attaining e-health interoperability because it undermines public trust relating to electronic storage and exchange of health information (Bincoletto, 2020; Lenz et al., 2005; Pharr et al., 2022; Rosati & Lamar, 2013). Security and privacy concerns should be considered during the design stage to ensure that interoperability is achieved in a secure way to avoid data breaches or violation of privacy policies (Aderonke et al., 2013; Bincoletto, 2020). This builds trust and confidence in e-health systems among stakeholders. Thus, **TR2** highlights the need for research on mechanisms for strengthening security capabilities of e-health systems (at their design and implementation stages) to adequately address privacy, confidentiality, and other security for patients' electronic medical records.

Complexity of healthcare systems (T5): Respondents reported that e-health systems are often complex because healthcare services are offered by many actors, ranging from general to specialized doctors and allied health practitioners. Hence, several large data sets are generated for patient administration, organizational information, clinical data, and laboratory services data (Ryan, 2006). These data sets often have different formats, which leads to conflict, ambiguity, and confusion when information is exchanged among healthcare professionals or institutions (Lenz et al., 2005; Wager et al., 2009). Thus, **TR5** indicates the need for research on how to develop simple, robust, and scalable e-health systems. Simplicity improves comprehension and the usability of the system and helps to reduce conflict, ambiguity, and confusion when information is exchanged between healthcare units (Aderonke et al., 2013). Scalability enables easier accommodation of changing needs and corresponding system adjustments (Aderonke et al., 2013). Addressing these aspects, therefore, promotes e-health interoperability, and prioritizing scalability and simplicity of e-health solutions will help to overcome the complexity issue (Iroju et al., 2013).

Use of restricted or closed technology standard interfaces (T6): Respondents revealed that some existing e-health systems use closed (proprietary) technology interfaces. This implies the need for research on how to foster the implementation or adoption of e-health solutions that use open standards. Without open interfaces it is difficult to specify and implement clear rules for communication between health information systems (Skrocki, 2013). Requirement TR4 in the next subsection addresses this issue.

Informational Level Issues and Requirements – Issues T1, T3 and T4

Health facilities still use legacy/old e-health systems (T1): Legacy systems are those that were implemented before the introduction of common national standards (Iroju et al., 2013). They were developed for a particular task without considering the need to exchange information with other systems, which implies that they have varying data formats and incompatible platforms that cannot communicate easily with new e-health systems (Adebesin et al., 2013). However, middleware translates and interprets the inputs and outputs of different systems so that they can interact with each other (Ijoru et al., 2013; Raghupathi & Kesh, 2007). The translation and interpretation roles performed by middleware support the complex operations required to meet the high-level requirements of different applications (Bhuyan et al., 2014). Thus, **TR1** indicates the need for research on mechanisms that can support the evaluation and selection of middleware platforms so that they can be adopted to facilitate the interaction of disparate/distributed applications in a secure and reliable manner.

Health facilities use incompatible clinical terminologies/vocabularies (T3): In this context, vocabularies describe words and related concepts which are related to data capture and storage, and information exchange and retrieval (Iroju et al., 2013). Hence, different systems vocabularies affect the ability of e-health systems to work together since the interacting systems may incorporate several disparate assumptions and uses, and possibly different terms that refer to the same concept (Bock et al., 2005). This leads to conflict, ambiguity, and confusion whenever there is an attempt to share information among healthcare professionals (Bock et al., 2005). In addition, different systems can only share patients' information if there are standardized interfaces (Raghupathi & Kesh, 2007). Standardizing interfaces helps to unify the different data types and formats that are used by various e-health systems (Zakaria et al., 2013). This is necessary because separate databases differ in data type, data terminologies and form design and run on different platforms and as such require some level of interface unification in order to support interoperability (Aderonke et al., 2013). TR3 indicates the need for research on mechanisms for standardizing and developing common interfaces that can help to unify data types and formats used by various e-health systems.

Lack of a unified healthcare standard for different health facilities (T4): According to Iroju et al. (2013), standards are agreed-upon specifications that enable independently manufactured products to interoperate. However, various low-income countries lack unified and authoritative healthcare standards (Gambo et al., 2011). Different facilities conform to different healthcare standards, a practice that can breed confusion, misunderstanding and medical errors whenever different systems attempt to exchange information with each other (Lau & Shakib, 2005). Chen (2012) suggests the use of open standards when developing e-health systems so that it is easy for e-health systems to operate seamlessly with each other. Open standards help to connect heterogeneous e-health systems regardless of the technologies and programming language used (Papazoglou & Georgakopoulos, 2003). Thus, to address issues T4 and T6, **TR4** highlights the need for research on mechanisms that promote the use of universal and open e-health standards across e-health systems. Since specifications and documentation of open standards are available for public use, interoperability among disparate e-health systems is promoted and challenges like vendor lock-in are minimized (Adebesin et al., 2013; Wager et al., 2009).

Organizational Level Issues and Requirements – Issues M1 to M6

Lack of top management support and willingness to share information (M1): The absence of strong leadership and governance structures that foster information sharing makes it difficult to coordinate e-health initiatives and to ensure that they are aligned with national health priorities (WHO & ITU, 2012). Pardo and Burke (2009) note that without good leadership and governance from top management it becomes difficult to provide decision-making rules and procedures that direct and shape interoperability initiatives. Thus, **MR1** indicates the need for research into ways of creating awareness among top management to secure their commitment to sharing healthcare information.

Lack of a coherent e-health strategy at both national and organizational level (M2): An e-health strategy encourages stakeholders to invest in e-health initiatives that promote national coordination and interoperability (WHO & ITU, 2012). An e-health strategy helps to identify interoperability goals and provides a plan of action for achieving them so that well-connected and sustainable e-health systems are developed (Adebesin et al., 2013). Thus, **MR2** highlights the need for low-income countries to develop coherent e-health strategies that prioritize and synchronize the national, sub-national and organizational needs.

Lack of adequate funds to acquire physical infrastructure for secure exchange of healthcare information (M3): Implementing interoperable e-health systems requires adequate funding from central government (Mwakilama et al., 2014). Physical infrastructure forms the foundation for the exchange of health information across geographical and health-sector boundaries (Adebesin et al., 2013; WHO & ITU, 2012) and consequently the absence of reliable infrastructure limits the ability to initiate and support e-health interoperability. Thus, **MR3** indicates the need for research into ways of securing funding to establish physical infrastructure to enable information sharing.

Lack of policies and guidelines for sharing information e-health solutions (M4): Policies and guidelines for information sharing build trust and confidence among healthcare providers, which encourages them to obtain e-health systems that are compatible with those of other healthcare providers (WHO & ITU, 2012). e-Health interoperability policies should address the need to build e-health systems using open standards and prioritize privacy so as to ensure that system accessibility and information transfer occur within a specific security framework (NEHTA, 2005). Interoperability policies should also be regularly updated to ensure that they remain aligned with interoperability objectives, and a mechanism should be put in place to ensure compliance by institutions (WHO & ITU, 2012). Accordingly, **MR4** indicates the need for research on how to develop policies or guidelines that support information sharing across public and private health institutions.

Resistance to change (M5): Respondents also reported that e-health interoperability in healthcare units of Uganda is often negatively affected by stakeholders' resistance to changing from using disparate e-health systems to interoperable e-health systems. This is normally because some of these initiatives are introduced too rapidly, without comprehensive involvement of key stakeholders such as the end users. This affects acceptance of interoperable e-health systems because healthcare providers prefer to use disparate and stand-alone e-health systems instead of interoperable e-health systems if they do not see the relevance of the latter (Rosati & Lamar, 2005). Thus, **MR5** highlights the need for research on developing guidelines for adoption of change management approaches suited to the given environment when introducing interoperable e-health systems in a low-income country.

Lack of trained staff to build and operate interoperable e-health systems (M6): The healthcare domain suffers from a scarcity of people with the necessary skill sets to develop and implement interoperable e-health systems (WHO & ITU, 2012). Appropriate training and education programs help to build a workforce capable of designing, building, and operating interoperable e-health systems (Payne, 2013). Thus, there is need for research on how to develop and deliver continuous training programmes that build technical capacity in developing and operating interoperable e-health systems (**MR6**).

Limitations of the Exploratory Survey

During the exploratory survey it was found that the majority of the respondents at health facility level had a limited understanding of the concept of e-health interoperability. While it was understood by IT specialists and a few of the medical specialists, most nurses indicated that they had limited knowledge about e-health interoperability, but they had used e-health solutions or technologies. Thus, there was a need to first explain the concept of e-health interoperability to the respondents before they could complete the questionnaires. Although this was done, some questionnaires were not fully completed due to terminology-related issues. To minimize errors due to this issue, in some cases one of the researchers was available to explain technical terms to particular respondents when they completed the questionnaire. In addition, some healthcare facilities that had agreed to participate in the study did not do so due to their tight work schedule.

STRUCTURAL COMPOSITION OF SOFIEH

As indicated in the methodology section, the design science approach was used to derive SOFIEH. Inspired by the design procedure used in Nakakawa et al. (2013), the procedure used to design SOFIEH involved identifying and specifying elements that addressed requirements TR1 to TR5 and MR1 to MR6, synthesizing the elements, and describing them. These are elaborated on in the following subsections.

Specifying and Synthesizing Elements of SOFIEH

The elements specified in column 2 of Tables 5 and 6 are required in SOFIEH to address requirements TR1 to TR5 and MR1 to MR6.

Table 5

Elements that Should Constitute SOFIEH

Requirement code	The elements required by SOFIEH to guide development (i.e., pre-design, design, and post-design stages) of interoperable e-health systems in a low-income country
TR1	**TE1** prompts stakeholders to '*select and adopt existing middleware solutions'*.
TR2	**TE2** prompts stakeholders to '*identify and select appropriate security measures for electronic medical records*'.
TR3	**TE3** prompts stakeholders to '*develop unified and standardized interfaces, data types, and formats'*.
TR4	**TE4** prompts stakeholders to '*adopt universal and open e-health standards'*.
TR5	**TE5** prompts stakeholders to '*develop simple or modular but scalable e-health systems*'.
MR1	**ME1** prompts stakeholders to '*secure top management commitment to e-health interoperability and information sharing'*.
MR2	**ME2** prompts stakeholders to '*develop national and sub-national e-health strategies*'.
MR3	**ME3** prompts stakeholders to '*formulate a value proposition for shared physical infrastructure for enabling information sharing'*.
MR4	**ME4** prompts stakeholders to '*develop principles of information sharing'*.
MR5	**ME5** prompts stakeholders to '*devise contextualized change management strategies that will promote understanding and acceptance of e-health information sharing'*.
MR6	**ME6** prompts stakeholders to '*specify procedures and mechanisms that will guide the training of staff on how to implement, operate, and maintain and interoperable e-health systems'*.

Note. Elements of SOFIEH that are derived from findings of the exploratory study. They are coded to enable traceability with respect to specific requirements and challenges that each element addresses.

Table 6

Additional Elements that Should Constitute SOFIEH – Elements Derived from Existing Frameworks

Existing Framework in Literature	Element adopted for SOFIEH
Mashup-based framework for multi-level healthcare interoperability (Sadeghi et al., 2011)	**TE6** prompts stakeholders to 'embrace and promote the practice of data reuse among health institutions or initiatives'.
Using SOA with Web Services for effective integration of Hospital Information Systems via an Enterprise Service Bus (Kester, 2013)	**TE7** prompts stakeholders to 'promote use of web services in developing e-health solutions'.

Note. SOA = Service oriented architecture. The elements of SOFIEH that are derived from existing frameworks are also coded to enable traceability with respect to the kind of requirements or challenges it addresses.

Each element in Tables 5 and 6 can be perceived as a sub-process in the development of interoperable e-health systems and must be executed by target users of SOFIEH. However, in order to ensure that the elements (TE1 to TE7 and ME1 to ME6) are harmoniously implemented or operationalized to guide the development of the system, the following two steps were undertaken.

The first step involved grouping elements in a logical way. The life cycle of constructing a sustainable solution, such as a building, (by Kim & Ridgon, 2005) was adapted to developing sustainable artifacts, which in this case are interoperable e-health systems. The life cycle of sustainable buildings or designs comprises 3 phases, namely, the pre-build or pre-design stage, where preparatory activities are carried out; the build or design stage, where the actual building of a solution is done; and the post-build or post-design stage, where efforts focus on ensuring the solution works according to the specified requirements (Kim & Ridgon, 2005). Thus, elements (in column 2 of Tables 5 and 6) were categorized into those that guide target users of SOFIEH on what to do at each of these stages of developing an e-health system or solution. The pre-design stage comprises elements ME1 to ME5, the design stage comprises elements TE1 to TE7, and the post-design comprises element ME6.

The second step involved synthesizing elements into a coherent solution, which can be harmoniously operationalized throughout all stages in developing interoperable e-health systems. This was done by adapting HIFA (NEHTA, 2005) because it clearly defines the three levels of e-health interoperability (organizational, information and technical levels). The original version of HIFA was adapted by extending and blending its components with elements TE1 to TE5 and ME1 to ME6 and with other service-oriented perspectives (TE6 and TE7), as indicated in Tables 5 and 6 (see the Appendix for this adapted HIFA). These additional elements supplement HIFA as sub-processes that need to be executed during the planning and implementation processes. Fig. 1 shows the derived or resultant design of SOFIEH, as a synthesis of elements for guiding the development of interoperable e-health systems in a low-income country such as Uganda.

Description of Elements in SOFIEH

The elements in Fig. 1 reflect guide the identified users of SOFIEH during the planning or pre-design stage of developing interoperable e-health systems (elements ME1 to ME5), in the building or design stage (elements TE1 to TE7), and during implementation or post-design (element ME6). These are elaborated below.

Elements for Pre-design Stage of Developing Interoperable e-Health Systems

ME1 prompts developers of e-health solutions to secure top management commitment to e-health interoperability and information sharing. To achieve ME1, the following insights are key: a) Creating a clear strategy that provides estimates of the resources required; b) Conducting senior management briefings that emphasize the expected payoffs; c) Engaging members of senior management as quality-control officers in the implementation team, who are responsible for assessing the extent to which operational efficiency the initiative is realized through prioritizing interoperability; and d) Keeping top management informed of the status of the initiative.

ME2 prompts stakeholders to develop e-health strategies for national and sub-national level entities. To realize ME2, there is need to ensure that the e-health strategy: a) Contains (or specifies the need for) architectural blue-prints or plans that spell out the desired information flows, sources of the required information, and the required consents; b) Identifies the types of information that are most important to clinical outcomes and other healthcare goals, and highlights any known difficulties in exchanging this information; c) Prioritizes clinical and healthcare outcomes and goals so as to guide the scheduling of implementations and the establishment of inter-institutional partnerships that can deliver the envisioned value of sharing healthcare information; and d) Highlights envisioned risks in data and information sharing and specifies mitigation strategies.

ME3 prompts stakeholders to formulate a value proposition for establishing shared physical infrastructure to enable information sharing. A reliable technology infrastructure supports sharing of health records by healthcare providers within a patient’s healthcare network (WHO & ITU, 2020).

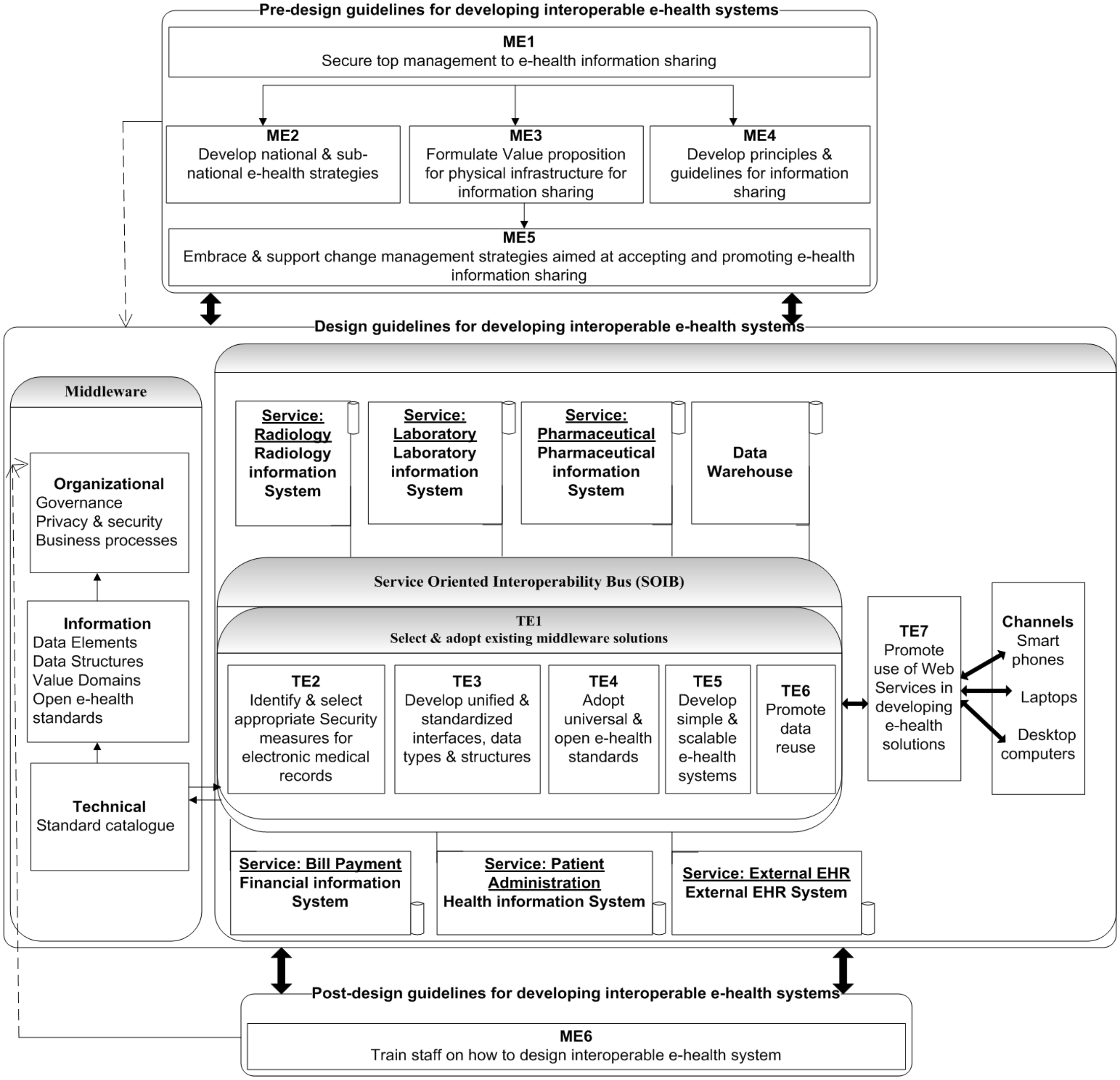
However, funding is critical in ensuring the acquisition of physical infrastructure that will deliver e-health interoperability in a sustainable way (Scheibner et al., 2021). Thus, realizing ME3 requires comprehensive engagement of top management, to collaboratively devise a sustainable model for mobilizing funding towards realizing a shared infrastructure for e-health interoperability.

ME4 prompts stakeholders to develop principles and guidelines for sharing healthcare information. According to Ndlovu et al. (2021), principles and guidelines are essential in achieving excellent stakeholder coordination and collaboration, as well as compliance with the standards of e-health interoperability. Therefore, it is necessary to develop a contextualized policy and implementation guidelines that can serve as a local standard and guide the planning, design, implementation, and evaluation of such systems. This encourages all healthcare providers to support initiatives for implementing interoperability between the e-health systems of groups of healthcare providers. Moreover, the comprehensive engagement of health managers at national, subnational, and health facility levels is critical in ensuring proper governance and appropriate development of the policy and implementation guidelines and securing the commitment of health managers to financially and technically support the shared establishment of technology infrastructure. Thus, to realize ME4, stakeholders need to be comprehensively engaged to: a) Formulate contextualized policies and guidelines for governing information sharing in healthcare; b) Regularly review policies and implementation guidelines on e-health interoperability, and ensure that they are aligned with interoperability goals of healthcare development and implementation partners; c) Continuously monitor the extent to which health facilities and e-health service providers comply to its elements; and d) Devise means of ensuring institutional compliance to principles and guidelines for e-health interoperability and sharing healthcare information.

ME5 prompts stakeholders to devise contextualized change management strategies that will promote an understanding and acceptance of e-health information sharing. Change management approaches avoid resistance by explaining reasons for a given change, the expected benefits, risks, and mitigations and hence, prepare stakeholders for a change (Payne & Frow, 2006). Informing medical specialists of the benefits of interoperable e-health solutions encourages them to support the planning, implementation, and evaluation of such solutions. This helps to overcome the existing low awareness levels on e-health interoperability at all levels in the ecosystem and thereby reduces stakeholder resistance to change. Thus, to achieve ME5, there is need to engage key stakeholders to: a) Identify all potential changes in institutions that are associated with a given e-health interoperability initiative; and b) Devise context-specific change management strategies for sensitizing key stakeholders about e-health interoperability, its benefits, and corresponding challenges.

Figure 1

Structural Composition of SOFIEH



Note. HER = Electronic health record; SOIB = service oriented interoperability bus. The elements of SOFIEH are coded so that they can be traced back to the requirements and challenges that they address.

Elements for Design Stage of Developing Interoperable e-Health Systems

TE1 encourages developers of e-health solutions to select and adopt existing middleware solutions. Tran (2016) identifies middleware as the heart of an e-health solution because it seamlessly connects multiple health records including those in legacy systems, providing a convenient, consistent, and universal view of patient records via a single platform, regardless of where it is accessed. This suggests the use of SOA-based Enterprise Service Bus (ESB) middleware to provide connectivity services between different e-health systems within and across different healthcare units. This implies that to achieve TE1, there is need for developers and IT specialists in the health sector to: a) Identify available middleware technologies; b) Collaboratively assess the strengths and weaknesses of each middleware technology with respect to the service-oriented paradigm and the contextual aspects in healthcare service delivery; and c) Collaboratively determine the most appropriate middleware technologies.

TE2 prompts stakeholders to collaboratively identify and select appropriate security measures for managing electronic medical records. Katehakis and Kouroubali (2019) emphasize the need for security measures that guarantee privacy, confidentiality, authenticity, integrity, and non-repudiation of information provided by patients and other users. However, according to Pathmaker Group (2011), the level of integration that SOA provides is compromised by the use of standard security features that are traditionally embedded into individual applications. This security deficiency can be addressed through ensuring specialized SOA security, which can take the content validation, time stamps and JavaScript protection (Pathmaker Group, 2011). Basing on these insights, achieving TE2 requires developers of e-health systems to a) Identify and catalogue potential security threats and attacks to SOA technologies; b) Identify and catalogue available security measures to address SOA threats and attacks; c) Assess the strengths and weaknesses of each security measure; and d) Determine the most appropriate security measures to use to secure SOA.

TE3 prompts developers of e-health solutions to develop unified and standardized interfaces, data types, and formats; and promote their use or adoption. The standardized data formats make it easy to link new software with existing software (Gessa et al., 2015). Standardized and interoperable interfaces can be realized through the use of the Multi-Speak specification standard (a standard for realizing the potential of enterprise application interoperability) (Gary et al., 2012). Gary et al. (2012) further indicate that the Multi-Speak specification helps vendors to develop standardized interfaces that enable software products from different systems to interoperate without requiring the development of extensive custom interfaces and can be used to support SOA in overcoming the heterogeneity of systems. Therefore, basing on MultiSpeak (2020), achieving TE3 would require: a) Defining common data semantics (an agreement about a specific item used in a business process); b) Defining data syntax, so as to support the required data interchanges; and c) Defining which messages are required to support specific steps in a business process.

TE4 prompts developers of e-health systems to adopt and use universal and open e-health standards. Open standards are encouraged because they make it easier for systems from different parties or those using different technologies, to interoperate with one another regardless of the differences in their hardware and software specifications (Almeida et al., 2011). Examples of architecture development approaches that support open standards include SOA, enterprise architecture, open standard system architecture among others (Papazoglou & Georgakopoulos, 2003). SOA-based ESB is seen as a way to speed up the application development process; and to become more agile and flexible when responding to ever-changing business needs (Fook et al., 2006). Thus, this study suggests the use of SOA-based ESB. This implies that TE4 can be achieved by a) Identifying and cataloging existing e-health standards; b) Collaboratively assessing strengths and weaknesses of each identified e-health standard with respect to context and support for service-oriented perspectives; c) Selecting contextually appropriate e-health standards from those evaluated; and d) Training staff in technical skills on how to use open standards during application development.

TE5 prompts developers of e-health solutions to develop simple but scalable systems. Scalability can be attained through use of middleware platforms because they allow the addition of non-functional features (Al-Jaroodi & Mohamed, 2011). SOA is one of the middleware platforms that embrace scalability by providing options related to granularity, enabling scalability from small to more complex distributed applications (Raghupathi & Kesh, 2007). SOA-based ESB supports scalability, because the enterprise service bus allows the dynamic addition and removal of services (Zeppenfeld & Finger, 2009). SOA allows services to run on different servers, thus increasing scalability further. Additionally, SOA (through its standard communication protocol) allows organizations to reduce the level of interaction between clients and services, which allows applications to be scaled without extra pressure (Red Hat, 2020). Thus, to achieve TE5, there is need to: a) Create an infrastructure plan that supports scalability; b) Develop proper load-sharing or distribution policies among servers, so that systems can scale and respond during heavy loads; c) Establish a scalability governance process (Shivakumar, 2015); and d) Use software pipelines which increase scalability, by providing concurrent computing of business services within and across services while preserving business rules (Linthicum, 2007).

TE6 prompts stakeholders to promote data reuse within, and between health institutions. Reusability requires the sharing of interoperability solutions, concepts, frameworks, specifications, tools and components with others (Katehakis & Kouroubali, 2019). SOA-based ESB supports the reuse of system functionalities/services, which means that valuable legacy system functionalities do not have to be discarded (Erik & Gregor, 2012). Reusing components enables new business requirements to be realized faster, which is very important for companies with legacy applications that want to improve their business agility. Thus, basing on insights from Kalali (2009), realizing TE6 implies the need for developers of e-health solutions and IT specialists in the health sector to: a) Provide standard interfaces for data/service access, such that other developers can easily access the data or service for reuse; b) Offer standardized publications of business processes of institutions, such that the respective schema data types, object definitions and underlying service components can be reused by other developers; c) Make the data or services interoperable to major technology platforms; d) Decouple services from transport, distribution, access pattern and standard messaging interfaces so as to make it easy for reusability.

TE7 prompts developers of e-health systems to promote the use of web services when developing e-health solutions. Web services enable software components to be published, located, and invoked on the web as a part of distributed applications and hence achieving interoperability between heterogeneous and distributed software components in an ad-hoc manner (Sathya, 2014). According to González et al. (2010), web services are the most common way to provide technical interoperability and are the preferred technology for implementing services in SOA. This makes SOA the most common way to provide technical interoperability among heterogeneous software systems. Thus, according to Fisher et al. (2006), achieving TE6 requires developers of e-health solutions to: a) Establish profiles for web services, which contain listings of named and versioned web services specifications, together with a set of implementation and interoperability guidelines that recommend how specifications should be used to develop an interoperable web service; b) Use interoperability guidelines in addition to references to specification or services so as to resolve ambiguities or specify how to achieve consistent usage; and c) Use testing tools to monitor and analyze interactions with a web service, to determine whether or not the messages exchanged conform to web services interoperability guidelines.

Element for Post-design Stage of Developing Interoperable e-Health Systems

ME6 prompts stakeholders to specify procedures and mechanisms for training staff on how to design, implement, operate, and maintain interoperable e-health systems. There is need for human resource capacity development to support the realization of such systems (Ndlovu et al., 2021). This calls for a specialized approach that is geared towards building local IT specialists' capacity in e-health interoperability, which could also attract collaboration with international experts and foster peer-to-peer knowledge transfer. Thus, achieving ME6, implies the need for stakeholders to a) Identify training needs for different categories of staff concerning the implementation of e-health interoperability using SOA; b) Provide specialized training, so as to equip staff with skills on how to design and operate interoperable e-health systems using SOA; and c) Conduct continuous evaluation to ascertain the impact of training in improving skill sets of staff.

EVALUATION OF SOFIEH

In design science, artifacts need to be rigorously evaluated to explore their quality in terms of usability, simplicity, understandability, functionality, completeness, traceability, applicability, utility, and efficacy (Gonzalez, 2009; Hevner et al., 2004; Offermann et al., 2009; Peffers et al., 2007). However, evaluating an artifact against a range of parameters or quality attributes takes a lot of time and some parameters are difficult to apply (Van Hee & Van Overveld, 2012) and some criteria are difficult to assess. Thus, based on the intended purpose of SOFIEH, it was considered cost effective to first assess its applicability, usability, and understandability. Assessing SOFIEH on only these three attributes did not require its deployment in a real-life context, which would have significant financial implications. Thus, the affordable evaluation that is described herein focused on investigating participants' views on the extent to which the design of SOFIEH accommodated features associated with its applicability, usability, and understandability. These are described in Table 8.

Design science artifacts can be evaluated using analytical methods, observational methods, experimental methods, and descriptive methods (Hevner et al., 2004). Given the three quality attributes that were chosen to be assessed in the first evaluation of SOFIEH, analytical methods were considered to be the most cost-effective way of guiding the evaluation. Analytical evaluation includes optimization, dynamic analysis, static analysis – assessing static qualities of the design of an artifact, and architecture analysis – assessing how an artifact fits within a given system architecture (Hevner et al., 2004). Static analysis and architecture analysis seem to be the only methods that can support analytical evaluation of artifacts that are not in execution mode. In this study, static analysis was considered most appropriate. Analytical evaluation can be done using techniques such as usability inspections and structured walkthroughs with subject matter experts (Jody, 2017; Sharp et al., 2007). In this study, SOFIEH was evaluated using structured walkthroughs. This involved engaging medical and IT specialists as subject matter experts in the context of this study. Twenty participants were purposively selected from ten healthcare units (as the intended end users of SOFIEH) and six from e-health development projects (with IT specialists who were willing to participate in the study). Table 7 specifies how the walkthroughs were conducted.

Evaluation Findings

A total of 26 participants were engaged to evaluate SOFIEH (see Table 7). For each of the three chosen quality attributes in the evaluation, statements were composed to serve as evaluation criteria or key features that the artifact should possess if it is to satisfy a given quality attribute (see column 2 of Table 8). Participant responses to prompts associated with the evaluation criteria were captured using a 5-point Likert scale, where 1 is Strongly Disagree (SD), 2 is Disagree (D), 3 is Neutral (N), 4 is Agree (A), and 5 is Strongly Agree (SA). Accordingly, percentages of participants' views or responses on SOFIEH's applicability, usability, and understandability are presented in columns 3 to 5 of Table 8.

Table 7

Summary on the Setup of Walkthroughs Used in the Analytical Evaluation of SOFIEH

No	Parameter	How each parameter was addressed in the evaluation
1.	Aim of the evaluation	The aim of each walkthrough was to explain the layout and composition of SOFIEH to a selected participant and elicit the participant's views on the set of evaluation criteria, so as to identify and eliminate faults in the design of SOFIEH.
2.	Target participants in the evaluation exercise and response rate	• First, twenty medical practitioners and computing practitioners were purposively selected from 10 health facilities (where at least 2 personnel were selected from each health facility). However, only 16 participants responded in the evaluation exercise and provided their views using an evaluation questionnaire (that contained prompts/questions indicated in Table 8). • Second, six software developers with experience in implementing e-health solutions in Uganda were purposively selected and they all participated in the evaluation exercise. • Therefore, the evaluation involved a total of 22 participants and the response rate was 85%.
3.	Inputs of the evaluation exercise	Before the walkthrough session, participants were provided with 4 items: • Communication about the role of the participant in the walkthrough and expectations from the walkthrough • The structural composition of SOFIEH (i.e., the initial version of Fig.1), • The description of SOFIEH elements, and • A questionnaire for evaluating the design of SOFIEH, comprised of questions to elicit participant views on the quality criteria (see Table 8).
4.	Agenda of the evaluation exercise	The walkthrough sessions involved: • Explaining the purpose and design of SOFIEH and the purpose of the evaluation • Discussion of elements in SOFIEH and their underlying guidelines/principles • Discussion of feedback from a participant on characteristics of the SOFIEH's design with respect to the quality attributes and insights on how its design could be improved.
5.	Evaluation instrument/tool	• Key questions in the questionnaire (that were used to assess its applicability, usability, and understandability) are shown in Table 8 column 2.
6.	Outputs of the evaluation exercise	• Feedback regarding the extent to which the design of SOFIEH fulfilled the quality attributes or evaluation criteria specified above (see columns 3 to 5 in Table 8).

Note. SOFIEH = Service oriented framework for developing interoperable e-health systems in a low-income country.

Table 8

Evaluation Findings on SOFIEH from Participants in the Evaluation

#	Findings on Applicability of SOFIEH	D + SD	N	A +SA
(i)	SOFIEH accommodates elements that are likely to address key challenges hindering (or requirements for realizing) e-health interoperability in low-income countries.	15.7%	2.6%	81.7%
(ii)	SOFIEH's elements provide insights into guidelines or principles that can be followed by target users during the planning, implementation, and maintenance of interoperable e-health solutions.	12.0%	4.2%	83.8%
(iii)	SOFIEH's individual elements can be applied in the real-life operational context of key stakeholders.	14.3%	2.0%	83.7%

#	Findings on Usability of SOFIEH	D + SD	N	A + SA
(i)	The design or visual layout of SOFIEH does not have aspects/features that can cause confusion and ambiguity for a user, or that can negatively affect its successful use.	6.2%	0.6%	93.2%
(ii)	The design or visual layout of SOFIEH is presented using a format that can be (easily) followed by a user (with little or no training).	7.6%	1.4%	91.0%
(iii)	SOFIEH can be comfortably used by target users to realize its intended purpose even in the absence of its developers.	8.3%	0.5%	91.2%
#	Findings on Understandability of SOFIEH	D + SD	N	A + SA
(i)	SOFIEH's phases/steps, elements, and their guidelines are described in a language that is understandable by target users (with little or no training).	6.0%	0.5%	93.5%
(ii)	SOFIEH's elements and their interactions or interdependencies are understandable by target users.	10.2%	1.2%	88.6%
(iii)	SOFIEH's phases/steps, corresponding elements, and corresponding guidelines or principles are interdependent.	8.8%	3.3%	87.9%

Note. SD = strongly disagree; D = disagree; N = neutral; A = agree; SA = strongly agree; SOFIEH = service oriented framework for developing interoperable e-health systems in a low-income country.

Findings in Table 8 indicate that SOFIEH's general score on the three quality attributes is good. Considering the percentages of participants who gave positive responses (i.e., A + SA) in column 5 of Table 8:

- For applicability of SOFIEH, average proportion of positive responses is 83%.
- For usability of SOFIEH, average proportion of positive responses is 91.8%
- For understandability of SOFIEH, average proportion of positive responses is 90%.

In addition, 84% of participants in the evaluation indicated that they would recommend the adoption of SOFIEH as a mechanism for supporting planning and implementation of interoperable e-health systems. This is because "there are hardly explicit guidelines for supporting development of interoperable e-health systems" (as indicated by 79% of the participants). SOFIEH addresses this gap by providing key phases/steps, elements, and underlying guidelines that can be followed to achieve e-health interoperability (as indicated by 77% of the participants). Qualitative responses on how to improve the applicability, usability, and understandability of SOFIEH were addressed in the version of SOFIEH that is presented in Fig. 1. Additional views that could not be addressed in this paper are to be addressed in future work (as elaborated in the next section).

CONCLUSION AND FUTURE WORK

Due to various contextual issues, existing e-health interoperability frameworks are difficult to adopt and hence are not readily implemented in low-income countries. As a *building block* towards addressing this gap, this paper provides answers to three research questions that are specified in the introduction.

The first question (A) raises issues hindering development of interoperable e-health solutions in Uganda (as an instance of a low-income country). The second question *(B)* looks for ways of addressing hindrances to e-health interoperability. Ninety healthcare and IT specialists from 67 health facilities in Uganda participated in an exploratory survey probing contextual challenges hindering e-health interoperability in order to explore these research questions. Key issues highlighted in the results were the lack of unified healthcare standards across healthcare units, the use of legacy systems, incompatible clinical terminologies across healthcare units, inadequate security measures in managing personal health data, the scarcity of trained staff to operate interoperable e-health systems, resistance to interoperability efforts from owners of existing disparate systems, a lack of guidelines/policies for sharing information across healthcare units, an ineffective or no e-health strategy at national and institutional levels, and insufficient funds to acquire shared physical infrastructure.

e-Health systems requirements to address the challenges were derived from the survey findings and from existing frameworks and best practices for e-health interoperability. Key requirements include the need to: devise adequate security mechanisms in managing electronic patient medical information; adopt standardized and interoperable interfaces; use middleware platforms; adopt universal and open e-health standards; develop simple but scalable e-health systems; train staff on how to operate such systems; implement change management strategies; enact policies and guidelines to support information sharing; develop an e-health strategy that streamlines e-health implementation efforts at national and institutional levels; secure top management commitment to sharing information; and acquired dedicating funds from top management towards a shared physical infrastructure.

The third question (C) derives elements that should constitute SOFIEH as a mechanism for guiding the development of interoperable e-health solutions in a low-income country. To address this, the elements needed to address specific requirements for e-health interoperability were identified from existing literature on service-oriented approaches. The elements were classified and a synthesis (coined as SOFIEH) of elements was compiled by adapting concepts from two major existing approaches – the Sustainable Design Model (Kim & Ridgon, 2005) and the HIFA (e-Health Interoperability Framework for Australia) (NEHTA, 2005). The design or structural layout of SOFIEH depicts three phases (the pre-design, design, and post-design phases of e-health systems); and two main components (the interoperability layer and the SOIB layer). The interoperability layer was adapted from the HIFA. This research presents the SOIB layer as an extension of HIFA as a way to address the particular requirements for e-health interoperability in a low-income country. In addition, the SOIB layer shows how technical interoperability can be realized.

The most cost-effective way to evaluate the design of SOFIEH was considered to be to conduct structured walkthroughs in which medical and IT specialists at health facility level, and software developers who are specialists in implementing e-health solutions were engaged. The evaluation focused on assessing the applicability, usability, and understandability of SOFIEH. Findings from the evaluation of SOFIEH by a sample of 22 medical and IT specialists indicate that it is likely to achieve its intended purpose, because it scored well on the quality attributes of applicability, usability, and understandability.

Theoretical Contributions to the ICT4D Knowledge Base

Gregor (2006) specifies five categories of theory in information systems research: A) those focusing on analysis of phenomena in a given context; B) those focusing on explaining the how, why, when, and where details of phenomena in a given context; C) those focusing on predicting what is and what will be aspects of phenomena in a given context; D) those focusing on explaining and predicting details of what is, how, why, when, where, and what will be aspects of phenomena in a given context; and E) those focusing on design and action – specific prescriptions on the composition of an artifact in form of methods, techniques, principles of form and function. Based on this taxonomy, SOFIEH can be perceived as a design and action type of theory because SOFIEH is a method that specifies tasks that key stakeholders need to execute in order to develop interoperable e-health systems in a low-income country. SOFIEH is represented in three forms: (i) Tables 5 and 6 show the catalogue of its elements; (ii) Fig. 1 is the structural setup and orchestration or synthesis of its elements; and (iii) the description of elements TE1 to TE7 and ME1 to ME6 is the articulation of tasks involved in each element and expected outputs thereof.

In addition, under the design and action type of theory, Gregor and Jones (2007) classify artifacts into two types: (A1) theories or abstract artifacts in the form of constructs, models, methods, and principles; and (A2) a material artifact derived from instantiating a theory, which could be in the form of an instantiated product or instantiated method. Based on this classification, SOFIEH is an artifact under category A1 since it is a method for building interoperable e-health systems in a low-income country. This implies that if SOFIEH is instantiated (in future work) to guide the implementation of at least one real life project involving the development of an interoperable e-health solution in Uganda, such an effort will yield a contribution under category A2.

Contributions to the ICT4D Practice

Each element of SOFIEH comprises high level guidelines or prescriptions of what has to be done to implement it. However, to accelerate the implementation of the prescribed elements of SOFIEH, there is a need to clarify key operational aspects that can maximize its adoption within and across e-health implementation projects. For example, to provide actionable guidance towards the realization of all prescribed guidelines, it is vital to specify the intended users or stakeholders of specific elements in SOFIEH and their corresponding responsibilities. To achieve this, guidelines by Van Biljon and Osei-Bryson (2020) on creating knowledge visualizations that can effectively communicate context to stakeholders are adopted and instantiated in Tables 9 and 10.

Table 9

Guidance on the Adoption and Operationalization of SOFIEH

Key parameters in knowledge visualization for effective communication (based on van Biljon and Osei-Bryson, 2020) and their instantiations to guide adoption and operationalization of SOFIEH
1) Why visualize – reason or motivation for visualizing information/guidance on SOFIEH's operationalization: The purpose of this summary visualization is to guide stakeholders in e-health implementation efforts on how to adopt and operationalize SOFIEH, so as to address the requirements for e-health interoperability.
2) Visualize for whom – target audience or intended recipients of the visualization of information/guidance on SOFIEH's operationalization: e-Health managers, funders/sponsors of e-health initiatives, development teams or innovators of e-health solutions, end-users of e-health solutions.
3) What is relevant – type of knowledge visualized in the operationalization guidance on SOFIEH: Practical insights/actions on how to operationalize SOFIEH in a given e-health project, which essentially specify which actors to engage in operationalizing SOFIEH elements and their roles or responsibilities. These are explained in detail below.
4) How to visualize the adoption or operationalization guidance of SOFIEH – means of visualizing knowledge so as to effectively communicate: Table 10 is used to present the summary of actors in operationalizing SOFIEH elements and their responsibilities.

Note. SOFIEH = service oriented framework for developing interoperable e-health systems in a low-income country.

Table 10

Required Teams for the Adoption and Operationalization of SOFIEH

Required teams that should be constituted in an e-health project	Specific responsibilities of teams and elements of SOFIEH that a given team should focus on.
1) Applications development team	• Responsible for executing activities under elements TE1, TE2, TE5, TE7 so as to obtain an intelligent and interactive knowledge base that can crowd-source, process, and evaluate information on: a) Middleware solutions for e-health initiatives b) Security threats, measures, and best practices c) Best practices for modularity and scalability of e-health solutions
2) Standards enforcement team	• Responsible for executing activities under element TE4, which serves a governance-related or compliance adherence role for elements TE1 to TE3, TE5 to TE7, and ME1 to ME6.
3) Data quality management team	• Responsible for executing activities under elements TE3 and TE6 so as to promote data standardization and reuse.
4) Strategy development team	• Responsible for executing activities under elements ME1 to ME4 so as to develop and enforce implementation of appropriate policies, sustainable funding models, and e-health strategies.
5) Deployment, user support, and evaluation team	• Responsible for executing activities under elements ME5 and ME6, so as to ensure continuous monitoring and evaluation of the success of e-health interoperability efforts; and proactively address change management aspects

Note. SOFIEH = service oriented framework for developing interoperable e-health systems in a low-income country. Codes TE1 to TE7 and ME1 to ME6 are codes of elements that constitute SOFIEH, and they are defined in tables 5 and 6.

Future Work

SOFIEH concentrates on supporting the realization of the technical level of interoperability. Thus, there is need to extend SOFIEH with elements that can further support the realization of the informational and organizational levels of interoperability. Also, there is need to empirically evaluate SOFIEH using case studies of specific e-health systems that need to acquire a certain level of e-health interoperability. Such an evaluation will yield insights towards extending the design of SOFIEH, to ensure that it can fully support service-oriented planning, implementation, and evaluation of interoperable e-health solutions in a low-income country. Furthermore, there is need to extend SOFIEH with a mechanism that supports comprehensive user involvement in the continuous evaluation of the interoperability of e-health solutions, so as to proactively identify interoperability needs in existing and planned e-health solutions. Such an approach is envisioned to elicit perspectives that will further guide contextualization during the development of interoperable e-health solutions, create a sense of ownership, and partially address the issue of resistance to change, because peer-to-peer interactions will lead to an increased understanding of the need for e-health interoperability.

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REFERENCES

Achampong E. K. (2012). The state of information and communication technology and health informatics in Ghana. *Online Journal of Public Health Informatics, 4*(2). 1-13. https://doi.org/10.5210%2Fojphi.v4i2.4191

Adebesin, F., Foster, R., Kotz, P., & Greuneny, D. (2013). A review of interoperability standards in e-health and imperatives for their adoption in Africa. *South African Computer Journal*, *50*(1), 55-57. https://hdl.handle.net/10520/EJC139542

Aderonke, O., Akinde, N., Goga, N., & Oludele, A. (2013). Gaining the competitive advantage in e-health interoperability solutions. *International Research Journal of Computer Science and Information Systems*, *2*(4), 58-64.

Alanezi, F. (2021). Factors affecting the adoption of e-health system in the Kingdom of Saudi Arabia. *International Health*, 13(5). 456-470. https://doi.org/10.1093/inthealth/ihaa091

Al-jaroodi, J., & Mohamed, N. (2011). Service-oriented middleware. *Journal of Network and Computer Application*, *35*, 211-220. https://doi.org/10.1016/j.jnca.2011.07.013

Almeida, F., Oliveira, J., & Cruz, J. (2011). Open standards and open source: Enabling interoperability. *International Journal of Software Engineering & Applications (IJSEA)*, *2*(1), 1-11. https://doi.org/10.5121/ijsea.2011.210

Al-Shorbaji, N., Househ, M.S., Taweel, A., Alanizi, A., Mohammed, B.O., Abaza, H., Bawadi, H.A., Rasuly, H., Alyafei, K., Fernández-Luque, L., Shouman, M.G., El-Hassan, O.E., Hussein, R., Alshammari, R., Mandil, S., Shouman, S., Taheri, S., Emara, T.H., Dalhem, W., Al-Hamdan, Z. M., & Serhier, Z. (2018). Middle East and North African health informatics association (MENAHIA) – Building sustainable collaboration. *Yearbook of Medical Informatics*, 27(1), 286 - 291. https://doi.org/10.1055/s-0038-1641207

Alunyu, A., Wamema, J., Kiwanuka, A., Moses, B., Amiyo, M., Kambugu, A. & Nabukenya, J (2021) Investigating the impediments to accessing reliable, timely and integrated electronic patient data in healthcare sites in Uganda. In *Proceedings of the 14th International Joint Conference on Biomedical Engineering Systems and Technologies*, (Vol. 5, pp. 522-532). Science and Technology Publications. https://doi.org/10.5220/0010266705220532

Archer, N., Lokker, C., Ghasemaghaei, M & DiLiberto, D. (2021). eHealth implementation issues in low-resource countries: Model, survey, and analysis of user experience. *Journal of Medical Internet Research. 23*(6). 1-12. https://doi.org/10.2196/23715

Anderson, P. (2007). *What is Web 2.0? Ideas, technologies and implications for education*. JISC Technology and standards watch. http://21stcenturywalton.pbworks.com/f/What%20is%20Web%202.0.pdf

Atalag, K. (2013). Using a single content model for e-health interoperability and secondary use. *Studies in Health Technology and Informatics*, *193*, 282–296.

Avison, D., & Young, T. (2007). Time to rethink health care and ICT? *Communications of the ACM*, *50*(6), 69-74.

Bauer, J, Rohner-Rojas, S., & Holderried, M. (2020). Cross-enterprise interoperability: Challenges and principles for technical implementation. *Dadiologe, 60*, 334–341. https://doi.org/10.1007/s00117-019-00626-9

Babyl (2019). *Babylon – The largest digital health service provider in Rwanda*. Retrieved on August 7, 2021, from https://www.babyl.rw

Bediang, G., Perrin, C., Castaneda, R. R. D., Kamga, Y., Sawadogo, A., Bagayoko, C. O., & Geissbuhler, A (2014). The RAFT telemedicine network: Lessons learnt and perspectives from a decade of educational and clinical services in low- and Middle-incomes countries. *Frontiers in Public Health*, *2*(1), Article 180. https://doi.org/10.3389/fpubh.2014.00180

Bestek, M., & Stanimirović, D. (2017). Special topic interoperability and EHR: Combining open EHR, SNOMED, IHE, and continua as approaches to interoperability on national eHealth. *Applied Clinical Informatics*, *8*(3), 810–825. https://doi.org/10.4338/ACI-2017-01-RA-0011

Biltoft, J & Finneman L. (2018). Clinical and financial effects of smart pump-electronic medical record interoperability at a hospital in a regional health system. *American Journal of Health-System Pharmacy*, *75*(14), 1064-1068. https://doi.org/10.2146/ajhp161058

Bincoletto, G (2020). Data protection issues in cross-border interoperability of electronic health record systems within the European Union. *Data & Policy*, *2*(3), 1–11. https://doi.org/10.1017/dap.2020.2

Bhuyan, B., Sarma, H. D., & Sarma, N. (2014). A survey on middleware for wireless sensor networks. *Journal of Wireless Networking and Communications*, *4*(1), 7-17. https://doi.org/10.5923/j.jwnc.20140401.02

Bock, C., Carnahan, L., Fenves, S., Gruninger, M., Kashyap, V., Lide, B., Nell, J., Raman, R., & Sriram, R. (2005). *Healthcare strategic focus area: Clinical informatics*. National Institute of Standards and Technology. https://nvlpubs.nist.gov/nistpubs/Legacy/IR/nistir7263.pdf

Boyd, A. D., Saxman, P. R., Hunscher, D. A., Smith, K. A., Morris, T. D., & Kaston, M (2009). The University of Michigan honest broker: A web-based service for clinical and translational research and practice. *Journal of the American Medical Informatics Association*, *16*(6), 784-79. https://doi.org/10.1197/jamia.M2985

Bridges, M. W. (2007). SOA in healthcare, sharing system resources while enhancing interoperability within and between healthcare organizations with service-oriented architecture. *Health Management Technology*, *28*(6). 6-10.

Canfora, G., Fasolino, A., Frattolillo, G., & Tramontana, P. (2008). A wrapping approach for migrating legacy system interactive functionalities to service-oriented architectures. *Journal of Systems and Software*, *81*(4). 463-480. https://doi.org/10.1016/j.jss.2007.06.006

Car, J., Tan, S. W., Huang, Z., Sloot, P., & Franklin, B. D. (2017). eHealth in the future of medications management: Personalization, monitoring and adherence. *BMC Medicine*, *15*, Article 73. https://doi.org/10.1186/s12916-017-0838-0

Charalabidis, Y., Lampathaki, F., & Askounis, D. (2009). A review of interoperability standards and initiatives in electronic government. In *Proceedings of the* Mediterrranean Conference of Information Systems, (pp. 1487-1501). Association for Information Systems. https://aisel.aisnet.org/cgi/viewcontent.cgi?article=1128&context=mcis2009

Chen, L. (2012). Integrating Cloud Computing services using enterprise service bus. *Business and Management Research*, *1* (1), 26-31.

Cho, Y., Kim, M. & Choi, M (2021). Factors associated with nurses' user resistance to change of electronic health record systems. *BMC Medical Informatics Decision Making*, *21*(1), 1-12. https://doi.org/10.1186/s12911-021-01581-z

Costa, C., Tortosa, M., & Breis, J. (2011). Clinical data interoperability based on archetype transformation. *Journal of Biomedical Informatics*, *44*(5), 869-880. https://doi.org/10.1016/j.jbi.2011.05.006

Cruickshank, J., Packman, C., & Paxman, J. (2012). *Personal health records: Putting patients in control?* 2020health.org. Retrieved July 27, 2021, from https://2020health.org/publication/personal-health-records-putting-patients-in-control/

Daniel, F., & Matera, M. (2014). Data and application integration. In *Mashups* (pp. 15-40). Springer.

Dawes, S. S. (1996), Interagency information sharing: Expected benefits, manageable risks. *Journal of Policy Analysis and Management*, *15*(3), 377-394. https://doi.org/10.1002/(SICI)1520-6688(199622)15:3%3C377::AID-PAM3%3E3.0.CO;2-F

Hammond, W. E. (2008). eHealth interoperability. *Studies in Health Technology and Informatics*, *134*, 245-253.

Eng, T. (2001). The e-health landscape: A terrain map of emerging information and communication technologies in health and health care. Robert Wood Johnson Foundation.

Erik, F., & Gregor, S. (2012). *Conception of implementing a service-oriented architecture (SOA) in a legacy environment*. IDEAS. Retrieved on April 10, 2021, from http://ideas.repec.org

Fichman, G., Kohli, R. & Krishnan, R. (2011). The role of information systems in healthcare: Current research and future trends. *Information Systems Research*, *22*(3), 419−327. https://doi.org/10.1287/isre.1110.0382

Fisher, M., Lai, R., Sharma, S., & Moroney, L. (2006) Java EE and .NET interoperability: Integration strategies, patterns and best practices. Pearson.

Fook, V. F. S., Maniyeri, J., Wai, A. A. P., Thang, P. V., & Biswas, J. (2006). Service oriented architecture for patient monitoring application. In *Proceedings of the 2006 4th IEEE International Conference on Industrial Informatics* (pp. 160-165). IEEE. https://doi.org/10.1109/INDIN.2006.275753

Furusa, S. S., & Coleman, A. (2018). Factors influencing e-health implementation by medical doctors in public hospitals in Zimbabwe. *South African Journal of Information Management,* 20(1), 1-9. https://doi.org/10.4102/sajim.v20i1.928

Gambo, I., Oluwatolani, O., & Achimugu, P. (2011). Lack of interoperable health information systems in developing countries: An impact analysis. *Journal of Health Informatics in Developing Countries*, *5*(1), 186-196.

Gazzarata, R; Giannini, B and Giacomini, M. (2017). A SOA-based platform to support clinical data sharing. *Journal of Healthcare Engineering*, *2017,* Article 2190679. https://doi.org/10.1155/2017/2190679

Gessa, N., Frascella, A & De Sabbata, P. (2015). Supporting software interoperability using standardised interfaces: Issues and needs. In M. Zelm (Ed.), *Proceedings of the 6th Workshop on Enterprise Interoperability*. https://ceur-ws.org/Vol-1414/paper12.*pdf.*

George, C., Whitehouse, D., & Duquenoy, P. (Eds.). (2012). *eHealth: Legal, ethical and governance challenges*. Springer.

Granja, C., Janssen, W., & Johansen, M. A. (2018). Factors determining the success and failure of eHealth interventions: systematic review of the literature. *Journal of Medical Internet Research*, *20*(5), Article 10235. https://doi.org/10.2196/10235

Gonzalez, R. A. (2009). Validation of crisis response simulation within the design science framework. In *Proceedings of the International Conference on Information Systems 2009*, (pp. 1-8). Association of Information Systems.

González, L., Llambías, G., & Pazos, P (2010). Towards an e-health integration platform to support social security services. In *Proceedings of the 6th International Policy and Research Conference on Social Security*. International Social Security Association. https://ww1.issa.int/sites/default/files/external-references/files/2Gonzalez-paper_3-1--57728.pdf.

Gary, A. M., Robinson, G., & Gray, G. R. (2008). *MultiSpeak and IEC 61968 CIM: Moving towards interoperability*. Grid-Interop Forum. https://www.multispeak.org/wp-content/uploads/2016/11/GridInterop08MultiSpeakCIMInteroperability_Final_110308.pdf

Gregor, S. (2006). The nature of theory in information systems. *MIS Quarterly, 30*(3), 611-642. https://doi.org/10.2307/25148742

Gregor, S., & Jones, D. (2007). The anatomy of a design theory. *Journal of the Association for Information Systems*, *8*(5), 312-335.

Gregor, S., Chandra Kruse, L., & Seidel, S. (2020). Research perspectives: the anatomy of a design principle. *Journal of the Association for Information Systems, 21*(6), Article 2. https://doi.org/10.17705/1jais.00649

Global Digital Health Partnership. (2020) *Advancing interoperability together globally*. White Paper on Interoperability. https://www.healthit.gov/sites/default/files/page/2021-01/GDHP Advancing%20Interoperability%20Together%20Globally.pdf

Guo, Y., Hu, Y., Afzal, J., & Bai, G. (2011). Using P2P technology to achieve eHealth interoperability. In *Proceedings of the 8th International Conference on Service Systems and Service Management*, (pp. 1-5). IEEE. https://doi.org/10.1109/ICSSSM.2011.5959430

Halamka, J., Overhage, J., Ricciardi, L., Rishel, W., Shirky, C., & Diamond, C. (2005). Exchanging Health Information: Local Distribution, National Coordination. *Health Affairs Health Systems Trust*, *24*(5), 1170-1179. https://doi.org/10.1377/hlthaff.24.5.1170

Heacock, M. L., Lopez, A. R., Amolegbe, S. M., Carlin, D. J., Henry, H. F., Trottier, B. A., Velasco, M. L & Suk, W. A. (2022). Enhancing data integration, interoperability, and reuse to address complex and emerging environmental health problems. *Environ Sci Technol*, *56*(12), 7544-7552. https://doi.org/10.1021/acs.est.1c08383

Health Information Management System Society. (2023). *Interoperability in healthcare podcast*. Retrieved June 8, 2023, from http://www.himss.org/interoperability-healthcare

Hevner, A., March, S., Park, T., & Ram, S. (2004). Design science in information systems research. *MIS Quarterly*, *28*(1), 75-105. https://doi.org/10.2307/25148625

Heeks, R. (2003). *Most eGovernment-for-development projects fail: How can risks be reduced*? (e-Government Working Paper No. 14). SSRN. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3540052

Hollin, E. A., Barry, J & Kachnowski, S. (2010). Barriers to cross-institutional health information exchange: A literature review. *Journal of Healthcare Information Management, 24*(3), 22-34.

Hosseini, M., Ahmadi, M and Dixon, E. B. (2014). A service-oriented architecture approach to achieve interoperability between immunization information systems in Iran. In *AMIA Annual Symposium Proceedings*, (pp. 1797-1805). National Library of Medicine.

International Telecommunication Union. (2008). *Implementing e-health in developing countries: Guidance and principles*. Retrieved March 13, 2020, from http://www.itu.int/ITU-T/e-health-prefinal

International Telecommunication Union. (2012). E-health standards and interoperability. Retrieved March 14, 2020, from http://www.itu.int/ITU-T/techwatch

Iroju, O., Gambo, S., & Olaleke, J. (2013). Interoperability in healthcare: Benefits, challenges and resolutions. *International Journal of Innovation and Applied Studies, 3*(1), 262-270. http://www.issr-journals.org/ijias/

Ittefaq, M & Iqbal, A (2018). Digitization of the health sector in Pakistan: Challenges and opportunities to online health communication: A case study of MARHAM social and mobile media. *Digital Health*, *4*, 1–13. https://doi.org/10.1177/2055207618789281

Jody, P. (2017). Structured walkthroughs and formal technical reviews. Retrieved October 10, 2022, from http:// www.jodypaul.com/SWE/WT/walkthroughs.html

Kaplan, B. (2020). Revisiting health information technology ethical, legal, and social issues and evaluation: Telehealth/telemedicine and COVID-19. *International Journal of Medical Informatics*, *143*, Article 104239. https://doi.org/10.1016/j.ijmedinf.2020.104239

Katehakis, D. G., & Kouroubali, A. (2019). A Framework for eHealth Interoperability Management. *Journal of Strategic Innovation and Sustainability*, *14*(5), 51-61.

Kalali, M (2009). *Building reusable services*. Retrieved October 11, 2022, from https://dzone.com/articles/building-reusable-services/

Kaushal, R., Kern, L. M., Barrón, Y., Quaresimo, J., & Abramson, E. L. (2010). Electronic prescribing improves medication safety in community-based office practices. *Journal of General Internal Medicine*, *25*(6), 530–536. https://doi.org/10.1007/s11606-009-1238-8

Kester, Q. (2013). Using SOA with web services for effective integration of hospital information systems via an enterprise service bus. *International Journal of Research in Engineering and Advanced Technology*, *1*(2), 1-6. https://doi.org/10.48550/arXiv.1307.7790

Kiberu, V. M., Mars, M & Scott, R. E. (2017). Barriers and opportunities to implementation of sustainable e-Health programmes in Uganda: A literature review. *African Journal of Primary Health Care and Family Medicine, 9*(1). 2071-2928. https://hdl.handle.net/10520/EJC-9762b8fd2

Kiberu, V. M., Scott, R. E & Mars, M. (2019). Assessing core, e-learning, clinical and technology readiness to integrate telemedicine at public health facilities in Uganda: a health facility – based survey. *BCM Health Services Research, 19*, Article 266. https://doi.org/10.1186/s12913-019-4057-6

Kim, J., & Rigdon, B. (2005). *Sustainable architecture module: Introduction to sustainable design*. National Pollution Prevention Center for Higher Education. Retrieved June 30, 2021, from http://www.umich.edu/~nppcpub

King, G., O'Donnell, C., Boddy, D., Smith, F., Heaney, D., & Mair, F. S. (2012). Boundaries and e-health implementation in health and social care. *BMC Medical Informatics and Decision Making*, *12*(1), 1-11. https://doi.org/10.1186/1472-6947-12-100

Kolodner, R. M., Cohn, S. P., & Friedman, C. P. (2008). Health information technology: Strategic initiatives, real progress. *Health Affairs Project Hope*, *27*(5), 391–395. https://doi.org/10.1377/hlthaff.27.5.w391

Kuziemsky, C., & Weber-Jahnke, J. (2009). An ebusiness-based framework for ehealth interoperability. *Journal of Emerging Technologies in Web Intelligence*, *1*(2), 129-136. https://doi.org/10.4304/jetwi.1.2.129-136

Kujala, S., Ammenwerth, E., Kolanen, H., & Ervast, M. (2020). Applying and extending the FITT framework to identify the challenges and opportunities of successful eHealth services for patient self-management: Qualitative interview study. *Journal of Medical Internet Research*, *22*(8), Article 17696. https://doi.org/10.2196/17696

Kyalo, C., Odhiambo-Otieno, G., Otieno, G., & Tenambergen, W. (2018). Technical factors influencing integration of health management information systems in the health system in Kenya. *International Journal of Scientific and Research Publications, 8*(8), 161-167. https://doi.org/10.29322/IJSRP.8.8.2018.p8021

Lancaster, K., Abuzour A., Khaira M., Mathers A., Chan A., Bui V., Lok A., Thabane L., & Dolovich L. (2008). The use and effects of electronic health tools for patient self-monitoring and reporting of outcomes following medication use: Systematic review. *Journal of Medical Internet Research, 20*(12), Article 294. https://doi.org/10.2196/jmir.9284

Landsbergen, D. J., & Wolken, G. J. (2001). Realizing the promise: Government information systems and the fourth generation of information technology. *Public Administration Review, 61*(2), 206-220. https://doi.org/10.1111/0033-3352.00023

Laskaridis, G., Markellos, K., Panayiotaki, A., Sakkopoulos, E., & Tsakalidis, A. (2007). E-government and interoperability issues. *International Journal of Computer Science and Network Security*, *7*(9), 28-38.

Lau, L., & Shakib, S. (2005). Towards data interoperability: Practical issues in technology implementation and mapping. Retrieved December 20, 2022, from https://library.ahima.org/doc?oid=59324

Lenz, R., Beyer, M., & Kuhn, A. (2005). Semantic integration in healthcare networks. *Connecting Medical Informatics and Bio-Informatics*, *76* (2-3), 201-207. https://doi.org/10.1016/j.ijmedinf.2006.05.008

Li, E., Clarke, J., Ashrafian, H., Darzi, A., & Neves, A. L. (2022). The impact of electronic health record interoperability on safety and quality of care in high-income countries: Systematic review. *Journal of Medical Internet Research*, *24*(9), Article 38144. https://doi.org/10.2196/38144

Linthicum, D. (2007). Scalable SOA solutions continue to emerge. Retrieved October 12, 2022, from https://www.infoworld.com/article/2641422/scalable-soa-solutions-continue-to-emerge.html

Malley, A., Grossman, J., Cohen, N., Kemper, & Pham, H. (2010). Are electronic medical records helpful for care coordination? Experiences of physician practices. *Journal of General Internal Medicine*, *25*, 177-185. https://doi.org/10.1007/s11606-009-1195-2

Manpaa, T., Suominen, T., Asikainen, P., Maass, M., & Rostila, I. (2009). The outcomes of regional health care information systems in health care: A review of the research literature. *International Journal of Medical Informatics, 78*(11), 757-77. https://doi.org/10.1016/j.ijmedinf.2009.07.001

Mandirola Brieux H. F., Bhuiyan Masud J. H., Kumar Meher S., Kumar, V., Portilla, F., Indarte, S., Luna, D., Otero, C., Otero, P., & Gonzalez Bernaldo de Quirós, F. (2015). Challenges and hurdles of ehealth implementation in developing countries. *Studies in Health Technology and Informatics*, *216*, 434-437.

Mburu, S. & Oboko, R. (2018). A model for predicting utilization of mHealth interventions in low-resource settings: Case of maternal and newborn care in Kenya. *BMC Medical Informatics Decision Making*, *18*(1), 1-16. https://doi.org/10.1186/s12911-018-0649-z

Milosevic, Z. (2006). Addressing interoperability in e-health: An Australian approach. *In Proceedings of the 10th International Enterprise Distributed Object Computing Conference Workshops*, (pp. 1-7). IEEE. https://doi.org/10.1109/EDOCW.2006.17

Mugo, D. M., & Nzuki, D. (2014). Determinants of electronic health in developing countries. *International Journal of Arts and Commerce*, *3*(3), 49-60. http://hdl.handle.net/123456789/289

Muhaise, H., Muwanga-zake, J. W. F. & Kareeyo, M. (2019). Assessment model for electronic health management information systems success in a developing country context: A case of the greater Bushenyi districts in Uganda. *American Scientific Research Journal for Engineering Technology, and Sciences, 61*(1), 167–185.

Mwakilama, S., Chawani, M., Monawe, M., Kapokosa, G., & Gadabu, O. (2014). Interoperability, integration, and standardization of e-health initiatives in Malawi: Current efforts and prospects. In *Proceedings and Report of the 7th UbuntuNet Alliance Annual Conference,* (pp. 285-294). UbuntuNet Alliance. https://repository.ubuntunet.net/handle/10.20374/163

MultiSpeak. (2020). *Demystifying multiSpeak*. Retrieved October 12, 2022, from https://www.multispeak.org/what-is-multispeak

Nakakawa, A., Bommel, P. V., & Proper, H. E. (2013). Supplementing enterprise architecture approaches with support for executing collaborative tasks – A case of TOGAF ADM. *International Journal of Cooperative Information Systems*, *22*(02), Article 1350007. https://doi.org/10.1142/S021884301350007X

National E-Health Transition Authority. (2005). Towards an interoperability framework, version 1.8. Retrieved October 30, 2021, from http://www.providersedge.com

Ndlovu, K., Scott, R. E., & Mars, M. (2021). Interoperability opportunities and challenges in linking mhealth applications and eRecord systems: Botswana as an exemplar. *BMC Medical Informatics and Decision Making, 21*(1), Article 246. https://doi.org/10.1186/s12911-021-01606-7

Novakouski, M., & Lewis, G.A. (2012) *Interoperability in the e-government context*. Software Engineering Institute. https://pdfs.semanticscholar.org/e730/5d94d96ec0d5dbe4c14ad8e698a07bad2390.pdf

Offermann, P., Levina, O., Schönherr, M., & Bub, U. (2009). Outline of a design science research process. In *Proceedings of the 4th International Conference on Design Science Research in Information Systems and Technology*, (pp. 1-11). Association for Computing Machinery. https://doi.org/10.1145/1555619.1555629

Okunade, K., Bashan Nkhoma, K., Salako, O., Akeju, D., Ebenso, B., Namisango, E., Soyannwo, O., Namukwaya, E., Dandadzi, A., Nabirye, E., Mupaza, L., Luyirika, E., Ddungu, H., Chirenje, Z. M., Bennett, M. I., Harding, R., & Allsop, M. J. (2019). Understanding data and information needs for palliative cancer care to inform digital health intervention development in Nigeria, Uganda and Zimbabwe: Protocol for a multi-country qualitative study. *BMJ Open*, *9*(10), 1–9. http://doi.org/10.1136/bmjopen-2019-032166

Omary, Z., Lupiana, D., Mtenzi, F. & Wu, B. (2009). Challenges to e-healthcare adoption in developing countries: A case study of Tanzania. In *Proceedings of the First International Conference on Networked Digital Technologies*, (pp. 201-209). IEEE. https://doi.org/10.1109/NDT.2009.5272067

Omary, Z., Lupiana, D., Mtenzi, F. & Wu, B. (2010). Analysis of the challenges affecting e-healthcare adoption in developing countries: A case of Tanzania. *International Journal of Information Studies*, *2*(1), 38-50.

Pagliari, C., Sloan, D., Gregor, P., Sullivan, F., Detmer, D., Kahan, J., Oortwijn, W., & MacGillivray, S. (2005). What is ehealth (4): A Scoping exercise to map the field. *Journal of Medical Internet Research*, *7*(1), Article 9. https://doi.org/10.2196/jmir.7.1.e9

Papazoglou, M., & Georgakopoulos, D. (2003). Service oriented computing. *Communication of the ACM*, *46*(10), 24-49.

Parajuli, R., Bohara, D., Malati, K. C., Shanmuganathan, S., Mistry, K. S & Yadav, U. N (2022). Challenges and opportunities for implementing digital health interventions in Nepal: A rapid review. *Frontiers Digital Health*, *4*, 1-14. https://doi.org/10.3389/fdgth.2022.861019

Pardo, T., & Burke, G. (2009). *IT Governance Capability: Laying the Foundation for government interoperability.* Research Foundation of State University of New York.

Pathmaker Group. (2011). *Understanding the basics of SOA security*. Retrieved October 11, 2022, from https://www.pathmaker-group.com/understanding-the-basics-of-soa-security/

Payne, J. D. (2013). The state of standards and interoperability for mhealth among low- and middle-income countries. Retrieved April 14, 2015, from http://www.mhealthknowledge.org/

Payne, A., & Frow, P. (2006). Customer relationship management: From strategy to implementation. *Journal of Marketing Management*, *22*(1-2), 135-168. https://doi.org/10.1362/026725706776022272

Peffers, K., Tuunanen, T., Rothenberger, M., & Chatterjee, S. (2008). A design science research methodology for information systems. *Journal of Management Information Systems, 24*(3), 45- 78. https://doi.org/10.2753/MIS0742-1222240302

Pharr. P (2022). *What are the main barriers to achieving interoperability in healthcare*? Meridian Blog. Retrieved June 8, 2023, from http://www.whymeridan.com

Pirnejad, H., Bal, R., Berg, M. (2008). Building an inter-organizational communication network, and challenges for preserving interoperability. *International Journal of Medical Informatics*, *77*, 818-827. https://doi.org/10.1016/j.ijmedinf.2008.05.001

Protti, D. (2008) e-Health in Canada: Lessons for European health systems. *Eurohealth, 14*(3), 30–32.

Qureshi, Q. A., Shah, B., Kundi, G. M., Nawaz, A., Miankhel, A. K., Chishti, K. A., & Qureshi, N. A. (2013). Infrastructural barriers to e-health implementation in developing countries. *European Journal of Sustainable Development*, *2*(1), 163-170. https://doi.org/10.14207/ejsd.2013.v2n1p163

Raghupathi, W., & Kesh, S. (2007). Interoperable electronic health records design: Towards a service-oriented architecture. *e-Service Journal*, *5*(3), 39-57. https://doi.org/10.2979/esj.2007.5.3.39

Raymond, K., & Armstrong, L. (Eds.). (2013). *Open distributed processing: Experiences with distributed environments IFIP Advances in Information and Communication Technology*. Springer.

Red Hat. (2020). *What is a service-oriented architecture?* Retrieved October 20, 2022, from https://www.redhat.com/en/topics/cloud-native-apps/what-is-service-oriented-architecture

Reed, M., Huang, J., Brand, R., Graetz, I., Jaffe, M. G., & Ballard, D. (2020). Inpatient-outpatient shared electronic health records: Telemedicine and laboratory follow-up after hospital discharge. *The American Journal of Managed Care, 26*(10), 327-332. https://doi.org/10.37765/ajmc.2020.88506

Reisman, M. (2017). EHRs: The challenge of making electronic data usable and interoperable. *Pharmacy and Therapeutics, 42*(9), 572-575.

Rinty, M. R., Prodhan, U. K., & Rahman, M (2022). A prospective interoperable distributed e-health system with loose coupling in improving healthcare services for developing countries. *Array*, *13*, Article 100114. https://doi.org/10.1016/j.array.2021.100114

Rockerfeller Foundation. (2010). From silos to systems: An overview of e-health's transformative power. Retrieved November 20, 2021, from http://www.rockefellerfoundation.org

Rosati, K., & Lamar, M. (2005). The Quest for interoperable electronic health records: A guide to legal issues in establishing health information networks. *American Health Lawyers Association*, 1-107. Retrieved July 17, 2023, from https://www.crowell.com/en/insights/publications/

Ryan, A. (2006). Towards semantic interoperability in healthcare: Ontology mapping from SNOMEDCT to HL7 version 3. *Conferences in Research and Practice in Information Technology*, (Vol, 72, pp. 69-74). Association for Computing Machinery. https://doi.org/10.5555/1273659.1273668

Sadeghi, P., Benyoucef, M., & Kuziemsky, C. (2011). A mashup-based framework for multi-level healthcare interoperability. *Information Systems Frontiers*, *14*(1), 57-72. https://doi.org/10.1007/s10796-011-9306-0

Safi, S., Thiessen, T., & Schmailzl, K. J. (2018). Acceptance and resistance of new digital technologies in medicine: Qualitative study. *JMIR Research Protocols*, *7*(12), Article 11072.

Sanderson, P., Banks, D., Deakin, S., & Udagawa, C. (2015). *Encouraging inter-regulator data sharing: the perceptions of regulators.* Cambridge Centre for Housing and Planning Research. Retrieved September 27, 2022, from https://www.cchpr.landecon.cam.ac.uk/system/files/documents/Report_102.pdf

Sathya, C. (2014). An adaptive framework for autonomic person identification system using pervasive computing. *International Journal of Innovative Research in Computer and Communication Engineering*, *2*(4), 3762-3767.

Savage, M & Savage, L.C (2020). Doctors routinely share health data electronically under HIPAA and sharing with patients and patients' third-party health apps is consistent: Interoperability and privacy analysis. *Journal of Medical Internet Research, 22*(9), Article 19818. https://doi.org/10.2196/19818

Scheibner, J., Sleigh, J., Ienca, M., & Vayena, E. (2021). Benefits, challenges, and contributors to success for national eHealth systems implementation: A scoping review. *Journal of the American Medical Informatics Association*, *28*(9), 2039–2049. https://doi.org/10.1093/jamia/ocab096

Serbanati, L. D., Ricci, F., Mercurio, G. & Vasilateanu, A. (2011). Steps towards a digital health ecosystem. *Journal of Biomedical Informatics*. *44*(4), 621-636. https://doi.org/10.1016/j.jbi.2011.02.011

Sharp, H., Rogers, Y., Preece, J. J. (2007). *Interaction design - beyond human-computer interaction* (2nd ed.). John Wiley.

Shekelle, P. G., Morton, S. C., & Keeler, E. B. (2006). Costs and benefits of health information technology. *Evidence Report/technology Assessment*, *132*(132), 1-71. https://doi.org/10.23970/ahrqepcerta132

Sheng, Q., Qiao, X., Vasilakos, A., Szabo, C., Bourne, S., & Xu, X. (2014). Web services composition: A decade's overview. *Information Science*, *28*(1), 218-238. https://doi.org/10.1016/j.ins.2014.04.054

Shivakumar, S.K (2015). *Architecting scalable enterprise web applications*. Retrieved October 12, 2022, from https://www.sciencedirect.com/science/article/pii/B9780128022580000019/

Shrivastava, U., Song, J., Han, B. T., & Dietzman, D. (2021). Do data security measures, privacy regulations, and communication standards impact the interoperability of patient health information. A cross-country investigation. *International Journal of Medical Informatics, 148,* Article 104401. https://doi.org/10.1016/j.ijmedinf.2021.104401

Silveira, M., & Guelfi, N. (2008). Exploiting service-oriented architecture for design of e-health systems. In *Proceedings of the First International Conference on Health Informatics*, (pp. 219-224). SciTePress.

Skrocki, M. (2013). *Standardization needs for effective interoperability*. Retrieved October 21, 2022, from https://scholarworks.wmich.edu/ichita_transactions/32/

Soares, D., & Amaral, L. (2011). Information systems interoperability in public administration: Identifying the major acting forces through a Delphi study. *Journal of Theoretical and Applied Electronic Commerce Research*, *6*(1), 61-64. https://doi.org/10.4067/S0718-18762011000100006

Sroetmann, K., Artmann, J., Dumortier, J., & Erhenneman, G. (2012). Legal challenges on the road: Towards interoperable ehealth solutions in Europe. *European Journal for Biomedical Informatics*, *8*(2), 3-10.

Tambouris, E., Liotas, N., & Tarabanis, K. (2007). A framework for assessing e-participation projects and tools. In *Proceedings of the* 40th Annual Hawaii International Conference on System Sciences (HICSS'07), (pp. 90-90). IEEE. https://doi.org/10.1109/HICSS.2007.13

Thun, S., & Dewenter, H. (2018). ICD-11, ICHI und SNOMED CT – was bedeuten die Systematiken für E-Health-Anwendungen? [ICD-11, ICHI and SNOMED CT-What do the standards mean eHealth applications?]. *Bundesgesundheitsblatt, Gesundheitsforschung, Gesundheitsschutz, 61*(7), 812–820. https://doi.org/10.1007/s00103-018-2759-2

Tran, T. (2016). Middleware integration solutions gaining popularity as interoperability sling shot. The Healthcare Guys. Retrieved September 27, 2022, from https://www.healthcareguys.com/2016/11/09/middleware-integration-solutions-gaining-popularity-interoperability-sling-shot/

United Nations Conference on Trade and Development. (2019). *Digital economy report. Value creation and capture: Implications for developing countries*. Retrieved July 20, 2021, from https://unctad.org/system/files/official-document/

Uganda Ministry of Health. (2011). Towards a consolidated national health information System: A key to sustainable health care. Retrieved May 13, 2020, from http://www.library.health.go.ug

Vaishnayi, V., & Kuechler, B. (2010). Design science research in information system. Retrieved November 14, 2020, from, http://desrist.org/design-research-in-information-systems/

Van Hee, K., & Van Overveld, K. (2012). *New criteria for assessing a technological design*. Retrieved October 15, 2022, from https://www.4tu.nl/sai/testimonials/2012-12-10_2012_April_NewCriteriaSAI.pdf

Van Biljon, J. & Osei-Bryson, K. (2020) The communicative power of knowledge visualizations in mobilizing information and communication technology research. *Information Technology for Development, 26*(4), 637-652, https://doi.org/10.1080/02681102.2020.1821954

Wager, K., Lee, W., & Glaser, J. (2009). Health care information systems: A practical approach for health care management. Wiley

Whiteman, L., & Panetto, H. (2006). The missing link: Culture and language barriers to interoperability. *Annual Reviews in Control*, *30*(2), 233-241. https://doi.org/10.1016/j.arcontrol.2006.09.008

World Health Organization, & International Telecommunication Union. (2020). *Digital health platform handbook: Building a digital information infrastructure (infostructure) for health*. World Health Organization. https://apps.who.int/iris/handle/10665/337449

World Health Organization, & International Telecommunication Union. (2012). *National ehealth strategy toolkit*. http://www.itu.int/en/publications

World Health Organization. (2018). *Classification of digital health interventions v1. 0: A shared language to describe the uses of digital technology for health*. World Health Organization. https://apps.who.int/iris/handle/10665/260480

Yu, H. Q., Dietze, S., Li, N., Pedrinaci, C., Taibi, D., Dovrolls, N., Stefanut, T., Kaldoudi, E & Domingue, J. (2011). A linked data-driven & service-oriented architecture for sharing educational resources. In *Proceedings of the 1st International Workshop on eLearning Approaches for Linked Data Age (Linked Learning 2011), 8th Extended Semantic Web Conference (ESWC2011),* (pp. 1-16). The Open University.

Zakaria, S., Rand, O., & Yaser, K. (2013). A framework for an e-government based on service-oriented architecture for Jordan. *Information Engineering and Electronic Business*, *3*, 1-10. https://doi.org.10.5815/ijieeb.2013.03.01

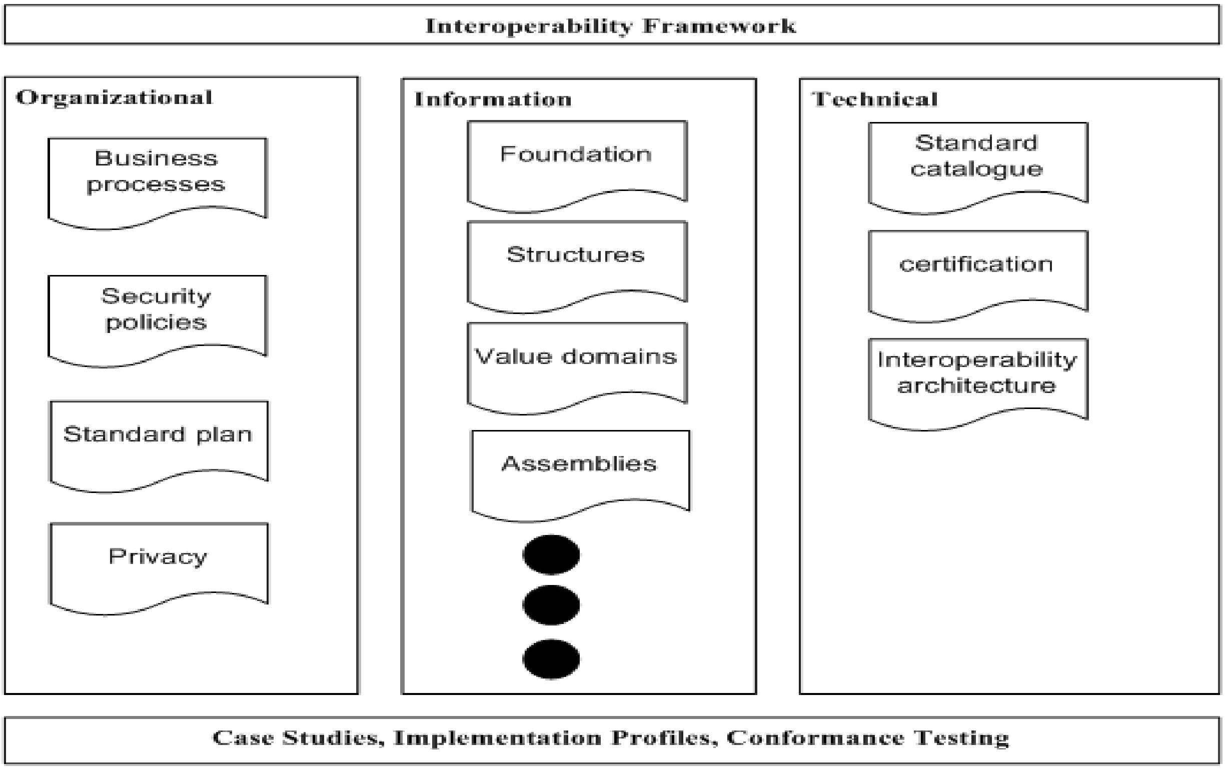
Zayyad, M. A., & Toycan, M. (2018). Factors affecting sustainable adoption of e-health technology in developing countries: An exploratory survey of Nigerian hospitals from the perspective of healthcare professionals. *PeerJ, 6*(6), Article 4436. https://doi.org/10.7717/peerj.4436

Zeppenfeld, K., & Finger, P. (2009). *SOA und web services*. Springer. https://doi.org/10.1007/978-3-540-76991-0_4

Zhang, L. J., Zhang, J., & Cai, H. (2007). *Services computing*. Springer.

APPENDIX

E-HEALTH INTEROPERABILITY FRAMEWORK FOR AUSTRALIA [HIFA]



Note. Adapted from NEHTA, 2005.