

**SUSTAINABILITY MODEL FOR DIGITAL
SOLUTIONS IN HEALTHCARE**

BY

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Dedication

This thesis is dedicated to my parents, my siblings, my teachers, and all my friends who supported me throughout my education. Thank you all for providing me with all I needed to become who I am today.

*It is not the impact of a change that matters, but its
sustainability*

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Firstly, all thanks to Allah. All my achievements and successes would not happen without his help and will. All grace and thanks are due to him.

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LIST OF ABBREVIATIONS

AHP	:	Analytic Hierarchy Process
AI	:	Artificial Intelligent
CLD	:	Causal Loop Diagram
DHT	:	Digital Health Transformation
eHMIS	:	Electronic Health Management Information System
EHR	:	Electronic Health Record
EMR	:	Electronic Medical Record
HIE	:	Health Information Exchange
HIE	:	Health Information Exchange
HIS	:	Health Information System
ICT	:	Information and Communications Technology
IHRBs	:	Independent Health Record Banks
IoT	:	Internet of Things
IS	:	Information System
IT	:	Information Technology

JD-AHP	:	Judgment-Decomposition Analytic Hierarchy Process
m-Health	:	Mobile Health
ML	:	Machine Learning
PEU	:	Perceived Ease of Use
PU	:	Perceived Usefulness
RHIO	:	Regional Health Information Organization
ROI	:	Return on Investment
SLR	:	Systematic Literature Review
TCMMI	:	Technical-Capability Maturity Model Integration
TCT	:	Technology Continuance Theory
TMMM	:	Telemedicine Maturity Model
UN	:	United Nations
VRS	:	Voice Recognition System

ABSTRACT

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The digital health transformation (DHT) has been deployed rapidly worldwide where many e-health solutions are invented and improved on an accelerating basis. Healthcare already faces many challenges in terms of reducing cost and allocating resources optimally while improving provided services. E-solutions in healthcare can be a key enabler for improvements while controlling the budget; however, if the sustainability of those solutions is not assessed, many resources allocated to e-solutions and the cost of adoption and implementation will be wasted. Thus, it is important to assess the sustainability of newly proposed or already in-use e-health solutions. In literature, there is a paucity of empirically driven comprehensive sustainability models and assessment tools to guide practices in real-world cases. Hence, in this study, I propose a novel sustainability model for e-health solutions, that is used to assess the essential sustainability aspects of e-health solutions and anticipate the likelihood of their sustainability. To build the model, a systematic literature review (SLR) was conducted to extract the e-health sustainability dimensions and elements. The sustainability model has five dimensions namely technology, organization, economic, social, and resources. Each dimension has aspects that provide another level of required details to assess the sustainability. In addition, assessment method was developed in this model to assess the aspects of each dimension, resulting in the overall prediction of the e-health solution's sustainability level.

Both sustainability model and assessment method were validated by experts in terms of comprehensive, correctness, and applicability to be used in healthcare. Also, sustainability model and assessment method were evaluated by three case studies conducted in three hospitals in Saudi Arabia. The sustainability model and assessment method were illustrated to be effective in evaluating the sustainability of e-solutions, and to be more comprehensive and systematic than the evaluation used in the hospital. Moreover, the sustainability assessment method was implemented through a tool support to facilitate the use of the sustainability model and its assessment method.

ملخص الرسالة

الاسم الكامل: عزه إبراهيم العجلان

عنوان الرسالة: نموذج الاستدامة لحلول الصحة الرقمية في الرعاية الصحية

التخصص: علوم الحاسب

تاريخ الدرجة العلمية: ديسمبر ٢٠٢١

تم نشر التحول الصحي الرقمي (DHT) بسرعة في جميع أنحاء العالم حيث تم تطوير العديد من حلول الصحة الإلكترونية وتحسينها بشكل متسارع. تواجه الرعاية الصحية حاليًا العديد من التحديات من حيث تقليل التكلفة وتخصيص الموارد على النحو الأمثل مع تحسين الخدمات المقدمة. يمكن أن تكون الحلول الإلكترونية في مجال الرعاية الصحية عاملاً تمكينياً رئيسياً للتحسينات مع التحكم في الميزانية؛ ومع ذلك، إذا لم يتم تقييم استدامة هذه الحلول، فسيتم إهدار العديد من الموارد المخصصة للحلول الإلكترونية وتكلفة اعتمادها وتنفيذها. وبالتالي، من المهم تقييم الاستدامة المقترحة حديثاً أو حلول الصحة الإلكترونية التي قيد الاستخدام حالياً. في الأدبيات، هناك ندرة في نماذج الاستدامة الشاملة المقترحة تجريبياً وأدوات التقييم لتوجيه الممارسات في الحالات الحقيقية. ومن ثم، في هذه الدراسة، أقترح نموذجاً جديداً للاستدامة لحلول الصحة الإلكترونية، يتم استخدامه لتقييم جوانب الاستدامة الأساسية لحلول الصحة الإلكترونية وتوقع احتمالية استدامتها. لبناء النموذج، تم إجراء مراجعة منهجية للأدبيات (SLR) لاستخراج أبعاد وعناصر استدامة الصحة الإلكترونية. نموذج الاستدامة له خمسة أبعاد هي التكنولوجيا والتنظيم، والاقتصاد، والاجتماعي، والموارد. يحتوي كل بُعد على جوانب توفر مستوى آخر من التفاصيل المطلوبة لتقييم الاستدامة. بالإضافة إلى ذلك، تم تطوير طريقة التقييم في هذا النموذج لتقييم جوانب كل بُعد، مما يؤدي إلى التنبؤ العام بمستوى استدامة حل الصحة الإلكترونية. تم التحقق من صحة نموذج الاستدامة وطريقة التقييم من قبل الخبراء من حيث الشمولية والصحة وقابلية التطبيق لاستخدامها في الرعاية الصحية. كما تم تقييم نموذج الاستدامة وطريقة التقييم من خلال ثلاث دراسات حالة أجريت في ثلاثة مستشفيات في المملكة العربية السعودية. تم التوضيح بكون نموذج الاستدامة وطريقة التقييم فعالين في تقييم استدامة الحلول الإلكترونية، وأنها أكثر شمولية ومنهجية من التقييم المستخدم في المستشفى. علاوة على ذلك، تم تنفيذ طريقة تقييم الاستدامة من خلال أداة دعم لتسهيل استخدام نموذج الاستدامة وطريقة تقييمه.

CHAPTER 1

INTRODUCTION

The digital health transformation (DHT) is expected to have a fundamental impact on the improvement of healthcare systems and provided services [1]. DHT refers to the employment of digital solutions and technologies in healthcare systems, which digitalizes the way that healthcare services are organized, produced, and delivered [1]. DHT happens through shifting to patient-centered design, mobile health (m-Health) delivery, electronic medical record (EMR), personalized medicine, social media health applications [2], virtual clinics, and wearable devices [3]. Unlike digitizing (i.e., transforming data from paper-based into digital/electronic-based), the process of digitalizing an healthcare system is not mainly about technology and digital solutions, it also touches and impacts other aspects, such as the organizational culture and the role of healthcare providers [1]. Also, a healthcare system consists of multidisciplinary stakeholders, which results in interrelations of several elements, such as economic, functional, emotional, cultural, and ethical and sometimes opposite needs and expectations [4][5]. Therefore, for the DHT to be successful, it is essential to understand the context of the transformation, including the current situation, desired outcomes, how to effectively bridge between them [1], and most importantly, how to sustain these outcomes. Even though digital solutions exist widely in the healthcare system, the sustainability of those solutions is unclear and undetermined yet [6]. This creates a need to ensure the sustainability of the e-health solutions as their

development and implementations are costly and could impact a healthcare organizational structure and operations [6]. Hence, in this study, I propose a sustainability model for e-solution in healthcare. The sustainability model captures the essential aspects and elements of sustainability of e-health solutions and their relationships. In addition, I provided an assessment method to evaluate the sustainability of e-health solutions based on the sustainability model. The comprehensiveness and correctness of the proposed model and assessment method in real-world cases were validated with experts in healthcare. Moreover, the effectiveness and applicability of using the model to assess the sustainability level of e-solutions in practice were illustrated through conducting three real-world case studies.

1.1. Problem Description

Sustainability has been a challenge in many domains and development context. In e-health in particular, it is challenging to define and apply sustainability into real projects due to several reasons [7]. Some of these reasons are the complex nature of healthcare, the increasing demand of resources [8], and the lack of a clear and consensus definition of sustainability in healthcare [9][10]. The importance of sustaining digital solutions in healthcare laid upon the fact that healthcare is a critical sector involving many obstacles, in where implementing changes is difficult due to the strict regulations and complex interrelated processes [4]. Hence, any application of unsustainable e-health solutions will result not only in waste of money and resources, but it might affect the healthcare provision, especially if the solution has replaced another major process in the healthcare system [7]. The exposure to the risk increases in the absence of clear guidelines, that can be used to assess e-health sustainability.

The objective of this research is to help the managerial level of healthcare institutions to assess the sustainability of the applied or to-be-adopted e-health solutions; by proposing a sustainability model, that captures the elements and dimensions of the sustainability of e-health solutions along with assessment methods, which will help in providing a prediction of the e-health solutions' sustainability.

1.2. Motivation

Despite the pressure Covid-19 brought to healthcare systems worldwide, it is assumed that it positively impacted the DHT implementation by having a rapid shift to remote and digital services of healthcare [11]. In Saudi Arabia for example, many digital solutions have been deployed during Covid-19, such as *Takasi*, *Tataman*, *Seha*, and *Tawakkalna* [12][13][14]. These solutions provided many benefits to the healthcare system, such as reducing patients' waiting time, saving resources (e.g. time, money, and staff), facilitating and enhancing the process of providing care, and resulting a high level of stakeholders' satisfaction [4]. However, there is a risk that those e-solutions will not sustain, as their sustainability has not been assessed.

Previous meetings conducted with healthcare experts showed that there was no clear unified definition of sustainability in healthcare context. The study held a focus group consists of 5 management representatives of a Saudi hospital to discuss the sustainability of the digital solutions applied in Saudi healthcare system. The main provided definitions of a sustainable digital change were: (1) minimizing the demand on resources and cost (e.g. human capital), in which no human should be involved to execute the processes that involves the introduced digital solution, while the other definition specified the dimensions

of sustainability as (2) the continuous demand, the stakeholders' awareness of the importance of digital change, the infrastructure capability and technical support, and the available continuous fund. Moreover, some of the digital solutions, such as virtual clinics, that was applied to encounter Covid-19, were stopped in some clinics, or minimized at some point after the pandemic passed its first phase. Some of the terminated solutions were deployed to only encounter a particular situation (e.g., Covid-19 pandemic), in which the demand on them stopped after the situation has been resolved or vanish. However, some other solutions are not dependent on a temporary situation, and they were cost-effectiveness and provided a significant improvement to the work process, yet they have been minimized. Absence of sustainability evaluation arose as one of the reasons that such solutions have stopped. Some of the reasons that fall under sustainability is the lack of unified sustainability definition for healthcare solutions, lack of clear sustainability guidelines, and negligence of sustainability in planning phase of these solutions.

1.3. Research Questions

This research addresses the following research questions:

- **RQ1:** What are the dimensions and elements of the sustainability model that fits and reflects the adoption of e-solutions in healthcare systems?
- **RQ2:** To what extent the proposed sustainability model is comprehensive in covering all aspects of e-solution sustainability in real-word cases in healthcare?
- **RQ3:** To what extent the sustainability model and the assessment method are effective in evaluating the sustainability level of e-solution in healthcare in practice?

1.4. Methodology

As this thesis provides a solution (i.e., sustainability model) for a business problem in healthcare system, the Design Science Methodology in Information Systems (IS) (see Figure 1) will be adapted to the thesis's methodology as presented in Figure 2.

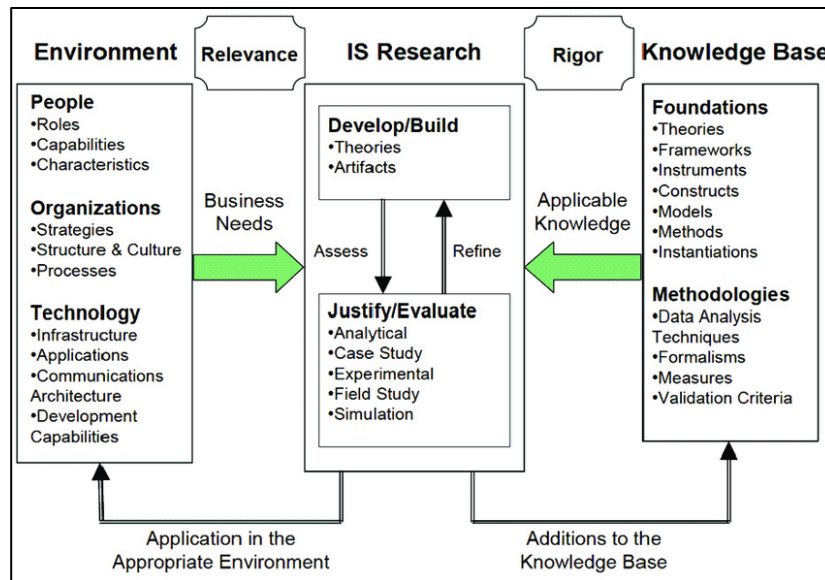


Figure 1 Design Science framework [15]

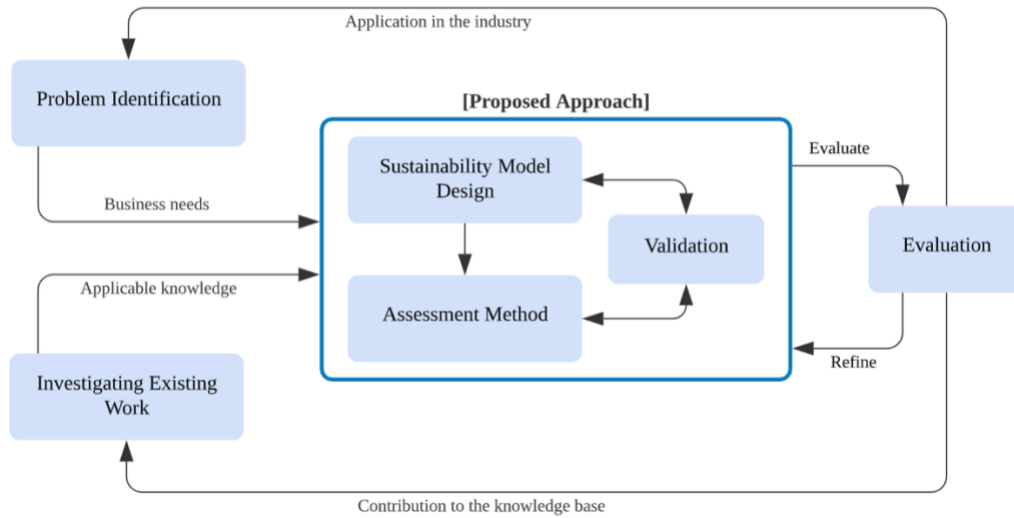


Figure 2 Thesis methodology

The thesis was conducted by applying the four phases of the research methodology as follows:

1. **Problem identification:** I had many meetings with healthcare experts (eight physicians and five hospital's management representatives). The aim was to investigate the sustainability of the applied solution (i.e., virtual clinics). We concluded that there is no existing sustainability model designed for digital solutions in healthcare, as well as the lack of a unified definition of sustainability in the healthcare context.
2. **Investigating existing work:** a systematic literature review (SLR) was conducted to synthesize sustainability definitions and other sustainability models proposed in the literature as well as their dimensions, elements, and assessment methods. The aim of this phase was to provide a comprehensive view of the existed sustainability

models in healthcare, in which the SLR findings were used to construct the proposed sustainability model in this study.

3. **Proposed approach:** two subphases are included in this phase, which are designing the sustainability model and the assessment method. Based on the data collected from the problem identification, that includes the business needs, and the extracted relevant knowledge from the SLR, the sustainability model was designed, and in consequence, the assessment method was formulated.
4. **Validation:** the sustainability model and its assessments methods have gone through three iterations of validation. Table 1 illustrates the three iterations of the validation phase. In each iteration, I met technology experts in healthcare and asked them to evaluate the comprehensiveness and correctness of the sustainability model. In addition, they were asked about the effectiveness of the assessment method to evaluate the overall sustainability of e-solution.
5. **Evaluation:** In this phase, three case studies in Saudi hospitals were conducted to evaluate how effective the model is in evaluating the expected sustainability of e-solutions. In addition, the model was evaluated in terms of comprehensiveness, correctness, and applicability in real-world cases.

Table 1 Iterations of the evaluation phase

Iterations	Description	Results
Iteration 1	Presenting the initial version of the proposed approach to experts in Saudi healthcare.	Modifications and refinements to the sustainability model and the assessment method.
Iteration 2	Evaluating the modified version of the proposed approach with a case study in the hospital.	Modifications and refinements to the sustainability model and the assessment method.
Iteration 3	Validating the modified version of the proposed approach with interviews with experts.	Final version of the proposed approach.

1.5. Thesis Contributions

This thesis provides three main contributions:

1. A sustainability model that captures the main dimensions and elements of e-solution's sustainability in healthcare.
2. A sustainability assessment method to that is used to evaluate the sustainability of e-solutions in healthcare; hence, support healthcare management in decision making and e-solution adoption.
3. A tool support that implements the sustainability model and the assessment method to facilitate the use of the model in practice.

1.6. Thesis Outline

The rest of the thesis is organized as follows:

Chapter 2: presents the conducted SLR on the aspects and dimensions of e-health sustainability. The results conclude the extracted sustainability aspects that were used to build the e-health sustainability model.

Chapter 3: contains the e-health sustainability model. It explains the building phases of the model and its aspects and dimensions and how they impact the sustainability of e-health solutions. Also, the validation iterations of the sustainability model are provided in this chapter.

Chapter 4: presents the proposed sustainability assessment method. It discusses the evaluation tools, the phases and steps of the sustainability assessment, and the sustainability levels' scale.

Chapter 5: includes three real-word cases studies conducted in Saudi hospitals, to evaluate the applicability and effectiveness of sustainability model and assessment method in practice.

Chapter 6: concludes the thesis and discusses the future work.

CHAPTER 2

SYSTEMATIC LITERATURE REVIEW

2.1 Introduction

Sustainability of e-health has been recognized in the literature to be a problem that concerning the implementation of digital solutions such as the health information system (HIS) [16]. Although some studies emphasized on the need for sustainability assessment methods that is customized for e-health [17][18], the lack of unclear definition and aspects of sustainability in e-health was the most noticed issue that hinders the achievement of assessing the e-health sustainability [19].

Most of the previous studies discussed the sustainability in healthcare from a managerial level. In other words, none of the studies shed light on assessing the sustainability of digital solutions in healthcare. Also, several studies stated that there is no clear definition of sustainability in the literature resulting in the absence of rigor evaluation methods of sustainability [10][20][17][21][22]. Doyle et al. [23] proposed a sustainability model for changes in healthcare. The model was in a form of self-assessment tool, which consists of 10 factors, that were prioritized over 100 identified factors. These factors were categorized into three main domains and given weights as follows: process (31%), staff (52%), and organization (17%). Each of the 10 factors has four levels, by which the user chooses one level for each factor, that describes the current situation. However, some important aspects were missing in these factors, such as the economic and funding estimation, the probability

of laying off staff and its impact on the organization, and social-cultural aspects of the organization and the staff. Molfenter et al. [24] constructed a model to predict the sustainability of changes in healthcare. They had nine factors associated with levels for each factor. However, this model lacks factors concerning patients, such as their satisfaction toward the change. An important aspect of sustaining changes in healthcare is the willingness of healthcare stakeholders (e.g. patients, healthcare providers, families, and managers) to adjust themselves to the change [25].

Penzenstadler and Femmer [26] proposed a sustainability model consisted of three levels for software products. In their work, they defined the sustainability dimensions to be individual, social, economic, environmental, and technical. The dimensions were in the top level of the model. While middle level included the values, indicators, and regulations. The activities of the model, such as reduce waste are placed in the lower level. This model focused on the environmental sustainability and lacked steady assessment method, that can measure the impact of each factor in anticipating the sustainability of the solution. A systematic integrative review [10] on healthcare sustainability revealed that out of 92 studies, only six studies used purpose-designed tools to evaluate sustainability. Braithwaite et al. [10] emphasized on the lack of a unified and rigor sustainability definition, and inconsistency in the way it is conceptualized [10]. Another study [20] concluded the lack of a comprehensive definition of sustainability, in which it was considered the essential challenge that hindered the field from moving forward. Other studies discuss sustainability in healthcare focused on developing tools [7] and frameworks [27][8] for sustaining the healthcare organizations rather than focusing on the changes within these organizations. Also, another study discussed the role of digital solutions in sustaining the healthcare in

general by presenting different types of interactions, that can happen via digital platforms [5].

Hence, this systematic literature review (SLR) aims to investigate the sustainability of e-health solutions in the context of healthcare system; by focusing on the sustainability definitions, models, and assessment methods. It contributes to the body of knowledge by analyzing and providing a comprehensive overview of the existing sustainability definitions, aspects, models, and assessment methods for e- e-health solutions in healthcare.

2.2 Study Protocol

This section contains the designed protocol that was followed when conducting the SLR. It contains the research questions, search strategy, quality assessment, data extraction and data synthesis. The protocol was validated by an expert in software engineering.

2.2.1 Research Questions

This SLR was intended to answer the following research questions:

- **RQ1: What are the definitions, dimensions, and elements of sustainability of e-solutions in the context healthcare system?**
 1. ***Objective 1:*** analyze the sustainability definitions found in the literature for e-solitons in healthcare and provide a comprehensive definition.
 2. ***Objective 2:*** analyze the sustainability models found in the literature for e-solitons in healthcare by eliciting their dimensions and aspects.

- **RQ2: What are the metrics, measures, and assessment methods/models of evaluating sustainability for e-solutions in the context healthcare system?**

3. **Objective 3:** a) analyze the assessment methods of sustainability models found in the literature for e-solutions in healthcare; and b) their effectiveness in predicting/evaluating the sustainability of e-solutions.

2.2.2 Search Strategy Design

2.2.2.1 Search Process

The search was conducted over three rounds as shown in Figure 3. First, the search string was used to search the selected databases and filter the studies based on the relevance of their titles and abstracts. Second, the full text of the resulted studies from the first round was skimmed in order to exclude papers that did not meet the inclusion criteria or matched one of the exclusion criteria. Third, the studies that passed the second round were evaluated using the quality assessment criteria. All papers, whose score in the quality assessment is less than the threshold, were excluded from the set of selected studies. Finally, all papers that passed the third round were considered in the final set and used in data extraction and synthesis.

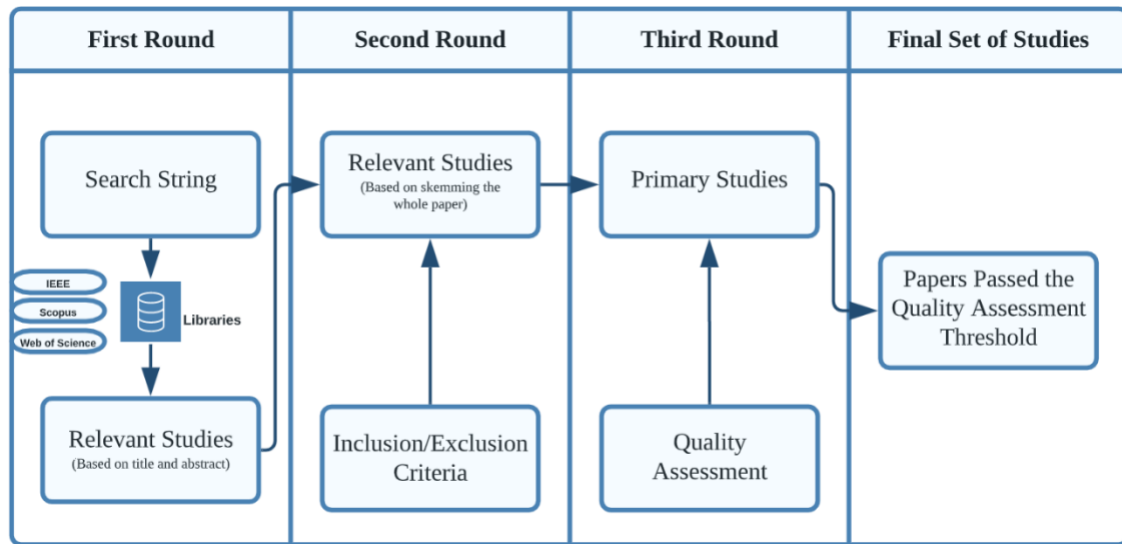


Figure 3 Search process

2.2.2.2 Search String

Table 2 contains the search string that was used to find the primary studies. It consists of all keywords that are relevant to the focus of the study. The keywords terms were derived from two SLRs [28] [29]. Both SLRs investigated the sustainability issue in healthcare in general [29] and sustaining hospital-based interventions [28]. Also, keywords and search strategy in study [28] was peer-reviewed by an academic librarian in accordance with PRESS guidelines [30].

The keywords were then refined to match the scope of this work. Boolean operators and wildcards (e.g., “*” and “?”) were used to account for plurals and variations in spelling.

Table 2 Search string

Scope	String
Sustainability	(sustainability OR long-term OR continuous OR lasting) AND

Main issue	((Model OR Definition OR Elements OR dimension* OR Component*) OR (Assess* OR evaluat* OR measure* OR metric*)) AND
Technology	(electronic* OR digital OR technolog* OR software OR service* OR smart) AND
Healthcare	(healthcare OR e-health OR m-health)

2.2.2.3 Selected Digital Libraries

A pilot search using the search string was conducted to perform the search for the papers. Based on that, the databases of three digital libraries were chosen, of which were found to have relevant results to the research scope than other libraries (e.g., PubMed, ACM, etc.). In addition, a snowballing technique was used to collect relevant studies. The selected libraries are *Web of Science*, *IEEE Xplore*, and *Scopus*.

2.2.3 Study Selection Criteria

All collected studies were evaluated by the inclusion and exclusion criteria before admitting them to the selected studies. The inclusion and exclusion criteria are presented in the following subsections.

2.2.3.1 Inclusion Criteria

A paper is selected if and only if it met all inclusion criteria presented in Table 3. The year range was chosen upon a previous SLR conducted in 2018 [29]. The SLR searched the studies from 1980 until 2017. Its objective was to investigate the sustainability approaches in healthcare. Also, in the SLR [29], some of the primary studies, that are relevant to this research scope, were found in the years 2002-2014. Therefore, I decided to expand the

range to be from year 2000 to year 2021. Also, as from piloting the search string, there were not many studies discussing sustainability in healthcare, especially with respect to e-health.

Table 3 Inclusion criteria

No.	Criteria
IC1	The paper was published between 2000 - 2021.
IC2	The paper discusses sustainability in healthcare with respect to e-health solutions.
IC3	The paper discusses at least one of the following: sustainability model or components (dimensions or elements), sustainability measurements or assessment/evaluation methods, or sustainability definition.
IC4	The paper must be a full research paper (not an abstract).
IC5	The paper is written in English.
IC6	The paper is available in full-text version.

2.2.3.2 Exclusion Criteria

The papers that met at least one of the following exclusion criteria in Table 4 were excluded:

Table 4 Exclusion criteria

No.	Criteria
EC1	Meeting abstracts, book chapters, workshop descriptions, tutorials, posters, progress reports, masters and doctoral dissertations.
EC2	Papers discuss sustainability from purely environmental perspective, such as recycling or energy conservation etc.

EC3	Papers discuss sustainability of the healthcare system/organization instead of the sustainability of e-health solutions within healthcare system.
EC4	Papers discuss sustainability of a medical device/tool instead of e-health solution related to healthcare system and its processes.
EC5	Papers discuss sustainability from a general perspective without proposing or providing results related to constructs of sustainability models, definitions, or assessment methods.

2.2.4 Quality Assessment

The purpose of quality assessment, that is presented in Table 5, is to assess the quality of each selected paper to be included in the final set. Questions were deduced from Zhou, et al. study [31], which is a tertiary study about the quality assessment criteria used in software engineering SLRs. The maximum score a study could obtain by meeting the quality criteria, which are illustrated in five quality questions, is 5 points. The threshold is 2.5.

Table 5 Quality assessment checklist

No.	Quality Assessment Question	Score
QA1	Does the paper have a clear statement (definition) of the aims (goals, purposes, problems, and research questions)?	(+1) Yes/ (+0) No/ Partially (+0.5)
QA2	Does the paper explicitly propose/discuss the sustainability aspects of e-health solutions?	(+1) Yes/ (+0) No/ Partially (+0.5)
QA3	Does the paper evaluate/investigate sustainability of e-health solutions through using case studies, surveys, etc.?	(+1) Yes/ (+0) No/ Partially (+0.5)
QA4	Are conclusions, implications for practice, and future research, reported suitably for its audience?	(+1) Yes/ (+0) No/ Partially (+0.5)
QA5	Where the aspects extracted from interviews, case studies, etc.?	(+1) Yes/ (+0) No/ Partially (+0.5)

2.2.5 Data Extraction

The data extraction form was filled by the relevant data of each selected study. To maintain ease of subsequent data synthesis, I grouped the items in data extraction form based on definition, sustainability constructs, assessment methods, e-health solution, validation, and limitations. The data was documented into an excel file, which was used in the data synthesis. Table 6 presents the data extraction form.

2.2.5.1 Data Extraction Form

Table 6 Data extraction form

Data extraction log
• Data extractor • Data reviewer
Paper information
• Study ID • Title • Author(s) • Publication year • Publication type (conf/journal) • Database • Summary
Extracted data
Sustainability Definition
• Definition(s) • Target (General sustainability definition or specific definition for e-health solutions?) • Source (whether proposed or cited) • Focus/scope of definition (e.g., technical, health provision, stakeholders, etc.)
Sustainability aspects
• Number of constructs • The aspects • Details/notes • Extraction method (literature, case study, etc.) • Target (general/customized)
E-health solution

• E-health solution type • Focus of e-health solution • Replace an existed process? (Y/N) – if no, it means it works align with a process, or provides a new service. • Status (running, proposed, etc.) • Users (e.g., patients, nurses, physicians, staff, etc.) • Benefits
Assessment methods
• Existence of assessment method (yes/no) • Method (model, framework, diagram, etc.) • Type of the assessment methods (standards, formula, checklist, etc.) • List of assessment methods • Used for which aspects? • Source (literature, proposed, etc.)
Evaluation/Validation
• Evaluated/validated? • Method (with experts, case study, etc.) • Number of iterations • Duration • Context
Additional information
• Limitations/challenges • Future work • Notes

2.2.6 Data Synthesis

Data synthesis was conducted on the extracted data in order to analyze the results and draw conclusions. The used method for synthesizing the data is narrative synthesis [32]. By using this method, the data was tabulated in a consistent manner of three main categories: sustainability definitions, sustainability dimensions, and sustainability assessment methods. After that, the data was visualized using tables.

2.3 Results

This section reports the findings of the SLR. First, an overview of the selected studies is presented. Then, the findings were discussed in terms of e-health sustainability's definitions, dimensions and elements, and assessment methods. The study selection process took place in February 2021 and then updated in November 2021. The newly added studies from the updated search are PS21 and PS22. An excel file (i.e., Appendix A in Table 41) was used to document the selection process and search results of each of the selected digital libraries along with quality assessment of the primary studies and their data extraction.

In the first search round, a total of 4811 papers were obtained by applying the search string in three digital libraries (i.e., Web of Science, IEEE Xplore, and Scopus) in addition to 16 studies retrieved by the snowballing technique, as shown in Figure 4. It is worth noting that the same search string was also applied in four other libraries, which are PubMed, Medline, SpringerLink, and ACM. Yet, these four libraries were excluded because they did not contain any relevant papers within their search results. The title and abstracts of all papers appeared in the search results of the selected libraries were checked for relevancy, and if they found to be relevant, they passed to second round. Of the 4811 papers, 125 papers passed to the second round, that is shown in Figure 3. Many papers found irrelevant due to the polysemy of some keywords in the search string, such as the term “long-term”, that was used in this SLR as a synonym of sustainability. Nonetheless, “long-term” was found to mean a different thing in the healthcare context as many irrelevant papers used this term to refer to the technologies that are used to help people with chronic diseases and need a “long-term” healthcare provision. Therefore, such papers were excluded in the first round.

Simultaneously, the backward snowballing approach was conducted in the first and second rounds to collect relevant studies, that were not included in the digital libraries results. In the second round, all 125 papers that passed the first round were fully read and then compared against the inclusion and exclusion criteria. Only 22 out of 125 papers passed the second round. The rest were eliminated because they did not meet the inclusion and exclusion criteria presented in Table 7. The third round was conducted, and all the 22 papers passed the quality assessment. Therefore, the final set of the selected papers contained 22 papers. Table 8 shows the quality assessment scores of all 22 papers.

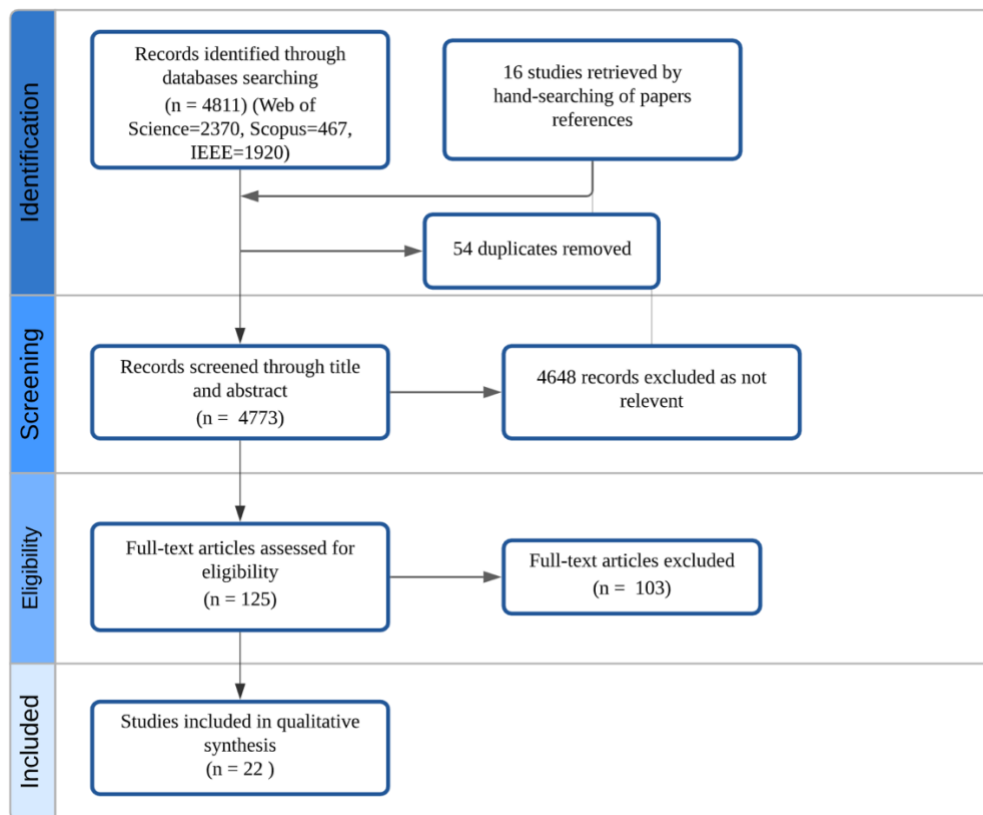


Figure 4 PRISMA flow diagram of studies selection process

Table 7 Number of studies excluded in the second round

Inclusion/Exclusion Criteria	# Of Studies
IC2	72
IC3	16
IC4	2
IC5	1
IC6	3
EC3	1

Table 8 Studies' quality assessment scores

Primary Studies	Quality Assessment Score
PS1, PS2, PS7, PS8, PS11, PS14, PS17, PS20	2.5
PS12, PS19	3
PS6, PS10, PS13, PS22	3.5
PS4, PS5, PS15, PS18, PS21	4
PS3	4.5
PS9, PS16	5

2.3.1 Overview of The Search Results

The primary studies reviewed in this work are reported in Table 9. The selected studies discussed the sustainability of different e-health solutions, such as telehealth and electronic health records (EHRs). Table 10 demonstrates the other e-health solutions mentioned in the reviewed studies.

Table 9 The final set of the relevant studies reviewed in this work

Study ID	Ref.	Title	Database	Year
PS1	[33]	A global socio-economic-medico-legal model for the sustainability of longitudinal electronic health records - Part 1	Web of Science	2006
PS2	[34]	A global socio-economic-medico-legal model for the sustainability of longitudinal electronic health records Part 2	Web of Science	2006
PS3	[19]	A multi-phased QFD based optimization approach to sustainable service design	Web of Science	2016
PS4	[17]	A Qualitative Study of Sustainability and Vulnerability in Australian Telehealth Services	Web of Science	2010
PS5	[35]	Assessing the suitability of smart technology applications for e-health using a judgment-decomposition analytic hierarchy process approach	Web of Science	2020
PS6	[36]	Challenges, Alternatives, and Paths to Sustainability for Health Information Exchange Efforts	Web of Science, Scopus	2013
PS7	[37]	Complexities in securing sustainable IT infrastructures in Hospitals: The many faces of Local Technical Support	Web of Science	2010
PS8	[38]	Efficacy and sustainability of a telerehabilitation program	IEEE	2003

PS9	[39]	EMR continuance usage intention of healthcare professionals	Web of Science	2017
PS10	[40]	How to Sustain Smart Connected Hospital Services: An Experience from a Pilot Project on IoT-Based Healthcare Services	Web of Science	2018
PS11	[41]	Information systems in healthcare - state and steps towards sustainability.	Web of Science	2009
PS12	[42]	Information Technology in Healthcare: HHC-MOTES, a Novel Set of Metrics to Analyse IT Sustainability in Different Areas	Web of Science	2018
PS13	[43]	Organizational Dynamics of Sustainable eHealth Implementation: A Case Study of eHMIS	IEEE	2017
PS14	[44]	Proposed model for evaluation of mHealth systems	IEEE	2015
PS15	[21]	Sustainability requirements for connected health applications	Web of Science	2018
PS16	[45]	An evaluation of eHealth systems implementation frameworks for sustainability in resource constrained environments	snowball	2015
PS17	[46]	Business Models for Sustained eHealth Implementation: Lessons from Two Continents	Snowball	2012
PS18	[47]	Clinician acceptance is the key factor for sustainable telehealth services	Snowball	2014
PS19	[48]	From health technology assessment to health technology sustainability	Snowball	2018
PS20	[22]	Towards sustainability of health information systems: How can we define, measure and achieve it?	Snowball	2007
PS21	[49]	Exploring factors that affect the uptake and sustainability of videoconferencing for healthcare provision for older adults in care homes: a realist evaluation	Web of Science	2021
PS22	[50]	Identification of critical quality dimensions for continuance intention in mHealth services: Case study of onecare service	Scopus	2019

Table 10 Primary Studies and Proposed E-Health Solutions

Primary study	e-health Solutions
PS1, PS2, PS6, PS9	electronic health records (EHRs), electronic medical records (EMRs), Health information exchange (HIE)
PS3, PS14	m-health
PS4, PS8, PS18	Telehealth
PS5	Smart e-health applications
PS7, PS11, PS13, PS20	Hospital/health information systems (HIS), Electronic Health Management Information System (eHMIS)
PS10, PS15	Internet of Things (IoT) technology, connected health applications
PS12, PS16, PS17, PS19	General e-health systems and application

2.3.2 The Sustainability of E-health Solutions

2.3.2.1 Sustainability Definitions

Five studies defined the sustainability, in which most of them were cited definitions. The scope of the definitions was centered around demand, continuity, and cost. Three studies [PS15, PS16, PS20] used the general sustainability definition, that is provided by the United Nations (UN): “meets the needs of the present without compromising the ability of future generations to meet their own needs” [51]. However, both Wade et al. [PS4] and Garde et al. [PS20] defined the sustainability of e-health solutions as the ability of the solution to continue a defined behavior and functioning into the future. Moreover, Ouhbi et al. [PS15] and Fanta et al. [PS16] referred to sustainability as the continuous use; by addressing the three dimensions of sustainability and other important factors of the

intended system. On the other hand, Lenz [PS11] associated sustainability of IT systems in healthcare with the cost of needed for replacements over the years; “a sustainable IT systems in healthcare should prevent the necessity of costly system replacements every five to ten years” [41].

2.3.2.2 Sustainability Dimensions

The studies discussed sustainability of e-health by presenting dimensions or aspects of the e-health sustainability. In the data extraction, the results of the studies were categorized into dimensions and aspects. The dimensions are the essential pillars of sustainability, which are high-level categories that involve set of aspects, which influence the sustainability of e-health solution. The aspects are a fine-grained level of details that includes elements and items through which data could be collected and sustainability evaluation is enabled. Table 11 presents the dimensions mentioned in the studies, which are technology, economic, social/human, organization/management/environment, political/legal, and resourcing. In addition, the aspect is a subset that belongs to a dimension, which contributes along with other aspects to achieve the dimension's fulfillment. Table 13 contains all aspects mentioned in the studies.

Table 11 The mentioned sustainability dimensions of e-health solutions

Dimension	Study ID
Technical	PS2, PS15, PS17
Economic	PS13, PS15, PS17, PS19
Social/Human	PS5, PS17, PS13, PS15, PS19
Organization/ Management/ Environment	PS3, PS4, PS6, PS8, PS10, PS11, PS12, PS13, PS15, PS16, PS17, PS20
Political/legal	PS1, PS2, PS5, PS6, PS13, PS17, PS19
Resourcing	PS4, PS5, PS8, PS13, PS18

Two studies [PS15, PS16] discussed the issue of sustaining the implementation of e-health solutions and identified similar sustainability dimensions, which are social, environmental, economic, technological, and individual dimensions. In both studies, explicit definitions of the identified dimensions were provided as presented in Table 12. It is worth noting that the focus of the environment dimension in both studies was different. In [PS15], the focus was on the sustainability from ecological perspective, by raising the environmental issues such as energy consumption and emissions of carbon dioxide. The study underlined how the e-health solution should consider this aspect in order for it to sustain. Same conception of environment dimension was found in study [PS12]. On the other hand, study [PS16] focused on the work and organizational environment, such as organizational culture, values, leadership, and resources.

Table 12 Definitions of e-health sustainability dimensions according to studies

Dimensions	PS15	PS16
<i>Economic</i>	“It aims to maintain capital assets and added-value (interest) assets. Economic sustainability can be taken care of in terms of costs, budget constraints, long-term business objectives, and market requirements among other economic requirements.”	“It refers to financial issues such as the availability of sustainable funding, affordability of technology, cost-effectiveness and return on investment (ROI). The economic factors aim to improve profits; reduce costs and deliver affordable healthcare service.”
<i>Social</i>	“It aims to preserve the social capital and preserve services and solidarity of social communities. Social sustainability can be handled via computer-supported collaborative work that aims to strengthening community building and improve community interaction.”	“Social factors represent the eHealth framework’s ability to address the ethical, behavioral, cultural, and stakeholder related issues in the process of eHealth systems development, implementation, operation and improvement. It aims at improving clinical safety, quality of care, equity of healthcare services, decision making, and speed of service delivery to all stakeholders.”
<i>Environment</i>	“It seeks to improve human welfare by protecting natural resources, such as water, land, air, minerals, and ecosystem. Any system applied in a real-world context is situated within a natural environment which means that it has an impact on the environment. Environmental sustainability can be managed by controlling resource flow: waste management, life cycle analysis, and environment impact assessment.”	“The environmental factors address legal, organizational and individual readiness; technical, management and political supports; policy and capacity building aspects of the system operational environment.”
<i>Technical</i>	“It refers to software systems longevity and their adequate evolution. with changing surrounding conditions and respective requirements. Technical sustainability requirements include all requirements which lead to the longevity of a system such as non-obsolescence requirements and the ISO/IEC 2501029 quality characteristics (eg, maintainability, reliability, and transferability). Moreover, energy efficiency is also part of technical sustainability requirements.”	“It focuses on the technical capability of the eHealth system to meet the users’ expectation where it is deployed. They also address technical indicators such as user-friendliness, flexibility, reliability, availability, accuracy, efficiency, data quality, scalability and adaptability.”
<i>Individual</i>	“It refers to the maintenance of the individual human capital, eg, health, education, skills, and access to services. Individual sustainability can be covered by privacy, safety, security, human-computer interaction, usability, personal health, and well-being.”	NA

Joshua et al. [PS6] concluded some issues that impact the sustainability of Health Information Exchange (HIE). These are financial, political, and organizational issues. In their study, they discussed the strengths and weaknesses of organizational models used for HIE in New York State, such as regional health information organization (RHIO). In addition, they provided suggestions to ensure the sustainability and effectiveness of exchange efforts. Financial issues were perceived as upfront costs, decreased profits, and funding, while political and organizational issues were summarized in the difficulty of cooperation and collaboration among healthcare organizations (e.g., other competitive hospitals). The authors suggested that existing of public/government funding and codifying health laws that enforce and facilitate the HIE would help in solving these issues. Another paper [PS10] investigated the sustainability of pilot smart connected health services that used Internet of Things (IoT) technology and were provided for both patients and health professionals. The results showed that in order to sustain smart connected hospital services, it is necessary to consider the technical feasibility, economic feasibility, and organizational commitment and support.

Iandolo et al. [PS19] argued that the focus of healthcare technology assessment should be shifted from efficiency and effectiveness to the sustainability. By proposing a reference framework, they stated that the sustainability of the technology can be achieved by assessing three aspects along with considering the relations and interactions between them [25]. These aspects are economic, social, and political. Garde et al. [PS20] analyzed the inhibitors and enablers, that influence the sustainability of health information systems (HIS). They proposed a high-level sustainability framework based on four pillars, which are clinical, technical, socio-technical, and political/ business. Wade et al. [PS4]

investigated 54 telehealth services in Australia to understand the reasons behind the continuing and ceased services, and to assess their sustainability. The results revealed that insufficient demand, issues with technology, funding, loss of senior management support, and loss of interest of clinicians found to be the failure reasons among the ceased telehealth services. On the other hand, the success factors of sustainable healthcare services are sufficient demand, available funding, and developing organizational structures that help to integrate telehealth into their regular operations. Also, they demonstrated the importance of routinization and integration of telehealth service, especially when it is executed withing an existing clinical unit. Moreover, they stated that in public sector, the funding is not a major issue as long as the need and the support could be demonstrated, then the fund would follow. In addition, the sustainability of a telehealth application called TeleRehab was discussed by Scheideman-Miller et al. [PS8] and concluded six factors that impact the sustainability of TeleRehab. These are organizational strategy, establishment of need, organizational stakeholders, organizational commitment, human factors, revenue/cost savings, and outcomes. Organizational strategy addresses the customer, clinical operations, financial, and clinical development for health care providers and the organization. The human factors involve acceptance, long-term commitment of healthcare providers, specialized training, and user satisfaction. In addition, the outcomes of the e-solution vary whether they are clinical, financial, technical, or social outcomes. Therefore, they should be defined by the organization itself and needed to be evaluated regularly. They stated that a partnership of collaborators within an organization including clinical, technical, and administrative professionals will help in ensuring the success and sustainability of a telemedicine program.

Similar dimensions were mentioned in some studies, that presented frameworks and methods to assess e-health sustainability. Fanta et al. [PS16] evaluated the contribution of four frameworks for the implementation of e-health systems in a resource constrained environment. The evaluation was in terms of four sustainability dimensions. These are social, environmental, economic, and technological. They underlined that it is essential to consider the social, economic, and environmental factors in alignment with the technology factor to ensure the sustainability of e-health. In a following study [PS13], Fanta et al. presented the topic of sustaining the e-health implementation and emphasized on the importance of technological, social, organizational, and economic dimensions in this regard. The study proposed a conceptual framework for the sustainability of e-health implementation, that only focused on both organizational and technological dimensions. The organizational dimension comprises some aspects such as resources (i.e., human, physical, and financial resources), workflow process, and management support. While the technological dimension encompasses system quality, information quality, and service quality. Also, they underlined the techno-organizational processes that are essential for the success of e-health implementation. These processes are user training, data management, stakeholder engagement, project management, organizational communications. Remondino [PS12] proposed a framework that includes five dimensions, which are management, organization, technology, environment, and social. The framework helps in the long-term assessment of sustainability of IT applications and projects in healthcare and their implications on the healthcare organization, with respect to the five mentioned dimensions.

With regard to requirements engineering, Ouhbi et al. [PS15] have demonstrated the need for defining sustainability software requirements that are not focused only on the energy consumption of the software. Instead, they developed a design catalog called (SCH-CAT) for sustainable connected health applications. The catalog contains five dimensions; economic, individual, social, environment, and technical, all of which have their own sustainability requirements except for the economic dimension; that its requirements were not covered in the catalog because they are not considered inherent requirements. The catalog was used in the study to evaluate the sustainability of a connected health app for blood donation. Dyk et al. [PS17] discussed two models, that aim to assist in the successful implementation and sustainability of e-health solutions. The technology, users, work processes, finances, and policies categories were included in both models, as they contribute to the sustainability of e-health solutions. Along with that, Chowdhury et al. [PS3] proposed an optimization integrated Fuzzy QFD methodology to determine the optimal strategies that can be used to mitigate service's barriers and achieve organization's sustainability goals. They emphasized on three dimensions that must be considered and balanced for sustainable service design. These dimensions are social, environmental, and economic. The proposed methodology was applied to m-health services setting in Bangladesh, by which lists of barriers and strategies to mitigate them were identified regarding m-health service sustainability. From the results, the authors emphasized on the importance of training the service providers and collecting customers' feedback in improving the service quality and service receivers' satisfaction. Also, they stated that mitigating service's barriers has a substantial impact on the sustainable health service.

Table 13 The mentioned sustainability aspects of e-health solutions

Aspect	Study ID
Functional suitability	PS14, PS13, PS16
Performance Efficiency	PS12, PS13, PS14, PS16
Usability	PS12, PS13, PS16, PS22
Security	PS14, PS13, PS16, PS22
Modifiability/Changeability, accessibility, reusability	PS12
Interoperability	PS11, PS13, PS14, PS16
Portability	PS12, PS13, PS16, PS20
Flexibility	PS16, PS13
Reliability	PS12, PS16, PS13, PS22
Scalability	PS16
Accuracy	PS13, PS16
Completeness, consistency, data accessibility, confidentiality, relevance	PS13
Timeliness	PS13, PS16
Semantic interoperability	PS1, PS20
Electromagnetic compatibility, power, physical parameters, data exchange, compatible architecture	PS14
Mobility and unobtrusiveness	PS5, PS14
Supporting online social networking	PS5
Attitude	PS9, PS16
Perceived ease of use	PS9, PS14, PS16
Perceived usefulness	PS9, PS14, PS16
User satisfaction	PS9, PS3, PS8, PS16
Confirmation	PS9, PS16
Trust in using eHealth, readiness to make changes, human computer interaction, benefit in learning, satisfaction & willingness, users' technology adoption, awareness about eHealth	PS16
Acceptance (patients & clinicians)	PS8, PS14, PS18
Social	PS5, PS17, PS13, PS15, PS19
Workforce Availability	PS3, PS18, PS21
Technical Support	PS7, PS16, PS13, PS12
Technical Training	PS8, PS3, PS20, PS16, PS13
Physical Structures	PS13, PS3
Network management and Communication	PS14
Environment (ecological: natural resources)	PS15, PS12

Support and commitment of top management	PS4, PS6, PS8, PS10, PS13, PS16, PS21
Organizational structures	PS4, PS8, PS13, PS16, PS20
Process workflow & process integration	PS13, PS17, PS11
Laws and standards related to ICT and eHealth	PS16, PS2, PS5, PS6
Financial policy of e-health	PS16, PS12
Agreement on clinical content	PS20
Privacy and security policy	PS16, PS1
Data Management	PS14, PS2, PS13, PS16
Stakeholders' involvement/engagement	PS4, PS8, PS13, PS16, PS22
Direct benefit to users in routine work	PS16
Incentives and recognition	PS3
Organizational culture of electronic information use	PS16, PS13
(Outcomes of the solution are defined by the organization itself and needed to be evaluated regularly. They vary whether they are clinical, financial, technical, or social outcomes)	PS8
Sufficient demand and establishment of need	PS4, PS5, PS8, PS16, PS18
User and Organizational Readiness, eGovernment policy, efficiency of legal systems in settling disputes, intellectual property protection, procedures to enforce contracts	PS16
Policy	PS17, PS20
Available and sustainable funding	PS4, PS6, PS16, PS20
Economic feasibility	PS10
Affordability of e-solution, Return on Investment	PS16
Cost-effectiveness/cost minimization	PS16, PS8
Revenue and reducing the cost of data archiving	PS2, PS8

Moreover, some studies argued that user acceptance is significant to sustain e-health solutions. Wade et al. [PS18] developed an explanatory model for the telehealth services' sustainability. In their work, they argued that the clinician acceptance is the key factor that influences the sustainability of telehealth services. The model shows how other components, such as workforce availability, clinician demand, adequate technology, and resourcing are related to clinician acceptance. The two factors, clinician demand for service and the adequate technology impact the clinician acceptance factor of the service, which in result influences the clinician workforce availability factor and therefore leads to sustain

the telehealth service. To achieve clinician acceptance, they suggested two strategies, which are legitimation and relationship building. Legitimation composed of promoting positive beliefs about telehealth among clinicians, while relationship building is concerning with maintaining good relationship with those who provide the care. Both of which are shown in the model as parts of champions promoting telehealth. The continuous usage intention of electronic medical records (EMRs) among healthcare professionals was evaluated using technology continuance theory (TCT) in [PS9]. With continuance usage being one factor of sustainability, the study focused on the six acceptance constructs, that influence continuance usage. These are confirmation, satisfaction, perceived usefulness (PU), perceived ease of use (PEU), attitude, and continuance intention. Spies [PS14] identified the concerns of m-health implementation when the sustainable use is the intended goal for the system. The concerns were discussed in terms of the patient and health practitioner perspectives (e.g., acceptance, usefulness, wearability, and quality of service), as well as the considerations of hardware and software design (e.g., compatibility, data management, functionality, and interoperability).

Technical, political, and management dimensions were the focus of other studies. Petersen [PS7] addressed the role of technical support for hardware, software, and people-ware in sustaining the hospital information system (IS) and information technology (IT) infrastructure. Lenz [PS11] stated that two goals must be considered equally for the sustainability of healthcare information systems, which are process integration and systems integration. Chen and Wu [PS5] proposed a judgment-decomposition analytic hierarchy process (JD-AHP) approach to help decision makers in assessing the sustainability of smart e-health applications, such as smart body analyzer. The main factors that critically

influence the sustainability of a smart technology application are unobtrusiveness, supporting online social networking, relaxation of the related medical laws, future e-health market size, correct identification of need and situation. Shabo discussed the sustainability of electronic health records (EHRs) in [PS1, PS2]. In the first paper, he discussed sustainability issues of three different models of EHR from (i.e., conflicts of interests and access restriction for some special cases), legal (i.e., patients' bill of rights), and technological (i.e., semantic interoperability standards) aspects. Also, he proposed the Independent Health Record Banks (IHRBs) model that would help in sustaining the EHR. In the following paper [PS2], he discussed sustainability considerations of IHRBs, which are legal and ethical (e.g., authentication, access control, privacy, data integrity), business (i.e., revenue and reducing the cost of data archiving), and technological (i.e., information exchange standards). These considerations act as guidelines for the new legislation needed for IHRBs to be established and operate successfully.

2.3.2.3 Evaluation/ Assessment Methods

Eight of the primary studies [PS5, PS9, PS12, PS13, PS14, PS15, PS16, PS17] have discussed a method, framework, model, or theory to evaluate the sustainability of e-health solutions. These are: JD-AHP approach [PS5], technology continuance theory (TCT) model [PS9], HCC-MOTES framework [PS12], a conceptual framework to sustain e-health implementation [PS13], a model to evaluate mHealth systems [PS14], (SCH-CAT) catalog [PS15], a conceptual framework for e-health systems in a resource constrained environment [PS16], and model for sustaining telemedicine projects [PS17]. The e-health solutions mentioned in the studies are smart e-health applications, EMRs, information

technology in healthcare, Electronic Health Management Information System (eHMIS), mHealth systems, and telehealth.

Chen and Wu [PS5] identified several factors that are critical to the sustainability of technology applications in healthcare. By using the JD-AHP method proposed in their study, the priority of critical sustainability factors in two or more technologies are compared by a decision maker to determine which technology is more likely to sustain. Using 10 smart technologies in e-health, the proposed method was compared against existing methods, which are AHP, OWA, and MACBETH. However, as stated in the study, this method works for one decision-maker, if more were involved, then the sustainability problem becomes considerably complicated.

Gilani et al. [PS9] used TCT model to evaluate the continuance usage intention of EMR system among users (i.e., healthcare professionals) in the post-adoption phase. In their study, the hypotheses discussed the positive effects of satisfaction, attitude, perceived usefulness, perceived ease of use of healthcare professionals on their continuance intention to use EMR system. In order to test the hypotheses, a survey was carried out on 195 respondents consisting of various healthcare professionals from five hospitals. Results showed that all hypotheses in the TCT model were supported, which indicates the significant power of TCT to explain EMR system continuance usage intention of both short- and long-term users. As indicated in their study, TCT will help policymakers and managers in the healthcare sector to understand the factors that result in the ongoing use of an EMR system after adoption phase.

Remondino [PS12] developed a framework named HHC-MOTES, that contains a novel set of Key Performance Indicators (KPIs) to evaluate the sustainability of healthcare IT projects in terms of five dimensions (i.e., management, organization, technology, environment, and social). The framework aimed to provide a qualitative measurement of various aspects related to the sustainability of IT applications in healthcare. It is stated in the study that HHC-MOTES framework can be used by healthcare decision-makers to strategic decisions regarding introducing or updating IT systems or examining current systems and identify limitations and shortcomings. However, it worth noting that the mentioned KPIs of all dimensions other than the technology dimension, were focusing on assessing the positive impact of IT systems on the efficiency of the healthcare system. For example, in the environment dimension, the indicators were evaluating the reduction of paper use and energy consumption, that were caused by using the IT system. However, the technological KPIs discussed the aspects that should be considered to ensure the sustainability of IT system in healthcare. Example of these indicators is ensuring the modifiability, reusability, portability, and supportability of the IT system.

Fanta et al. [PS13] developed a conceptual framework that describes how organizational and technical factors influence the sustainability of eHealth implementation. The framework has four sections. These sections are 1) inputs, which contains organizational and technological factors, 2) processes, that deals with activates executed to achieve desired outputs, 3) outputs, consists of intention to use, actual use, and user satisfaction, and 4) outcomes, which represents organizational benefits (i.e., improving the decision-making process and internal communications in the organization). By using a causal loop diagram (CLD), the study presented the dynamic interactions between organizational

factors and the technological dimensions. Also, the study concluded insights from the literature about measuring the technological aspects. For system quality, it could be measured by ease of use, functionality, reliability, flexibility, portability, integration, and importance of the system [52][53][54]. The measures of information quality consist of accuracy, timeliness, completeness, relevance, and consistency of information produced by IT system [55], [52][53][54]. Moreover, the service quality measures include up-to-date hardware and software, reliability, responsiveness, assurance, and empathy of technical support [53][54].

Table 14 Tools and assessment methods mentioned in the primary studies

Study ID	Method of assessment	Type of Assessment methods	Source	E-health solution	Evaluated/validated in real context?
PS5	AHP method	Mathematical equations	Proposed	Smart e-health applications	No
PS9	Model	Theory	Technology Continuance Theory (TCT)	Electronic medical records (EMRs)	Yes, evaluated
PS12	Framework	Qualitative metrics and KPIs	Existing literature and validated sets	Information Technology (IT) in Healthcare	No
PS13	Conceptual framework	NA	Proposed	Electronic Health Management Information System (eHMIS)	Yes, evaluated
PS14	Model	Standards	1. Clinical and Laboratory Standards Institute (CLSI) 2. “Institute of Electrical and Electronics Engineers Standards Association (IEEE)”	mHealth systems	No

			3. “International Electrotechnical Commission Technical Report (IEC/TR)” 4. “International Organization for Standardization -Technical Report (ISO/TR)” 5. “German Institute for Standardization (DIN)		
PS15	Catalog	Checklist of software quality requirements	Elicited from several sources in software engineering	Connected health apps (e.g., telemedicine, mHealth, etc.)	Yes, evaluated
PS16	Conceptual framework	Qualitative indicators	Literature and international agencies’ reports	e-health	Yes, evaluated
PS17	Model	Qualitative feedback and quantifiable scale	Combination of two existing models (CeHRes roadmap and TMMM)	Telehealth	Yes, evaluated

The model proposed by Spies [PS14] aimed to be used as an evaluation method for the developed and developing m-health systems to assess the sustained use of them. The model focuses on evaluating aspects related to the user (i.e., patients and physicians) and system design (i.e., hardware and software). Each of which are intended to be measured by endorsed standards. The standards were included from the bodies presented in Table 14.

As requirements engineering play a vital role in software sustainability, Ouhbi et al. [PS15] designed SCH-CAT catalog for software quality requirements; that are critical to the sustainability of connected health (CH) applications. Although SCH-CAT catalog targets the design phase of CH applications, a checklist can be generated from it, in which it includes a set of requirements to be used to evaluate the sustainability of CH applications

in the implementation phase. The catalog was applied to assess the sustainability of a running CH application called Blood Donor+. A questionnaire containing requirements as checklist questions was used to evaluate the CH app, in which the answer is one of the three options: yes (+1), No (+0), and partially (+0.5). The coverage score was calculated and the threshold score that determines the app's sustainability was set to be 50%.

Based on a literature survey, Fanta et al. [PS16] constructed a conceptual framework that can support the efforts of developers, researchers, managers, and policy makers to ensure the implementation of sustainable eHealth systems in resource constrained settings. In the study, the framework was used to assess the contribution of four e-health frameworks. The framework consists of four sustainability aspects, namely social, environmental, economic, and technological, all of which contain indicators, that can be used to evaluate the sustainability of e-health systems.

Dyk et al. [PS17] discussed two models Telemedicine Maturity Model (TMMM) and CeHRes roadmap, that were proved to be effective in facilitating, implementing, and sustaining telemedicine projects. The CeHRes roadmap serves as a guide to the establishment of a telemedicine service, whilst the TMMM is concerned with maturation of the existing telemedicine service. In the study, the authors proposed a new model by combining these two models. In the proposed model, it was suggested that each maturity level of TMMM serves as a stage gate for each of the phases of the CeHRes roadmap. Maturity levels are initial, managed, defined, quantitatively managed, and optimized. The maturity levels are used to evaluate the maturity categories, which are technology, users,

work processes, finances, and policies. By applying the proposed model to an e-health solution, the resulted maturity level of each category determines its sustainability.

Iandolo et al. [PS19] argued that the focus of healthcare technology assessment should be shifted from efficiency and effectiveness to the sustainability. They proposed a reference framework containing efficiency and effectiveness dimensions to achieve the sustainability dimension of healthcare technology. They defined efficiency as the plans (i.e., things are done in the right way), effectiveness to be the goals (i.e., the right things get done.), and sustainability is the right relationships exist with other service systems. As they indicated, efficiency can be measured with reference to the structure, whilst effectiveness of a system is measured with its specific context of reference. And in relation to the general environment, sustainability therefore can be achieved.

2.4 Discussion

Although sustainability is a critical issue in all sectors, it is more important in healthcare due to the complexity and sensitivity of this sector [34][41][43][21][16]. As e-health solutions being involved in many processes of healthcare provision, the sustainability of these solutions should be particularly considered by healthcare decision makers and management. However, the results of this SLR indicated a significant scarcity of studies investigating the sustainability of e-health solutions and providing methods to assess and evaluate their sustainability.

The issue of not having a unified sustainability definition in healthcare was mentioned on most of the primary studies, yet their scope did not focus on resolving this issue or referring to other studies that tackled it. There exists some studies that focused on defining

sustainability in healthcare [56][20]. However, the scope of these studies was defining sustainability of the healthcare innovation generally, and not focusing on the e-health solutions. Therefore, a unified definition of sustainability of e-health solutions remains a need and further studies are required to investigate how e-health sustainability is perceived and defined in practical and literature. Based on the focus of the definitions elicited from the literature, the sustainability of e-health solutions is defined by the ability of e-health to continue meeting the expanding demand for facilitating healthcare provision through the cost-efficient use of digital technologies.

Moreover, the studies emphasized on the importance of having multidimensions to assess the e-health sustainability as it is not enough to focus on only one dimension such as financial, environmental, or technology [48][42][17]. Correspondingly, the organization dimension was found to be dominating more than the technology and aspects related to the e-health solution [43]. That is because the same e-health solution can exhibit different levels of success when implemented in different healthcare organizations [43]. As the budget for e-health is a global issue in all healthcare systems, top management support is one of the organizational factors that help overcome this issue [35]. That is because when the top management is supporting the adoption of the e-health solution, then the funding will be readily facilitated [35], which contributes to its sustainability.

Also, it is important to consider the variation of the influence on sustainability among the dimensions, in which sustainability should not be an all-or-nothing concept [35]. Instead, each dimension impacts the sustainability of e-health at different degree according to the context of the e-health solution [35]. Although all dimensions are intrinsically

interconnected and must be considered as they influence each other [42], most of studies that stated the dimensions of e-health sustainability did not explore the influence degree of dimensions on the sustainability and on each other. Except for study [PS18], in which it argued that the clinical acceptance has the greatest influence on sustaining telehealth, that was the focus of the study. Determining the degree of influence of the dimension reflects the importance of each dimension and therefore helps assessing the sustainability of the e-health solution, which was not discussed in depth in the primary studies [48].

Some of the selected studies in this review have proposed a model or framework containing dimensions of e-health sustainability. Yet, all the mentioned evaluation methods were either too narrow, in which it was designed to evaluate a specific type of e-health (e.g., health connected applications), or too general and do not comprehensively evaluate the sustainability of the e-health solutions. Therefore, there is a need for a sustainability assessment method, that comprehensively assesses all sustainability aspects of e-health solutions.

To cover a wider range of studies, I used OpenGrey¹ database to search for relevant papers in the grey literature. Yet, the papers found in the results were irrelevant to the focus of this SLR. For example, some papers discussed sustainability from a manufacturing perspective rather than focusing on the sustainability of digital solutions. Also, some of them focused on software are sustainability from developers' perspectives, in which no relevant aspects can be extracted and used to reflect the sustainability of e-health solutions. The rest of the results were discussing sustainability from an ecological perspective. In addition, I

¹ <http://www.opengrey.eu/>

searched other types of documents (i.e., other than articles and conference papers) in the three libraries (Scopus, Web of Science, and IEEE), no relevant documents were found. Therefore, the grey literature was not included in this review.

2.4.1 Threats to validity

The validity of this SLR has some construct, internal, and external threats. In terms of the construct validity, the SLR protocol, especially the search string, might be biased or does not lead to covering all relevant studies. However, to mitigate this threat, I had the SLR reviewed by an expert and the search string's terms were extracted from relevant studies.

For the internal validity, data extraction might be biased, or some relevant data might be missed as the data was extracted by the author. However, having the template that includes what data to extract and documentation of extracted data might reduce the risk if this issue (see Table 6). In addition, some of the questions of the quality assessment are not decisive, they depend on how I interpreted the study. Hence, this might exclude some relevant studies.

2.5 Chapter summary

This SLR aimed to investigate the e-health sustainability in terms of aspects and assessment methods. The results showed that there is a scarcity in e-health sustainability assessment. Therefore, it is necessary to redirect the focus of e-health research towards developing a sustainability model that encompasses all aspects that impact the sustainability of e-health solutions. Hence, this thesis proposed a comprehensive sustainability model for the e-

health solutions, and assessment method that assess all dimensions and aspects appropriately. The model is presented in next chapter.

CHAPTER 3

E-HEALTH SUSTAINABILITY MODEL

This chapter discusses the process of building the proposed e-health sustainability model. It contains the phases of building the model, the definitions of sustainability dimensions, the criteria of categorizing the aspects into the dimensions, and the validation of the model.

3.1 Phases of designing and validating the e-health sustainability model

Figure 5 presents the phases of building the model. Based on the SLR results (Chapter 2), the extracted sustainability aspects were grouped into five dimensions to form the e-health sustainability model. These dimensions are technology, organization, resources, social, and economic. The categorization of the dimensions was deduced from the literature as they were mentioned to be the main dimensions of e-health sustainability [19]. The significance of representing sustainability of e-health solutions through multiple dimensions arises from the fact that focusing on only one dimension is insufficient for evaluating software's sustainability [57]. Following that, the extracted aspects (refer to Table 13) were categorized into the five sustainability dimensions based on the criteria of each dimension. As presented in Table 15, the definitions of the dimensions were obtained from SLR studies (Chapter 0) and were used as guidance to the development of the categorization criteria, that is used to map the aspects with dimensions in this thesis. Table 16 presents the criteria

used to categorize the aspects. Each dimension is explained in detail in the following section.

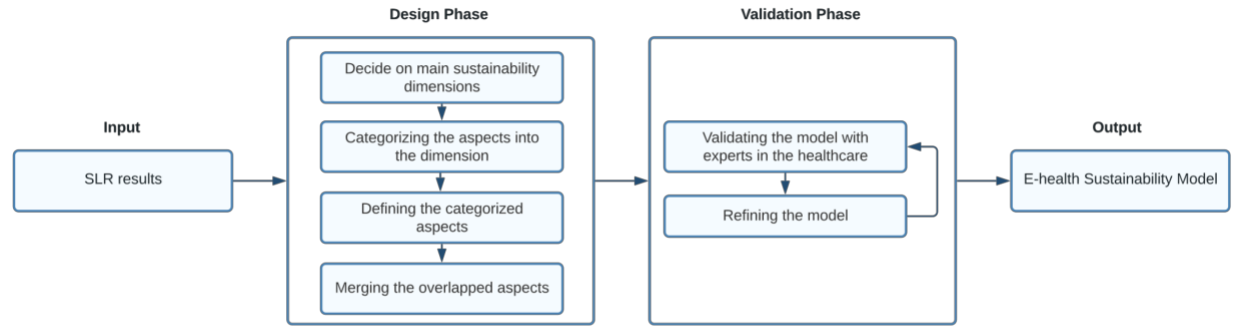


Figure 5 Building phases of the sustainability model

Table 15 Developed definitions of sustainability dimensions

Dimension	Definition
Technology	The technology dimension includes the aspects that determine the quality of the system itself regardless of the context it is applied to [45].
Organization	The organization dimension is concerned with the aspects that influence the readiness of the organization to adopt the system and accommodate the changes that followed the adoption [45].
Resources	The resources dimension involves all aspects that facilitate the installation of the e-health solution and assist the e-health to operate and be used at the optimal level [42].
Social	The social dimension comprises all aspects that are related to the users' perspectives and behaviors towards adopting and using the system [42].
Economic	The economic dimension is related to the funding directed to e-health solutions, and the financial benefits gained from using the system [45].

Table 16 Aspects' categorizing criteria

Dimension	Criteria of aspects categorization
Technology	Any aspect fits under the technology category is an external entity/attribute that is associated with the new technology itself and does not depend on or belong to the organization. The aspect in this category should • contribute directly to the overall soundness of an e-health solution that is under evaluation OR • be a part of hardware or software of an e-health solution that is under evaluation (i.e., it could be input/output, components, properties, or attributes, etc.).
Organization	• The aspects in this category are associated with the readiness of the organization to adopt an e-solution. • The aspect regulates, defines, and impacts the way an e-solution is adopted in the organization.
Resources	Any aspect belongs to this category represents or belongs to an organization's resources that affect the deployment of an e-solution. The aspect should: • contribute to the operating environment of the e-health solution AND • help in maintaining acceptable level of using e-health solution.
Social	The aspects belong to this category is concerned with the user interaction and use of an e-solution. The aspect should • directed to the user of e-health. • contribute to assessing the users' perception and behavior towards the use of the e-health.
Economic	The aspect in this category is associated with the financial affordability and benefits associated with an e-solution the: The aspect should • contribute to covering the costs of adopting and operating e-health solution • concern with the financial benefits gained from adopting and using the e-health solution.

Figure 6 illustrates the three levels (i.e., dimensions, aspects, and elements) of the sustainability model. Dimensions are in the first level of the sustainability model and can't be eliminated as each one of them influences the sustainability of e-health. Each dimension contains aspects, which represent the second level in the model. The fulfillment of these aspects is reflected in their dimension and indirectly impacts the sustainability of e-health.

In the third level, some of the aspects contain elements, that are used in the assessment phase to assess the sustainability of e-health. The importance of having the dimensions decomposed into aspects and elements is to support a fine-grained analysis of the sustainability level. After that, the model was validated by experts in healthcare. The validation phase is described in section 3.3.

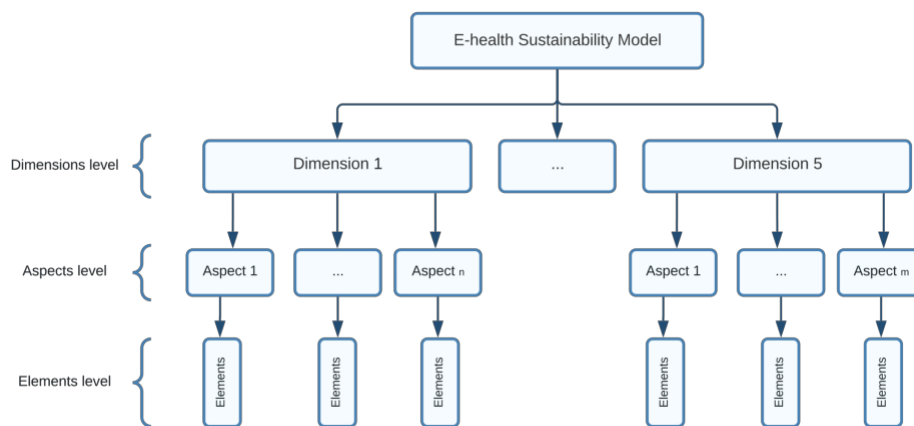


Figure 6 The levels of the e-health sustainability model

3.2 E-health Sustainability Model

This section describes the dimensions of the e-health sustainability model. Figure 7 presents the e-health sustainability model with all its components. Appendix B in Table 41 contains the definitions of the sustainability elements. Technology, organization, resources, social and economic dimensions are explained in detail in the following subsections respectively.

3.2.1 Technology

The technology dimension contains three aspects: system quality, data quality, and hardware quality. All these aspects are concerned with the quality of the e-health solution.

The system quality aspect refers to the soundness of the e-solution, which comprises system's functional suitability, performance efficiency, usability, security, maintainability, compatibility, portability, flexibility, reliability, scalability, and integrability. The existence of these elements ensures that the system operates efficiently and therefore contributes positively to the solution sustainability. Similarly, the data quality aspect refers to the quality of the content information produced by the e-health solution. Elements of this aspect, such as data confidentiality, accuracy, and completeness are critical in the context of e-health solutions as they deal with sensitive health data such as drug prescriptions and patients' information. Hardware quality aspect refers to the suitability of the hardware components of the e-health solution to the users' needs and comfort. Some elements of this aspect are the amount of electrical power consumed by e-health and the degree of mobility it provides to the user. This aspect is mostly applicable to e-health solutions that are related to m-health contexts or in case of the existence of special hardware components required to operate the e-health (i.e., hardware components used directly by the users such as a microphone to dictate medical reports). Although some unmentioned elements in the technology dimension can be used to determine the quality of a software product, the elements outlined in the model were found in the literature to significantly affect the sustainability of e-health solutions.

3.2.2 Organization

The organization dimension addresses changes introduced to the organization because of the adoption of the e-health solution. The organization dimension is important for the sustainability of the e-health solution because it ensures the availability of plans, policies,

and practices that streamline the workflow integration of the e-health solutions and acceptance of users. In the results of the SLR (refer to Table 11), some studies (i.e., PS1, PS2, PS5, PS6, PS13, PS17, PS19) represented the political/legal as aspects while in other studies they were mentioned as dimensions. As the definition of the political/legal overlaps partially with the organization's definition, I followed studies (PS15 and PS16) and included political/legal as aspects under the organization dimension. The aspects of this dimension are support and commitment, organizational structures and strategy, planning and policies, stakeholders, the culture of electronic information use, outcomes identification, and demand and need.

The support and commitment of the top management and their awareness of the importance of adopting the e-health solution are essential to its sustainability. The importance of this aspect is that the top management always has the final decision on whether to continue running and funding the e-health or not and whether to enforce the changes associated with the e-solution or not. The absence of their support may result in an unplanned suspension of the e-solution; hence, waste of money and resources were allocated to it. Similarly, the support and commitment of the e-health solutions vendors to continue providing the services impact the sustainability of the e-health solution. Therefore, it is necessary to consider this when assessing sustainability.

Also, having well-established plans and policies that deal with the e-health regulations provide a solid foundation to adopt and sustain any e-health solution. In addition, it is the responsibility of the healthcare organization to identify the outcomes of adopting and using e-health and to have an evaluation plan to assess these outcomes regularly. Moreover,

determining the need and demand on e-health plays a key role in its sustainability because low demand or unfulfilled needs will be a waste of the organization's resources leading to stopping the e-health solution.

3.2.3 Resources

The resources dimension is concerned with the aspects needed for the continuity of e-health's operation. These aspects are human resources, financial resources, availability of technical support and training, and readiness of ICT infrastructure within the healthcare organization. Human resources refer to the availability of enough users to use and support the e-health solution to provide the healthcare service or complete its tasks. Even with the existence of needs and demands for e-health, the shortage in human resources will affect the work process and cause to suspend or stop the e-health solution. Also, the financial resources aspect refers to the availability of financial resources that support operating the e-health solution, such as covering the expenses of purchasing a new system feature or upgrading the software license to cover more features such as technical support and maintenance. The technical support and training aspect involves the technical support and maintenance for the e-health solution's components and users, and providing them with the necessary knowledge to use the e-health. Maintaining the soundness of the e-health solution and technical skills among users will contribute to using the system, hence, a higher sustainability of the e-health solution is expected. The readiness of the ICT infrastructure is reflected on the e-health performance and therefore has an impact on its sustainability. Because even with an efficiently designed e-health solution, its capabilities will not be optimally utilized if the ICT infrastructure within the organization is not ready

to operate the e-health (e.g., no steady networking system, no sufficient servers' cabalists, or outdated equipment.), hence affecting its performance.

3.2.4 Social

The social dimension consists of all elements that are related to the users' perceptions towards the e-health solution. These elements were grouped into two aspects, which are the continuous usage intention and the user behavior. The intention of the users to continue using e-health must be highly considered especially if the regulations do not enforce the use of the e-health solution. This interrelates with the human resources aspect in the resources dimension, having enough users using the system to achieve its outcomes. Also, users' behavior towards e-health influences the work process and e-health productivity. The users who trust the use of e-health and have the requisite skills and training are most likely to be ready to make the necessary adjustments corresponding to the adoption of e-health, which contributes to the achievement of the outcomes and goals of the e-health solution.

3.2.5 Economic

The economic dimension contains three aspects, which are affordability of the e-health solution, sustainable funding, and financial benefits. The affordability of e-health refers to the degree to which all expenses of the e-health solution are covered. This is not limited to the technical expenses but extends to operational costs such as staff salaries and required equipment. Yet, even in the case of the capability of affording the e-health solution, it is of great importance to have sustainable funding for the e-health solution. Therefore, the

sustainability of funding must be considered and ensured when approving the e-health affordability as it is not a one-time activity. The financial benefits aspect concentrates on the direct or indirect pecuniary or material benefit, that is obtained by implementing and using the e-health solution [58]. This can be in a form of direct cost-saving (cost reduction) or indirect cost-saving through operative, regulative, or social aspects, that eventually affect the financial business aspects [58]. This aspect can interrelate with the outcome's identification aspect in the organization dimension. However, it is worth noting that it depends on the healthcare organization's goals and objectives of using the e-health solution. In other words, if the healthcare organization does not consider financial benefits in the adoption of e-health then this aspect can be eliminated in the context of the healthcare organization.

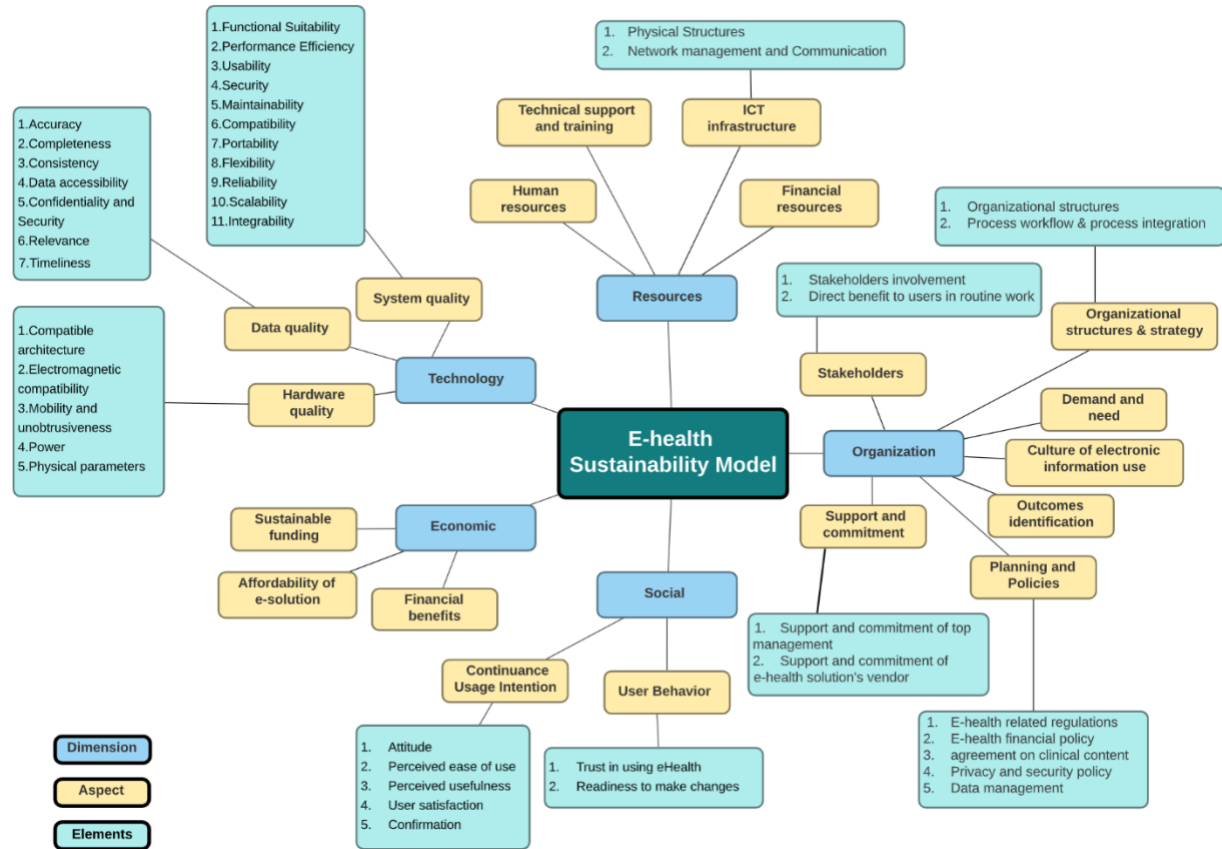


Figure 7 E-health sustainability model

3.3 Validation of the Sustainability Model

To verify the validity and the comprehensiveness of the e-health sustainability model, interviews and discussions were conducted with three experts in IT from three different hospitals. One hospital is in the eastern province of Saudi Arabia and the other two are in the western province of Saudi Arabia. The objectives were to collect their feedback on 1) the validity and correctness of the dimensions and their elements and aspects, 2) comprehensiveness of the model in terms of representing the e-health sustainability dimensions, 3) the importance of each dimension and their aspects, and 4) applicability of dimensions and their aspects in reasoning about sustainability of e-solution in healthcare. The data collected from first and second feedback on the validity and comprehensives of

the sustainability model were used to refine the model. While the feedback on the importance and applicability were used to select the most relevant and important elements, based on the context, to assess the sustainability (to be explained in Chapter 4). Table 17 summarizes the feedback iterations and the suggested changes in each of them.

Table 17 Summary of the results of the feedback iterations

Iterations	Description	Suggested changes
Iteration 1	Presenting the initial version of the proposed sustainability model to validate the correctness of its dimensions and their elements and aspects.	• Adding software integration as an element in the system quality aspect in technology dimension. • Considering the commitment and support of the e-health vendor as an element that impact the sustainability.
Iteration 2	Validating the comprehensiveness of the model in terms of representing the e-health sustainability dimensions.	The expert assessors should decide on the weights of the dimensions and select the applicable aspects based on their judgment.
Iteration 3	Determining the importance and applicability of each dimension and their aspects	The aspects and elements with high importance should be mandatory in assessment, while other aspects with less importance can be eliminated based on the context.

The experts are healthcare providers and staff, who have been working for an average of 10 years in the healthcare industry. They have direct experience in managing the adoption of e-health solutions within their hospitals. The used sampling technique is judgmental sampling [59]. The duration of the interview discussions was from 45 to 60 minutes.

During the interview discussions, the experts were asked about the sustainability aspects, that they consider when they evaluate an e-health solution. The aspects they mentioned aligned with the model, by which they were a subset of the set that composes the model. After that, the e-health sustainability model was presented to the experts to validate the

other aspects. All three experts agreed on the importance of the aspects on determining the sustainability of the e-health solutions. One expert suggested adding an additional aspect in the technology dimension, which is the integration aspect. As stated by that expert, who is the head of the IT department in the hospital, the integration aspect is critical as most of the e-health solutions should be connected to the hospital information system (HIS) because it is the core system in the hospital. Therefore, the e-health solution must be integrable if there is any sort of required communication between the e-health solution and the HIS. Another suggestion was regarding the organization dimension, in which they emphasized on considering the commitment and support of the e-health vendor as an element that impact the sustainability. Also, he highlighted that the maintainability element in the technology dimension depends on the organization's objectives of the e-health solution project. He illustrated that reusability, which is part of the maintainability definition, is not always important as most of the e-health solutions projects are adopted and implemented to serve a specific goal. This element was therefore considered to have a weak effect on e-health's sustainability and should only be considered if reusing the e-health solution is an objective. Accordingly, experts will assign the weights to the dimensions and select the elements based on their applicability to the context of the e-health solution. The mandatory and optional aspects were suggested and identified by an independent technology expert in healthcare as they are shown in Table 18. The identification for the mandatory/optional evaluation was for the purpose of guiding the healthcare institution on what is essential to be evaluated and what is optional. For example, the system quality aspect in the technology dimension exists in any software and it must be evaluated, and thus it is mandatory. On the other hand, the hardware quality

aspect is optional because not all e-solutions need a special hardware. For other aspects such as organizational structures & strategy and stakeholders, they are optional because some e-health solutions are not necessary impacting an organization structure or require stakeholders' involvement (e.g., e-solutions for a specific department such as IT department). Also, for the ICT infrastructure, some e-health solutions do not need to be run on the hospital's ICT infrastructure such as health applications that are not connected to the hospital database or servers but are used by patients and physicians. However, it is up to technology experts in hospitals to discard some of the mandatory aspects.

Table 18 The mandatory and optional aspects in the sustainability assessment

Dimensions	Aspects	Assessment Status
Technology	System quality	Mandatory
	Data quality	Mandatory
	Hardware quality	Optional
Organization	Support and commitment	Mandatory
	Organizational structures & strategy	Optional
	Planning and Policies	Mandatory
	Stakeholders	Optional
	Culture of electronic information use	Mandatory
	Outcome's identification	Mandatory
	Demand and need	Mandatory
Resources	Human resources	Mandatory
	Technical support and training	Mandatory
	ICT infrastructure	Optional
	Financial resources	Optional
Social	Continuance Usage Intention	Mandatory
	User Behavior	Mandatory
Economic	Sustainable funding	Mandatory

	Affordability of e-solution	Mandatory
	Financial benefits	Optional

3.4 Chapter summary

This chapter presented the e-health sustainability model, that contains the main dimensions and aspects that impact the sustainability of e-health solutions. The model was constructed based on the dimensions and aspects extracted from the SLR conducted in Chapter 2. The model was built and designed through multiple iterations. The model was validated by three experts in healthcare, in which their comments were accommodated to refine the model and produce the final and validated version of it.

CHAPTER 4

E-HEALTH SUSTAINABILITY ASSESSMENT METHOD

This chapter presents the assessment method used to assess the sustainability aspects of e-health solutions and predicts their contributions to the overall sustainability. It illustrates the tools used to evaluate the model's aspects and elements, and the assessment procedures that propagates the evaluation of the elements to compute the overall sustainability level.

4.1 Related work

Saputri and Lee proposed a framework for evaluating software sustainability from a software engineering perspective, in which it focused on analyzing software artifacts [57]. Their framework consists of four major phases, that combine static analysis, dynamic analysis, and machine learning (ML) approaches. The evaluation results determine the sustainability achievement of the aspects and the aspects that require improvements. This is done based on the baseline scenarios (i.e., below, same, and above) defined by the knowledge experts according to the context. Another work done by Abdellatif et al. [60] focuses on software product maturity. In their work, they developed a Technical-Capability Maturity Model Integration (TCMMI) framework to assess the software product quality, which consists of two components: a reference model and an assessment method. Figure 8 presents the reference model of the TCMMI framework.

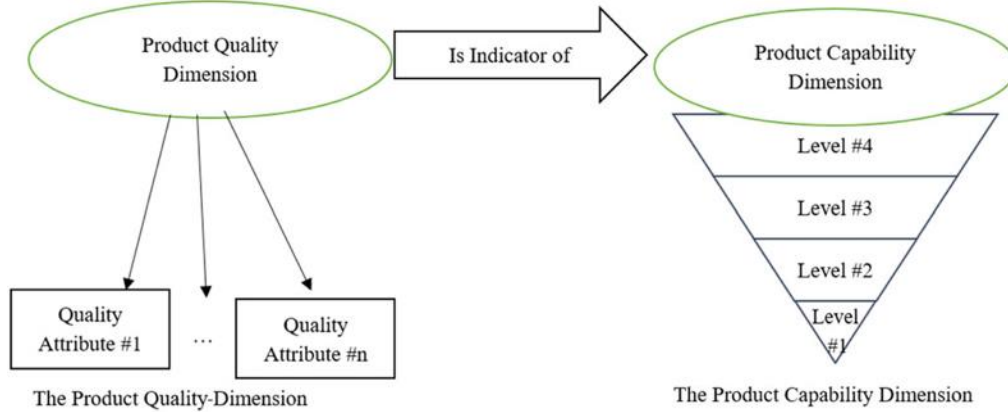


Figure 8 Dimensions of the TCMMI reference model (PMMI) [60]

A study conducted by Siedler et al. proposed a model that assesses companies' digitalization maturity level [61]. These levels are explorer, beginner, intermediate, and expert with scale from 1-4 as presented in Figure 9. The digitalization maturity level (ML_{total}) is calculated by obtaining the arithmetic mean of the achieved maturity level of the four product lifecycle phases and the Corporate Level [61]. The maturity level of the four product lifecycle phases and the Corporate Level is achieved through calculating the mean of the belonging criterion digitization, that is specified in the study [61].

Increasing maturity level →				
	Explorer	Beginner	Intermediate	Expert
Overall description of maturity levels	The company has limited digitalization.	Digitalization is the focus of only some company divisions and their linkage is rare.	Digitalization is the focus of most company divisions, which are mostly horizontally and vertically linked. The digitalization mindset is enshrined within the corporate culture.	Digitalization is fully implemented within the company. The divisions are all horizontally and vertically linked. Furthermore, digitalization is actively implemented and fully enshrined within the corporate culture and strategy.
ML_{total} value	$1,0 < ML_{total} < 1,4$	$1,5 < ML_{total} < 2,4$	$2,5 < ML_{total} < 3,4$	$3,5 < ML_{total} < 4,0$

Figure 9 Description of company maturity levels [61]

4.2 Sustainability Evaluation

4.2.1 Evaluation Tools

The elements of each aspect are assessed by either checklist or survey questions. Both checklists and surveys have a five-point Likert scale. The scales are strongly agree, agree, neutral, disagree, and strongly disagree, which are equivalent to the numerical scale 5-1 respectively. The questions used to assess the aspects' elements were gathered from different recourses found in the literature. It is worth mentioning that most of the resources focus on evaluating software products in general, and in this work, they have been adapted for the context of e-health solutions. To illustrate, some of the questions in the evaluation tools were altered in terms of the wordings to fit the context of e-health solution evaluation. Also, the questions' focus of some aspects was deduced from the literature, and based on that the questions were developed by the author. Table 19 shows how each aspect's questions were customized.

In addition, some aspects need to be evaluated regularly (e.g., every year or after a major change/update on the e-health). The importance of regular evaluation is that some changes might happen to the e-health solution after the assessment phase, and thus the predicted sustainability level may change as a result. Also, with the rapid changes in demands on healthcare environment's, the goals and needs might differ quickly, hence, a deployed e-solution might not be the optimal solution anymore. Thus, it is better to assess the sustainability regularly in order to avoid wasting money and other resources or to invest more in highly sustainable systems. The sustainability assessment is expected to be tun at least annually. Table 19 shows the types of evaluation tools for each aspect along with their

evaluation frequency. Examples of checklists and surveys questions are listed in Table 20.

The complete evaluation checklists and surveys are listed in Appendix C in Table 41.

Table 19 Types of evaluation tools of each sustainability aspect

Dimensions	Aspects	Type of evaluation tool	Customization	Evaluation frequency	Reference
Technology	System quality	Checklist	Change of wording	On system change or update	[62][63][64]
	Data quality	Checklist	Change of wording	On system change or update	[65]
	Hardware quality	Checklist	Developed*	On system change or update	[44]
Organization	Support and commitment	Checklist	Change of wording	Annually	[66]
	Organizational structures & strategy	Checklist	Change of wording	Once	[66][29]
	Planning and Policies	Checklist	Developed*	Annually	[66][67][68][69]
	Stakeholders	Checklist	Developed*	Annually	[66][29][67][70]
	Culture of electronic information use	Checklist	Change of wording	Once	[71]
	Outcome's identification	Checklist	Developed*	Annually	[38]
	Demand and need	Checklist	Developed*	Annually	[66]
Resources	Human resources	Checklist	Developed*	Annually	[29][67]
	Technical support and training	Checklist	Change of wording	Annually	[29][66][72][73]
	ICT infrastructure	Checklist	Change of wording	Annually	[66][70][73][45]
	Financial resources	Checklist	Developed*	Annually	NA
Social	Continuance Usage Intention	Survey	Change of wording	Periodically	[39]
	User Behavior	Survey	Change of wording	Periodically	[74][75][76]
Economic	Sustainable funding	Checklist	Developed*	Annually	[17][36]
	Affordability of e-solution	Checklist	Developed*	Once	[45]
	Financial benefits	Checklist	Developed*	Annually	[58]
* Developed by the author based on the aspect's definition.					

Table 20 Examples of evaluation questions in each aspect

Dimensions	Aspects	Example of evaluation questions/statements
Technology	System quality	- Does the e-solution's main function directly resolve the user's primary need? - Is the e-health solution able to work with different environment such as different operating systems and different hardware?
	Data quality	- The e-solution's information is useful to users' work. - The e-solution's information is protected against unauthorized access.
	Hardware quality	Is the hardware of the e-health solution capable to integrate seamlessly with different hardware directly or through additional layer?
Organization	Support and commitment	Top management is willing to allocate the resources required to operate e-health successfully.
	Organizational structures & strategy	The proposed e-health solution is appropriate according to the conditions within the healthcare organization.
	Planning and Policies	Users of E-health are aware of their accountability regarding securing and protecting the data of e-health they use.
	Stakeholders	The direct users of e-health have been involved during the planning phase. (i.e., to collect their need and perspective of the intended e-health solution).
	Culture of electronic information use	There is an active concern among employees to obtain and apply new information to respond to changes and to promote innovation.
	Outcome's identification	The outcomes of the e-health solution are defined by the organization, whether they are clinical, financial, technical, or social outcomes.
	Demand and need	Organization has properly identified the need for the e-health solution
Resources	Human resources	There are adequate number of available IT professionals to provide technical support to the users of the e-health solution.
	Technical support and training	- There is a plan for preventive maintenance (periodic maintenance of hardware/software) for the e-health solution. - Technical training is always provided for new users via in-person or online courses.

	ICT infrastructure	Hardware and software required for the e-health solution are readily available.
	Financial resources	The additional funding to cover emerging operational costs is readily available. (e.g., costs to scale up the system or to integrate it with a new system)
Social	Continuance Usage Intention	Interaction with the e-health solution does not require a lot of mental effort.
	User Behavior	I can describe how my job changes after implementing the e-health solution.
Economic	Sustainable funding	Is there a continuous funding that covers the operational and ongoing costs of the e-health (e.g., software license renewal)?
	Affordability of e-solution	Is there a realistic calculation of the costs considering the costs of the procurement, operation, life cycle, archive, and system replacement?
	Financial benefits	Are the financial benefits of adopting the e-health solution identified?

4.3 Procedures of Sustainability Assessment

The designed sustainability assessment method in this research was found to be aligned with the work of Abdellatif et al. [60]. The e-health sustainability model is comparable to the reference model of the TCMMI framework, in which the quality attributes in their work correspond with the sustainability aspects, and the product quality dimensions correspond with sustainability dimensions. Hence, we designed the sustainability assessment method to be aligned with previously published work (TCMMI) [60], and it is also aligned with the ISO/IEC 15504 standard (Guidance on performing an assessment) [77]. The sustainability assessment method propagates the scores of each level of the sustainability model to produce the overall sustainability level of the e-health solution. All assessment method's procedures and steps are explained in the following subsections. Figure 10 presents the main phases of sustainability assessment procedures.

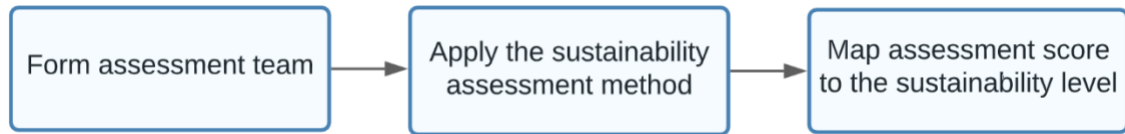


Figure 10 Procedures of sustainability assessment

4.3.1 Assessment Team

The ideal assessment is conducted by at least three expert assessors. One expert from the IT department, another from the finance department, and one from hospital management. The existence of experts from the three domains will ensure a high level of accuracy and validity in the sustainability assessment [57]. The IT expert shall assess the technology dimension, the finance expert shall assess the economic dimension, and the hospital management expert shall assess the organization, recourses, and social dimensions. It is worth noting that the assessment of the social dimension must be completed by the users of the e-health solution. Therefore, the selection of the reflective sample is important for results reliability. Also, as all three expert assessors work in one team, each expert shall help in assessing aspects of other dimensions, that are related to their specialty.

4.3.2 Assessment Steps

As presented in Chapter 0, the e-health sustainability model consists of three levels. The first level contains the sustainability dimensions, the second level contains the aspects under each dimension, and the third level contains the elements under each aspect. The assessment tools are applied to the elements of the sustainability model. The assessment results of the elements will be reflected on the aspects' fulfillment to achieving sustainability, which in the end contributes to predicting the overall sustainability of the e-

health solution. Figure 11 shows the assessment steps, which are explained in the following subsections.

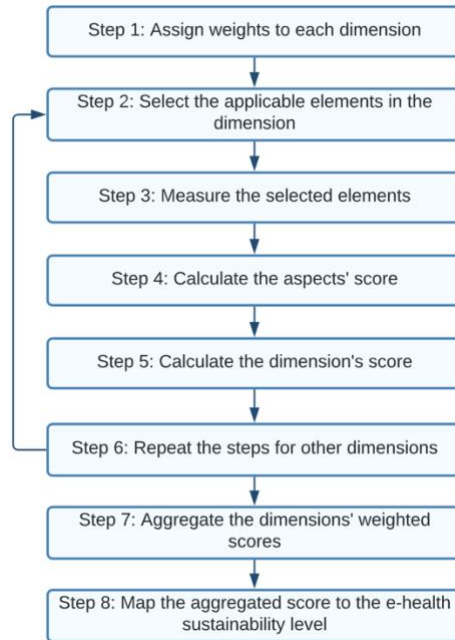


Figure 11 Sustainability assessment steps

4.3.2.1 Step 1: Dimensions' Weights

As the dimensions represent the first level of the e-health sustainability model, they will be given weights based on assessors' judgment. The given weights reflect the importance of each dimension according to the context in which e-solution is going to be used [35]. For example, if the proposed system is going to be used by healthcare providers, the social dimension becomes very important compared to a situation where the system is going to be used by the IT department only. The weight of each dimension must be between 0-1, in which the sum weights of all dimensions must add up to one.

Because the assessment will be conducted by a team, it is recommended to use the group analytic hierarchy process (AHP) method. This method assists the team to decide on the

weights that will be assigned to each dimension in the sustainability model [78]. In AHP, the priority of a dimension is compared to all other dimensions in the model, and by applying the complete AHP method, the appropriate weight will be assigned to each dimension based on the calculated priorities. The validity of the computed priorities is evaluated by conducting sensitivity and consistency analysis [78]. Figure 12 abstractly illustrates the group AHP method.

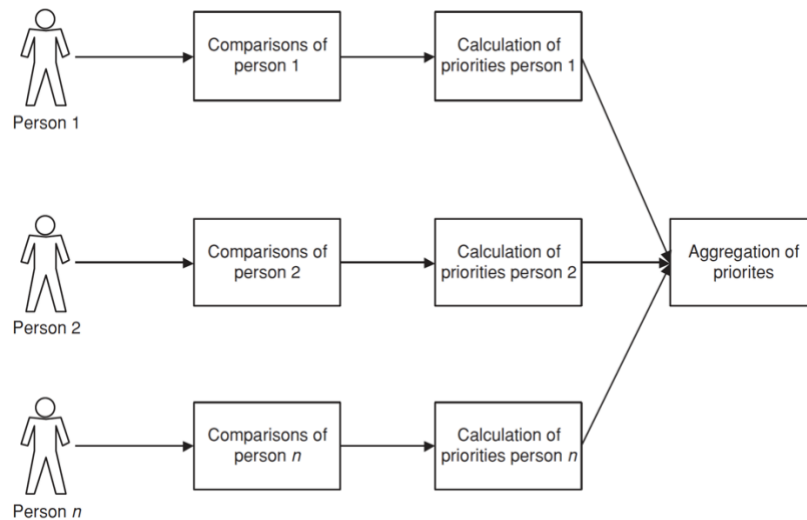


Figure 12 Aggregation at the priorities level [78]

4.3.2.2 Step 2: Selection of Sustainability Elements

Software products vary and there is no unified context of use to all of them [60]. Therefore, the elements under each aspect will be selected based on their applicability to the e-health solution's context. The selection of aspects and elements is done by the assessment team and must be based on the applicability not the availability of the aspects. For example, if the e-health solution should be used with special hardware components then the hardware quality aspect in the technology dimension is applicable to be a part of the evaluation even

if the required information about the hardware quality is not available. In the case where hardware quality is required but the relevant data is not available, the hardware quality aspect will be giving a very low score that means its assessment is not fulfilled. To differentiate between low score in assessing an aspect that is resulted from unavailable data or low scores resulted from available data, when experts decide that an aspect is relevant, they have to also to indicate whether data is going to be available for the evaluation or not. Hence, if data can be collected or it is already available, the experts can proceed with filling the survey or the checklist; otherwise, the aspect will be assigned the lowest score until data becomes available and the assessment is run again.

After selecting the elements, the checklists and surveys will be completed by the assessment team and the overall sustainability level will be calculated based on the following steps and formulas.

4.3.2.3 Steps 3-7: Calculating Evaluation Score

As each aspect has a set of five-point Likert scale questions. Therefore, to determine the score of each aspect, the following formula is applied:

$$\frac{\sum \text{Evaluation value of each question of elements of the selected aspects}}{\# \text{ of total questions in the aspect}} \times 5$$

This step is applied to all aspects within the dimension. As it is shown in illustrative example 1 in Table 21, this step was applied to all aspects of the technology dimension and resulted the score in column “Evaluation score of each aspect”. To calculate the dimension’s score, the average of its aspects’ scores is calculated, which is found to be 93.7% in the illustrative example 1. Steps 2-5 in Figure 11 are applied to all dimensions.

Table 22 presents illustrative example 2, which contains the evaluation score of all other dimensions along with their assigned weights.

Table 21 Illustrative example 1

Dimension	Dimension's weight	Aspects	Evaluation score of each aspect	Dimension's score	Dimension's weighted score
Technology	0.4	System quality	95%	93.7%	37.5%
		Data quality	88%		
		Hardware quality	98%		

Lastly, the overall score of the e-health solution sustainability is the aggregation of the weighted scores of the dimensions, which is calculated by the below formula. Table 22 presents the result of aggregating the dimensions' weights, which is in column "aggregated weighted score".

$$\sum Score (D_n) \times Weight (D_n)$$

Table 22 Illustrative example 2

Dimension	Dimension's weight	Dimension's calculated score	Dimension's weighted score	Aggregated weighted score	Sustainability level
Technology	0.4	93.7%	37.5%	89.7%	High
Organization	0.15	88%	13.2		
Resources	0.15	90.3	13.6		
Social	0.15	77%	11.6		
Economic	0.15	92%	13.8		

4.3.2.4 Step 8: Mapping Evaluation Score to Sustainability Level

The sustainability levels indicate the prediction of to which extent the e-health solution is considered to be sustainable. There are four levels for e-health sustainability: high, moderate, low, and unknown. All of which has a specific range of values that is used to map the aggregated score of the sustainability assessment to the corresponding level. As presented in Table 23, the aggregated sustainability score that is less than or equal to 35% is mapped to unknown sustainability level, while the low sustainability level is for the score between 35% and 61%. The aggregated score that is between 60% and 86% is mapped to moderate level, and any score that is greater than 85% is mapped to a high sustainability level. Table 23 presents the four sustainability levels along with their threshold scale. According to the illustrative example in Table 22, the sustainability level of the evaluated e-health solution is high because the overall score is 89.7%.

The levels and their scale values were inspired by Siedler et al. work, in which they used a scale from 1-4 (refer to Figure 9) to assess the maturity level of digitalization in a company [61]. I adopted the definitions that describe each digital maturity level (Explore, Beginner, Intermediate, and Expert) to the sustainability levels in my study (Unknown, low, Moderate, and High). Also, I converted their numerical scale to a percentage scale. Table 23 presents the resulted sustainability levels, their definitions, and the corresponding percentage scale. This aligned with the threshold scale that was proposed in another study conducted by Ouhbi et al., in which they stated that the minimum score for a sustainability level is above 50% [21].

Table 23 Sustainability levels

Scale of Sustainability level				
Level	Unknown	Low	Moderate	High
Overall description of sustainability levels	There is no/rare contribution of the dimensions to the overall sustainability	There is limited contribution of some dimensions only to the overall sustainability	Some of dimensions and their selected elements highly contributed to the overall sustainability	Most of dimensions and their selected elements contributed to the overall sustainability
Aggregated score (x)	$x \leq 35\%$	$35\% < x \leq 60\%$	$60\% < x \leq 85\%$	$85\% < x \leq 100\%$

4.4 Tool Support

To facilitate the sustainability evaluation, I provided a tool support. The sustainability model and the assessment method were implemented in using MS excel. By this tool, all required calculations are automated, by which the sustainability level of the e-health solution is produced. Experts can use this tool to enter the dimensions' weights, select applicable aspects and elements, and fill out the checklists and survey questions. By completing the required input, the sustainability level of the e-health solution will be provided immediately. Figure 13 presents a snapshot of an example of the sustainability assessment results produced by the tool. Also, in this tool, the expert should enter weights for all dimensions. In case of missing data in required fields, the color of the required filed will turn into red, indicating missing data. This is also applied when selecting the applicable aspects and elements, in which the mandatory fields will be red as they can't be left empty (refer to Figure 14). Figure 15 shows part of the checklist of the economic dimension, and as the financial benefits aspect is not applicable, the input fields of its questions turned

automatically into black, indicating unrequired data. The tool is found in Appendix D in

Table 41

Name of the E-health solution:		Hospital Information System (HIS) [Hospital B]	
Sustainability level is		Low	
Dimension	Weight	Score	Weighted score
Technology	0.3	72%	21%
Organization	0.25	42%	10%
Resources	0.15	58%	9%
Social	0.05	67%	3%
Economic	0.25	30%	8%
Total	1		51%

Figure 13 Experts are required to enter a value between 0-1 as dimension weight

Dimension	Item	Included
Organization		6
	ORG-A: Support and commitment	0
	ORG-A1: Support and commitment of top management	
	ORG-A2: Support and commitment of e-health solutions vendor	
	ORG-B: Organizational structures & strategy	2
	ORG-B1: Organizational structures	1
	ORG-B2: Workflow process & process integration	1

Figure 14 Applicable elements and aspects are selected by entering 1

Item	Value	Score	%
ECO-A: Sustainable Funding		1	20%
1. Is there a continuous funding that covers the operational and ongoing costs of the e-health (e.g., software license renewal)?	1	1	
ECO-B: Cost affordability of e-solution		4	40%
1. Is there a realistic calculation of the costs considering the costs of the procurement, operation, life cycle, archive, and system replacement?	1	1	
2. Does the healthcare organization the able to afford the calculated cost of adopting and operating the e-health solution?	3	3	
ECO-C: Financial Benefits		0	0%
1. Are the financial benefits of adopting the e-health solution identified?		0	
2. Is there an evaluation plan to assess the achievement of the defined financial benefits?		0	

Figure 15 Input fields of unapplicable aspects/elements are turned into black

4.5 Chapter summary

This chapter presented the assessment method used to evaluate the sustainability of e-health solutions. The sustainability assessment is conducted by using evaluation tools, which composed of checklists and surveys to assess the aspects of the e-health sustainability model. The assessment has three phases, which are forming assessment team, applying assessment steps, and mapping the overall score to the sustainability levels. The sustainability levels are high, moderate, and low. They indicate to which extent the e-health solution is sustainable.

CHAPTER 5

EVALUATION OF E-HEALTH SUSTAINABILITY

MODEL

This chapter discusses the evaluation of the e-health sustainability model and its assessment method in terms of comprehensiveness, effectiveness, and applicability to be used in real-world contexts. The sustainability model and the assessment method were evaluated through conducting three case studies in Saudi hospitals. This chapter presents the protocol of the case study and the implementation of the three case studies. The e-health sustainability model and assessment method were applied to each of the e-health solutions of the three case studies to predict their sustainability and test the model's applicability in real word cases.

5.1 Case Study Protocol

To maintain the consistency of the three case studies, a protocol was designed, that will be followed in all case studies. The design of the case study's protocol was inspired by the paper of Runeson and Höst on "Guidelines for conducting and reporting case study research in software engineering" [1]. The case study protocol is presented in the following subsections.

5.1.1 Objectives

The case study aims to:

- 1) Evaluate the comprehensiveness of the e-health sustainability model in the real-world cases.
- 2) Evaluate the applicability and effectiveness of the sustainability model and the assessment methods in anticipating the sustainability of e-health solutions.

5.1.2 Research questions

The case study is conducted to answer the following research questions:

- 1) **RQ1:** To what extent the dimensions of the e-health sustainability model are comprehensive?
- 2) **RQ2:** To what extent having an assessment method will aid healthcare management in anticipating and assessing the sustainability of e-health solutions?

5.1.3 Characteristics of the Case Study

The case study is applicable to be conducted on an e-health solution that is 1) proposed or already in use in a healthcare institution, and 2) used by staff in a healthcare institution, healthcare practitioners, or patients. The selection of the e-health solution is based on availability.

5.1.4 Units Under Test

There are two units under tests: 1) the sustainability model, and 2) the assessment method that is proposed to evaluate the sustainability of e-solutions in healthcare. The model is going to be assessed in terms of its comprehensiveness in covering all essential dimensions and aspects that technology experts consider in practice. The assessment method is going to be evaluated in terms of its applicability and effectiveness in anticipating the sustainability levels of e-solutions in healthcare.

5.1.5 Data Gathering

Qualitative data is gathered from interviews and discussions with stakeholders and technology experts in the hospital's management, who are involved in the decision of adopting and using the e-health solutions. I conducted two type of interviews that are pre the implementation if the case study and after the implementation. The pre-implementation interviews' questions focused on extracting information about the e-health solution to be used to evaluate the sustainability model and assessment method. The post-implementation interviews aim to gather stakeholders' feedback on the evaluation's results and to compare their sustainability evaluation, if exist, to the sustainability evaluation generated by our assessment method. The social dimension is expected to be evaluated by the intended users of the e-solutions (refer to Chapter 4); hence, an online survey was designed and distributed to the users.

5.1.6 Implementation

The case study is conducted through three phases: data gathering, applying the assessment method to the e-health solution, and finally validating the results with the hospital's management. In the data gathering phase, the experts were asked to talk about the e-solutions, how it was introduced, and what aspects were evaluated before the adoption of technology. If the answers did not cover all sustainability model's dimensions and aspects, I asked more questions about the missing data. The answers were used to evaluate the comprehensiveness of the model, and to fill the assessment tools in order to apply the assessment method. In validation, I presented the findings that are the suitability evaluation score/level and details about the dimensions and aspects evaluations. The scores calculation in the assessment method was done using the sustainability evaluation tool (refer to tool support in Chapter 4).

5.1.7 Reporting

The results are reported in a way that answers the research questions and address the issues related to the e-health sustainability model. For confidentiality, the names of the hospitals are referred to as A, B, C, etc.

5.2 Case Study 1 - Voice Recognition System

This case study assessed the sustainability of a voice recognition system (VRS) that has been implemented in a hospital A in Saudi Arabia since 2010. The VRS is used by health practitioners in the hospital to dictate patients' reports instead of typing them into the health record system. The system was adopted to solve the issue of the backlog of incomplete patients' reports and the consumed time and effort needed to complete them in the traditional work process. The legacy model of completing the patients' report was as follows: the care provider writes the patient's report of the visit or dictates it on a tape, and then the care provider gives the written/recorded report to the transcriptionist, who types it on the computer and then returns it to the care provider for approving and accepting it in the patient health records system. This process tends to waste time of care providers, consume resources, and the backlog of patients' reports extends to years, which affects the hospital's accreditation and productivity of the healthcare provision.

The VRS needs a special-designed hardware (i.e., microphone), that is provided by the software company. The accuracy of the voice recognition was 95% among most of the physicians in the training session. In the training session, the new user is asked to read two to three paragraphs to the system and the system adopts the user's voice signal and saves it in the user's profile in the server. As the user uses the system, the system keeps adapting to the user's voice and accent. Also, besides the ability of the users to choose their accent, they can choose their specialty as well, so the system can import the vocabulary of that specialty (e.g., radiology) and compile the user's profile according to the accent and the used vocabulary. The system is integrated with the hospital information system (HIS), in which the entered information of the patient's report is not stored the entered data. Instead,

the entered data is instantaneously uploaded to the patient record after the health practitioner checks and approves the correctness and completeness of the dictated information. The software has a mobile application version, that allows users to dictate reports offline instead of using the computer. This provides a certain level of mobility. However, for the reports to be uploaded to the health records system, the user's mobile should connect to the hospital's network.

5.2.1 Preparing the Model Input

The required information was collected through an interview discussion with a technology consultant in IT department in the hospital. The interview focused on collecting the data needed to assess the applicable aspects of the five dimensions in the sustainability model. In addition, the expert was asked to provide weights to each dimension. The description of the gathered information is grouped below according to the dimensions.

5.2.1.1 Technology

The assigned weight for technology dimension is 0.3. The three aspects in technology dimension were applicable to the context of VRS and were selected accordingly.

In the system quality aspect, all elements were selected except for maintainability because the system was adopted to serve a specific purpose (i.e., dictating patients' reports) and there was no interest in using it for other purposes. For data quality aspect, all elements were selected except for the timeliness and relevance elements, which were not applicable to the context according to their definition in this work and because the system does not store any of the entered data. As the system needs a special-designed microphone, all

elements in the hardware aspect were selected. Table 24 presents the evaluation score of each aspect, that were achieved by filling out the assessment checklist of each of them.

Figure 16 presents a snapshot of part of the technology dimension's evaluation.

Table 24 Evaluation score of Technology dimension's aspects

Aspects	Evaluation score
System quality	97%
Data quality	100%
Hardware quality	88%

Item	Value	Score	%
TECH-A: System quality		112	97%
TECH-A1: Functional Suitability			
1. Does the e-solution's main function directly resolve the user's primary need?	5	5	
2. Is it consistent enough to address the user's need with precision on a regular basis?	5	5	
3. Are the e-solution's specific functions successful in meeting specific user needs?	5	5	
TECH-A2: Performance Efficiency			
1. Do the e-solution's functions respond with reasonable speed considering the task being requested?	5	5	
2. Does the e-solution actively utilize its resources economically when tasked to fulfill functions?	5	5	
3. Is the functional limits of the e-solution within acceptable set requirements?	5	5	
TECH-A3: Usability			
1. Does the e-solution define itself well enough for users to easily recognize if it is appropriate to their needs?	5	5	
2. Is the difficulty of learning to use the e-solution reasonable considering its intended functions and the user's needs?	5	5	
3. Is the e-solution reasonably easy to use considering the function being utilized, and the user's need?	5	5	
4. Can the e-solution be used by people with the widest range of characteristics and capabilities to achieve a specified goal in a particularized context of use?	5	5	
TECH-A4: Security			
1. Does the e-solution ensure that confidential data is only accessible to authorized users?	5	5	
2. Is the e-solution capable of resisting unauthorized access attempts through program modification and other malevolent means?	3	3	
3. Is the e-solution capable of verifying the identity of an entity before allowing access?	5	5	

Figure 16 Part of assessment checklist of the Technology dimension

5.2.1.2 Organization

The assigned weight for this dimension was 0.25. All aspects and elements were applicable except for incentives and recognition element in stakeholders' aspect. The exclusion of this element was because physicians and healthcare practitioners were not obligated to use the system, and the task of documenting patients' reports can be done through other

alternatives. That were perceived more convenient for some physicians who do not use the system. The top management approved and supported the adoption of the system as they perceived its benefits. The necessary adjustments were made to the workflow process, such as eliminating the role of the transcriptionists, whose job was to type the patients' reports and enter them to the system. Also, the policies and plans to support and maintain the adoption and use of the VRS already existed in the hospital. The main stakeholders were involved in either the planning phase or in the trial version of the system. The adoption of the system was based on an existing need and sufficient demand that were identified by the hospital. The system's outcomes evaluation was done only after one year of the system's deployment by the quality department in the hospital. Table 25 presents the evaluation score of each aspect, that were achieved by filling out the assessment checklist of each of them. Figure 17 presents a snapshot of part of the organization dimension's evaluation.

Table 25 Evaluation score of Organization dimension's aspects

Aspects	Evaluation score
Support and commitment	96%
Organizational structures & strategy	89%
Planning and Policies	84%
Stakeholders	100%
Culture of electronic information use	80%
Outcome's identification	100%
Demand and need	100%

ORG-B: Organizational structures & strategy		31	89%
ORG-B1: Organizational structures			
1. The proposed e-health solution is appropriate according to the conditions within the healthcare organization.	5	5	
2. There are plans in place to increase users' trust and confidence in the e-health solution.	3	3	
3. A specialized individual or group has taken responsibility for e-health solution planning and implementation (i.e., identifying problem, appropriate solution, implementation processes, etc.).	5	5	
4. The implementation plan includes proper budgeting and identification of resources.	5	5	
5. There is an appropriate evaluation plan for the e-health solution.	3	3	
ORG-B2: Workflow process & process integration			
1. There is a strategy to integrate e-health solution with the current services and workflow processes in the healthcare organization.	5	5	
2. Roles and responsibilities involved in the e-health solution are clearly defined and outline with necessary distribution across teams as necessary.	5	5	
ORG-C: Planning and Policies		46	84%
ORG-C1: E-health related regulations			
1. There are institutional policies in place to manage the use of the e-health in the healthcare organization.	3	3	
ORG-C2: Financial policy of e-health			
1. There are financial policies in place for assessing the charges and cost of the e-health solution.	3	3	
ORG-C3: Agreement on clinical content			
1. The clinical content within the e-health solution has been revised and approved by the charged committee if necessary.	4	4	
ORG-C4: Data security and protection policy			
1. There are policies that ensure the security and protection of data used in e-health.	4	4	
2. E-health users have received awareness training sessions regarding the importance of data security and protection.	3	3	
3. Users of E-health are aware of their accountability regarding securing and protecting the data of e-health they use.	4	4	

Figure 17 Part of assessment checklist of the Organization dimension

5.2.1.3 Resources

The assigned weight for this dimension was 0.2. All aspects in the resources dimension were selected. The ICT infrastructure was ready in terms of physical resources and networks system, which made it easier to run the trial version of the software in the first place. After adopting the system officially, the needed hardware (i.e., servers, special-designed microphones) was provided by the vendor company along with the software. Users received training during the trial period. Also, training sessions are provided to the new users. Regarding the technical maintenance support, it has been provided by the company upon yearly contract agreement and its cost is separate from the cost of the system's license. Overall, the system is stable, and even if a downtime occurred, it is not critical to the work process as the user can write the paper report, and then when the system

is active again the user can use it to document the report. Regarding the users' technical support, it is provided by the IT team in the hospital. For financial resources aspect, since some of the upgrades and updates are not considered critical to the top management, they sometimes do not allocate a budget for renewing or purchasing some of the additional features and services. However, the funding of the essential system's licenses is sustainable as stated in the economic dimension.

Table 26 presents the evaluation score of each aspect, that were achieved by filling out the assessment checklist of each of them. Figure 18 presents a snapshot of part of the resources dimension's evaluation.

Table 26 Evaluation score of Resources dimension's aspects

Aspects	Evaluation score
Human resources	95%
Technical support and training	87%
ICT infrastructure	92%
Financial resources	70%

Item	Value	Score	%
RES-A: Human Resources		19	95%
RES-A1: Workforce Availability			
1. There are adequate number of available people involved in the usage and operation of the e-health solution.	5	5	
2. There are adequate number of available IT professionals to provide technical maintenance to the software and hardware of the e-health solution.	4	4	
3. There are adequate number of available IT professionals to provide technical training to the users of the e-health solution	5	5	
4. There are adequate number of available IT professionals to provide technical support to the users of the e-health solution.	5	5	
RES-B: Technical Support and Training		65	87%
RES-B1: Technical Support			
Maintenance technical support:			
1. There is a plan for preventive maintenance (periodic maintenance of hardware/software) for the e-health solution.	4	4	
2. There is a mechanism for inventory of e-health solution's equipment.	2	2	
3. There is a mechanism for protection against robbery, theft, or damage of e-health solution's equipment.	2	2	
4. There are downtime policies and procedures for the e-health solution.	5	5	

Figure 18 Part of assessment checklist of the Resources dimension

5.2.1.4 Social

The social dimension received a weight of 0.1, and all aspects were selected. The social dimension is assessed by the intended users through a survey. However, it was challenging to reach the users in short period. Hence, for the sake of illustration, the assessment tool in this dimension was filled based on the expert judgment. No regular evaluation was conducted to assess users' satisfaction or behavior towards the system. At the same time, no complaints or technical issues were noticed since the adoption of the system. The acceptance and success rate of the system was very high. Table 27 presents the evaluation score of each aspect, that were achieved by filling out the assessment checklist of each of them.

Table 27 Evaluation score of Social dimension's aspects

Aspects	Evaluation score
Continuance Usage Intention	93%
User Behavior	89%

5.2.1.5 Economic

The economic dimension was given a weight of 0.15. All its aspects were applicable and selected. Before adopting the system, the cost of purchasing the system was presented to the top management for their approval. The cost of acquisition was approved, and a budget was assigned for the system's license renewal. Regarding the financial benefits, the hospital was interested in the cost-effectiveness, which was measured by the enhancement of the workflow processes and reducing the backlog in patients' reports. As a result, it

increased the overall productivity of healthcare provision. Also, the solution helped in cost-minimization, by which it eliminated the transcriptionist job and therefore saved money. Table 27 presents the evaluation score of each aspect, that were achieved by filling out the assessment checklist of each of them.

Table 28 Evaluation score of Economic dimension's aspects

Aspects	Evaluation score
Sustainable funding	100%
Affordability of e-solution	100%
Financial benefits	100%

5.2.2 Sustainability Assessment Results and Discussion

The sustainability assessment steps (refer to Figure 11 in Chapter 4) were applied on the VRS to assess its sustainability. Table 29 presents the dimensions' weights that were assigned by the expert. Also, it presents the assessment scores of each aspect after applying the sustainability assessment method on the VRS. The assessment results show that the sustainability level of VRS is high as its aggregated score was found to be 93%. The sustainability evaluation, that was generated by our sustainability assessment, is aligned with the expected sustainability that the hospital's IT department had. Although they had assessed most of the aspects, the IT expert found that our model and assessment method are more comprehensive and systematic than the evaluation they do. The complete assessment scores of the VRS are found in Appendix E in Table 41.

Table 29 Assessment results of case study 1

Dimension	Dimension's weight	Aspects	Evaluation score	Dimension's score	Dimension's weighted score
Technology	0.3	System quality	97%	95%	29%
		Data quality	100%		
		Hardware quality	88%		
Organization	0.25	Support and commitment	96%	93%	23%
		Organizational structures & strategy	89%		
		Planning and Policies	84%		
		Stakeholders	100%		
		Culture of electronic information use	80%		
		Outcome's identification	100%		
		Demand and need	100%		
Resources	0.2	Human resources	95%	86%	17%
		Technical support and training	87%		
		ICT infrastructure	92%		
		Financial resources	70%		
Social	0.1	Continuance Usage Intention	93%	91%	9%
		User Behavior	89%		
Economic	0.15	Sustainable funding	100%	100%	15%
		Affordability of e-solution	100%		
		Financial benefits	100%		
Total					93%

5.2.3 Discussion

The dimensions' weights were assigned based on the experts' judgment on the impact of each dimension on the context of the e-health solution and the hospital. Regarding the VRS context, the technology dimension received the highest weight because the overall quality of the solution will impact the adoption and usage continuity. Hence, it was assigned a weight of 0.3 to it. Same goes to the organization dimension, which its weight was 0.25 as the readiness of the organization to adopt and support the e-health solution is important to sustain it and positively influence the other dimensions.

Since the VRS needs a special-designed microphone, this limits the mobility of the system as users need to be next to a computer device to use the microphone. Although this can be resolved to some extent by using the mobile application version of the system, yet as the microphones in the mobiles are not sufficiently designed for voice recognition purposes, the accuracy of the dictating might decrease. For that, the result of the hardware quality aspect was 88%.

There were no plans to increase users' trust and confidence in the e-health solution, as it was a supportive solution and did not replace the old work process. Therefore, the intended users were not obligated to use the system to complete the tasks. Also, there was no established plan to evaluate the system regularly. All of this resulted the aspect of organizational structures & strategy to get a score of 89%.

5.3 Case Study 2 - Hospital Information System

This case study assessed the sustainability of a HIS of hospital B, which is a public hospital located in Saudi Arabia. The system has been running for six years. It was adopted two years after the opening of the hospital. The main goal of adopting the system was to digitalize the work process in the hospital's pharmacy, such as medicines dispensing and laboratory tests process. Also, another intended use of the system was to manage healthcare records and information within the hospital. Hence, the system was expanded to allow physicians to write the prescriptions of medicines to patient's report and place the order of medication to the hospital's pharmacy. However, as stated in the interview discussion, the system was found to be insufficient regarding meeting the minimum users' needs and allowing a full or efficient level of digitalization within the hospital as some tasks are still paper-based.

5.3.1 Preparing the Model Input

The required information was collected through an interview discussion with a pharmacy quality specialist who collected relevant data from other experts in the hospital. The interview focused on collecting the data needed to assess the applicable aspects of the five dimensions in the sustainability model. In addition, the expert was asked to provide weights to each dimension. The description of the gathered information is grouped below according to the dimensions.

5.3.1.1 Technology

The assigned weight to this dimension was 0.3, and the selected aspects were the system quality and data quality. The hardware quality aspect was unapplicable to the context of HIS as there were no specially designed hardware required to use this system. The system is operating and used through regular computer devices.

Regarding the system quality aspect, the system did not meet the users' needs. Although the initial goal was to serve and facilitate the pharmacy work, after the system adoption, it was found that it has limited features and the essential ones were not provided. That was because the adopted version of the system was a basic license that does not include customization or extension to the basic features. Also, maintainability of the system was not fulfilled because after each update, some of the systems' permissions change without user's request. To illustrate, in the medicines dispensing features, the input fields of the patient information was changed from mandatory to optional after each update. The users need to ask the IT support to reset the input fields to mandatory. Therefore, some of the elements in this aspect were not fulfilled, which resulted in this aspect to get an assessment score of 67%.

Regarding the data quality, the accessibility, confidentiality, consistency, relevance, and timeliness of the information produced by and stored in the system passed the evaluation. However, because the system has limited features, the produced information is not sufficiently complete and accurate to cover the needs of users' tasks.

Table 30 presents the evaluation score of each aspect, that were achieved by filling out the assessment checklist of each of them. Figure 19 presents a snapshot of part of the resources dimension's evaluation.

Table 30 Evaluation score of Technology dimension's aspects

Aspects	Evaluation score
System quality	67%
Data quality	75%
Hardware quality	NA

Item	Value	Score	%
TECH-A: System quality		87	67%
TECH-A1: Functional Suitability			
1. Does the e-solution's main function directly resolve the user's primary need?	1	1	
2. Is it consistent enough to address the user's need with precision on a regular basis?	1	1	
3. Are the e-solution's specific functions successful in meeting specific user needs?	2	2	
TECH-A2: Performance Efficiency			
1. Do the e-solution's functions respond with reasonable speed considering the task being requested?	4	4	
2. Does the e-solution actively utilize its resources economically when tasked to fulfill functions?	4	4	
3. Is the functional limits of the e-solution within acceptable set requirements?	1	1	
TECH-A3: Usability			
1. Does the e-solution define itself well enough for users to easily recognize if it is appropriate to their needs?	4	4	
2. Is the difficulty of learning to use the e-solution reasonable considering its intended functions and the user's needs?	4	4	

Figure 19 Part of assessment checklist of the Technology dimension

5.3.1.2 Organization

The assigned weight for the organization dimension was 0.25. All aspects were selected as applicable. The top management supported the adoption of the system at first. However, this support did not sustain after the system found to have limited features and more fund was needed to upgrade it. Also, this system was supposed to work as comprehensive health information system for the hospital. However, the features of the adopted basic version were limited to tasks in specific departments in the hospital, which hindered the integration

of work process. Although the IT department requested to purchase the HIS and got the approval on the basic version, they did not know that its features are limited to only pharmacists and laboratory tests without covering the physicians and nurses' needs. This indicated lack of a proper planning and that the important stakeholders were not involved in the planning and deciding on the appropriate system to choose. Instead, the decision of choosing the system was based on the lowest price and meeting the minimum users' needs without consulting all stakeholders. The culture of information use among users and in the organization was ready to adopt the system. In addition, the needs, demands, and outcomes of adopting the system were not identified and analyzed. Therefore, the goals of adopting the system were not achieved. Instead, some of the tasks in hospital are still running paper-based because the system is not covering all features that could replace the paperwork. The received score of each aspect is presented in Table 31.

Table 31 Evaluation score of Organization dimension's aspects

Aspects	Evaluation score
Support and commitment	20%
Organizational structures & strategy	31%
Planning and Policies	69%
Stakeholders	40%
Culture of electronic information use	80%
Outcome's identification	30%
Demand and need	20%

5.3.1.3 Resources

The resources dimension was assigned weight of 0.15. All its aspect were selected. The human resources aspect lacked the availability of individuals to provide technical support and training. The ICT infrastructure was fully ready to adopt the system. Also, the technical support and maintenance was not available because the basic version of the system does not cover these services. New users did not receive any technical training. Also, the financial resources were not available to upgrade the system to the full version. Table 32 presents the evaluation score of each aspect, that were achieved by filling out the assessment checklist of each of them.

Table 32 Evaluation score of Resources dimension's aspects

Aspects	Evaluation score
Human resources	65%
Technical support and training	45%
ICT infrastructure	100%
Financial resources	20%

5.3.1.4 Social

The weight that was given to the social dimension was 0.05, and all aspects were selected. Although the social dimension is assessed by the intended users through a survey, in this case study the survey was filled based on the expert judgment. This was because reaching users in short period was challenging.

Based on the estimation, the users were found to be unsatisfied with using the system and they do not perceive the usefulness of using it. This inconvenience was because the tasks were partially completed by the system, and the users were required to do an extra work to complete the tasks, which consumes more effort and resources. Although the users were ready to adopt the system, they did not trust the use of it as it is not reliable to complete their work. As stated by the expert, if the current system continues to run despite all these limitations, the healthcare provision will be negatively impacted and the work productivity among healthcare practitioners and staff will decrease as their efforts are wasted on work processes that could be easily done with the full version of the system. Table 33 presents the aspects' results.

Table 33 Evaluation score of Social dimension's aspects

Aspects	Evaluation score
Continuance Usage Intention	69%
User Behavior	64%

5.3.1.5 Economic

The economic dimension's weight was 0.25, and all aspects were selected except for the financial benefits aspect as the hospital was not interested in any type of financial benefits that can be provided by the system.

There was a sustainable funding that covers the expenses of the basic version of the system. Although purchasing the basic version of the system was affordable, the accumulative cost, including upgrade cost, was not analyzed. Table 34 presents the aspects' results.

Table 34 Evaluation score of Economic dimension's aspects

Aspects	Evaluation score
Sustainable funding	20%
Affordability of e-solution	50%
Financial benefits	NA

5.3.2 Sustainability Assessment Results

Based on the gathered data, the sustainability assessment method was applied to the HIS (refer to Figure 11 in Chapter 4). Table 35 presents the dimensions' weights and the assessment scores of the selected aspects after applying the assessment method. In the results, the aggregated score was found to be 52%. Hence, the sustainability level of HIS is considered low according to the e-solution sustainability levels. The complete sustainability assessment of the HIS in this case study is found in Appendix F in Table 41.

Table 35 Assessment results of case study 2

Dimension	Dimension's weight	Aspects	Evaluation score	Dimension's score	Dimension's weighted score
Technology	0.3	System quality	67%	71%	21%
		Data quality	75%		
		Hardware quality	NA		
Organization	0.25	Support and commitment	20%	42%	10%
		Organizational structures & strategy	31%		
		Planning and Policies	69%		
		Stakeholders	40%		
		Culture of electronic information use	80%		
		Outcome's identification	30%		
		Demand and need	20%		
Resources	0.15	Human resources	65%	58%	9%
		Technical support and training	45%		
		ICT infrastructure	100%		
		Financial resources	20%		
Social	0.05	Continuance Usage Intention	69%	67%	3%
		User Behavior	64%		
Economic	0.25	Sustainable funding	20%	35%	9%
		Affordability of e-solution	50%		
		Financial benefits	NA		
Total					52%

5.3.3 Discussion

As the evaluated system is a health information system that is supposed to manage all information in the hospital, its quality was important and therefore the weight of the technology dimension was 0.3. The assigned weight to organization and economic dimensions were 0.25 for each because in the context of this HIS both dimensions contribute equally to the system sustainability. The absence of readiness and support of the organization will impact the availability of sustainable funding. Similarly, even if the organization dimension is fulfilled but there is no sustainable funding, the sustainability of the HIS will be impacted. The social dimension received the lowest weight of 0.05 as the unfulfillment of this dimension will not impact, greatly, the sustainability because the system was supposed to be mandatory to be used by all healthcare practitioners and staff in the hospital. However, that was not applied because the adopted HIS has features limited.

Moreover, the involvement of stakeholders and analyzing the identified need are critical to the sustainability of the e-health solution. From this case study, stakeholders (e.g., physicians and pharmacists) were not fully involved in the planning phase, which led to waste of resources, unsatisfied users, and unachieved outcomes.

5.4 Case Study 3 - Hospital Information System

This case study assessed the sustainability of an HIS of hospital C, that is a hospital in Saudi Arabia. The system has been running for more than 10 years. The system is used to manage all health information within the hospital.

5.4.1 Preparing the Model Input

An interview discussion was conducted with a clinical pharmacist who was involved in the adoption of the HIS. Similar to the previous case studies, the expert was asked to provide weights to each dimension and collect relevant data from other stakeholders.

5.4.1.1 Technology

The technology dimension was given weight of 0.25 and all aspects were selected except for hardware quality.

The HIS has been used in all departments in the hospital by healthcare practitioners and hospital staff. The system is integrated with other systems within the hospital such as the systems in the radiology department. The system has been running in the hospital for long time and has many features that fulfill the needs of users. All aspects of data quality of the system were strongly satisfied. Table 36 presents the evaluation score of each aspect.

Table 36 Evaluation score of Technology dimension's aspects

Aspects	Evaluation score
System quality	92%
Data quality	100%
Hardware quality	NA

5.4.1.2 Organization

The organization dimension was assigned weight of 0.25, and all aspects were selected by the expert as applicable. The top management has been committed to support the system in which it continued allocating required resources for the system. Stakeholders were always involved in changing or implementation of new features. The demand and need for certain features in the system were identified and continuously evaluated as well as the outcomes of applying current and newly requested system's features. The plans and policies that are related to the use of the HIS have been set to enforce the proper use of the system and support the hospital in achieving the identified outcomes. Table 37 presents the evaluation score of each aspect.

Table 37 Evaluation score of Organization dimension's aspects

Aspects	Evaluation score
Support and commitment	92%
Organizational structures & strategy	86%
Planning and Policies	93%
Stakeholders	76%
Culture of electronic information use	80%
Outcome's identification	100%
Demand and need	100%

5.4.1.3 Resources

The resources dimension's weight was assigned to be 0.2, and all aspects were selected. Human resources are available as well as the technical training and support. All new users receive training sessions on how to use the system. On system updates or changes, the users receive training through either in-person training sessions or recorded tutorials. This depends on the number target users impacted by the system's update/change, and the cruciality of the system update/change. Moreover, the ICT infrastructure was sufficient to meet the system's requirements. Also, the financial resources were available to as long as the requested fund is to purchase system features/services that have high demand. Table 38 presents the score of the aspects in this dimension.

Table 38 Evaluation score of Resources dimension's aspects

Aspects	Evaluation score
Human resources	95%
Technical support and training	80%
ICT infrastructure	92%
Financial resources	100%

5.4.1.4 Social

The weight of the social dimension was 0.1 and all aspects were selected. The assessment of this dimension was filled based on the expert estimation as it was challenging to reach the users in short period.

Although the users are obligated to use this system because all operations must be done digitally through it, the users were found to be satisfied with it. The comprehensiveness and ability of the system to assist in task execution and completion allowed users to rely completely on it, by which users perceived the usefulness and ease-of-use in the system. Table 39 presents the evaluation score.

Table 39 Evaluation score of Social dimension's aspects

Aspects	Evaluation score
Continuance Usage Intention	93%
User Behavior	93%

5.4.1.5 Economic

The weight of the economic dimension was assigned to be 0.2 and all dimensions were selected. There is a sustainable funding for the system whether for ongoing costs (i.e., licenses' renewal) or for purchasing new system features. The financial benefit that the hospital is interested in is the cost-effectiveness of the system, in which using the system reduced the needed recourses to complete the tasks and increased the overall productivity. All aspects got a score of 100% in the evaluation.

5.4.2 Sustainability Assessment Results

Table 40 presents the dimensions' weights that were assigned by the expert. Also, it presents the assessment scores of the aspects after applying the assessment method on the HIS. The overall sustainability level of the HIS is high that is aligned with the positive

perception and evaluation of the HIS in the hospital. The complete sustainability assessment of the HIS in this case study is found in Appendix G in Table 41.

Table 40 Results of case study 3

Dimension	Dimension's weight	Aspects	Evaluation score	Dimension's score	Dimension's weighted score
Technology	0.25	System quality	92%	96%	24%
		Data quality	100%		
		Hardware quality	NA		
Organization	0.25	Support and commitment	92%	89%	22%
		Organizational structures & strategy	86%		
		Planning and Policies	93%		
		Stakeholders	76%		
		Culture of electronic information use	80%		
		Outcome's identification	100%		
		Demand and need	100%		
Resources	0.2	Human resources	95%	92%	18%
		Technical support and training	80%		
		ICT infrastructure	92%		
		Financial resources	100%		
Social	0.1	Continuance Usage Intention	93%	93%	9%
		User Behavior	93%		
Economic	0.2	Sustainable funding	100%	100%	20%
		Affordability of e-solution	100%		
		Financial benefits	100%		
Total					94%

5.5 Discussion

The model and the assessment method were demonstrated to evaluate the sustainability level of all three e-health solutions successfully. The first and third case studies concluded a high level of sustainability for the evaluated e-health solutions (i.e., VRS and HIS). The results match the actual status of these solutions, in which they have been successfully running for more than 10 years and are expected to sustain as they satisfied the sustainability dimensions of the model proposed in this thesis. However, both hospitals did not have a comprehensive method to capture all sustainability aspects and evaluate them. On the other hand, the sustainability assessment of the e-health solution in the second case study was low with a score of 52%. Before applying the sustainability assessment method, the gathered information indicated low level of sustainability, which means the e-health solution will not sustain. Similar sustainability evaluation was predicted by the sustainability assessment method which means only few aspects contributed to the sustainability, hence, the e-solution will not sustain in long -term unless most of the performance in most of the aspects got improved. The major issue is that the model evaluation results reveal the unsustainability risk of this e-health solution and highlight where improvements could be introduced.

By analyzing the assessments scores in the three case studies, it was observed that the organization dimension has the greatest influence on the other dimensions. This conclusion aligned with the results of the SLR (refer to Chapter 2), in which the organization dimension was found to be frequently in the studies as an important dimension that influence the sustainability the most. This can be explained by the second case study, in which the organization dimension received a score of 42%. This score resulted from

unfulfillment of most of the organizational aspects, such as the top management support and stakeholder's involvement. By this, the other dimensions (i.e., resources and economic dimensions) were negatively impacted, in which the fund was not provided which impacted the availability of the resources. Furthermore, the unfulfillment of the resources and economic dimensions negatively impacted the social dimension, as users were not satisfied with using a system that has a lot of limitations and does not meet their needs. Moreover, the lack of sustainable funding is an issue that directly impact the sustainability of the e-health solutions. Because e-health solutions are improving rapidly and the demand for new changes and updates is increasing respectively. In order to keep up with the demand, adequate sustainable funding is required to sustain the use of the system. The resistance to providing funds is hindering the efficient employment of the technology in healthcare and increasing the burden on the healthcare practitioners, which does not achieve the digital health transformation goals.

5.6 Chapter Summary

This chapter presented the evaluation of the e-health sustainability model and assessment method that were introduced in Chapter 0 and Chapter 4. The evaluation was conducted by three case studies in three different hospitals in Saudi Arabia. The results showed the applicability and effectiveness of the sustainability assessments method to predict the sustainability level of the e-health solutions in real-word cases.

CHAPTER 6

CONCLUSION AND FUTURE WORK

This chapter presents the threats to validity, recalls the thesis contributions, and answers the research questions. Additionally, it discusses some of the future directions on sustainability recommendations based on the e-health sustainability model.

6.1 Threats to Validity

Despite the perceived effectiveness of the proposed sustainability model and its assessment method, there are some threats that might affect the validity of this work.

6.1.1 Construct validity

The sustainability aspects in the model were extracted from the conducted SLR. However, because the grey literature was not fully explored, the risk of missing important aspects exists, which may affect the comprehensiveness of the model. Also, the evaluation tools, surveys and checklists, of the aspects were gathered from the studies that discuss the evaluation of the intended aspect without relating it to the sustainability of digital solutions. To mitigate those risks, the model and the assessment method were validated by IT and domain experts in the healthcare. Lastly, there is a threat to the validity of the as there is no clear evaluation scale of the sustainability of e-solutions in healthcare exist in literature, I proposed an evaluation scale, which might impact the validity of it. However, to mitigate this risk, the proposed scale was inspired from other studies that was published to assess

the maturity level of digitalization of companies, which is close to the subject under study in this thesis.

6.1.2 Internal validity

In evaluating the model, the social dimension was supposed to be filled by the users of the e-health. However, because reaching the users in short period was challenging, the evaluation of the social dimension was done by estimating the scores based on the experts' responses and judgment. This might impact the resulted score for the social dimension. However, to mitigate these risks, I asked the experts to consult the end users before providing data on this dimension. In addition, the IT and domain experts were of different level of sustainability of e-solution's knowledge. This might have impacted the validity of weights they assigned to the dimensions and the data they provided to each aspect. To mitigate this, I had an introductory session where I explained each dimension and their aspects.

6.1.3 External validity

Although the case studies illustrated the effectiveness of the sustainability model and its assessment methods in evaluating the sustainability e-solution in public Saudi hospitals, the result might not be generalized to include the private sector. Hence, I plan to further investigate the effectiveness of the model with cases studies from the private sector.

6.2 Contributions

There are significant contributions in this thesis. The thesis proposed a novel and comprehensive sustainability model for e-solution in healthcare that

1. Captures empirically the main dimensions, aspects, elements of e-solution in healthcare.
2. Provides an assessment method that is used to evaluate the sustainability of e-solutions in healthcare, which supports healthcare management in decision making and e-solution adoption through
3. Provides a tool support that implements of the sustainability model and the assessment method to facilitate the use of the model in practice.

6.3 Research Questions

This thesis addresses two main research questions related to the sustainability of the e-health solutions:

- **RQ1:** What are the dimensions and elements of the sustainability model that fits and reflects the adoption of e-solutions in healthcare systems?

Answer: this question was answered by the conducted SLR, in which the dimensions and elements were extracted and then used to build the sustainability model empirically.

- **RQ2:** To what extent the proposed sustainability model is comprehensive in covering all aspects of e-solution sustainability in real-word cases in healthcare in practice?

- **RQ3:** To what extent the sustainability model and the assessment method are effective in evaluating the sustainability level of e-solution in healthcare in practice?

Answer: those two questions were answered by 1) conducting several meetings with technology and clinical experts in healthcare to assess the validity, comprehensiveness, and correctness of the model and 2) conducting three case studies in three hospitals in Saudi Arabia to validate and evaluate the comprehensiveness and effectiveness of the model and assessment method in practice. The experts agreed that the model is more comprehensive and systematic than what they do in practice. Also, the assessment method to be applicable and useful in evaluating the sustainability level of e-solutions. In addition, the case studies illustrated the expected effectiveness and applicability in real-world cases where the evaluation results were aligned with the expected sustainability that the hospitals had or discovered after the adoption of the systems.

6.4 Future Directions

In the future I'm planning to do the following:

- **Sustainability recommendations:** the sustainability model and assessment method predict only the sustainability level and identify the aspects with low score. However, the current work does not provide recommendations on how to improve the sustainability level of the e-health solution. Recommendations are useful to guide healthcare top management in investigating the chances of improving the sustainability of current e-solution or, instead, considering other digital solution. Hence, I'm planning to analyze the sustainability practices in the context of e-health and survey the literature in order to provide set of informative recommendations that can be used to support

decision making about the sustainability e-solutions (e.g., whether to improve the sustainability level of an e-health solution or discard it and look for other options).

- **Further evaluation of the sustainability model:** more case studies can be conducted to improve the generality of the sustainability model by considering case studies from private hospitals.
- **Tool support:** enhance the current tool support by providing a smart engine and usable interface that supports the technology experts in filling relevant data and assigning weights to the sustainability dimensions. Also, add an Artificial Intelligent (AI) component that better estimates the sustainability of e-solutions using historical data of similar solutions adopted in similar healthcare settings.

6.5 Conclusion

The undergoing digital health transformation has introduced many changes that followed the adoption of e-health solutions in healthcare. Although those e-health solutions positively impact the healthcare provision, they bring dramatic to healthcare environment changes such as changes to workflows, roles, and provided services. Thus, it is essential to assess the suitability and sustainability of those e-solutions in order to minimize waste and optimize the use of resources. In this thesis, I proposed an e-health sustainability model and assessment method that support decision making in adopting new digital technology. The sustainability model captures the dimensions and aspects of e-health sustainability and provide a systematic method to evaluate and predict the sustainability of e-health solutions.

The validity and comprehensiveness of the proposed mode and its assessment method were assessed through multiple meetings with experts. In addition, I conducted three real-world

case studies in which the effectiveness of the proposed sustainability model in evaluating the sustainability of currently used e-solutions and the applicability of using it in practice is illustrated. The assessment method considers the singularity of each healthcare context by allowing each dimension to be assigned different weights based on its importance of the context of evaluation. This customization was proved to be essential as the weights of dimensions in each of the three conducted case studies vary. The sustainability model and its assessment are expected to provide a holistic evaluation and insights about the enablers and challenges in adopting e-solutions. In addition, they are expected to reduce wasting resources as they will support assessing the overall sustainability level of an e-solution before adoption or deployment.

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APPENDICES

All appendices mentioned in Table 41 are found in below link.

<https://drive.google.com/drive/folders/1y31-gcrmpXxR33zQQRFXvSkZkdeRagzM?usp=sharing>

Table 41 List of appendices

Appendix	File Name	Description
A	Appendix-A_SLR	The file contains documentation of the selection process and search results of each of the selected digital libraries along with quality assessment of the primary studies and their data extraction.
B	Appendix-B_Sustainability Elements Definitions	The file contains definitions of all elements of sustainability model along with their references. The definitions are provided to clarify the focus of using them in context of sustainability model.
C	Appendix-C_Evaluation Tools	Contain the complete evaluation checklists and surveys that are used in the sustainability assessment method.
D	Appendix-D_Tools Support	It is the tool support that can be used to conduct the sustainability assessment on e-health solution.
E	Appendix-E_Sustainability Evaluation-Case Study 1	The complete assessment with all scores and results of the e-health solution that was evaluated in the case study 1
F	Appendix-F_Sustainability Evaluation-Case Study 2	The complete assessment with all scores and results of the e-health solution that was evaluated in the case study 2
G	Appendix-G_Sustainability Evaluation-Case Study 3	The complete assessment with all scores and results of the e-health solution that was evaluated in the case study 3

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