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Factors influence the behavioural intention to use Digital Twin Healthcare by the elderly: a cross-sectional survey

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Abstract

With an aging population, the need to improve the elderly's health becomes critical. Digital Twin in Healthcare (DTH) is a game changer in the medical field. DTH enables continuous inspection of health status; thus, it effectively assists medical staff to monitor, predict illness and come up with the best prevention or treatment plans (Erol et al., 2020; Y. Liu et al., 2019a). However, the adoption of DTH does not only depend on the features of the technology but also the user's acceptance (Davis, 1989; Venkatesh et al., 2003). The objective of this thesis is to discover determinants of the use intention towards DTH by the elderly. This thesis answers the main research question:

What factors influence the elderly's behavioural intention to use DTH?

The main question was answered by means of literature review and cross-sectional survey. The survey was conducted using 131 participants of 50+ years old. Derived from both theoretical and empirical literature, the research model includes seven factors. To better understand the behavioural intention from the elderly perspective, the author did a systematic review and derived four different DTH usage levels. The hypotheses were tested with the DTH usage level 1 and 2. Specifically, DTH usage level 1 is offline patient monitoring that uses e-health dossier, with no real-time monitoring or medication intervention. At DTH usage level 2, Internet of Things wearable devices are integrated, which allows real-time monitoring and real-time intervention. Partial least squares structural equation model (PLS-SEM) was then applied to analyse the collected data. The outcome was performance expectancy, social influence and facilitating conditions are significant predictors of the intention to use DTH usage level 1. In DTH usage level 2, performance expectancy and price value are noteworthy predictors. The result suggests each usage level has different predictors to its behavioural intention; thus, researchers need to direct the effort to understand the factors with strongest influence for each level.

Keywords: Digital Twin Healthcare, UTAUT2, Digital Twin in Healthcare usage levels, Performance Expectancy, Effort Expectancy, Social influence, Facilitating Conditions, Hedonic Motivation, Habits, Price Value, PLS-SEM

Preface

This thesis ends my Master program of Information Management at Tilburg University. This master program has been an exciting, challenging and wonderful journey. I am deeply grateful for my professors who inspired and gave me the knowledge during the years at the university. This thesis also marks the end of my academic career, and I am excited for the opportunities ahead.

First of all, I would like to express my gratitude to my supervisor, Khoa Nguyen, for his academic guidance and encouragement. Second, I would like to thank my second reader, who was also my professor, Martin Smits, for his time and effort during the evaluation process.

I am also grateful for my family, my friends, and Gijs Trepels who gave me all the love, care and support. They encouraged me and provided me guidance whenever I need through this whole journey. Their support means the world to me.

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Chapter 1 - Introduction

This chapter covers an overview of the research topic and its context. In the first part, the problem is introduced, indicated and stated. Its purpose is to provide readers with an understanding of the problem and its significance from a theoretical and managerial perspective. In the second part, research questions are formed to guide a large part of this thesis. The third part covers the scope and limitations, while the fourth part highlights the research methodology briefly. The last part of this chapter looks at the structure of this report.

1.1 Introduction

In most countries nowadays, the demographic structures shift towards an aging population given a rise in life expectancy, and a drop in birth-rates (Cristea et al., 2020). In 2018, The European Commission's Aging reported that the old age dependency ratio rose to 29.6% in 2016, and it is forecasted to increase further up to 2050. Eventually, it will reach to 51.2% in 2070 (European Commission, 2018). The World Population Aging (2017) predicts that healthcare for the elderly will consume nearly 50% of medical resources, which poses a risk for limited medical resources.

Digital Twin in Healthcare (DTH) is a solution that shorten patient's waiting time, and reduce the risk for limited medical and personnel resources (Erol et al., 2020). The way DTH work is based on cloud and advanced architecture, which allow Internet of Things (IoT)-connected devices and wearables to transmit the physical human's real-time data to their digital twin. Not only that, the DTH takes into account other factors such as age, lifestyle, genetic background, etc. that enable dynamic individualised models to be made (Elayan et al., 2021). Consequently, DTH drives precise and personalised treatment (Y. Liu et al., 2019), which allows doctors to deliver services more efficiently.

However, the healthcare industry cannot reap these benefits if the users do not accept the technology. Thus, this report looks into the perception of the elderly to understand the determinants of use intention towards DTH. Additionally, this enables the Information Management discipline to evolve a better DTH artifact that would be accepted and used; thus, having a wider impact in the society.

1.2 Problem indication

An aging population leads to the potential of increased medical costs and long-term care services. With regards to the elderly, they might not be able to prevent or get medical needs on time. This is due to (1) low visiting rate to medical centres (long registration time, long waiting line, long payment time due to limited medical resource); (2) missed or delayed diagnosis; (3) corrupted health data. With that said, a solution for real-time monitoring, crisis warning, and health consultation for the elderly is critical (Y. Liu et al., 2019). One game changer in this domain is DTH. The DTH can improve the elderly's health and hospital processes significantly (Bruynseels et al., 2018; Erol et al., 2020; Kummar et al., 2015; Y. Liu et al., 2019). In 2021, Accenture (2021) reported that over the next three years, 66% of healthcare executives will progressively invest in DTH for their organisations.

Given the success of the technology depends on the elderly acceptance, it is crucial to address the elderly's perception, attitudes and concerns towards DTH (Rouidi et al., 2022). This enables forming effective strategies to endorse DTH usage, and shaping the innovation accordingly if necessary. Digital Twin is not yet an established fact (Erol et al., 2020), but is an emerging technology that is malleable as it is still in its early development stage (Bruynseels et al., 2018). As a result, understanding the factors that potentially influence DTH adoption is important to promote the acceptance of DTH in the elderly.

1.3 Problem statement

Given each life and physiology are different; the medical intervention should also be different (Bruynseels et al., 2018). The DTH can improve the elderly's health significantly. Based on review of multiple papers, DTH usage can be summarised into four levels, which will be further discussed in Chapter 3. In short:

- The first level is offline patient monitoring that uses e-health dossier.
- At the second level, IoT wearable devices are integrated, which allows real-time monitoring and medication. Therefore, doctors can prescribe more effectively without seeing the patient in person.
- At the third level, doctors can test scenarios in the virtual patient for a customised medicine dose.

- At the fourth level, doctors can practice surgery on the virtual patient using 3D technology.

DTH technologies across the four levels of usage help the doctors increase their expertise, and deliver faster and more accurate services to the elderly patient (Bruynseels et al., 2018). DTH also helps hospitals improve its processes and reduce the risk for limited medical resources. (Bruynseels et al., 2018). To leverage the advantage of DTH for the elderly, it is crucial to look into the factors that might support or prevent the elderly from using DHT. From then, better strategies can be found to improve the acceptance level. Over the years, there has been research studying the healthcare technology acceptance in the elderly. For example, Kavandi and Jaana (2020) looked into possible barriers to the health technology adoption by the elderly. It was done by means of systematic review conducted from December 2017 to February 2018. Low et al. (2021) used semi-structured interview to understand the perspectives of the elderly towards healthcare technology. Abdelrahman et al. (2020) went in more specific with technology acceptance for brain health in the elderly, while Charness et al. (2016), Nikou et al. (2020), Talukder et al. (2020) and Zhou et al. (2019) investigated the matter with different approaches. However, there has been no study into the specific factors that could affect the behavioural intention of the elderly in DTH. The research in this report aims to provides healthcare executives insights into elderly’s perception, attitudes and concerns towards DTH. As a result, they can invest in the most effective strategies so the DTH can be applied widely and reap the mentioned benefits.

1.4 Research question

To investigate the elderly’s perceived perception, attitudes and concerns towards DTH, the main research question is: “What factors influence the elderly’s behavioural intention to use DTH?”

To produce information to answer the main questions, the following sub-questions are used:

1. What factors influence the elderly’s behavioural intention to use a healthcare technology according to existing research?
2. What must be done from the elderly side to get DTH implemented?
3. What factors influence behavioural intention to DTH at different usage levels?

1.5 Scope and limitation

Since the elderly need to have regular checks, and require more medical services (World Population Aging, 2017), this thesis focuses on this population's acceptance of DTH. Besides, time limitation leads to (1) only the first two levels are studied because these levels require the most effort from the elderly patients; (2) a limited population is studied; thus, not all personality characteristics are included; (3) only the consumer side is studied, that is, the elderly side. For a more comprehensive picture, future research examining the service provider (e.g: hospital, clinics, etc) is strongly recommended. Research with a larger scale considering all four levels of DHT usage, and including the service providers' perception of DTH would be suggested in the future.

1.6 Research method

This thesis used both secondary and primary method. To conduct secondary research, first, literature review was done. The literature review answers sub-question 1 and 2, which supports to construct the research model and propose hypotheses. The secondary sources include academic papers from google scholar, web of science, etc. The combination of keywords such as (1) Digital Twin in Healthcare, (2) Technology acceptance elderly (3) Elderly healthcare is used. Regarding primary method, survey was used to test the proposed hypotheses which reveals the answer for sub-question 3. The survey method was chosen to perform in this study as it is useful to find out people's perceptions, attitudes and behaviour (Boynton & Greenhalgh, 2004); and the targeted participants is 50+.

In constructing questionnaires for the survey, questionnaires adapted from existing academic paper were slightly modified and extended to fit with the DTH context. Using 'off-the shelf' scales ensures the questionnaires are of high validity and reliability (Gideon, 2012), but still tailored to this research needs due to the slight modification. The questionnaire was first created in English and translated to other languages. Following existing research, this research uses Likert scale questions to capture constructs from research model, with 5 stands for "strongly agree", 4 is equal to "agree", 3 symbolizes "neutral", 2 is equal to "disagree", and 1 represent "strongly disagree". The survey results in quantitative research. The time frame for this thesis is around 11 weeks; thus, survey was conducted via convenience sampling. Finally, the results were analysed using a Partial Least Squares Structural Equation Modelling (PLS-SEM) modelling approach.

The validity and reliability of a survey also play an important role. To improve measurement validity, expert input and pilot testing were executed. First, two experts were asked if the questionnaires could adequately capture the construct definitions. Second, to control ambiguous items, around 10 people were pre-tested as a rule of thumb. Moreover, to solve social desirability bias in which respondents answer accordingly to how others favour, this survey emphasizes the confidentiality of the information, and highlights there is no right or wrong answer. Finally, Factor Loading, Composite Reliability, Average Variance Extracted, Formel-Larcker Criterion, Heterotrait-Monotrait Ratio, Cross Loading and Collinearity statistics were used to ensure the reliability and validity of the survey items.

1.7 Structure

The general structure of this thesis is as follows. The next chapter covers the most important literature related to the research topic. Chapter 3 presents a systematic review of the DTH levels from the end-user perspective by means of literature review. Chapter 4 outlines the hypotheses derived from literature review. Chapter 5 looks at the way the research methodology was carried out, and chapter 6 deals with the findings. After that, chapter 7 covers the major outcomes, implications and suggestions for future research. The final chapter concludes the answer to the main question. For a more comprehensive understanding, supplementary material is included in the Appendix.

Chapter 2 - Literature review

This section introduces the most important literature related to the research topic. To answer the research questions, this thesis uses the Technology Acceptance Model (TAM) and the Unified Theory of Acceptance and Use of Technology 2 (UTAUT2) paradigms, which are similar to research approaches used to investigate health technology adoption by the elderly (Charness et al., 2016; Hsieh et al., 2015; Kavandi & Jaana, 2020; Talukder et al., 2020). These paradigms see the adoption of a technology not only depends on the capability of the technology itself, but rather on the experience the user has (Davis, 1989; Venkatesh et al., 2003). More details about the paradigms are elaborated in section 2.2. To perform a literature review, keywords including (1) Digital Twin in Healthcare, (2) Technology acceptance of elderly, (3) Factors affecting new technology in healthcare consumers, (4) Elderly healthcare services Digital Twin, (5) Wearable technologies, (6) Elderly healthcare, (7) Personal health management were used, leading to the main articles used that is summarised in Table 19, 20, and 21 in Appendix A. The knowledge obtained supports to form key concepts, hypotheses and research model.

The literature review is structured as followed. The first section is devoted to DTH. It covers how DTH works, and the must-have requirements from the elderly side to get DTH implemented. The second section covers the TAM and UTAUT2 paradigms. The third section looks at empirical research. It combines with the first and second part to reveal the potential determinants to use intention of DTH by the elderly.

2.1 Digital Twin in Healthcare

Digital Twin is defined extensively nowadays in several pieces of literature (Fuller et al., 2020; Z. Liu et al., 2018; Popa et al., 2021); however, the following definition seems to capture all the aspects of the DTH: “A digital twin is a living model of the physical asset or system, which continually adapts to operational changes based on the collected online data and information, and can forecast the future of the corresponding physical counterpart” (Z. Liu et al., 2018; Popa et al., 2021). The Digital Twin has encountered great success in multiple fields. First, it was used in the aviation field to detect damages and trigger self-healing actions. Second, it was used in the manufacturing field to predict and optimize its processes (Erol et al., 2020). Digital Twin is now spreading in the healthcare sectors. Any Digital Twin system includes (1) Internet of Things, big data technologies, and self-adoptive autonomous systems to gather, process and manage large volumes of data, and (2) machine learning to produce new knowledge (Erol et al., 2020). Digging further into how Digital Twin works in healthcare for the elderly, Y. Liu et al. (2019) introduces a conceptual framework for the DTH. This framework enables constant monitoring of the elderly patient's health status; and it is discussed in detail in 2.1.1, 2.1.2, and 2.1.3.

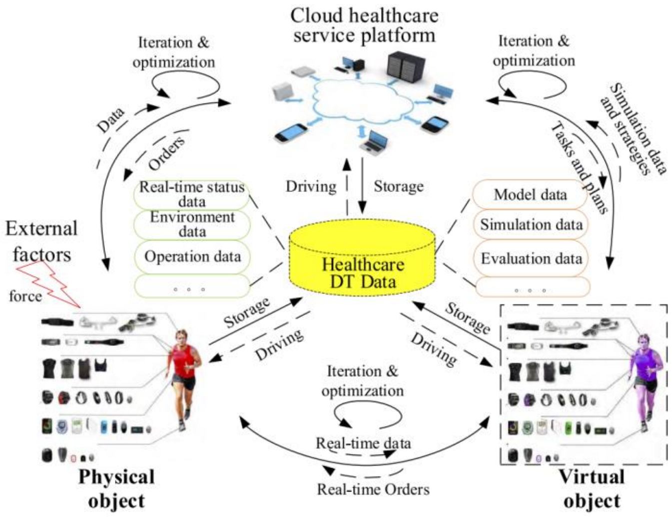

Figure 1. Conceptual Digital Twin model framework to monitor elder's patient health

Source: Y. Liu et al., 2019b

2.1.1 How DTH framework operates?

The DTH framework strives to create a virtual human twin. Y. Liu et al. (2019) present that there are four main stages in DTH framework. First, sophisticated modelling techniques and tools can connect to the physical object (e.g physical human with wearable devices) to create a detailed virtual object. Second, for a real-time interaction between the physical object and virtual object, health IoT wearables can interconnect and interact with each other. The wearables also interact with the system, and mobile internet is used to ensure data connection. Third, to ensure the virtual object is modelled correctly, the system reconfigures itself, and makes sure all elements are synchronised. Accordingly, virtual objects are constantly evolving. Lastly, when detecting a problem, the virtual object sends orders to the physical object for self-healing actions in real-time (Y. Liu et al., 2019). In short, by linking to physical human, DTH receives data from the physical human. The DTH system then synchronizes data, applies AI to detect possible problems, and informs the physical human self-healing actions (Erol et al., 2020).

2.1.2 Which components are needed for DTH framework?

Y. Liu et al. (2019) found that there are three components in DTH. First, the external factors (e.g news, weather, social, etc) influence the mood, decisions, and health of the physical object. For this reason, these external factors impact the digital simulation and affect the decision-making of the DHT service system. Second, the internal forces of the DTH system include physical object data, digital object data, and service data. Third, the DTH database is an important component. It manages all data from the physical object, virtual object, and DHT systems (Y. Liu et al., 2019). With that said, the components needed for DTH framework includes external factors, internal factors, and DTH database.

2.1.3 What is needed from the elderly side to get DTH implemented?

Based on the operation mechanism and components of DTH mentioned, physical object and its data are most necessary for starting any Digital Twin models. Y.Liu et al. described physical people data comprises of (1) health-related data conducted by hospitals, for instance, medical examinations, results, diagnosis, reports, health scans, imaging systems; (2) health related data obtained from wearables, such as heart rate, blood pressure, etc.; (3) health-related data from a third party such as health insurance or health consultancy. This being said, the information required by the elderly comprises personal health records and wearables such as ‘smart bracelets, smart step counters or smart sphygmomanometers, and other smart systems for daily care of the elderly’ (Y. Liu et al., 2019).
The summary of key findings from existing literature for section 2.1 can be found in Appendix A table 19.

2.2 Acceptance concept level

Section 2.1 provides an overview of DTH, including (1) the conceptual framework for DTH, (2) its components, (3) the realization requirements from the elderly’s part. This section discusses the theoretical model of technology acceptance.

Over the years, literature points out that the adoption of a new technology does not simply depend on the features of the technology itself but also on the user’s acceptance (C. Lee & Coughlin, 2015; Talukder et al., 2020). There are two most noteworthy models investigating this matter: The Technology Acceptance model (TAM), as shown in figure 2, and the Unified Theory of Acceptance and Use of Technology 2 (UTAUT2), as shown in figure 3. (Charness et al., 2016; Hsieh, Tsai, Chih, & Lin, 2015; Kavandi & Jaana, 2020; Talukder et al., 2020).

TAM was first presented by Davis in 1989. The model argues that besides the capability of the technology itself, the experience the user has also plays a critical role. Davis postulates that the potential users' attitude towards the technology/system is the main determinant of behavioural intention to adopt a new technology. And the attitude towards the new technology is based on two primary factors: perceived usefulness (individual believes that the technology/system is useful) and ease of use (individual thinks that the system/technology is easy to use) (Davis, 1989). The TAM model is illustrated in figure 2.

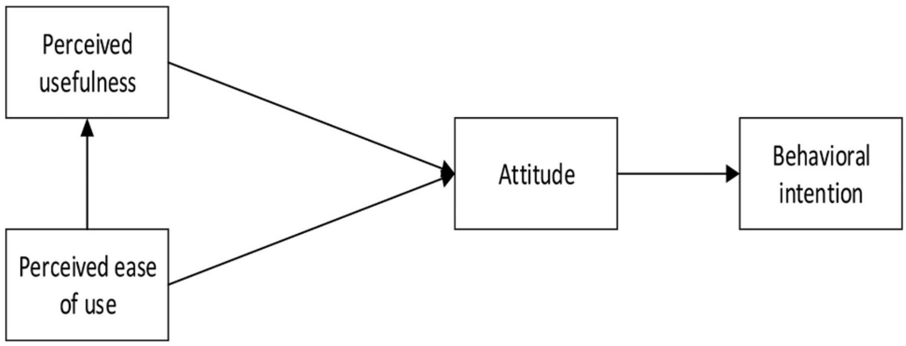

Figure 2. Technology Acceptance Model (TAM)
Source: Davis, 1989

Nevertheless, more research in this field suggests that successful adoption of a technology also depends on more complex factors (Kuo, Liu, & Ma, 2013; C. Lee & Coughlin, 2015; Talukder et al., 2020). A range of theories and models have subsequently developed based on TAM over the years (Talukder et al., 2020). Combining eight different competing models (including TAM), Venkatesh et al. (2003) present the Unified Theory of Acceptance and Use of Technology (UTAUT). Even though UTAUT enriches the technology acceptance model, it applies mostly in organizational context (Talukder et al., 2020; Williams, Rana, & Dwivedi, 2015). Thus, Venkatesh et al. (2012) present UTAUT2 to understand the technology acceptance of the consumer.

As shown in figure 3, UTAUT2 has theorised seven constructs directly lead to the behavioural intentions to use a new technology/system. They comprise of (1) Performance expectancy (same as perceived usefulness in TAM), refers to an individual believes that the new technology is useful; (2) Effort expectancy (same as perceived ease of use in TAM), refers to an individual thinks the new technology does not require much effort and easy to use; (3) Social influence, refers to important person of the individual think the individual should use the technology; (4) Facilitating conditions, refers to the individual thinks there are enough conditions (such as training programs or relevant resources) to support them using the technology; (5) Hedonic motivation, refers to the individual thinks using the technology gives them pleasure and fun; (6) Price value, refers to the cost the individual must pay to obtain the perceived benefits of the technology; and (7) Habit, refers to the individual performs a routinized and non-conscious behaviour (V. Venkatesh et al., 2012). Besides the mentioned predictors on behavioural intention, moderation effects of age, gender, and experience effects the strength of the predictors on the intention.

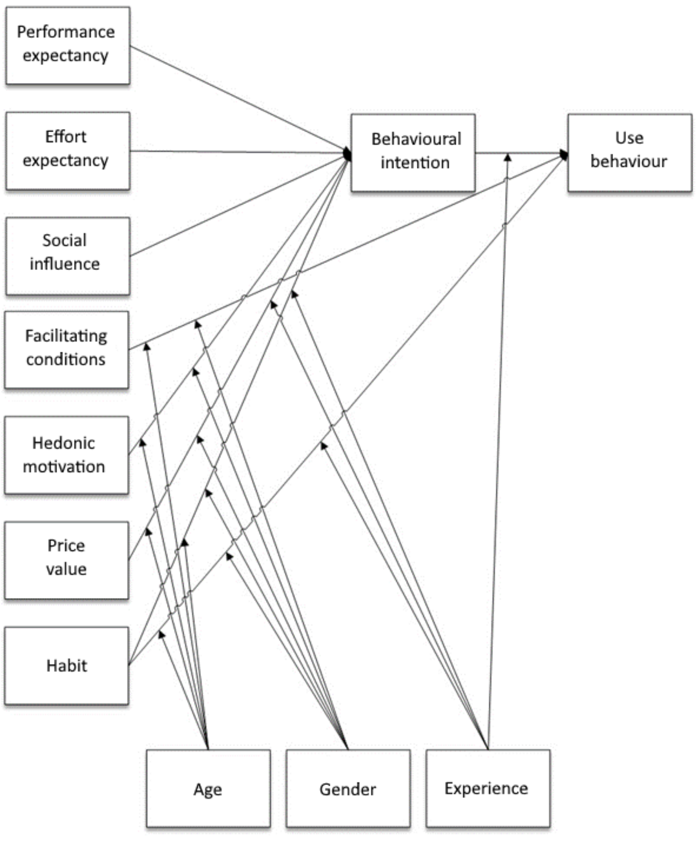

Figure 3. Extended Unified Theory of Acceptance and Use of Technology (UTAUT2)
Source: Venkatesh et al., 2012

The summary of key findings from existing literature for section 2.2 can be found in table 20, Appendix A.

2.3 Factors that influence the adoption of healthcare technology by the elderly

Section 2.1 provides an overview of DTH, while section 2.2 enriches the understanding of technology acceptance theoretically. Section 2.3 combines 2.1 and 2.2, using empirical research that is closest to the research topic to provide an overview of antecedents that might influence the elderly's use intention of DTH.

Theoretical and empirical literature has identified potential constructs that influence the behavioural intentions of the elderly to adopt a new healthcare technology: performance expectancy, current medical service satisfaction, effort expectancy, physical comfort, human interaction value, technology anxiety, resistance to change, price/cost, data privacy, facilitating conditions, social influence and hedonic motivation. The list of constructs in the literature is summarised in table 3 below. The table contains (1) Construct name, (2) Class that identifies the unit of analysis, (3) Definition of the construct, (4) Measurement of the construct (referring to what attributes can be used to measure that particular construct), and (5) Literature supporting the construct and measurement.

Table 1. List of constructs

Construct	**Class**	**Definition**	**Measurement**	**Supporting literature**
Performance expectancy	Individual	The degree to which an elderly person thinks that using the device/technology will improve the elderly's job performance	Improve quality of healthcare services; Faster accomplishment of elderly' daily requirement.	(Abdelrahman et al., 2020; Charness et al., 2016; Davis, 1989; Kavandi & Jaana, 2020; Low et al., 2021; Talukder et al., 2020; Venkatesh et al., 2003; Zhou et al., 2019)

Medical service satisfaction	Individual	The degree of satisfaction with the current healthcare system by the elderly	Affordability; Comfortability; Professionalism; Safety; Waiting time.	(Low et al., 2021; Zhou et al., 2019)
Effort expectancy	Individual	The degree to which an elderly thinks the device/technology is easy to use	Learning how to use easiness; Ease in use.	(Abdelrahman et al., 2020; Charness et al., 2016; Davis, 1989; Kavandi & Jaana, 2020; Low et al., 2021; Talukder et al., 2020; Venkatesh et al., 2003; Zhou et al., 2019)
Physical comfort	Individual	The degree of comfort associated with the physical device that helps facilitating the technology	Securely attached; Not feel painful; Not restrict movement; Not feel heavy; Not irritate the skin.	(Abdelrahman et al., 2020; Charness et al., 2016)
Product design	Individual	The degree of aesthetic of the designing products	Worried about the looks.	(Charness et al., 2016)
Human interaction value	Individual	The degree to which an elderly requires face-to-face interaction with healthcare professionals	Fear of losing emotional benefits; Interpersonal communication reference.	(Alsulami & Atkins, 2016; Low et al., 2021)
Self-actualization	Individual	The degree of satisfaction, actualizing personal potential and sense of achievement when the elderly learns and use the technology successfully	Learning the new technology is an opportunity for personal development; Learning a new technology increase feeling of self-fulfilment;	(Talukder et al., 2020)

			Learning a new technology gives a feeling of accomplishment.	
Self-efficacy	Individual	The degree to which the elderly is capable to perform a behaviour, or the ability to obtain objectives	Completion of a behaviour without assistance (e.g instructions, help, etc.).	(Kavandi & Jaana, 2020)
Technology anxiety	Individual	The degree of fear/lack of interest and motivation associated with the possibility of using a new technology	Nervous to use a new technology; Worried to use a new technology; Confused to use a new technology.	(Talukder et al., 2020)
Resistance to change	Individual	The degree to which an elderly resist to change in lifestyle, following the use of a new technology	Willingness to change healthcare routine; Willingness to change health maintenance method; Willingness to change human interaction method.	(Alsulami & Atkins, 2016; Talukder et al., 2020)
Price/cost	Individual	The degree to which an elderly is willing to bear the cost of adopting a new technology	Willingness to pay installation cost; Willingness to pay service cost; Willingness to pay repairment cost; Willingness to pay maintenance cost.	(Alsulami & Atkins, 2016; Claes et al., 2015; Davis, 1989; Kavandi & Jaana, 2020; Low et al., 2021; Venkatesh et al., 2003)
Data privacy	Individual	The degree to which an elderly is concerned about unauthorized access to personal	Willingness to share data with family;	(Abdelrahman et al., 2020; Low et al.,

		information, and information misuse when adopting a new technology	Willingness to share data with healthcare professional; Willingness to share data with insurance companies; Willingness to share data with governance; Worries about privacy invasion.	2021; Zhou et al., 2019)
Facilitating conditions	Individual	The degree to which an elderly thinks that he/she has enough resources and support to adopt a technology	Feeling of having sufficient resources; Feeling of having sufficient support.	(Low et al., 2021; Venkatesh et al., 2003)
Social influence	Individual	The degree of encouragement the elderly receives from important people in his/her social circle	Encouragement from people that an elderly finds important; Encouragement from opinions an elderly values.	(Talukder et al., 2020; Venkatesh et al., 2003)
Hedonic motivation	Individual	The degree of fun/entertaining/joyful associated to the use of technology	Usage is fun; Usage is entertaining; Usage is joyful.	(Talukder et al., 2020; Venkatesh et al., 2003)

In this section, each potential construct, together with the measurement approaches for each construct has been introduced. The summary of key findings from existing literature for section 2.2 can be found in table 21, Appendix A. The next chapters of this paper represent firstly the DTH usage levels derived from the literature review, and then the hypotheses to show the expected relationships between each construct.

Chapter 3 - Systematic review of DTH usage

Currently, there is no existing research on the DTH usage levels. However, to understand better the current usage of DTH, the main DTH usage can be systematically structured into four levels after studying numerous pieces of literature:

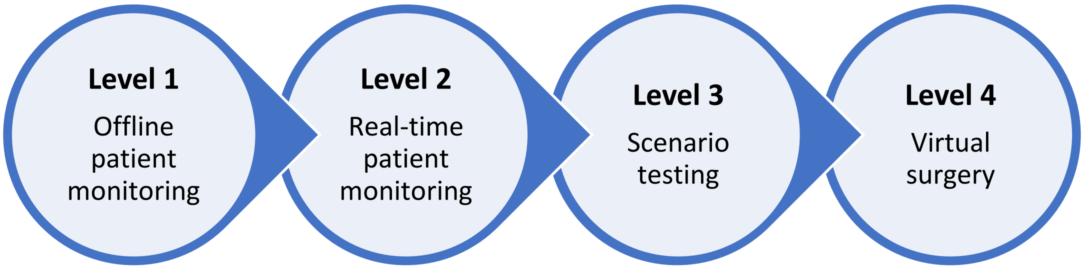

Figure 4. DTH usage levels

1. The first level is offline patient monitoring using an e-health dossier. At this level, patients can log into their medical account on a healthcare platform. This enables patients to gain insights into their health data and respond to questionnaires asked by doctors. Patients and doctors can use the computer to diagnose, communicate results, and exchange information. However, the data flow is done manually. Given that there is no real-time data coming to the patient's profile; no real-time monitoring or medical interventions in level 1.
   For example, Sooma Software Suite worked on a project to monitor patients offline at home. The patient was requested to download an application to their phone to update their mood and feeling every day. Accordingly, all the information is uploaded to a cloud where health professionals can access, monitor, and make changes to treatment if necessary (Erol et al., 2020).

2. At the second level, IoT-connected wearables are integrated, which enables real-time patient monitoring. The sensors transfer real-time data and feed the virtual patient continuously, letting the doctor prescribe and monitor their patients effectively without seeing the patient in person (Y. Liu et al., 2019). Due to the real-time data, DTH system

can map a detailed picture of each individual. Not only that, the DTH system takes into account the individual's detailed history such as lifestyle, genetic background, stress conditions, etc., make it possible to define what is normal for the individual. Thus, it enables doctors to identify deviations from the normal healthy state level more easily (Bruynseels et al., 2018). Additionally, the technology can pinpoint future diseases, so medical intervention is practiced precisely before the disease manifests (Bruynseels et al., 2018).

There have been multiple projects looking into DTH on this level. First, Bruynseels et al. found that Google spin-off is one of the projects that follows this direction. Google spin-off uses each individual's wearable devices and lifestyle to track his/her 'genome, microbiome, physiological parameters' (Bruynseels et al., 2018). Second, in 2017, there is 'the 100.000 Genomes project' tried to gather detailed modular data from patients (Bruynseels et al., 2018; Telenti et al., 2016). Third, in Helsinki, engineers have worked on a project to transmit health information to the cloud continuously. After that, a software is used to analyse the information, create a digital person, and inform the doctor when there is a crisis (Bruynseels et al., 2018). Erol et al. also found that IBM and Watson (supercomputer) worked together on a project using AI to detect cancerous cells. In a body, there are around 37 trillion cells. Despite having similar genetic information, each cell has its own distinct characteristics. Whenever a cell is injured, the damaged cells are divided and multiplied forming a tumor. IBM and Watson together developed and trained the Alacris computer model to understand why the cells are divided, thus it can interpret the situation (Erol et al., 2020). Finally, Semic Health's Digital Body Total has been using an AI Digital Twin to diagnose and forecast potential health problems based on the health data of patients in the past (Bruynseels et al., 2018; Erol et al., 2020; SEMIC Health, 2020).

3. On the third level, doctors can test scenarios in the DTH such as changing medicine dose. This enables the doctor to understand which drug and with what dose has the greatest results and slightest side effects (Kummar et al., 2015). Not only that, medicine properties can first be examined in the DTH before being administered to the patient to avoid any allergic reactions (Erol et al., 2020). This is made possible due to a large volume of data. It provides a detailed picture of the person in a healthy state, a detailed past diseases picture, and a series of action on how the body responds to the illness. As a result, it provides clues to doctors (Y. Liu et al., 2019).

Realizing the potential, many scientists have worked on personalized medicine projects (Bruynseels et al., 2018; Erol et al., 2020). Alacris computer model was developed to understand how a tumour is formed; consequently, the damaged cells multiplying scenario can be tested and the effect of the treatment can first be seen in DTH (Erol et al., 2020; Rauner, 2017). In 2018, being convinced that the DTH would enable personal treatment and medicines, the European CompBioMed project encouraged a research group to participate in the laboratory (Erol et al., 2020). Also, Enrol et al. mentioned that Semic Health's Digital Body Total developed a Digital Twin of artificial intelligence for realistic predictions. Based on more comprehensive health data, they can test on Digital Body Total, adjust the medicine dose to cure different types of cancer, Alzheimer's Disease, liver sclerosis, etc (Erol et al., 2020). In 2021, it is reported that researchers looked at how our body ages at a molecule level to find the right medicines to slow aging down (Price, 2021).

4. In the fourth level, Digital Twin together with 3D technology makes it possible to practice surgery. The detailed molecular picture of the digital twin model allows the physician to study the organ in-depth. The physician can rotate and zoom in the computational organ to fully understand the relationships involved in the surgery. Furthermore, a 3D model of the organ surrounding the blood vessels of the individual can be printed out so the physician can choose the ideal method to proceed (Erol et al., 2020).

   There have been projects that aim to tackle this level. First, Erol et al highlight that to cure an aneurysm, Sim & Cure created a 3D model of an aneurysm and blood vessels using 3D rotational angiography. Using Sim&Cure's software, together with ANSYS software, the artery model is then presented by the surgeon. The surgeon then can "zoom in and rotate to fully understand the relationship between the implant and aneurysm". The surgeon can also define the ideal way to place his medical devices during the surgery (Erol et al., 2020). Second, Siemen Healthineers made an algorithm that generates computational organ models based on comprehensive health data. The cardiologists can then test different treatments on these models, instead of on the real patient with chronic congestive heart failure (Erol et al., 2020). Third, Philips developed Philips Heart Model based on Digital Twin, combines with Philips HeartNavigator tool, together with Computed Tomography images helps the surgeon to simplify prior surgery planning. It also gives real-time 3D insight when the surgeon needs it (Erol et al., 2020; van Houten, 2018). Fourth, precision cardiology (accurately restoring heart health) was researched by Corral-Acero et al., using statistical models of data, modelling, simulation of multiscale knowledge and data (Corral-Acero et al., 2020).

The DTH levels are classified based on the end-user usage perspective. Interestingly, there has been research that strived to structure the Digital Twin by looking from a technical set-up perspective. Based on the data flow (e.g manual flow or automatic data flow), Fuller et al. classified Digital Twin technology into 3 levels: Digital Model, Digital Shadow and Digital Twin (Fuller et al., 2020). According to the model presented by Fuller et al., DTH usage level 1 would be Digital Model, while levels 2, 3, and 4 of DTH usage would be Digital Twin. The classification by Fuller et al. is illustrated in figure 5.

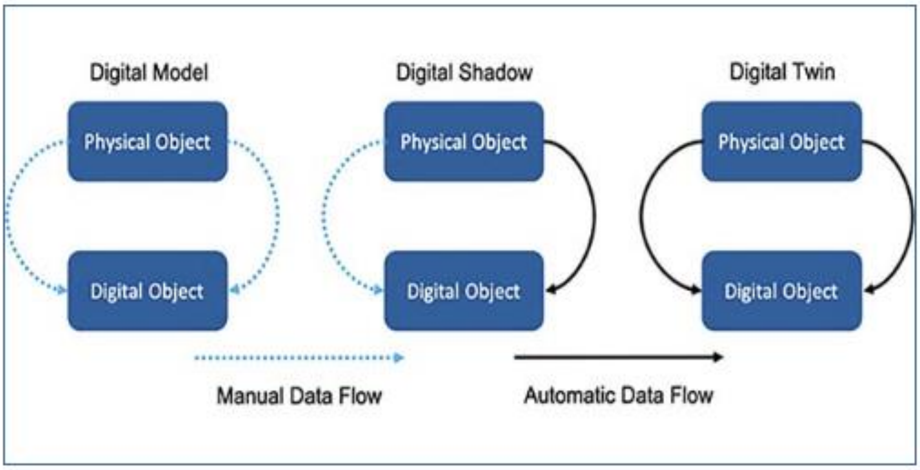

Figure 5. Levels of integration for a Digital Model, Digital Shadow and Digital Twin
Source: Fuller et al., 2020

Overall, these perspectives are useful to understand the Digital Twin technology better. As this thesis strives to understand the elderly's intention to use DTH, it is more useful to look at the Digital Twin from its usage perspective. Ideally, the acceptance factors of all four levels should be studied. However, only acceptance factor of level 1 and 2 are validated, given (1) time is limited, (2) DTH usage level 1 and 2 require more effort from the elderly. Key findings of this section can be found in table 22, Appendix A. The next chapter discusses which hypotheses are used to study the acceptance of levels 1 and 2, and how they were developed.

Chapter 4 - Hypotheses development

Chapter 2 discusses the academic knowledge related to the research topic. After literature review, potentially influential constructs were introduced in section 2.3. Next, chapter 3 covers the levels of DTH usage. Ideally, all constructs mentioned in chapter 2.3 should be studied across all four levels of DTH usage. Nevertheless, the scope would become too broad and challenging for this research. To narrow down the scope of this research, only level 1 and 2 of DTH usage are studied, and the hypotheses are developed based on the constructs presented in UTAUT2 model. These constructs include performance expectancy, effort expectancy, social influence, facilitating conditions, hedonic motivation, price value and habit. Narrowing the scope to these constructs ensures more accurate validation since the elderly can easier understand what was asked in the survey and willing to help validating the hypotheses. All things considered, this chapter outlines the hypotheses, in which the expected relationships between each construct and the behavioural intention are organised in the following sub-sections.

4.1 Performance expectancy and the behavioural intention to use DTH

There is ample evidence in the literature that performance expectancy is positively correlated to the elderly's behavioural intention to use healthcare technologies such as wearables, e-health, telemonitoring, home monitoring (Abdelrahman et al., 2020; Charness et al., 2016; Kavandi & Jaana, 2020; Low et al., 2021; Talukder et al., 2020; Zhou et al., 2019). Given DTH framework requires the elderly to have health-related data from different sources such as wearables, telemonitoring, home monitoring, etc. (Y. Liu et al., 2019), performance expectancy is also influential to behavioural intention to use DTH by the elderly. Additionally, studies have shown that the elderly have a positive attitude for new healthcare technologies. They are concerned about their health decline with aging; and they are willing to use a new technology if it enables them to maintain their health and increase life quality (Abdelrahman et al., 2020; Kavandi & Jaana, 2020; Low et al., 2021).

This seems to be in line with the Value Attitude Behavioural model, which suggests that customers are value-driven (Deng et al., 2014; Oliver et al., 1988). For every offer, they evaluate rewards and sacrifices. The more rewards and benefits they perceive, the more motivation for the intention to use (Deng et al., 2014; Oliver et al., 1988). The elderly's perception that the technology is useful has strong predictive power on their behavioural intentions (S. Gao et al., 2016; Hoque & Sorwar, 2017; Talukder et al., 2020). Thus, the hypothesis is formulated as:

- **Hypothesis 1**: Performance expectation will positively influence the behavioural intention to use DTH by the elderly.

4.2 Effort expectancy and the behavioural intention to use DTH

Effort expectancy is the degree to which an elderly believes the device/technology is easy to use (Venkatesh et al., 2003). As age increases, the physical and psychological conditions decrease, and information processing becomes more difficult (Birren et al., 1980). For this reason, a new and complex technology system might cause technological anxiety (Deng et al., 2014). Talukder et al. (2020) have found that technological anxiety has a significant negative affect on use intention. As the result, the better ease-of-use perceived by the elderly, the less technology anxiety, the higher chance they will use the technology.

In addition, despite the fact that Abdelrahman et al. (2020), Charness et al. (2016), Kavandi and Jaana (2020), Low et al. (2021), Talukder et al. (2020), and Zhou et al. (2019), performed their studies with different methods (quantitative, qualitative, systematic review, experiments) in different time frame, all proved the significance of effort expectancy to the behavioural intention of the elderly. In particular, the elderly would accept a technology if they perceive the technology require low effort. Thus, the following hypothesis:

- **Hypothesis 2:** Effort expectancy will positively influence the behavioural intention to use DTH by the elderly.

4.3 Social influence and the behavioural intention to use DTH

Social influence has also been found to be a determinant of behavioural intention towards a new technology (Abdelrahman et al., 2020; Low et al., 2021; Talukder et al., 2020). The elderly mentioned that encouragement and support of family members to use a new technology is a facilitator (Abdelrahman et al., 2021). In addition, Talukder et al. also found a significant positive effect between social influence and the behavioural intention to use wearable healthcare devices, which is in line with previous studies from Gao et al. and Hoque and Sorwar et al. (Gao et al., 2016; Hoque & Sorwar, 2017; as cited in Talukder et al., 2020). Given that the elderly is new to the concept during the adoption phase, their opinions are influenced by people in their social circle such as experts, superiors, friends or family (Talukder et al., 2020). For these reasons, social influence could potentially increase the use intention of DTH at the adoption phase.

This seems to be in line with Theory of Planned Behaviour, in which the subjective norm was found to predict behavioural intention "with high accuracy", it in turn leads to the actual behaviour (Ajzen, 1991). The subjective norm is considered "the perceived social pressure to perform or not to perform the behaviour" (Ajzen, 1991). This suggests that social influence has a predictive power on the behavioural intention. Thus, the following hypothesis:

- **Hypothesis 3:** Social influence will positively influence the behavioural intention to use DTH by the elderly.

4.4 Facilitating conditions and the behavioural intention to use DTH

From a qualitative study of the elderly, Low et al. (2021) reported that the elderly is more likely to use the technology if they believe that they have all the conditions to use a healthcare technology. Moreover, Cimperman et al. (2016) found that behavioural intention would increase if the elderly has the availability of technical support. Boontarig et al. (2012) also reported that helpful support is positively correlated with the intention to use e-health service by the elderly.

This seems to be in line with the Theory of Planned Behaviour, which was drawn from psychology. Fishbein and Ajzen (1975) posits that perceived behavioural control is one of the determinants of behavioural intentions, which refers to the degree the individual thinks he is capable to perform a behaviour. Facilitating conditions provides the elderly the capability to use the technology. Thus, facilitating conditions are argued to have a positive affect to behavioural intention.

- **Hypothesis 4:** Facilitating conditions will positively influence the behavioural intention to use DTH by the elderly.

4.5 Hedonic motivation and the behavioural intention to use DTH

Hedonic motivation is the joy results from using a new technology (V. Venkatesh et al., 2012). Vemkatesh et al. (2012) conducted research in the consumer context and found hedonic motivation is a significant enabler to technology acceptance. Not only that, Czaja et al. (2013) found that hedonic motivation is important for the adoption of healthcare wearables, since not only the wearable is beneficial for healthcare but also provides the joy for the elderly. Moreover, previous research found a positive effect between hedonic motivation the intention to use a new technology (Y. Gao et al., 2015; Oliveira et al., 2016; Talukder et al., 2020). Given DTH enables the users to gain insights into their health and check their physical conditions continuously, the users find it enjoyable to use that potentially influences the behavioural intention of DTH.

- **Hypothesis 5**: Hedonic motivation will positively influence the behavioural intention to use DTH by the elderly.

4.6 Habits and the behavioural intention to use DTH

Habit refers to routinised behaviour or a non-conscious decision-making process that is automatically done giving a situational cue (Kim & Malhotra, 2005; Limayem & Hirt, 2003). Limayem and Hirt, Kim and Malhotra reported that habit is a determinant of use intention. This is in line with Davis (1989) and Venkatesh et al. (2003) where they advise to consider habit to explain usage behaviour. However, these papers were introduced almost 20 years ago. From the more recent studied papers (see table 21, Appendix A), there is one paper from Kavandi and Jaana mentioning habit. In particular, Kavandi and Jaana systematically reviewed over 41 journals, and found that two papers mentioned about habits, with one showed negative effects and the other show no evidence of effects (Kavandi & Jaana, 2020). Nevertheless, the following hypothesis is formed to study better the effect of habit:

- **Hypothesis 6**: Habit will positively influence the behavioural intention to use DTH by the elderly.

4.7 Price value and the behavioural intention to use DTH

The price/cost is assessed by the "installation, service repairs and maintenance" of the technology (Kavandi & Jaana, 2020). Prior research has also proven that cost has a significant negative effect to senior's intention to use (Claes et al., 2015; Kavandi & Jaana, 2020; Low et al., 2021; Lu et al., 2014; Steele et al., 2009a). In particular, Claes (2015) found that 70% of their survey participants (172 / 245 elderly) refused to pay for the maintenance of the technology system. The participants also rejected to seek financial assistance from their relatives. Steele et al. (2009) found that even though a new healthcare system deems useful to the elderly, they will not use it unless the system it is affordable and has its cost offset. Alsulami and Atkins (2016) study was in line with the findings. They found that the cost of technology negatively influences the elderly' behavioural intention.

This seems to conform to Value Attitude Behavioural model stated that for every offer, the consumers evaluate the associated rewards and sacrifices. Paying additional cost means higher sacrifice. Therefore, the consumers have less motivation for the use intention (Deng et al., 2014; Oliver et al., 1988). Thus, the following hypothesis:

- **Hypothesis 7**: Increase in cost will negatively influence the behavioural intention to use DTH by the elderly.

4.8 Moderating variable: nationality

Research has shown that the technology knowledge varies widely from country to country (Foster & Rosenzweig, 2010). According to Lee et al. (2013), cultural difference impacts the adoption of a new technology. The authors found that people in individualistic cultures seek information from a formal source objectively, while collectivistic cultures seek information from like-minded individuals subjectively. Not only that, healthcare system varies per country (Deaton, 2008). Thus, different nationality with different culture has different perceptions, recognition, preference, satisfaction, etc. Since the research is potentially distributed to different countries; nationality of the participants is included as a moderating variable to understand if the value difference is influential to the independent variables and the dependent variable. Hence, the following hypothesis is proposed:

- **Hypothesis 1a:** Nationality significantly moderates the relationship between performance expectancy and behavioural intention to adopt DTH.
- **Hypothesis 2a:** Nationality significantly moderates the relationship between effort expectancy and behavioural intention to adopt DTH.
- **Hypothesis 3a:** Nationality significantly moderates the relationship between social influence and behavioural intention to adopt DTH.
- **Hypothesis 4a:** Nationality significantly moderates the relationship between facilitating condition and behavioural intention to adopt DTH.
- **Hypothesis 5a:** Nationality significantly moderates the relationship between hedonic motivation and behavioural intention to adopt DTH.
- **Hypothesis 6a:** Nationality significantly moderates the relationship between habit and behavioural intention to adopt DTH.
- **Hypothesis 7a:** Nationality significantly moderates the relationship between price value and behavioural intention to adopt DTH.

4.9 Moderating variables: age, gender and experience

Moderating effects including age and gender are inconclusive in most research. In the systematic review of 41 studies, Kavandi and Jaana (2020) found that age and gender remain inconsistent with poor impact. Wong et al. (2012) found no significant difference between different age group of elderly. Also, Peek et al. (2014) found age to be an inconclusive factor for a new technology acceptance by the elderly. Regarding gender, in line with Kavandi and Jaana, Or and Karsh (2009) performed a systematic review of 52 studies and found that gender has no effect in most of the studies on acceptance of health information technology by the elderly. Thus, investigation effects of age and gender are omitted.

Moreover, even though Digital Twin is entering the healthcare sector, DTH is still under development (Coorey et al., 2022; K. P. Venkatesh et al., 2022). Given that there is no evidence of DTH being used, it is assumed that the elderly is inexperienced. Thus, experience construct is also excluded from the model.

4.10 Research model

Taking everything into account, theoretical and empirical literatures have identified potential factors that affect the behavioural intentions of the elderly to adopt a new healthcare technology: performance expectation, effort expectancy, price value, facilitating conditions, social influence, hedonic motivation and habit. Using the factors and relationships reported, the potentially influential factors are organised into a research model shown in figure 6.

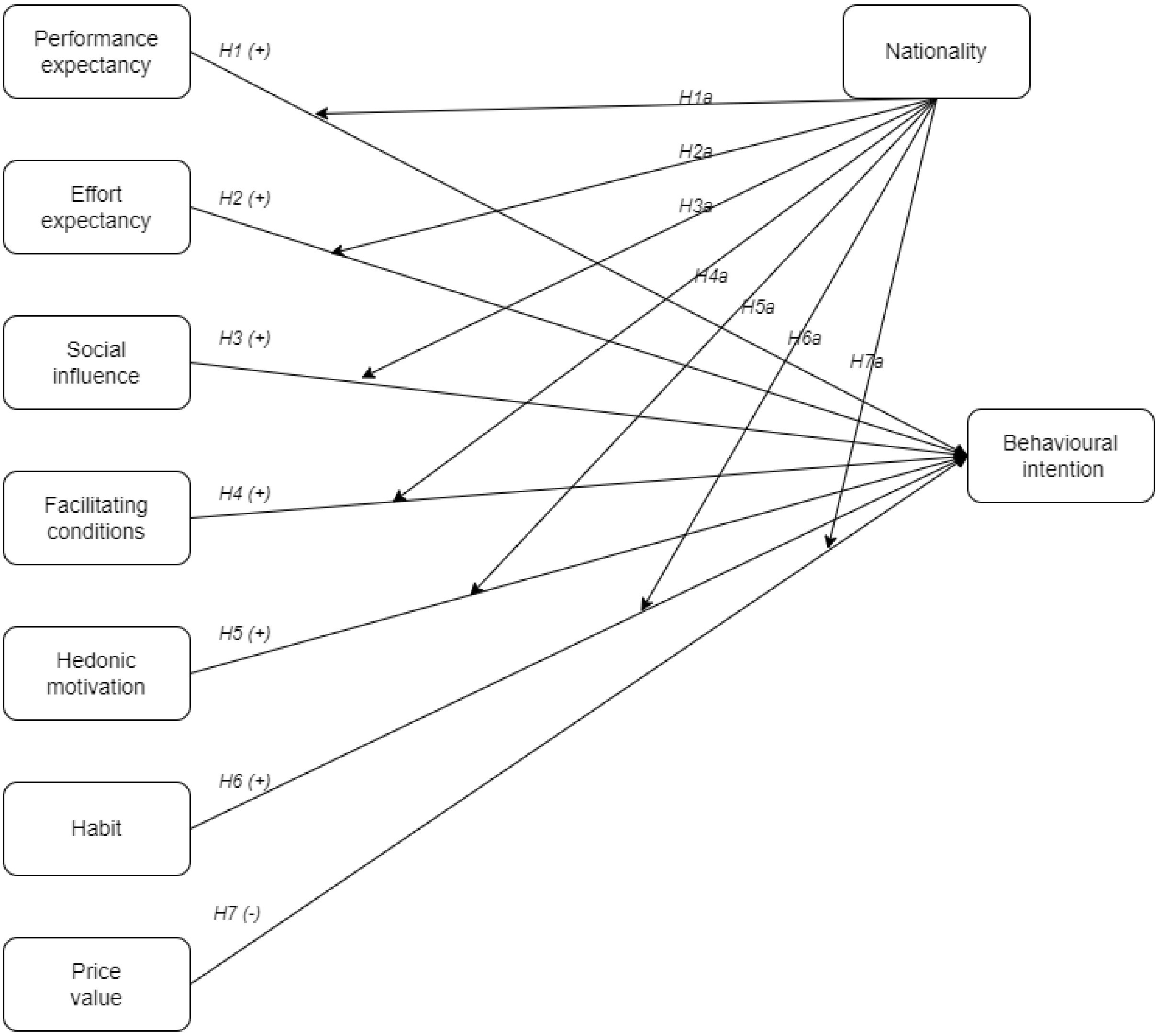

Figure 6. Research model

Chapter 5 - Research methodology

This chapter explains how the hypotheses were validated. The first section of this chapter looks at how the research was designed, the second section deals with data collection, and the last section covers the questionnaire design.

5.1 Research design

The survey method was chosen to test the proposed hypotheses as it is useful to find out people's perception, attitude and behaviour (Boynton & Greenhalgh, 2004). To ensure the validity of the measures, survey questionnaires were adapted from existing academic paper. However, they were slightly modified and extended to fit with the DTH context. The measurement items for each construct within the proposed model, together with their sources, are listed in Table 2 & 3 in section 5.3. To improve the validity of the survey before sending it out, two different experts were asked to validate if the measured items captured the construct definitions adequately. Based on the experts' consensus, the final questionnaire was constructed. To make sure that the respondents understand the questions, the questionnaire was tested by ten adults of 50 years and older. They were required to fill in the questionnaires, and provide any remarks or suggestions to improve the clarity of the measuring items. There were no major remarks, rather on the layout and adding more instructions.

5.2 Data collection

When it comes to survey, determining the requirements for the target audience is important. As old age starts from 60 (Forman et al., 1992), targeted participants is also 60+. According to Gartner hype cycle (2018), Digital Twin technology will mature in 5 to 10 years. Hence, as of 2022, the technology will mature in 1 to 6 years. However, it will most likely take even longer for DTH to mature since recent research shows that 99% of Digital Twin research or implementation are in other fields such as urban, manufacture, engineering, automotive, aerospace, etc., while medicine field accounts for 1% (Botín-Sanabria et al., 2022). Therefore, to get a sense of presumable DTH first users, the targeted participants is lowered to 50+. Besides the characteristics of the target audience, the sample method and sample size also determine the generalizability of the results.

To study the mentioned population, convenience sampling method was chosen due to the difficulty to access this target group. Although convenience sampling cannot fully represent the population, it would be the most appropriate method given the time and limited resource (Etikan, 2016). Concerning the sample size, the larger sample size, the more accurate inference can be made; thus, more representable to the population. However, Hair et al. (2018) caution a very large sample size leads to almost all the variables to be statistically significant. For this reason, the authors recommend each variable needs around 15-20 participants and the total number of participants should be at least 100 participants to have a sufficient coefficient of determination (R^2) value. Given the research model has eight variables, the desired sample size for this study lies between 120 – 160. The final sample size of this thesis is 131 which meets the sample size requirement. The participants were recruited from different sources.

The first source was direct contact with individuals, by which the author asked if the individuals are willing to fill in the survey and send the survey to their relatives and friends. The survey was distributed via the internet mostly to the Netherlands and Vietnam. To reduce the language barrier, the survey was translated into Dutch and Vietnamese. To ensure precision, the translators are: (1) native speakers, (2) adept in English, (3) knowledgeable about DTH.

For the second source, national and local organizations such as hospitals, elderly sport groups, and nursing homes were contacted for permission to approach participants for the survey. The meetings started with an introduction, purpose of the survey, and instruction to fill in the survey. The questionnaires were then collected when the participants were finished.
According to Dutch Personal Data Protection Art, the ethical of this study is approved since the answers provided by participants are confidential and were analysed anonymously (Autoriteit Persoonsgegevens, 2022). Another factor that is important for the survey is questionnaire design.

5.3 Questionnaire design

In the survey, an online medical program was first explained, then two scenarios of the program were introduced. After each scenario was a set of questions (see Table 2 and Table 3 below). Regarding survey items, the use of multiple-item per construct is usually recommended as it provides higher reliability. However, this places a heavy burden on the participants. Given the target group of this research is the elderly, the survey items are made short and simple for the constructs. Research by Drolet and Morrison found that when the number of items grow, participants tend to respond in a mindless way. This leads to an inflate in response error which in turn decreases the reliability. Moreover, Drolet and Morrison (2001) found that the additional items 'contribute little to the information obtained from the first item'. To solve social desirability bias in which respondents answer accordingly to how others favour, this survey emphasizes the confidentiality, and that there is no right or wrong answer. The questionnaires took around eight minutes in total.

Regarding the content, online medical program was first described as an online e-health program which manages the elderly's medical information, such as health summary, medical history, medication use, vaccinations, appointments, etc. The program reminds them of their medical activities and appointments via notifications. And the online program can be accessed via a laptop, tablet or phone. After the description are two scenario's.

In scenario 1, the online e-health program is extended to keep track of the elderly's daily medical condition, monitor their health condition, and raise an alert to the doctor if an issue is detected. This feature, however, requires daily information about the elderly's health, mood and feeling, which the elderly can provide by answering a few short questions (about 5 minutes). The doctor can then access their health information, monitor their health from remote distance, and give them a call if necessary. Scenario 1 consisted of 13 items measuring the constructs that might influence the behavioural intention to adopt DTH usage level 1.

Table 2. Summary of construct with measurement items – DTH usage level 1

Construct	Hypothesis	Survey item	Measurement	Sources
Independent variable Performance expectation (PE)	Performance expectation will positively influence the behavioural intention to use the Digital Twin healthcare (DTH) technology by the elderly	PE1.1: "I find it useful to receive notifications for medical activities and appointments." PE1.2: "I find it useful that my doctor can monitor my health status remotely." PE1.3: "It's useful to me that the doctor will be alarmed if the e-health program detects an abnormal issue."	Interval (Likert scale): 5-point Likert scale ranging from (1) "strongly disagree" to (5) "strongly agree	(Charness et al., 2016)
Independent variable	Effort expectancy will positively	EE1.1: "I am willing to fill in a short questionnaire (5 minutes	Interval (Likert scale): 5-point Likert scale ranging from (1)	(Talukder et al., 2020)

Effort expectancy (EE)	influence the behavioural intention to use DTH technology by the elderly	max) every day to keep my e-health status updated." EE1.2: "I think the online e-health program would be easy to use."	"strongly disagree" to (5) "strongly agree	
Independent variable Social influence (SI)	Social influence will positively influence the behavioural intention to use DTH technology by the elderly	SI1.1: "I would only enrol into this e-health program if people who are important to me encourage me to use it." SI1.2: "I would only enrol into this e-health program if my doctor recommends it."	Interval (Likert scale) 5-point Likert scale ranging from (1) "strongly disagree" to (5) "strongly agree	(Talukder et al., 2020)
Independent variable Facilitating conditions (FC)	Facilitating conditions will positively influence the behavioural intention to use DTH technology by the elderly	FC1.1: "Having technical support encourage me to use this e-health program." FC1.2: "I have easy access to internet."	Interval (Likert scale) 5-point Likert scale ranging from (1) "strongly disagree" to (5) "strongly agree	(Kohnke et al., 2014; Limayem & Hirt, 2003)
Independent variable Hedonic motivation (HM)	Hedonic motivation will positively influence the behavioural intention to use DTH technology by the elderly	HM1: "I find it nice to have access to my current health status and medical history whenever I want to."	Interval (Likert scale) 5-point Likert scale ranging from (1) "strongly disagree" to (5) "strongly agree	(Talukder et al., 2020)
Independent variable Habit (HA)	Habit will positively influence the behavioural intention to use DTH technology by the elderly	HA1: "Internet technology and devices (such as laptops, smartphones) are not new to me. I'm already using them in my daily life."	Interval (Likert scale) 5-point Likert scale ranging from (1) "strongly disagree" to (5) "strongly agree	(Limayem & Hirt, 2003)
Independent variable Price value (PV)	High additional cost will negatively influence the behavioural intention to use DTH technology by the elderly	PV1: "I'm willing to pay extra for my insurance so I can use this e-health program (monthly):" 1. €0 per month. 2. Up to €30 per month. 3. Up to €60 per month. 4. Above €60 per month.	Ordinal	(Claes et al., 2015)
Dependent variable Behavioural		BI1.1: "I want to enrol into this e-health program."	Interval (Likert scale) 5-point Likert scale ranging from (1)	(Claes et al., 2015;

intention (BI)		BI1.2: “I want to enrol into this e-health program when my health declines.”	“strongly disagree” to (5) “strongly agree	Zhou et al., 2019)

In scenario 2, instead of submitting daily health information via a questionnaire, the elderly can wear wearable devices that keep track of their health record, e.g heartbeat, blood pressure, physical activities, sleep pattern, etc. This information is gathered by the wearables and sent directly to the online e-health program. Additionally, an image of a wearable example (a smart watch) was presented in scenario 2. The scenario 2 includes 12 items measuring the constructs that might influence the behavioural intention to adopt DTH usage level 2.

Table 3. Summary of construct with measurement items - DTH usage level 2.

Construct	Hypothesis	Survey item	Measurement	Sources
Independent variable Performance expectation (PE)	Performance expectation will positively influence the behavioural intention to use Digital Twin healthcare (DTH) technology by the elderly	PE2.1: “I find it useful to get instant advice from the e-health program.” PE2.2: “I find it useful that my doctor can monitor my health status continuously.” PE2.3: “When there's a life-threatening medical condition such as a stroke, I find it useful that the wearable immediately recognizes it and notifies the hospital which can dispatch an ambulance immediately.” PE2.4: “It's useful to me that the doctor can prescribe more accurate treatment using my real-time health status.”	Interval (Likert scale) 5-point Likert scale ranging from (1) “strongly disagree” to (5) “strongly agree	(Charness et al., 2016)
Independent variable Effort expectancy (EE)	Effort expectancy will positively influence the behavioural intention to use DTH technology by the elderly	EE2: “Using a wearable device such as a smart watch is convenient for me.”	Interval (Likert scale) 5-point Likert scale ranging from (1) “strongly disagree” to (5) “strongly agree	(Talukder et al., 2020)
Independent variable Social influence (SI)	Social influence will positively influence the behavioural intention to use DTH technology by the elderly	SI2.1: “I would only use wearables if people who are important to me encourage me to use it.” SI2.2: “I would only use wearables if my doctor recommends it.”	Interval (Likert scale) 5-point Likert scale ranging from (1) “strongly disagree” to (5) “strongly agree	(Talukder et al., 2020)

Independent variable Facilitating conditions (FC)	Facilitating conditions will positively influence the behavioural intention to use DTH technology by the elderly	FC2: "Having technical support encourage me to use wearables."	Interval (Likert scale) 5-point Likert scale ranging from (1) "strongly disagree" to (5) "strongly agree	(Kohnke et al., 2014)
Independent variable Hedonic motivation (HM)	Hedonic motivation will positively influence the behavioural intention to use DTH technology by the elderly	HM2: "I find it nice to see my current health status continuously and whenever I want to."	Interval (Likert scale) 5-point Likert scale ranging from (1) "strongly disagree" to (5) "strongly agree	(Talukder et al., 2020)
Independent variable Habit (HA)	Habit will positively influence the behavioural intention to use DTH technology by the elderly	HA2: "I wear wearables or medical assistance devices such as hearing devices:"	Interval (Likert scale) 5-point Likert scale ranging from (1) "strongly disagree" to (5) "strongly agree	
Independent variable Price value (PV)	High additional cost will negatively influence the behavioural intention to use DTH technology by the elderly	PV2: "I'm willing to pay extra for my insurance so I can use the e-health program with wearables (monthly):" 1. €0 per month. 2. Up to €30 per month. 3. Up to €60 per month. 4. Above €60 per month.	Ordinal	(Claes et al., 2015)
Dependent variable Behavioural intention (BI)		BI2.1: "I want to enrol into this e-health program with wearables." BI2.2: "I want to enrol into this e-health program with wearables when my health declines."	Interval (Likert scale) 5-point Likert scale ranging from (1) "strongly disagree" to (5) "strongly agree	(Claes et al., 2015; Zhou et al., 2019)

Finally, age is added at the end of the survey to ensure the participants are 50 and older. Additionally, nationality of the participants was inserted in the analysis as moderating variables to understand whether the value difference is influential to the behavioural intention to use DTH.

Chapter 6 - Data analysis

In this chapter, the data gathered from participants was analysed. The first section of this chapter looks at the descriptive statistic to reveal the participant demographic and item-level results of the survey. The second section covers the statistical technique approach for this study. The third section considers the model measurement assessment analysis. Finally, the last section deals with structural model assessment in which the hypotheses of the model were tested.

6.1 Descriptive statistics

Descriptive statistics including frequency and percentage are used to briefly describe questionnaire results. This part first covers the demographic of the respondents, it then looks at the intention to use DTH results, and finally reveals the elderly perception of DTH for both usage levels.

6.1.1 Respondents

This survey gathered 178 participants. However, 15 participants were below 50, and 29 participants failed to complete the survey; thus, omitted from the analysis. Consequently, the final data set includes 131 participants. The response of 50-59 years old (n = 53, 40.5%) is the highest, followed by the response of 70-79 years old (n=36, 27.5%), the response of 60-69 years old (n=34, 26%) and the response of 80 years older is the lowest (n=8, 6%). Besides, 64.1% of the participants live in the Netherlands, and 35.9% live in Vietnam.

Table 4. Demographic of sample by age and nationality

Description	Options	Frequency	Percentage (%)
Age (years)	50-59	53	40.5
	60-69	34	26
	70-79	36	27.5
	>80	8	6.1
Nationality	The Netherlands	84	64.1
	Vietnam	47	35.9

6.1.2 Intention to use DTH

6.1.2.1 DTH usage level 1

In DTH usage level 1, 32.06% of the participants intended to use DTH, while 19.85% refused to use it.

Table 5. Intention to use DTH usage level 1

Intention to adopt DTH usage level 1 either when being healthy or when health decreases		
Description	Frequency	Percentage (%)
(Strongly) agree	42	32.06
Neutral	63	48.09
(Strongly) disagree	26	19.85

6.1.2.2 DTH usage level 2

Meanwhile, in DTH usage level 2 that involves wearable, the participants intended to use DTH accounts for 28.25%, and 25.19 % decline to use it.

Table 6. Intention to use DTH usage level 2

Intention to adopt DTH usage level 2 either when being healthy or when health decreases		
Description	Frequency	Percentage (%)
(Strongly) agree	37	28.25
Neutral	61	45.56
(Strongly) disagree	33	25.19

6.1.3 Perception of DTH

6.1.3.1 DTH usage level 1

Table 7 illustrates how the respondents perceived DTH usage level 1. In general, the majority finds it useful (56-68%), but almost half the participants find difficult to use (42.3%). Around half of the participants agrees that they would enrol DTH usage level 1 if there is encouragement from inner circle (49%) and doctor (60%). 53% agrees that having enough support will encourage them to use DTH. Besides, around 85% of the participants have easy internet access to use DTH level 1, with 76% use internet and internet devices in their daily life. Finally, 77.19 % would not pay any extra cost, and 19% would pay up to maximum 30 euros.

Table 7. Perception to use DTH usage level 1

Factors	(Strongly) disagree (%)	Neutral (%)	(Strongly) agree (%)
Performance expectation			
I find it useful to receive notifications for medical activities and appointments	9.8	21.6	68.6
I find it useful that my doctor can monitor my health status remotely	19.6	23.5	56.8
It's useful to me that the doctor will be alarmed if the e-health program detects an abnormal issue	16.7	15.7	67.6
Effort expectancy			
I am willing to fill in a short questionnaire (5 minutes max) every day to keep my e-health status updated.	42.75	21.37	35.87
I think the online e-health program would be easy to use	17.6	45.1	37.3
Social influence			
I would only enrol into this e-health program if people who are important to me encourage me to use it.	31.3	19.85	48.86
I would only enrol into this e-health program if my doctor recommends it.	12.97	27.48	59.54
Facilitating conditions			
Having technical support encourage me to use this e-health program	11.45	35.11	53.43
I have easy access to internet	4.58	10.69	84.73

Hedonic motivation			
I find it nice to have access to my current health status and medical history whenever I want to	5.35	12.21	82.44
Habit			
Internet technology and devices (such as laptops, smartphones) are not new to me. I'm already using them in my daily life	11.9	12.98	75.57
Price value			
I'm willing to pay extra for my insurance so I can use this e-health program (monthly)	96.19	3.05	0.76

6.1.3.2 DTH usage level 2

Table 8 shows how the respondents perceived DTH usage level 2. In general, the majority finds it useful (64-65%), and half of the respondents think it is easy to use (49.6%). Similar to usage level 1, around half of the participants agrees that they would enrol DTH usage level 2 if there is encouragement from people that are important to them (49%) and doctor (60%). 46% agrees that having enough support will encourage them to use DTH. In contrast to DTH level 1, only 28% of the participants have the habit of wearing wearables or medical assistance devices. Finally, 76% refuse to pay extra cost, and 19% would pay up to maximum 30 euros.

Table 8. Perception to use DTH usage level 2

Factors	(Strongly) disagree (%)	Neutral (%)	(Strongly) agree (%)
Performance expectation			
I find it useful to get instant advice from the e-health program.	13.74	25.95	60.3
I find it useful that my doctor can monitor my health status continuously.	17.56	27.48	54.96
When there's a life-threatening medical condition such as a stroke, I find it useful that the wearable immediately recognizes it and notifies the hospital which can dispatch an ambulance immediately.	9.16	12.98	77.86

It's useful to me that the doctor can prescribe more accurate treatment using my real-time health status.	8.4	23.66	67.94
Effort expectancy			
Using a wearable device such as a smart watch is convenient for me.	23.66	26.72	49.62
Social influence			
I would only use wearables if people who are important to me encourage me to use it.	31.3	19.85	48.86
I would only use wearables if my doctor recommends it.	12.97	27.48	59.54
Facilitating conditions			
Having technical support encourage me to use wearables	25.19	29.01	45.8
Hedonic motivation			
I find it nice to see to my current health status continuously and whenever I want to.	13.74	22.14	64.12
Habit			
I wear wearables or medical assistance devices such as hearing devices	71.75	0	28.24
Price value			
I'm willing to pay extra for my insurance so I can use the e-health program with wearables (monthly)	93.89	4.58	1.53

6.2 Data analysis

After the data had been gathered, IBM SPSS Statistics 28.0 software was used to test descriptive statistics, revealing results for the sample demographics and item-level results of the survey. Next, structural equation model (SEM) was used to make inferences on the hypotheses. SEM is widespread in many research disciplines owing to its ability to manage measurement error. Within SEM, Partial least squares (PLS)-SEM is designed to detect relationships and the significance between different constructs by using PLS Algorithm and Bootstrapping (Huang, 2021). In this thesis, PLS-SEM was chosen because it is a technique suitable for exploratory research, and it is considered better than linear regression to construct theoretical model (Huang, 2021; Ringle et al., 2012b). Additionally, PLS-SEM requires a smaller sample size compared to Covariance-based (CB) SEM modelling (Huang, 2021; Ringle et al., 2012).

According to Chin, PLS-SEM requires the minimum participants of "at 10 times dimension of most question items" (W. Chin, 1998; as cited in Huang, 2021). In this study, perceive usefulness has the most question items. There are four question items in performance expectancy, which makes 40 is the minimum participants this study must have. Thus, the final sample size of 131 respondents meets the sample size requirement.

In short, software IBM SPSS Statistics and Smart PLS4 were used for the analyses; and a significant test with alpha is 0.1 is applied for all analyses.

6.3 Measurement model assessment

Before modelling process, model assessment tests including reliability and validity test were performed. Reliability test ensures (1) individual item reliability, which is assessed by Factor loading, and (2) internal consistency, which is assessed by Composition Reliability (Huang, 2021). For factor loading, value of 0.708 and above is recommended; however, factor loading should be always eliminated if it is below 0.4 (Hair et al., 2019; Hulland, 1999). Regarding internal consistency, Hair et al. (2019) mention that Cronbach alpha is widely used to determine internal consistency. However, the authors highlighted that Cronbach alpha produces lower reliability measures since all items are unweighted. Instead, the authors point towards Composition Reliability (CR). The recommended value for CR is greater than 0.7 and lower than 0.95. Since CR uses indicator's individual loadings and weights all items; "reliability is higher than Cronbach alpha" (Hair et al., 2019). Besides reliability, validity is a criterion that must be fulfilled.

Convergent validity and discriminant validity are used to ensure the items correctly measure the assigned constructs. Convergent validity tests the correlation of the question items on each latent construct. It ensures that question items belonging to a latent construct measure the assigned constructs, rather than measuring the other latent variable (Hair et al., 2021). Convergent validity is determined using Average Variance Extraction (AVE) and the recommended value for AVE is >=0.5. (Hair et al., 2021; Hulland, 1999). Likewise, discriminant validity ensures items belong to one latent construct is uncorrelated to other items belong to other latent constructs. It can be assessed with Formell-Larcker Criterion and Heteotrait-Monotrait (HTMT) Ratio (Hair et al., 2019, 2021). In this part, the measurement model is first examined for DTH usage level 1, then DTH usage level 2 to ensure conditions for reliability (loading factors, CR), convergent validity (AVE), and discriminant validity (Formell-Larcker Criterion and HTMT) are met for both levels.

6.3.1 DTH usage level 1

The factor loadings for each indicator related to their exogenous latent variable were first assessed. As can be seen in table 9, one indicator value belongs to facilitating construct (FC1.2) was below the recommended loading factors of 0.708, but it was above 0.4. In 1999, Hulland found that when researchers measure models in science study, they often obtain weaker loading factors below 0.708 (Hulland, 1999). Therefore, the author suggests to interpret a loading factor with caution (Hulland, 1999). In particular, an item can be retained if its AVE is above 0.5 (Hair et al., 2021). Removing the loading factor of FC1.2 was unnecessary in this case because AVE was above the threshold value of 0.5. Owing to CR, behavioural intention usage level 1 had CR value of 0.979 which was higher than 0.95. Hair et al. (2019) suggest that CR values of >=0.95 can inflate the errors between the indicators which reduces the construct validity (Hair et al., 2019). Therefore, indicator BI1.1 was omitted. The results of the reliability and convergent validity results are presented in table 9.

Table 9. Reliability and convergent validity results - DTH usage level 1

Construct	Loading factors	CR	AVE
PE1.1	0.897	0.927	0.808
PE1.2	0.899		
PE1.3	0.902		
EE1.1	0.916	0.847	0.736
EE1.2	0.795		
SI1.1	0.915	0.927	0.809
SI1.2	0.883		
FC1.1	0.957	0.75	0.616
FC1.2	0.562		

Evidence illustrates that all the requirements for reliability and convergent validity of DTH usage level 1 are fulfilled. As mentioned, another criterion for model assessment is discriminant validity (Hair et al., 2019; Hulland, 1999). This can be assessed by Formel-Larcker Criterion. Formel-Larcker Criterion suggests that the value of square root of AVE (√AVE) by the construct must be greater than its correlation (Hair et al., 2019, 2021). Table 10 presents the result of correlation matrix and the square root of the AVE, with the diagonal line being the square root AVE per construct.

Table 10. Formel-Larcker Criterion - DTH usage level 1

	BI1	EE1	FC1	HA1	HM1	PE1	PV1	SI1
BI1	**1.000**							
EE1	0.498	**0.858**						
FC1	0.536	0.638	**0.785**					
HA1	0.181	0.437	0.455	**1.000**				
HM1	0.402	0.561	0.507	0.476	**1.000**			
PE1	0.630	0.670	0.562	0.206	0.579	**0.899**		
PV1	0.266	0.285	0.361	0.197	0.261	0.293	**1.000**	
SI1	0.489	0.506	0.491	0.098	0.339	0.432	0.217	**0.899**

It can be seen from table 10 that all the conditions are met for Formel-Larcker Criterion. However, Hair et al (2019) state that recent research showed Formel-Larcker Criterion is not sufficient enough to measure the discriminant validity. Instead, the authors propose heterotrait-monotrait (HTMT) ratio of the correlations (Hair et al., 2019; Henseler & Sarstedt, 2013). In particular, Henseler and Sarstedt (2013) recommend threshold value of 0.85 or lower, indicating the construct is distinct, and a HTMT value close to 1 means there's no distinctions between the constructs. After accessing HTMT value it was decided to drop FC1.2 since it resulted in insufficient HTMT value. After FC1.2 was eliminated, all requirements for reliability, convergent validity, and discriminant validity are met. Table 11 represents the results of HTMT Ratio.

Table 11. Heterotrait-Monotrait Ratio - DTH usage level 1

	BI1	EE1	FC1	HA1	HM1	PE1	PV1	SI1
BI1								
EE1	0.597							
FC1	0.551	0.776						
HA1	0.181	0.573	0.298					
HM1	0.402	0.693	0.430	0.476				
PE1	0.666	0.868	0.600	0.219	0.617			
PV1	0.266	0.348	0.346	0.197	0.261	0.313		
SI1	0.556	0.686	0.600	0.111	0.394	0.524	0.247	

In conclusion, the reliability and validity of all the constructs are confirmed by dropping FC1.2 and BI1.1. The model for DTH usage level 1 is ready for modelling process.

6.3.2 DTH usage level 2

Similarly, reliability, convergent validity, and discriminant validity were assessed for measurement model DTH usage level 2. The loading factors are all above the recommended value of 0.708. Correspondingly, all AVE values are above the recommended value of 0.5. The results for AVE values indicate that more than 70% of the variations in these constructs are explained by its associated items. By contrast, CR of BI2.1 and BI2.2 was above 0.95, therefore BI2.1 was eliminated and the model was re-estimated. The final values of factor loadings, CR, and AVE are presented in table 12.

Table 12. Reliability and convergent validity results - DTH usage level 2

Construct	Loading factors	CR	AVE
PE2.1	0.86	0.924	0.752
PE2.2	0.87		
PE2.3	0.8		
PE2.4	0.89		
SI2.1	0.89	0.898	0.815
SI2.2	0.88		

The evidence indicates satisfactory reliability and convergent validity. Likewise, the Formel-Larcker Criterion and HTMT Ratio are used to measure the discriminant validity.

Table 13. Formel-Larcker Criterion - DTH usage level 2

	BI2	EE2	FC2	HA2	HM2	PE2	PV2	SI2
BI2	**1.000**							
EE2	0.343	**1.000**						
FC2	0.419	0.662	**1.000**					
HA2	0.100	0.207	0.304	**1.000**				
HM2	0.359	0.545	0.588	0.185	**1.000**			
PE2	0.438	0.594	0.752	0.221	0.760	**0.867**		
PV2	0.034	0.273	0.217	0.228	0.276	0.300	**1.000**	
SI2	0.316	0.316	0.540	0.423	0.415	0.498	0.262	**0.903**

Table 14. Heterotrait-Monotrait Ratio - DTH usage level 2

	BI2	EE2	FC2	HA2	HM2	PE2	PV2	SI2
BI2								
EE2	0.343							
FC2	0.419	0.662						
HA2	0.100	0.207	0.304					
HM2	0.359	0.545	0.588	0.185				
PE2	0.459	0.626	0.796	0.232	0.802			
PV2	0.034	0.273	0.217	0.228	0.276	0.320		
SI2	0.357	0.362	0.613	0.480	0.467	0.600	0.298	

As demonstrated in table 13, the Formel-Larcker Criterion is satisfactory given the value of square root AVE of each variable (illustrated by the diagnose line) is greater than its correlation. Correspondingly, table 14 proves all HTMT values are smaller than the recommended value of 0.85. With all said, the measures above confirmed the reliability and validity of all the constructs in DTH usage level 2.

To conclude, measurement model assessment for both DTH usage level 1 and 2 are now satisfactory, thus, structural model can be assessed for both levels (Hair et al., 2019).

6.4 Assessment of structural model

Hair et al (2019) suggests that Collinearity statistic (VIF) must first be assessed before determining the structural model to ensure the results are not biased. Following Hair et al. advice, the VIF for both DTH usage level 1 and 2 were examined and the VIF values meet all the requirements; therefore, ready for assessing the structural relationship of PLS-SEM.

The following criteria were examined to assess the structural model of PLS-SEM. First, coefficient of determination (R^2) and Stone-Geisser's Q^2 measures were evaluated to determine predictive power of the model. R^2 is considered weak when $R^2=0.02$, moderate when $R^2=0.13$, substantial when $R^2=0.26$ (Cohen, 2013). Likewise, Q^2 measure>0 suggests that the model has predictive relevance, with Q^2 =0.02 is weak, Q^2=0.15 is moderate, Q^2=0.35 is substantial (Hair et al., 2019). Second, path co-efficient (β) together with its statistical significance (p-value) were assessed. The higher β value, the more effect it is on endogenous latent variable (Hair et al., 2019). All the assessments were initialised using a bootstrapping method (n=5000), and a significant test with α=0.1 was applied for all analyses. The structural model first starts with examining the relationship between endogenous and exogenous variable, then moderating effect of nationality.

6.4.1 DTH usage level 1

According to Chin (1998), the value R^2 determines the predictive power of a model. R^2 value of behavioural intention in DTH usage level 1 is 0.482, thus explaining exogenous latent variables cover 48.2% the variance of endogenous latent variable in the model (Chin, 1998). Since R^2 value is above 0.26, this model is satisfactory. Hair et al (2019) also points towards the Stone-Geisser's Q^2 measure to determine predictive power of a model. The result of Q^2 measure is 0.408, suggesting that the model has substantial predictive power, which is in line with R^2 value.

6.4.1.1 Primary hypotheses

As expected, the positive effect of the performance expectancy on behavioural intention were found to be significant; thus, supporting H1. A positive effect of social influence on behavioural intention was observed with $p < 0.05$; thus, supporting H3. Also, the proposed positive effect of facilitating conditions have on behavioural intention was found significant; thus, supporting H4. Finally, the proposed effect of effort expectancy, hedonic motivation, habit and price value on behavioural intention to use DTH were found insignificant; thus, providing no support to H2, H5, H6, H7. The results are illustrated in table 15.

Table 15. Structural model and hypothesis results - DTH usage level 1

Hyp.	Description	Path coefficient	Standard error	t-value	Results
H1	Performance expectancy ⇒ Behavioural intention (PE1⇒ BI1)	0.451	0.114	3.940***	Supported
H2	Effort expectancy ⇒ Behavioural intention (EE1 ⇒ BI1)	-0.054	0.100	0.535	Not supported
H3	Social influence ⇒ Behavioural intention (SI1⇒BI1)	0.201	0.086	2.576***	Supported
H4	Facilitating condition ⇒ Behavioural intention (FC1 ⇒BI1)	0.208	0.107	1.945**	Supported
H5	Hedonic motivation ⇒ Behavioural intention (HM1 ⇒BI1)	-0.011	0.116	0.091	Not supported
H6	Habit ⇒ Behavioural intention (HA1 ⇒BI1)	0.036	0.081	0.442	Not supported
H7	Price value ⇒ Behavioural intention (PV1 ⇒BI1)	0.03	0.044	0.688	Not supported

*** p < 0.01, **p < 0.05, *p < 0.1

6.4.1.2 Moderating effect of nationality

Finally, significant effect of nationality between the Netherlands and Vietnam was examined. The finding reveals a significant difference in the dimension of perceive expectancy; thus, supporting hypothesis H1a. The difference in path coefficient reveals that the impact of perceive usefulness on intention is stronger in Vietnam compared to the Netherlands. In terms of effort expectancy, social influence, facilitating conditions, hedonic motivation, habit and price value, there are no notable variations due to the difference of nationality. Thus, H2a, H3a, H4a, H5a, H6a and H7a are unsupported.

Table 16. Moderating effect of nationality - DTH usage level 1

Relationship	Difference (the Netherland-Vietnam)	p-value
PE1 ⇒ BI1	-0.426	0.084*
EE1 ⇒ BI1	0.038	0.859
SI1⇒BI1	0.242	0.167
FC1 ⇒BI1	0.011	0.975
HM1 ⇒BI1	0.227	0.392
HA1 ⇒BI1	0.147	0.451
PV1 ⇒BI1	0.002	0.980

the paths between the Netherlands and Vietnam are significantly different when ***p < 0.01, **p< 0.05, *p < 0.1

6.4.2 DTH usage level 2

Confirmed with satisfactory psychometric properties for measurement model, structural model was assessed for DTH usage level 2. Similar to DTH usage level 1, R^2 and Q^2 were measured to determine the predictive power of the model. R^2 value is 0.238 which means the 23.8% of the variance in behavioural intention is explained by this model. Additionally, Q^2 value is 0.147. Both values suggest that the predictive power of this model is moderate.

6.4.2.1 Primary hypotheses

Path co-efficient (β) and its significance in the model for DTH usage level 2 was assessed. The finding reveals the performance expectancy and price value have significant influence in predicting the behavioural intention to use DTH usage level 2; thus, supporting H1 and H7. The proposed effect of effort expectancy, social influence, facilitating condition, hedonic motivation and price value on the elderly’s use intention towards DTH usage level 2 were found unsignificant; thus, H2, H3, H4, H5 and H6 are unsupported.

Table 17. Structural model and hypothesis results - DTH usage level 2

Hyp.	Description	Path coefficient	Standard error	t-value	Results
H1	Performance expectancy ⇒ Behavioural intention (PE2⇒ BI2)	0.293	0.161	1.817*	Supported
H2	Effort expectancy ⇒ Behavioural intention (EE2 ⇒ BI2)	0.103	0.116	0.892	Not supported
H3	Social influence ⇒ Behavioural intention (SI2⇒BI2)	0.135	0.094	1.43	Not supported
H4	Facilitating condition ⇒ Behavioural intention (FC2 ⇒BI2)	0.095	0.168	0.566	Not supported
H5	Hedonic motivation ⇒ Behavioural intention (HM2 ⇒BI2)	0.014	0.117	0.116	Not supported
H6	Habit ⇒ Behavioural intention (HA2 ⇒BI2)	-0.045	0.075	0.602	Not supported
H7	Price value ⇒ Behavioural intention (PV2 ⇒BI2)	-0.129	0.070	1.831*	Supported

*** $p < 0.01$, **$p < 0.05$, *$p < 0.1$

6.4.2.2 Moderating effect of nationality

Besides, the effect of nationality was looked at in DTH usage level 2. The result found a significant moderating effect of nationality in the dimension of social influence; thus, supporting H3a. The difference in path coefficient reveals that the impact of social influence on intention is stronger in the Netherlands compared to Vietnam. Regarding performance expectancy, effort expectancy, facilitating conditions, hedonic motivation, habit and price value, there are no significant variations due to the difference of nationality; thus, H1a, H2a, H4a, H5a, H6a and H7a are unsupported.

Table 18. Moderating effect of nationality - DTH usage level 2

Relationship	Difference (the Netherland-Vietnam)	p-value
PE2 ⇒ BI2	-0.408	0.258
EE2 ⇒ BI2	-0.196	0.444
SI2⇒BI2	0.425	0.037**
FC2 ⇒BI2	0.004	0.991
HM2 ⇒BI2	0.1	0.695
HA2 ⇒BI2	-0.243	0.117
PV2 ⇒BI2	0.115	0.440

the paths between the Netherlands and Vietnam are significantly different when ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

Chapter 7 - Discussion

This chapter discusses the finding results. The first section of this chapter covers the key findings, while the second section looks into the theoretical and practical implications of the study. This chapter is finally concluded with the directions for future research.

7.1 Key findings

The purpose of this thesis was to shed light on the determinants of intention to use DTH by the elderly. By literature review the answers for sub-questions 1 "What factors influence an elderly's decision to adopt new technology according to existing research?" and sub-question 2 "What must be done from the elderly side to get Digital Twin implemented?" are found. These answers support to form the research model and create survey questionnaire. The data was then gathered and analysed. Emerging from the survey, support was found for performance expectancy, social influence and facilitating conditions in DTH usage level 1. Regarding DTH usage level 2, support was found for performance expectancy and price value. The moderation effect of nationality on performance expectancy was observed in DTH usage level 1, and on social influence in DTH usage level 2. More details are discussed in the following subsections.

7.1.1 The effect of performance expectancy on behavioural intention

In both DTH usage levels, performance expectancy emerged as a strong determinant to behavioural intention. The finding is consistent with numerous existing literature (Abdelrahman et al., 2020; Charness et al., 2016; Cimperman et al., 2016; de Veer et al., 2015; Kavandi & Jaana, 2020; Kohnke et al., 2014; Low et al., 2021; Venkatesh et al., 2003; Zhou et al., 2019). This suggests when the elderly believes that DTH is useful for their daily life, helps them to increase their quality of life or live longer, they are more likely to use it. Therefore, continuing education of DTH and its benefits to the elderly is paramount for the use intention of DTH in these two levels.

The finding also reports that there is a significant moderating effect of nationality on performance expectancy in DTH level 1. Even though in DTH usage level 2, the moderation is not significant, both levels show that perceived performance expectancy has a stronger impact on the Vietnamese elderly. This could be due to two reasons. First, there is an absence of comprehensive healthcare system in Vietnam (Dang et al., 2021). This leads to medical tests and results are not shared between different healthcare providers, inefficient disease prevention and treatment, regular medical errors or drug reactions (Dang et al., 2021). A study reported that more than one third of medication dose were found faulty in in two large urban hospital in Vietnam (Nguyen et al., 2015). Moreover, hospitals are overcrowded since there is no referral system such as in the Netherlands, which leads to a norm of 2-3 patients sharing a bed. To worsen the problem, lack of personnel makes the experience to visit a doctor unpleasant (Dang et al., 2021). Being aware of these serious problems, the Vietnamese elderly might view DTH as a favourable solution. Meanwhile, Dutch healthcare system is one of the best healthcare systems in the world, ranking number 11 in 2021 in CEOWORLD magazine Health Care Index (Sophie, 2021). As the Dutch elderly's needs are all met; they might see DTH is less useful and necessary than the Vietnamese elderly, and thus less necessary to adopt (Low et al., 2021). Second, according to Hofstede, Vietnam has a low preference for Uncertainty Avoidance (Uncertainty Avoidance Index of 30), which means that they are more comfortable to take risks and not afraid of innovation. Therefore, together with the first reason, they are more likely to try DTH out (Hofstede Insights, 2021; Hofstede & Bond, 1984). On the other hand, the Netherlands has Uncertainty Avoidance Index of 53, which suggests that Dutch elderly consider more consequences with their decisions and tend to resist innovation (Hofstede Insights, 2021; Hofstede & Bond, 1984). Thus, the effect of performance expectancy is stronger on the Vietnamese elderly to use intention of DTH.

7.1.2 The effect of effort expectancy on behavioural intention

For both use cases, there is not enough sufficient objective data to support the relationship of effort expectancy with intention to use DTH. In DTH usage level 1, β is negative (H2, β=-0.054, $p>0.1$). This suggests that even though the elderly think it is easy to use, they would rather choose not to use it. The result denied effort expectancy in UTAUT2 model proposed by Venkatesh et al. (2013). For DTH usage level 2, β is positive (H2, 0.103, $p>0.1$). The results of both use cases do not support the empirical results from existing research (Abdelrahman et al., 2020; Charness et al., 2016; Cimperman et al., 2016; de Veer et al., 2015; Low et al., 2021; Talukder et al., 2020; Zhou et al., 2019). This may be caused by several reasons. Even though an increase in age leads to a decrease in physiological conditions, study shows that the elderly continuously adapt (Brown, 1996). Specifically, the elderly use cues from their surroundings and take advantage of advanced information; thus, compensate for their slower information processing system compared to young adults (Brown, 1996; CZAJA et al., 1989; Papalia et al., 2007). According to Wang et al. (2014), in the modern world, ease of use is no longer an obstacle to technology adaption because the elderly are already exposed to many types of technologies and possess technical capability. Consequently, the reduction of physical conditions might not affect the effort expectancy. Additionally, since the result shows the significant effect of facilitating conditions on use intention in DTH usage level 1; possibly, the elderly is more willing to use it if they have constant support. Therefore, with facilitating conditions, the impact of effort expectancy is less influential. The facilitating conditions are further elaborated in section 6.1.4. With DTH usage level 2, when the wearables are involved, perhaps physical comfort is more important. Prior work found that the more comfortable the device is, the longer it will be worn (Abdelrahman et al., 2020; Charness et al., 2016). Therefore, the impact of effort expectancy is less influential in this usage level since physical comfort might compensate the effort.

7.1.3 The effect of social influence on behavioural intention

In DTH usage level 1, social influence was found to be a significant determinant of the use intention by the elderly (H3, $\beta=0.201$, $p<0.01$). This illustrates that the improvement of DTH usage level 1 alone is not enough, but the people that are vital in the elderly's social cycle also plays a remarkable role. This suggests that use intention of the elderly can be obtained through convincing of inner circle and healthcare professionals. The result also found that Dutch elderly tend to seek for objective and validated source of information. This brings the important role of doctor opinions. On the other hand, Vietnamese elderly trusts their inner circle slightly more than healthcare professionals. This brings the important role of inner circle opinions. Nevertheless, in both cases, the Dutch and Vietnamese elderly are significantly influenced by their inner circle members and doctors. Therefore, healthcare professionals could act as supporting figures. Hospitals could station staffs for questions and support the elderly. Also, doctors can promote the DTH usage level 1 to their patients, and correct misconceptions the elderly may have. Existing research has found that doctors can remain a trusted sources no matter what the communication channels may be (S. T. Lee et al., 2018). Thus, online communication channels with doctor opinions, such as on the television, radio, newspaper, etc, could also be leveraged to improve the use intention for the elderly. Moreover, inner circle members possibly can be trained in DTH usage so they can educate and support the elderly.

In DTH usage level 2, social influence was found insignificant ($\beta=0.135$, $p>.1$). This finding differs from the existing literature and the result found from DTH usage 1. The reason might be because the wearables come into the picture, their doctors can continuously receive an immense amount of personal data; thus, the elderly may perceive it as a threat that might reveal health information to their vital social cycle. The result also reveals that the impact of social influence on use intention is weaker in Vietnam compared to the Netherlands. The reason could be Vietnam is a collectivistic society, which indicates that greater emphasis is placed on the communities, and families come before the individuals (Hofstede Insights, 2021; Hofstede & Bond, 1984). This means they do not want to worry their ingroup if poor personal health is exposed. Also, they cherish ingroup harmony, and confrontation (when being asked about their sickness) is taboo (S.-G. Lee et al., 2013)

7.1.4 The effect of facilitating conditions on behavioural intention

In DTH usage level 1, the positive effect of facilitating conditions to use intention is confirmed (H4, $\beta=0.208$, $p<0.05$). This echoes the findings from existing literature (Boontarig et al., 2012; Cimperman et al., 2016; Fishbein & Ajzen, 1975; Low et al., 2021). The result suggests that increasing the availability of DTH usage level 1 support would enhance the use intention of the elderly.

Interestingly, facilitating conditions in DTH usage level 2 (H4, $\beta=0.095$, $p>.1$) is found insignificant. Results found that the elderly find it more difficult to use DTH usage level 1, with 42% find it difficult to use DTH level 1, and only 24% find it difficult to use DTH usage level 2. In the second case, perhaps the elderly feels they have sufficient capability to use wearables, the facilitating conditions is less influential.

7.1.5 The effect of hedonic motivation on behavioural intention

For both levels, even though hedonic motivation has a positive affect to use intention, the evidence remains weak with insignificant effect. This is not in line with the research from Czaja et al. and Taluker et al. (Czaja et al., 2013; Talukder et al., 2020). This could be due to the fact that the elderly finds the joy and fun to use DTH is less important. They might value other factors such as the usefulness, facilitating factors, etc; thus, hedonic motivation is less influential.

7.1.6 The effect of habit on behavioural intention

For both levels, the results are inconclusive with limited evidence. In level 1, habit has a positive affect while in level 2 has a negative effect. This could be due to the complex and novelty of DTH. The participants were more open to use technology that seem simpler such as an application in DTH usage level 1 (β=0.036, p>.1), while wearable technology is a less familiar technology in DTH usage level 2 (β=-0.045, p>.1). Taluker et al. (2020) mentioned that the less familiar a new technology is, the more technology anxiety the elderly has. And exiting research provides strong evidence that technology anxiety negatively affects behavioural intention (Deng et al., 2014; Guo et al., 2013). This is in line with continuity theory, where the elderly prefer to retain the same activities and behaviours as they had in their early life (Atchley, 1989). With a new technology emerges, the elderly perceives the technology as a discontinuity in their environment that might lead to mental distress (Winstead et al., 2014). Therefore, the novelty of a technology could possibly explain the inconclusive result of habit.

7.1.7 The effect of price value on behavioural intention

In DTH usage level 1, even though with weak evidence, price value is positively correlated to behavioural intention (β=0.03, p>0.1). This suggests that price is less influential to the behavioural intention to use DTH usage level 1. The result also illustrates that the ones willing to pay extra to use, tend to use DTH more. In contrast, price value was found to negatively influence the behavioural intention in DTH usage level 2 (β= -0.129, p<0.1). Consistent with prior studies, this finding confirms that the more the elderly have to pay extra, the less likely they would intend to use it (Alsulami & Atkins, 2016; Claes et al., 2015; Low et al., 2021; Lu et al., 2014; Steele et al., 2009b). Therefore, for DTH usage level 2, a transparent and comprehensive funding strategy should be developed to encourage the behavioural intention to use DTH usage level 2.

Despite the p-value>0.1 in DTH level 1, the positive coefficient suggests people are willing to pay extra to use it, while in level 2 people are unwilling to pay extra. This might suggest that the elderly perceive more values for DTH usage level 1. Given that price value is less important in DTH level 1, the financial support for DTH level 2 should be prioritized.

In conclusion, performance expectancy was found to be the most influential for both levels. The finding reveals the answer for sub-question 3: "What factors influence behavioural intention of DTH at different usage levels?" To be more specific, the enablers of behavioural intention to use DTH usage level 1 are performance expectancy, social influence and facilitating conditions. Meanwhile, the enabler of DTH usage 2 is performance expectancy, and price value is an inhibitor. Subsequently, the answer for the main research question is found. The factors influence the use intention of DTH is divergent for each level. Assuming the same determinants for DTH use intention in general is undesirable; instead, each level has to be studied separately. This could be due to the novelty and requirement difference in each level. Furthermore, studying the other factors such as data privacy, physical comfort, technology anxiety, self-actualisation, self-efficacy, product design, human interaction, medical service satisfaction could improve the predictive power of behavioural intention for each DTH usage level.

7.2 Implication

7.2.1 Theoretical implication

This thesis is one of the first to explore the perceptions of the elderly towards DTH using quantitative method. It is believed that looking at the DTH from its usage perspective is useful given this thesis studies the behavioural intention to use DTH. To the best of the author's knowledge, there is no existing research on the DTH usage levels. Therefore, the first contribution of this thesis is a systematic review of DTH usage which results in four levels. The first level is offline patient monitoring that uses e-health dossier, with no real-time monitoring or medication intervention. At the second level, IoT-connected wearables are integrated that allow real-time monitoring and real-time medication; thus, doctors can prescribe effectively without seeing the patient in person. At the third level, doctors can test scenarios in the virtual patient for a customised medicine dose. At the fourth level, doctors can practice surgery with Digital Twin combined with 3D technology. Categorising the DTH usage into these levels paves way for more future innovations to examine the behavioural intention towards DTH from the elderly's perspective. The results suggest that different DTH usage levels have different determinants to use intention. Thus, factors that either encourage or hinder the use intention are heterogenous per level. If treating DTH as a general term, desired output cannot be produced. The thesis also extends the existing literature by adding another new moderating factor, nationality, into the UTAUT2 model. Additionally, the UTAUT2 is validated again in DTH context, in the first two usage levels. The UTAUT2 variables provide initial evidence, and some variables in UTAUT2 were confirmed significant. Specifically, performance expectancy, social influence and facilitating conditions were confirmed to be significant in DTH usage level 1, and performance expectancy and price value were confirmed to be significant in DTH usage level 2. For the other factors, despite being insignificant, they provide initial evidence how each factor influences the use intention of the elderly; thus, providing insights for future research. Moreover, this thesis introduced potential enablers and inhibitors in section 2.3 and 6.1 that could shed a light on the use intention of DTH by the elderly more comprehensively.

7.2.2 Practical implication

The result of this thesis discloses the significant role of performance expectancy, social influence and facilitating conditions in DTH usage level 1; and performance expectancy and price value in DTH usage 2. It provides valuable insights for DTH developers, the Ministry of Health and healthcare executives to come up with the better strategies to promote the use of DTH. For both DTH usage levels, developers could incorporate a video educating the elderly the benefits of DTH given the importance of performance expectancy. Moreover, the Ministry of Health could perhaps create online forums with users, and continuously posting videos from healthcare professionals to promote DTH. Another way is to group the elderly who needs more medical intention and facilitate workshops. By this way the users can discuss with each other and promote its usefulness. Users might also complain about some features they dislike, providing the developers the ability to adjust the features better. As Enrol et al. stated that Digital Twin is not yet an established fact (2020) but an emerging technology that is malleable as it is still in its early development stage (Bruynseels et al., 2018), the developers could still create a better version with wider adoption. Consequently, these activities promote the performance expectancy factor and social influence.

Moreover, the result emphasizes that collaboration between the elderly, healthcare professionals, and the elderly’s inner circle members are important for DTH usage 1. The Ministry of Health could provide training of DTH to all healthcare professionals and inner circle members so they could communicate to the elderly, promote the use of DTH and correct misconceptions that might hinder the DTH usage. Besides, the minister could station extra hospital staff to support the elderly when they need it. These activities promote performance expectancy, social influence and facilitating conditions factors. Regarding the DTH usage level 2, besides educating the elderly the benefits, it is also important that the Ministry of Health comes up with a funding strategy to support the elderly financially given the importance of price value.

Consequently, DTH usage for both levels could be endorsed and used. This could benefit the healthcare sector significantly. It is predicted that future healthcare for the elderly would consume nearly 50% of medical resources which poses a risk for limited medical resources (World Population Aging, 2017). It is predicted that with the help of DTH, patients' waiting time will be shorten, personnel costs can be reduced and more resources can be saved (Erol et al., 2020).

7.3 Limitations

Even though the thesis provides valuable insights, there are still notable shortcomings:

- A small sample size that results in reduced statistical power.
- Due to time constraints, convenience sampling was chosen that leads to a concern for generalizability. As the thesis was conducted mostly in the Netherlands and Vietnam, and the participants were not randomly chosen, the findings might be under or over representing.
- The sample is more skewed to Dutch participants, with 64% Dutch and 36% Vietnamese; thus, the validity and the reliability of moderating effect (nationality) cannot be fully demonstrated.
- Drolet and Morrison (2001) found that multiple items take more time to complete and the participants has the tendency to engage in 'mindless response behaviour'. Therefore, to reduce the burden of additional items and response error, the researcher made the survey short and simple with a limited number of questions per construct. This could potentially harm the validity of the research.
- This thesis and most other research consider Likert scale as interval; but strictly speaking from statistical view, Likert scale is ordinal (Wu & Leung, 2017)
- This thesis investigates the behavioural intention to accept DTH, not the actual acceptance itself.
- Limited time and resource leads to (1) not all factors that potentially influence the DTH usage could be studied, (2) not all four levels of DTH usage were studied, (3) the

perspective of healthcare sector was not included; thus, improvements could be made to get a more comprehensive picture.

7.4 Future research

With that said, future research could aim to collect a larger and more presentative sample. Besides, cross-country observations should be more or less equal when investigating the moderating effect of nationality. In order to improve the reliability of the research, future studies could retest again to observe whether the same outcomes are produced, and it is recommended to include more survey items per construct. Moreover, future studies could study each DTH level usage one at a time to prevent mindless response behavioural effect caused by many questions.

For the research directions, since the other potential constructs outside UTAUT2 model were not yet studied, future research could extend the UTAUT2 model with medical service satisfaction, physical comfort, product design, human interaction value, self- actualisation, self-efficacy, technology anxiety, resistance to change, and data privacy. The definitions and measurement of the mentioned constructs can be found in section 2.3. By studying all these constructs, the predictive power of DTH usage model could be stronger. Given that the influential factors are diverse per usage level, future research should employ DTH usage level framework mentioned in chapter 3 to study the acceptance of the elderly. Ideally, all mentioned constructs should be studied across all 4 levels to fully understand the acceptance from the elderly perspective.

To have a more comprehensive picture of DTH usage acceptance, the perspective of the elderly alone is not enough, but the perspective of healthcare professionals should also be taken into account. Investigating the factors that might prevent healthcare professionals from using DTH is of interest. All things considered, an optimal product and strategy that are welcomed by both the healthcare professionals and the elderly would be created. Once the determinants that influence the elderly and healthcare professionals are established, how and to what extent these determinants are valid might be of interest to study further. Furthermore, continuous usage is important, and the success of any information system, including DTH, depends on it (Bhattacherjee, 2001; Talukder et al., 2020). Therefore, studies on the elderly's and healthcare professionals' continuous usage are highly recommended. That being the case, full benefits of DTH are reaped.

Chapter 8 - Conclusion

The current demographic and epidemiological changes, together with medical resources risk emphasize the need to focus on the elderly health. DTH is a good solution for the problems. Given that DTH allows doctors to accelerate diagnosis and treatment process with accuracy, DTH improves the elderly's health and hospital processes significantly (Bruynseels et al., 2018; Erol et al., 2020; Kummar et al., 2015; Y. Liu et al., 2019). Despite these opportunities, the success of DTH in healthcare is hindered by low or no adoption by the elderly. Thus, it calls for research to look into the attitudes and perspective of the elderly to discover determinants of the use intention.

This thesis was conducted by means of literature review and survey. Literature review was conducted to seek academic knowledge related to DTH, and factors influence the elderly's decision to use a new healthcare technology. All potential constructs and the measurement approach for each construct are then introduced. Next, derived from both theoretical and empirical literature, the research model was developed through the lens of UTAUT2 model. To investigate better the acceptance from the elderly, a systematic review was performed to categorise DTH usage. There are four DTH usage levels derived, and the hypotheses were tested with the DTH usage level 1 and 2. Data was then collected by survey questionnaires and PLS-SEM was applied to validate and answer research question:
What factors influence the elderly intention to use Digital Twin Healthcare?

The results from chapter 6 showed that not all hypotheses were supported for DTH usage level 1 and 2. Thus, the research question can only be answered partly. The predictive model revealed that performance expectancy, social influence and facilitating conditions are significant predictors of usage behaviour in DTH usage level 1. In DTH usage level 2, performance expectancy and price value are noteworthy predictors. The result suggests that the enablers and inhibitors to use intention are heterogenous per level; thus, different strategies have to be developed differently per DTH usage level. For both levels, performance expectancy is the most influential enabler to the use of DTH. This realised the value of continuing education of DTH and DTH benefits. Seabra et al. (2019) found that when educational activities are based on their needs, the elderly actively engage in. Therefore, online forums, groups and workshops with the elderly are good strategies, especially those who needs more medical intention. Such activities could promote the exchange of experiences and knowledge between the users and health professionals (Seabra et al., 2019). This would increase the DTH awareness and its benefits; thus, endorse the usage intention of DTH for both levels. Moreover, healthcare professionals should be responsible for DTH education since doctor plays a significant role. Therefore, the DTH education action must be carried out for health team. The Ministry of Health could form partnership between training institutes and healthcare team. Not only that, inner circle members also play an important role in DTH usage level 1; thus, the opportunity for elderly's inner circle members to attend the training is highly recommended. For DTH usage 2, data from this thesis suggest the Ministry of Health needs to come up with strategy to support the usage of DTH level 2 financially.

As the next step to better understanding of DTH usage by the elderly, there is a call for research to extend the UTAUT2 model with medical service satisfaction, physical comfort, product design, human interaction value, self- actualisation, self-efficacy, technology anxiety, resistance to change, and data privacy. Moreover, all these constructs need to be studied across all four DTH usage levels. This would provide throughout insights that would enable the stakeholders to deepen the knowledge of DTH usage by the elderly and come up with better strategies.

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Appendix

This part includes supplementary material for a more comprehensive understanding. First, the summary of key findings for literature review is listed in Appendix A. Then, questionnaires for survey used is shown in Appendix B. Appendix C illustrates the results for measurement model assessment, followed by the results of structural model assessment in Appendix D.

Appendix A: Summary of key findings for literature review

Digital Twin in Healthcare (section 2.1)

Table 19. Most important sources for Digital Twin in Healthcare

Author	**Title**	**Journal**	**Findings**	**DOI**
(Popa et al., 2021)	The use of digital twins in healthcare: socio-ethical benefits and socio-ethical risks	Life Sciences, Society and Policy	Define digital twin that captures all aspects of Digital twin in existing papers, which "is a living model of the physical asset or system, which continually adapts to operational changes based on the collected online data and information, and can forecast the future of the corresponding physical counterpart"	10.1186/s40504-021-00113-x
(Erol et al., 2020)	The Digital Twin Revolution in Healthcare	2020 4th International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT)	Technologies advanced the realization DTH: Internet of Things, big data technologies, self-adoptive autonomous system, machine learning	10.1109/ISMSIT50672.2020.9255249
(Y. Liu et al., 2019)	A Novel Cloud-Based Framework for the Elderly Healthcare Services Using Digital Twin	IEEE Access	Conceptual framework to monitor the elderly's health includes 5 stages: modelling techniques connect to physical objects, wearables connect and interact with each other and the system via mobile internet, system reconfigures and validates simulation, virtual objects evolve continuously, and fed back orders to physical objects. Also, the framework includes 4 components: digital object, cloud healthcare service platform, healthcare digital twin data and external factors. Last, information required by the elderly are personal health records and wearables	10.1109/ACCESS.2019.2909828

Acceptance concept level (section 2.2)

Table 20. Most important sources for Acceptance concept level

Author	Title	Journal	Findings	DOI
(Davis, 1989)	Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology	MIS Quarterly	TAM model, in which potential users' attitude (based on perceived usefulness and ease of use) towards the technology/system is the main determinant of behavioural intention to adopt a new technology	10.2307/249008.
(Venkatesh et al., 2003)	User Acceptance of Information Technology: Toward a Unified View	MIS Quarterly	UTAUT developed based on TAM, including effort expectancy, performance expectancy, social influence, facilitating conditions, hedonic motivation, price value, habit are the main determinant of behavioural intention to adopt a new technology. Including moderation effects of age, gender, and experience effects the strength of the predictors on the intention.	10.2307/30036540

Factors influence the adoption of healthcare technology in the elderly (section 2.3)

Table 21. Most important sources for Factors influence the adoption of healthcare technology in the elderly

Author	Sample	Title	Journal	Findings	DOI
(Talukder et al., 2020)	344 surveys with seniors older than 60 years old in China	Predicting antecedents of wearable healthcare technology acceptance by elderly: A combined SEM-Neural Network approach	Technological Forecasting and Social Change	Social influence, performance expectancy, self-actualization, hedonic motivation has positive relationship with adoption of wearable healthcare devices. Technology anxiety and resistance to change negatively affect wearable healthcare devices acceptance.	10.1016/j.techfore.2019.119793

				Difficulty of usage is a barrier Facilitating conditions influence attitudes towards wearable healthcare devices acceptance.	
(Kavandi & Jaana, 2020)	Systematic Review was conducted from December 2017 to Febuary 2018, with seach update in 2019. It studied 41 papers from academic sources	Factors that affect health information technology adoption by seniors: A systematic review	Health & Social Care in the Community	Social influence factors, ease of use, self-efficiency have positive effect to the healthcare technology acceptance Little mention of habit, and research found inconclusive impact of habit on the adoption of technology by the elderly Types of technology and age does not affect healthcare technology adoption	10.1111/hsc.13011
(Charness et al., 2016)	Field survey of 92 seniors in the US, over 2-week and 6-month intervals	Supportive home health care technology for older adults: Attitudes and implementation	Gerontechnology	Privacy and security were areas of concern. Devices that are uncomfortable to wear or feel heavy are unlikely to be worn. Designers should pay close attention to aesthetics may prove acceptable to elderly Perceived usefulness and perceived ease of use positively affect the use intention of healthcare technology	10.4017/gt.2016.15.4.006.00
(Abdelrahman et al., 2020)	2 focus groups of elderly in the US	Brain Health: Attitudes towards Technology	Healthcare	Participants are willing to use new technology to maintain health, in which, perceive of usefulness, ease of use,	10.3390/healthcare9010023

		Adoption in Older Adults		comfort, social factors (family members support or initiate use) positively influence the acceptance of the new technology.	
(Alsulami & Atkins, 2016)	Quantitative analysis based on the survey results	Factors Influencing Ageing Population for Adopting Ambient Assisted Living Technologies in the Kingdom of Saudi Arabia	Ageing International	Cost (includes installation, service, repairs and maintenance of new technology) negatively affect elderly's behavioural intention to technology usage. The elderly value human interactions and resists to changes	10.1007/s12126-016-9246-6
(Low et al., 2021)	In-depth semi-interviews with 20 seniors living in Singapore	Attitudes and Perceptions Toward Healthcare Technology Adoption Among Older Adults in Singapore: A Qualitative Study	Frontiers in Public Health	Social factors, performance expectancy, ease of use, facilitating conditions, affordability and personal data protection influence the acceptance of the new technology. Elderly stresses the need for human interaction in health-seeking for personal touch. They strongly prefer face-to-face. Participants is willing to try new healthcare technology, but they don't feel the need to adopt it immediately. If they're satisfied with the current healthcare system,	10.3389/fpubh.2021.588590

				adopting a new technology is unnecessary	
(Claes et al., 2015)	Cross-sectional survey with 245 sixty years and older via convenience sample (n=245)	Attitudes and perceptions of adults of 60 years and older towards in-home monitoring of the activities of daily living with contactless sensors: An explorative study	International Journal of Nursing Studies	70% participants report the price determine if they would accept the technology, and they are unwilling to pay for the costs of system maintenance, and refuse to ask for co-financing or family assistance	10.1016/j.ijnurstu.2014.05.010
(Cimperman et al., 2016)	Survey of 400 participants, 50 years old and above, in rural and urban in Slovenia	Analyzing older users' home telehealth services acceptance behavior—applying an Extended UTAUT model	International Journal of Medical Informatics	Cost is the most important factor that influence the behavioural intention	10.1016/j.ijmedinf.2016.03.002
(Lu et al., 2014)	Semi-structured interview of 8 participants and a focus group of 12 participants	Advocacy of home telehealth care among consumers with chronic conditions	Journal of Clinical Nursing	Cost has significant negative effect to senior's intention to use	10.1111/jocn.12156

(Steele et al., 2009b)	2 focus groups with participants aged 65+ in Sydney	Elderly persons' perception and acceptance of using wireless sensor networks to assist	International Journal of Medical Informatics	Even if the elderly thinks a new healthcare system is useful, they will not use it if high cost	10.1016/j.ijmedinf.2009.08.001
(Zhou et al., 2019)	436 seniors selected through multistage cluster sampling from four cities in mainland China.	Factors influencing behavior intentions to telehealth by Chinese elderly: An extended TAM model	International Journal of Medical Informatics	Expected performance, expected efforts, promotion conditions, and perceived security significantly affect the behavioural intentions of adopting Telehealth Services Easy to use, hedonic motivation influences the attitudes that leads to behavioural intention to new technology adoption. Current medical service satisfaction positively impacts behavioural intentions.	10.1016/j.ijmedinf.2019.04.001
(Hoque & Sorwar, 2017)	Survey of 300 participants aged 60+ from capital city of Bangladesh	Understanding factors influencing the adoption of mHealth by the elderly: An extension of the UTAUT model	International Journal of Medical Informatics	Social influence and performance expectancy significantly influence the behavioural intention at the initial adoption phase.	10.1016/j.ijmedinf.2017.02.002

(Kohnke et al., 2014)	Survey of 126 participants currently use or familiar with Tele-equipment	Incorporating UTAUT Predictors for Understanding Home Care Patients' and Clinician's Acceptance of Healthcare Telemedicine Equipment	Journal of technology management & innovation	Social influence is the most significant factor influence the behavioural intention at the initial adoption phase	10.4067/S0718-272420140002000003

DTH usage levels (chapter 3)

Table 22. Most important sources for DTH usage levels

most important sources				
Author	**Title**	**Journal**	**Findings**	**DOI**
(Bruynseels et al., 2018)	Digital Twins in Health Care: Ethical Implications of an Emerging Engineering Paradigm	Frontiers in Genetics	Fuelled by big data, together with individual's detailed history, lifestyle, genetic background, etc., the digital twin maps what is a normal healthy state; thus enables the doctors to see deviation. Doctors can optimize, tailor treatment to the medical history and actual status of the patient through model iteration. Existing projects mentioned: Google spin-off, project working on transmit information to the cloud continuously.	10.3389/fgene.2018.00031
(Telenti et al., 2016)	Deep sequencing of 10,000 human genomes	Proceedings of the National Academy of Sciences	The project discovers a way to gather detail on molecular levels of the patients	10.1073/pnas.1613365113

(Kummar et al., 2015)	Application of Molecular Profiling in Clinical Trials for Advanced Metastatic Cancers	JNCI Journal of the National Cancer Institute	With digital twin, doctors can test scenarios in the virtual patient such as changing medicine dose, understand medicine's impact and side effects in the individual. The technology can identify upcoming disease, so medical intervention is practiced before the disease manifests.	10.1093/jnci/djv003
(Erol et al., 2020)	The Digital Twin Revolution in Healthcare	2020 4th International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT)	Digital twin together with 3D printing technology make it possible to practice surgery. The physician can choose the ideal method to proceed. Existing projects were mentioned: home monitoring patients with Sooma Software Suite, IBM and Watson (supercomputer) using AI to detect cancerous cells, Semic Health's Digital Body, European CompBioMed project, Sim &Cure, Philips HeartNavigator.	10.1109/ISMSIT50672.2020.9255249
(Y. Liu et al., 2019)	A Novel Cloud-Based Framework for the Elderly Healthcare Services Using Digital Twin	IEEE Access	The real-time data let the doctor prescribe and monitor their patients effectively without seeing the patient in person	10.1109/ACCESS.2019.2909828
(Fuller et al., 2020)	Digital Twin: Enabling Technologies, Challenges	IEEE Access	Based on the data flow, Fuller et al. present levels of integration for a Digital Model, Digital Shadow and Digital Twin.	10.1109/ACCESS.2020.2998358

	and Open Research			

Appendix B: Survey

Welcome!

In this survey, we will ask you some questions about the use of an **online medical program**. The result of this study will help healthcare service providers, such as clinics and hospitals to improve their service.

First, we explain the program and then we describe two scenarios of the program. For each scenario we will ask a few questions. The survey will take 5 - 10 minutes in total. Please note that there's no right or wrong answer, we want to know your opinion.

The program

First, let us consider an online e-health program that manages your medical information, like your health summary, medical history, medication use, vaccinations, appointments, etc. The program reminds you of your medical activities and appointments via notifications. For instance, this online program sends regular notifications using email, SMS or app notification to remind you about doctor appointments, vaccination appointments, daily medicine usage, etc. This online program can be accessed via a laptop, tablet or phone.

This online program will form the basis for both scenarios.

Scenario 1

The healthcare provider would like to extend the online e-health program so that it can also keep track of your daily medical condition. This allows the program to monitor regularly your health condition, so it can raise an alert to the doctor if an issue with your health condition is detected. This feature, however, requires your daily information about your health, mood and feelings which you provide by answering a few short questions (about 5 minutes). The doctor can then access your health information, monitor your health from remote distance, and give you a call if neccessary.

Questions

	Strongly agree (1)	Somewhat agree (2)	Neither agree nor disagree (3)	Somewhat disagree (4)	Strongly disagree (5)
I find it useful to receive notifications for medical activities and appointments. (1)	○	○	○	○	○
I find it useful that my doctor can monitor my health status remotely. (2)	○	○	○	○	○
It's useful to me that the doctor will be alarmed if the e-health program detects an abnormal issue. (3)	○	○	○	○	○
I find it nice to have access to my current health status and medical history whenever I want to. (4)	○	○	○	○	○
I am willing to fill in a short questionnaire (5 minutes max) everyday to keep my e-health status updated. (5)	○	○	○	○	○
Internet technology and devices (such as laptops, smartphones) are not new to me. I'm already using them in my daily life. (6)	○	○	○	○	○
I have easy accesss to the internet. (7)	○	○	○	○	○
Having technical support encourage me to use this e-health program. (8)	○	○	○	○	○
I think the online e-health program would be easy to use. (9)	○	○	○	○	○
I would only enroll into this e-health program if people who are important to me encourage me to use it. (10)	○	○	○	○	○
I would only enroll into this e-health program if my doctor recommends it. (11)	○	○	○	○	○
I want to enroll into this e-health program. (12)	○	○	○	○	○
I want to enroll into this e-health program when my health declines. (13)	○	○	○	○	○

I'm willing to pay an extra monthly fee for my insurance so I can use this e-health program:

- ◯ €0 per month. (1)
- ◯ Up to €30 per month. (2)
- ◯ Up to €50 per month. (3)
- ◯ Above €50 per month. (4)

Scenario 2
Now consider a different scenario, instead of submitting daily your health information via a questionnaire, you can wear wearable devices that keep track of your health record, e.g your heartbeat, blood pressure, physical activities, sleep pattern, etc. This information is gathered by the wearables and sent directly to the online e-health program.
An example of a wearable is shown below, a smartwatch that keeps track of your heartbeat, number of steps, and sleep patterns.

With these wearables, the program can detect a problem more accurate and alerts your doctor in a timely manner. The doctor can monitor your health status continuously, and prescribe more accurate treatment without the need for a face-to-face appointment. The e-health program could also give instant advice on your health condition.

Questions

	Strongly agree (1)	Somewhat agree (2)	Neither agree nor disagree (3)	Somewhat disagree (4)	Strongly disagree (5)
I find it useful to get instant advice from the e-health program. (1)	○	○	○	○	○
I find it useful that my doctor can monitor my health status continuously. (2)	○	○	○	○	○
It's useful to me that the doctor can prescribe more accurate treatment using my real-time health status. (3)	○	○	○	○	○
When there's a life-threatening medical condition such as a stroke, I find it useful that the wearable immediately recognizes it and notifies the hospital which can dispatch an ambulance immediately. (4)	○	○	○	○	○
I find it nice to see my current health status continuously and whenever I want to. (5)	○	○	○	○	○
Using a wearable device such as a smart watch is convenient for me. (6)	○	○	○	○	○
Having technical support encourage me to use wearables. (7)	○	○	○	○	○
I would only use wearables if people who are important to me encourage me to use it. (8)	○	○	○	○	○
I would only use wearables if my doctor recommends it. (9)	○	○	○	○	○
I want to enroll into this e-health service with wearables. (10)	○	○	○	○	○
I want to enroll into this e-health service with wearables when my health declines. (11)	○	○	○	○	○

I wear medical assistance devices such as an hearing device:

- ◯ I often wear them. (1)
- ◯ I sometimes wear them. (2)
- ◯ I don't need to wear them. (3)
- ◯ My doctor advised me to wear them but I don't wear them. Reason (optional): (4) ________________

I'm willing to pay an extra monthly fee for my insurance so I can use the e-health program with wearables:

- ◯ €0 per month. (1)
- ◯ Up to €30 per month. (2)
- ◯ Up to €50 per month. (3)
- ◯ Above €50 per month. (4)

Finally, last question: What is your age?

- ◯ Below 40 years (1)
- ◯ 40 - 49 years (2)
- ◯ 50 - 59 years (3)
- ◯ 60 - 69 years (4)
- ◯ 70 - 79 years (5)
- ◯ Above 80 years (6)

Thank you for filling in the survey. This research is a part of my graduation research of master Information Management at Tilburg university. All the data collected is anonymous and confidential. Plus, the data is only for research purposes. If you have any questions, you can always send an email to n.p.k.bui@tilburguniveristy.edu

Appendix C: Measurement model assessment

DTH usage level 1

Table 23. Construct reliability and validity

	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
EE1	0.653	0.728	0.847	0.736
PE1	0.882	0.889	0.927	0.808
SI1	0.765	0.777	0.894	0.809

Table 24. Discriminant validity – Heterotrait-monotrait ration (HTMT)

	BI1	EE1	FC1	HA1	HM1	PE1	PV1	SI1
BI1								
EE1	0.597							
FC1	0.551	0.776						
HA1	0.181	0.573	0.298					
HM1	0.402	0.693	0.43	0.476				
PE1	0.666	0.868	0.6	0.219	0.617			
PV1	0.266	0.348	0.346	0.197	0.261	0.313		
SI1	0.556	0.686	0.6	0.111	0.394	0.524	0.247	

Table 25. Fornel-Larcker criterion

	BI1	EE1	FC1	HA1	HM1	PE1	PV1	SI1
BI1	1							
EE1	0.498	0.858						
FC1	0.551	0.626	1					
HA1	0.181	0.437	0.298	1				
HM1	0.402	0.561	0.43	0.476	1			
PE1	0.63	0.67	0.562	0.206	0.579	0.899		
PV1	0.266	0.285	0.346	0.197	0.261	0.293	1	
SI1	0.489	0.506	0.524	0.098	0.339	0.432	0.217	0.899

Table 26. Cross loading

	BI1	EE1	FC1	HA1	HM1	PE1	PV1	SI1
BI1.2	1	0.498	0.551	0.181	0.402	0.63	0.266	0.489
EE1.1	0.5	0.916	0.554	0.303	0.504	0.632	0.267	0.51
EE1.2	0.331	0.795	0.527	0.494	0.461	0.505	0.218	0.333
FC1.1	0.551	0.626	1	0.298	0.43	0.562	0.346	0.524
HA1	0.181	0.437	0.298	1	0.476	0.206	0.197	0.098
HM1	0.402	0.561	0.43	0.476	1	0.579	0.261	0.339
PE1.1	0.524	0.59	0.471	0.245	0.53	0.897	0.258	0.346
PE1.2	0.625	0.621	0.478	0.197	0.513	0.899	0.238	0.378
PE1.3	0.538	0.594	0.571	0.114	0.522	0.902	0.297	0.441
PV1	0.266	0.285	0.346	0.197	0.261	0.293	1	0.217
SI1.1	0.471	0.508	0.469	0.099	0.25	0.405	0.204	0.915
SI1.2	0.405	0.394	0.475	0.076	0.371	0.369	0.185	0.883

DTH usage level 2

Table 27. Construct reliability and validity

	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
PE2	0.89	0.898	0.924	0.752
SI2	0.774	0.789	0.898	0.815

Table 28. Discriminant validity – Heterotrait-monotrait ration (HTMT)

	BI2	EE2	FC2	HA2	HM2	PE2	PV2	SI2
BI2								
EE2	0.343							
FC2	0.419	0.662						
HA2	0.1	0.207	0.304					
HM2	0.359	0.545	0.588	0.185				
PE2	0.459	0.626	0.796	0.232	0.802			
PV2	0.034	0.273	0.217	0.228	0.276	0.32		
SI2	0.357	0.362	0.613	0.48	0.467	0.6	0.298	

Table 29. Fornel-Larcker criterion

	BI2	EE2	FC2	HA2	HM2	PE2	PV2	SI2
BI2	1							
EE2	0.343	1						
FC2	0.419	0.662	1					
HA2	0.1	0.207	0.304	1				
HM2	0.359	0.545	0.588	0.185	1			
PE2	0.438	0.594	0.752	0.221	0.76	0.867		
PV2	0.034	0.273	0.217	0.228	0.276	0.3	1	
SI2	0.316	0.316	0.54	0.423	0.415	0.498	0.262	0.903

Table 30. Cross loading

	BI2	EE2	FC2	HA2	HM2	PE2	PV2	SI2
BI2.2	1	0.343	0.419	0.1	0.359	0.438	0.034	0.316
EE2	0.343	1	0.662	0.207	0.545	0.594	0.273	0.316
FC2	0.419	0.662	1	0.304	0.588	0.752	0.217	0.54
HA2	0.1	0.207	0.304	1	0.185	0.221	0.228	0.423
HM2	0.359	0.545	0.588	0.185	1	0.76	0.276	0.415
PE2.1	0.424	0.599	0.687	0.219	0.698	0.86	0.258	0.39
PE2.2	0.407	0.465	0.631	0.196	0.65	0.884	0.231	0.494
PE2.3	0.337	0.435	0.589	0.148	0.599	0.825	0.267	0.385
PE2.4	0.335	0.549	0.698	0.196	0.678	0.898	0.292	0.455
PV2	0.034	0.273	0.217	0.228	0.276	0.3	1	0.262
SI2.1	0.306	0.26	0.497	0.395	0.42	0.438	0.235	0.919
SI2.2	0.26	0.315	0.477	0.368	0.322	0.465	0.239	0.886

Appendix D: Structural model assessment

DTH usage level 1

Table 31. Collinearity statistics (VIF)

	VIF
BI1.2	1
EE1.1	1.307
EE1.2	1.307
FC1.1	1
HA1	1
HM1	1
PE1.1	2.621
PE1.2	2.228
PE1.3	2.68
PV1	1
SI1.1	1.621
SI1.2	1.621

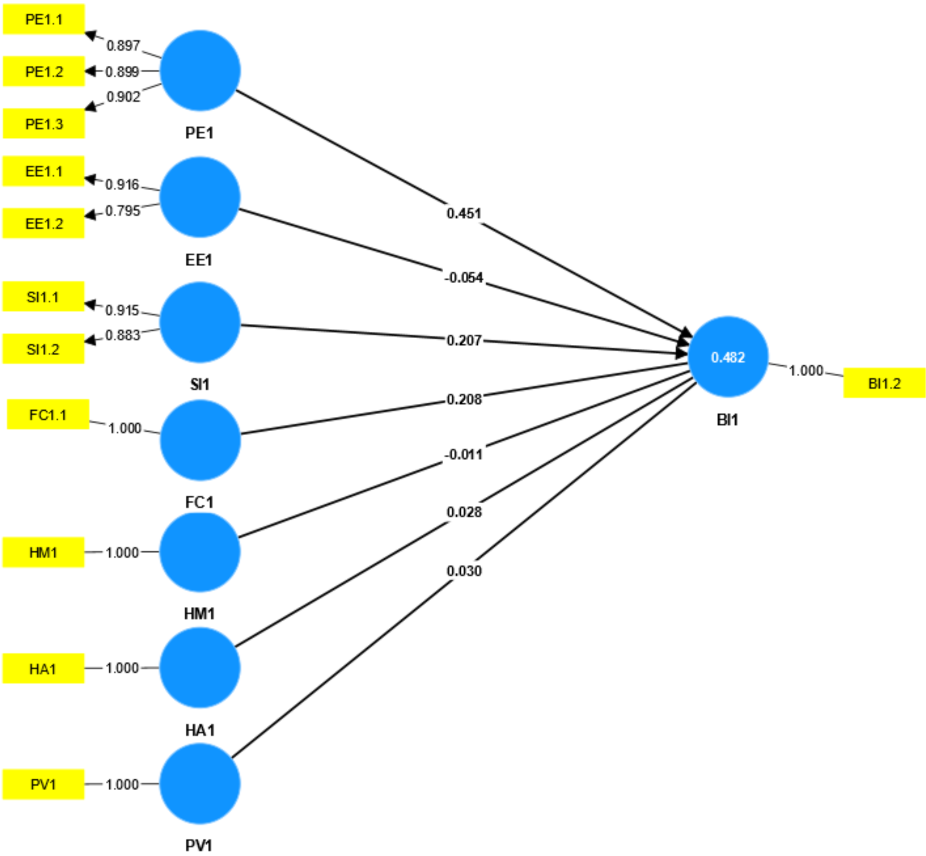

Figure7. SmartPLS model output

Table 32. R-square

	R-square	R-square adjusted
BI1	0.482	0.452

Table 33. Q-square

	Q²predict
BI1.2	0.408

Table 34. Path coefficients

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
EE1 -> BI1	-0.054	-0.046	0.1	0.535	0.593
FC1 -> BI1	0.208	0.199	0.107	1.945	0.052
HA1 -> BI1	0.028	0.03	0.08	0.355	0.722
HM1 -> BI1	-0.011	-0.009	0.116	0.091	0.927
PE1 -> BI1	0.451	0.445	0.114	3.94	0
PV1 -> BI1	0.03	0.029	0.044	0.688	0.492
SI1 -> BI1	0.207	0.21	0.08	2.576	0.01

Table 35. Multi-group analysis

	Original (Netherlands)	Original (Vietnam)	Original difference	Permutation mean difference	2.50%	97.50%	Permutation p value
EE1 -> BI1	0.014	-0.024	0.038	0.004	-0.416	0.421	0.859
FC1 -> BI1	0.211	0.2	0.011	-0.002	-0.496	0.486	0.975
HA1 -> BI1	0.085	-0.062	0.147	-0.005	-0.353	0.338	0.451
HM1 -> BI1	-0.002	-0.23	0.227	-0.009	-0.52	0.521	0.392
PE1 -> BI1	0.349	0.775	-0.426	0.01	-0.458	0.509	0.084
PV1 -> BI1	0.118	0.116	0.002	0.011	-0.179	0.203	0.98
SI1 -> BI1	0.265	0.023	0.242	-0.001	-0.354	0.34	0.167

DTH usage level 2

Table 36. Collinearity statistics (VIF)

	VIF
BI2.2	1
EE2	1
FC2	1
HA2	1
HM2	1
PE2.1	2.16
PE2.2	2.565
PE2.3	2.257
PE2.4	3.27
PV2	1
SI2.1	1.665
SI2.2	1.665

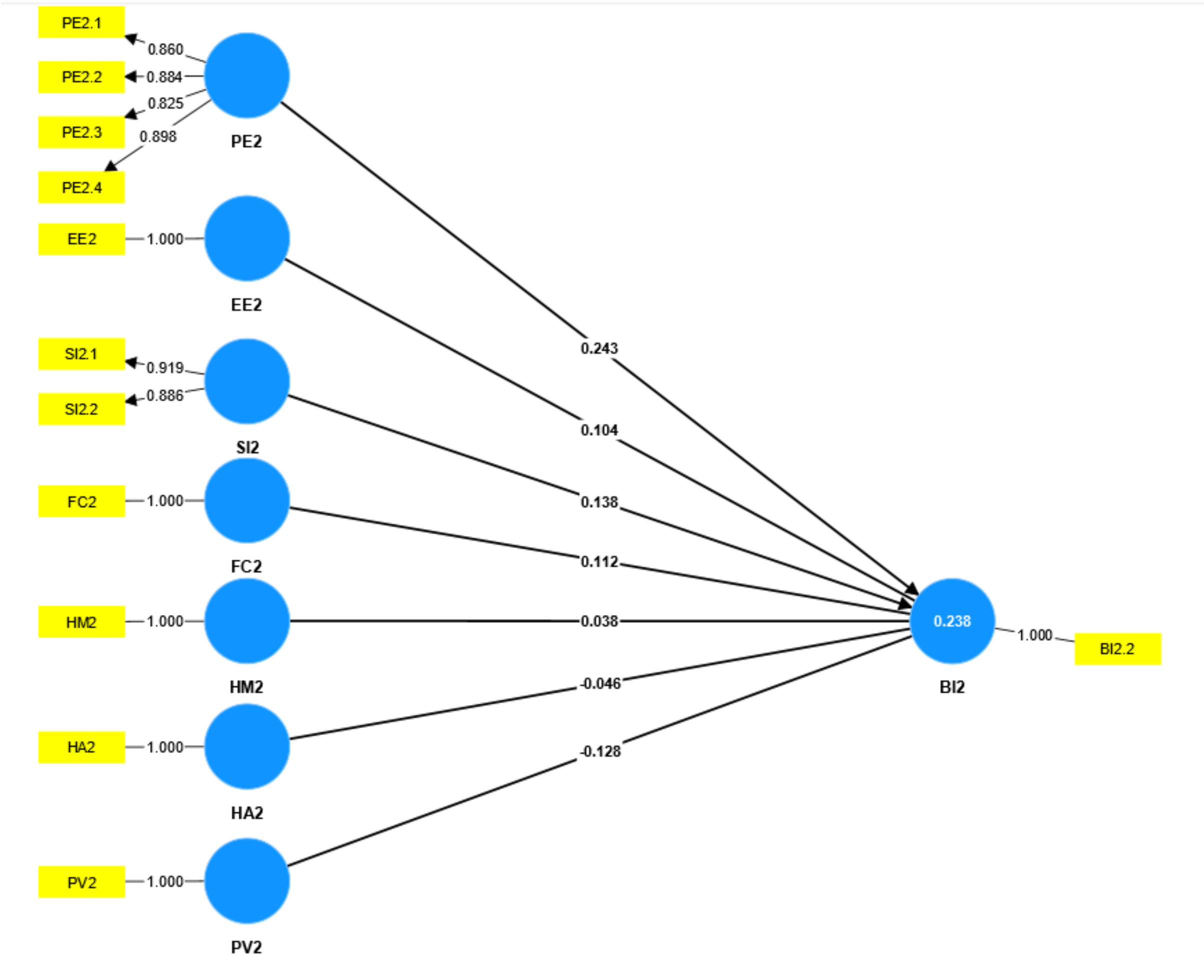

Figure 8. SmartPLS model output

Table 37. R-square

	R-square	R-square adjusted
BI2	0.238	0.194

Table 38. Q-square

	Q^2predict
BI2.2	0.147

Table 39. Path coefficients

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
EE2 -> BI2	0.104	0.106	0.117	0.893	0.372
FC2 -> BI2	0.112	0.086	0.169	0.663	0.507
HA2 -> BI2	-0.046	-0.043	0.076	0.597	0.551
HM2 -> BI2	0.038	0.028	0.121	0.317	0.751
PE2 -> BI2	0.243	0.269	0.172	1.415	0.157
PV2 -> BI2	-0.128	-0.133	0.071	1.807	0.071
SI2 -> BI2	0.138	0.15	0.095	1.464	0.143

Table 40. Multi-group analysis

	Original (NL)	Original (VN)	Original difference	Permutation mean difference	2.50%	97.50%	Permutation p value
EE2 -> BI2	-0.004	0.222	-0.226	n/a	-0.533	0.509	0.387
FC2 -> BI2	0.203	0.104	0.099	n/a	-0.707	0.786	0.783
HA2 -> BI2	-0.127	0.105	-0.232	n/a	-0.306	0.308	0.142
HM2 -> BI2	0.166	-0.016	0.181	n/a	-0.501	0.523	0.516
PE2 -> BI2	0.083	0.627	-0.543	n/a	-0.766	0.67	0.158
PV2 -> BI2	0.016	-0.135	0.151	n/a	-0.294	0.326	0.318
SI2 -> BI2	0.279	-0.154	0.433	n/a	-0.416	0.382	0.03