IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received August 9, 2018, accepted September 4, 2018, date of publication September 13, 2018, date of current version October 8, 2018.

Digital Object Identifier 10.1109/ACCESS.2018.2869599

Analyzing the Elderly Users' Adoption of Smart-Home Services

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This work was supported by the National Research Council of Thailand.

ABSTRACT A rapid increase in the percentage of elderly people over the past few years has been a cause of serious concern among the research fraternity worldwide. Active research is being carried out to leverage the benefits of information and communication technologies that enable them to live independently and promote a sense of overall well-being. Smart-homes are often employed to assist this group of people. However, there is a serious lack of relevant exploratory research that tries to measure and explain the intention of these people toward using such a service. In this paper, we propose and validate a new comprehensive research model called the elderly smart home technology acceptance model by extending the original technology acceptance model that can explain the elderly intention to use the smart-homes. An online questionnaire survey is conducted for this purpose, the results of which are analyzed using the Partial least squares Structural Equation Modeling approach on data collected from 254 subjects. Subjective norm, compatibility, automation, self-capability, and satisfaction are positively related to the elderly intention in using smart-homes, whereas there is a negative association between affordability, security/privacy, and usage intention. Two other factors, namely universal connectivity and enjoyment, have no effect on the behavioral intention. The present study is a first empirical attempt that tries to explore the adoption of smart-homes among the elderly, as all other previous research has focused only on the technical aspects and implementation issues rather than the actual usage intention.

INDEX TERMS Behavioral intention, elderly, quality of life, smart-homes.

I. INTRODUCTION

Recently a lot of focus is being given on research dedicated towards the well-being of the elderly population. A combination of longer life expectancy along with a decline in the fertility rate are primarily responsible for a gradual demographic transition from the once 'normal' population distribution of many young with few older people to a distribution that reflects many more people over the age of 50 than there are children [1]. Advancements in the modern information and communication technologies (ICT) are being utilized by the elderly people for supporting their various needs [2]. The main objective behind all these technologies/services is to improve the human quality of life (QoL). As per the World Health Organization (WHO), QoL is defined as "*individual's perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns*" [3]. QoL is an important area of concern for the aged population because it reflects their health status and overall well-being considering the vulnerable issues of their daily life [4].

Providing the elderly with various smart-home services is a step in the right direction for improving their QoL. For this work, smart-homes are defined as *"an amalgamation of technology and services through home networking that ensures a better QoL"* [5]. Typically, smart-homes contain many different types of sensors, appliances, and monitoring systems together with a central controlling hub that facilitates in creating an automated environment with which the users can interact. The market for smart-homes is gradually on the rise as the demand for it increases [6]. This is also evident from the efforts by major IT companies like Google, Amazon and Samsung Electronics who have heavily started promoting and commercializing their smart-home products and services recently.

Although, the advantages provided by smart-homes are numerous, yet they are not widely adopted either by the general mass or by the elderly people. This can be attributed to the fact that the different technologies, which function as the core towards providing these services, are still in a stage of development or pending commercialization. Another reason is most of the research in smart-homes focus on the underlying technologies, sensors, actuators and various other services that they are capable of providing [7]. However, very little is known about the services' acceptance among the end users and the motivations towards using such a system. A lack of adequate empirical research on the human intention and behavior towards using the smart-home services imply that the adoption and diffusion of this technology among the people is very less understood [8]. Age is another unique aspect that we take into consideration in this work, as it can be a deciding factor for technology acceptance [9]–[11]. Therefore, proposing a suitable theoretical framework that can sufficiently explain the various smart-home services usage intention by the elderly population is the prime problem that we aim to answer through this work.

In line with the research gap, the main objective of this study is to analyze the following two questions:

R_1: What are the real-life use-cases of various smart-home services usage by the elderly population?

R_2: Second, what is the underlying theoretical framework that explains the intention to use the smart-home services by the elderly people?

To answer the first question, an extensive literature review is conducted that explores the various use-cases of smart-home services usage by the elderly people. Five dimensions are identified based on which we classify them depending upon their provided service i.e. their functionalities. This has been discussed in depth in Section 2 of the paper. Based upon the literature review outcome, we identify the factors in the various domains that can have an impact on the elderly usage intention. These factors are used as the basic constructs of our proposed research model.

For answering the second question, we develop a comprehensive model called the elderly smart home technology acceptance model (ESHTAM) based upon the popular technology acceptance model (TAM) in order to investigate the core determinants and barriers towards using the smart-home services by the elderly. We use TAM as the core model since its effectiveness in explaining end users' intention towards using new technology/service is well established among the research fraternity [12], [13]. In order to propose and validate our research model this study introduces nine exogenous constructs that reflect an individual's psychology, economic value, hedonic value, usability, and security provided by smart-home systems.

The remaining paper has been divided into five sections. The second section is dedicated towards an in depth literature review of various smart-home services and their usage by the elderly along with pertinent theoretical background about TAM. Section 3 presents our research model and hypothesis development. In section 4, the research methodology is proposed. The results from data analysis and subsequent hypothesis testing are presented in Section 5. Section 6 provides the discussions, while the conclusion and scope of future work has been presented in Section 7.

TABLE 1. Search strategy for literature review [14].

Keyword	Synonyms
Elderly	"aged" or "old people" or "aging population" or "senior" or "60 and over age" or "older adult" or "Gerontechnology"
Smart-home services	"ICT" or "information and communication technology" or "ubiquitous home" or "ubiquitous technology" or "ambient assisted living" or "AAL" or "e-health" or "robots" or "robotics" or "automated home" or "automated home environment"
Quality of life	"quality of life" or "happy" or "happiness" or "wellness" or "wellbeing" or "life satisfaction"

TABLE 2. Inclusion and exclusion criteria [14].

Inclusion Criteria	Exclusion Criteria
Assessment of a smart-home or smart-home services or ICT use in home	Studies published in books, PhD or Master's thesis
Include elderly participants	Research conducted in hospitals, nursing homes, rehabilitation centers and likewise
The place of experiment or setup should be in a home	Research published before 2006
Only studies published in English and in peer-reviewed journals	Research focusing on effects of tele-health or tele-medicine on elderly
Asses the effectiveness and perception of the old people towards a smart-home	Research on the use of specific type of assistive devices like walkers, wheelchairs, etc.
-	Use of smart-homes by any people other than the elderly population

II. LITERATURE REVIEW

A. SMART-HOME SERVICES FOR THE ELDERLY

For a proper understanding of the various factors involved in the smart-home services acceptance by the elderly people, a systematic literature review is conducted. The search has been done over major multiple scholarly databases including Scopus, IEEE Xplore, ACM Digital Library, SpringerLink, ScienceDirect, PubMed, and Web of Science. This search has been conducted over a period of two months spanning August-September, 2017. For effective factor identification through the systematic review, relevant logical operators are used across a variety of keywords. TABLE 1 shows the details of the keywords used. The initial search results are examined by two researchers based upon an inclusion/exclusion criterion that has been created specifically for this purpose. This has been shown in TABLE 2. Fig. 1 presents the entire flow of the systematic literature review process [14].

Depending upon the intended purpose and actual usage scenario, the smart-homes are segmented into five different dimensions for the elderly as health monitoring (HM), environment monitoring (EM), providing companionship (PC), social communication (SC), and recreation and entertainment (RE) [14]. Fig. 2 shows the five dimensions along with the total number of published works in each segment.

The literature review outcome shows that much research has been done towards the well-being of the elderly people.

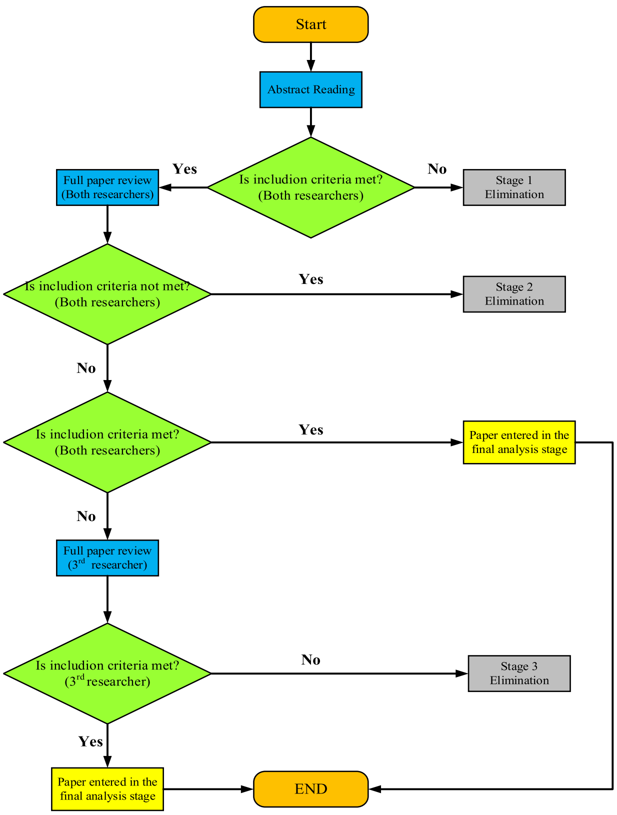

FIGURE 1. Literature review process [14].

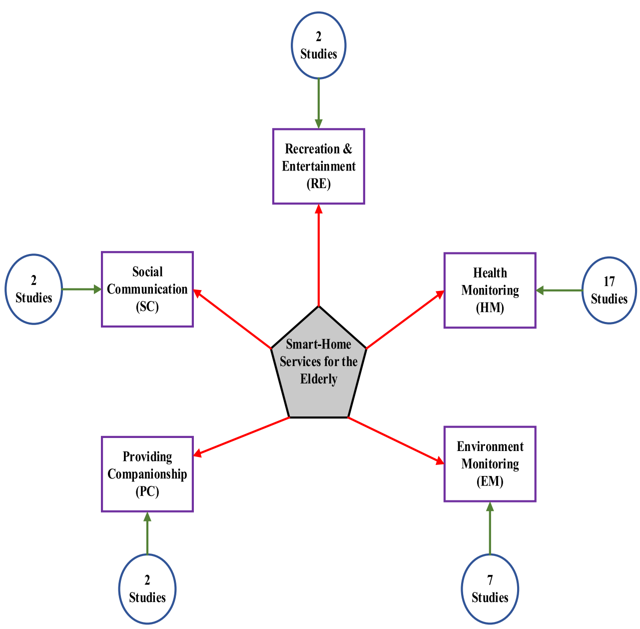

FIGURE 2. Five dimensions of smart-home services for the elderly.

In fact, healthcare is the most important domain that has been focused till date with 17 reported studies. Using various forms of smart-home services along with relevant Internet of Things (IoT) technologies researchers have attempted to provide assistance and improve the QoL of the elderly people suffering from common old age disorders like dementia, Parkinson's disease, and depression [15]–[20]. A lot of work has also been done with healthy elderly people with respect to monitoring their patterns of daily activities, fall detection, sleep tracking using bed sensors, gait monitoring, and creating indoor smart walking environment for staying fit [21]–[31]. Likewise, many researchers have also tried to monitor the surrounding environment in which the elderly people live using a myriad of sensors from light sensors, motion sensors, IR sensors, RFID sensors, to flow sensors with an aim to detect any abnormal conditions and provide assistance, thereby promoting the concept of ambient assisted living (AAL) [32]–[38]. Most of the elderly people either live alone or are accompanied by caregivers in today's society. Therefore, depression is a common problem among them. Research efforts have also been made to improve the overall mental state of the elderly people and enable them to live happily by providing companionships using robots, and designing personalized audio-visual systems [39]–[44].

The outcome of literature review of smart-homes for the elderly clearly indicates that a lot of work has been done towards their well-being. The majority of them are experimental projects that follow a technology centric approach. However, in order to promote and motivate the elderly people to use smart-home servicesit is very important to gauge their behavior and perception towards using the same. However, there is a lack of theoretical approach in this aspect of ageing research, which is also confirmed by [8]. Capturing the needs of these elderly people require an analysis of the factors affecting their behavior with respect to service adoption.

B. THEORETICAL BACKGROUND RELATED TO TAM

The key way to assess the success of any new technology or service is to explore the adoption pattern of the newly introduced services [45]. The TAM proposed by Davis is the most widely used theoretical framework for evaluating such adoption patterns [12]. In the original TAM version, there are four constructs: the behavioral intention, attitude, perceived ease of use and perceived usefulness. As per this model, the behavioral intention is determined by the attitude and perceived usefulness, while the attitude is determined by the perceived usefulness and perceived ease of use. There is also a significant relationship between perceived ease of use and perceived usefulness. TAM also assumes some 'external variables', such as user differences (cognitive style and other personality traits), system characteristics and task characteristics, the effects of which are fully mediated by perceived usefulness and perceived ease of use.

TAM has been used widely as a theoretical model for exploring the usage intention of various types of ICT technologies and smart systems. Yang *et al.* [46] and Adapa *et al.* [47] have successfully used TAM to explain the of user intention towards smart wearable devices. Findings show the intention to use, personal value and certain facilitating conditions to be the prime factors. Similar

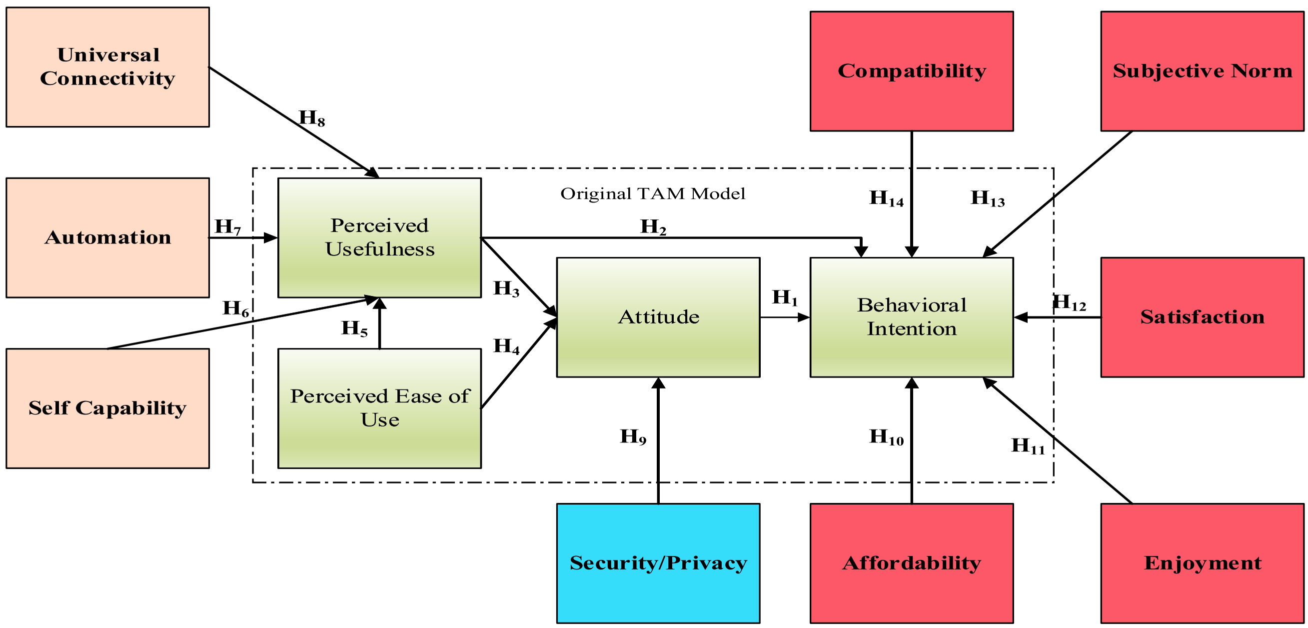

FIGURE 3. Proposed research framework ESHTAM.

research has been conducted for different use-cases ranging from smartphone usage to mobile payment adoption that highlight the effectiveness of TAM in explaining the user intention [48]–[50].

Likewise, the elderly people have special needs and different capability [51]. With ageing, there are a number of physiological and psychological changes that affect the needs of the elderly people and their capability to use new technology [52], [53]. Any new technology or service requires learning new skills for the end users. However, a degradation in the cognitive and other abilities with age can be a cause of concern for the elderly population and their acceptance of any new technology/ service [54]–[56]. From a theoretical perspective, the effectiveness of TAM in predicting adoption intention for a new technology or service cannot be undermined. At, the same time there are special needs of the elderly people that need to be addressed, which current theoretical research lacks. Therefore, in this work, we propose a research model for the elderly based on TAM and find out its effectiveness in the context of the various services provided by the smart-homes.

III. RESEARCH MODEL AND HYPOTHESIS

The proposed research model is shown in Fig. 3 along with the hypotheses. We define each of the constructs used with proper references and develop a theoretical rationale for all the causal relationships proposed in the model.

A. ORIGINAL TAM CONSTRUCTS

Attitude (ATT), perceived usefulness (PU), perceived ease of use (PEOU) and behavioral intention (BI) are the four original TAM constructs. Previous studies about technology acceptance have identified ATT to be an important predictor for BI [57]–[60]. For the present context, ATT is defined as *"an elderly individual's positive or negative feelings or appraisal about using smart homes"* [12]. PU is defined as *"the extent or degree to which an elderly individual believes that using smart homes can improve his/her overall QoL"* whereas PEOU is defined as *"the extent to which an elderly individual believes that using smart homes will be free of effort"* [12]. Apart from ATT, PU also affects BI, while ATT is affected by both PU and PEOU. PEOU is also a significant predictor of PU [12]. Therefore, based upon the original TAM the following hypotheses are proposed:

H_1: ATT positively influences the BI of the elderly adults to use the smart-home services.

H_2: PU of the smart-homes has a positive effect on the BI to use these services.

H_3: PU of the smart-homes has a positive effect on the ATT towards these services.

H_4: PEOU of the smart-homes has a positive effect on the ATT towards these services.

H_5: PEOU of smart-homes has a positive effect on the PU of the services.

Next, the remaining nine exogenous constructs are described.

B. SELF-CAPABILITY (SC)

As pointed out in the literature review there are many unique aspects of the elderly people. Due to a degradation in their cognitive capability, the acceptance of new technology is a matter of concern for them as it involves a continuous learning curve. Self-capability construct takes care of this situation and is defined, as *"the elderly individual's perception on his/her own capability, skill, and knowledge for naturally performing a particular task and using a particular service* *or system without any outside human help."* It is therefore a psychological/belief factor, which can help in improving the perceived usability of the smart-home systems and services. This construct holds true across all the five dimensions of smart-homes that has been previously identified through literature review. Other researchers have used this construct for measuring the proficiency level of the users in different contexts [61], [62]. However, this work defines SC in a different manner and the following hypothesis is thus proposed:

H_6: SC is positively associated with the PU of the various services provided by the smart-homes.

C. AUTOMATION (AM)

Automation refers to the execution of any task by a machine (usually a computer) that was previously carried out by a human-being [63], [64]. It affects all the five dimensions of the smart-homes that are identified above. The entire concept behind smart-homes is to create an intelligent and automated environment that will improve the QoL of its users. Thus, automation is one of the primary objectives of any smart-home system and there is a positive correlation between the various smart-home automation functions with the perceived usefulness of the system [65]. The overall positive association between automation and user intention has also been established in the context of autonomous cars [66]. In relation to the elderly people, researchers have investigated about their perception towards the use of ICT products like personal digital assistants, home automation systems, health monitoring systems and found out that these services are underutilized by this group of population [67]. Since most of the elderly people either live alone or have extremely limited number of family members (most of whom work outside during the entire daytime), automation is an important aspect for them, which can reduce their day-to-day activities and provide more convenience for those who suffer from some type of physical disabilities restricting their movements. Accordingly, we posit:

H_7: AM is positively associated with the PU of the smart-homes and related services.

D. UNIVERSAL CONNECTIVITY (UC)

Universal connectivity refers to "anywhere and anytime computing" [68]. The notion of universal connectivity allows access to information and services round the clock wherever the user goes without any interruption. This construct has been examined by a number of researchers in a variety of contexts ranging from mobile phone recommendation systems, mobile learning (m-learning) systems to near field communication (NFC) payment systems [50], [68], [69]. In all the cases, a significant relationship has been observed between this factor and the perceived usefulness of the system. Similar findings are also reported by researchers while examining the user acceptance of long-term evolution (LTE) services [70], [71]. The concept of universal connectivity fits well to the theme of smart-homes as it increases the user convenience and QoL by employing different type of sensors, display devices, mobile phones, and remote controls that allows access to the various services ubiquitously [72]. Therefore, in this study we define universal connectivity as *"the ability to access the smart-home services by the elderly people when they are away from their home or on the move by using mobile phones or related devices."* The corresponding hypothesis is:

H_8: UC is positively associated with the PU of the various services provided by the smart-homes.

E. SECURITY/PRIVACY (SP)

The basic aim of smart-homes is to create an automated environment for the user by collecting data about the inhabitant's lifestyle, daily activities, and preferences to support them effectively. Consequently, security and privacy of the user data is of prime concern [73], [74]. If the users perceive a risk with their personal data, then the chances of adopting a smart-home is very lean irrespective of the advantages that it can provide. Previous research has shown a negative association between the threats to security and privacy with the attitude of the users to use a smart-metering system [75]. The issue of security/privacy poses a unique challenge for the elderly population also. These groups of people are generally less technology savvy and have a slower learning curve for adopting a new technology/service. Hence, they are more vulnerable to the threats brought forward by the security/privacy issues of the smart-homes [76]. For this work, security/privacy is defined as *"the state of mind of the elderly people where they fear that their personal data will be lost and privacy will be infringed upon."* The relevant hypothesis is:

H_9: SP is negatively associated with the ATT of the elderly people towards using the smart-home services.

F. AFFORDABILITY (AF)

The success of any new technology is closely linked to the cost of that particular technology or service [77], [78]. A higher initial cost may prove to be a hindrance towards the acceptance of such a service [78]. Therefore, AF is defined as "*the price which the elderly users' considers to be an appropriate monetary sacrifice in return of the services that they get from using the smart-homes.*"If the elderly people feel that the price is not suitable for them, then the users' will show resistance in using those products/services [79], [80]. Affordability is particularly of concern for the elderly population as they lead a retired life and therefore have only a limited source of income. Thus, we posit:

H_{10}: AF is negatively associated with the BI of the elderly people to use the various smart-home services.

G. ENJOYMENT (EJ)

The close association between enjoyment and the intention to use any product/service has been well established by previous research [81], [82]. The relationship between enjoyment and intention is also valid for many Internet of Things (IoT) based smart products like smartwatches, fitness trackers to smart glasses [83], [84]. Concerning the elderly people, the smart-homes can provide a number of recreational services to them to enhance their moods and even provide companionship [43], [44]. Considering the fact that majority of them lead a solitary life, it will be extremely advantageous if the smart-homes can provide some sort of enjoyment services to these people. Therefore, we define enjoyment as "*the extent to which the elderly people perceive the smart homes to be enjoyable and provide recreational facilities*" and the corresponding hypothesis as:

H_{11}: EJ is positively influences the BI of the elderly people to use the various smart-home services.

H. SATISFACTION (SF)

The original definition of satisfaction is "the overall evaluation of an user's experience in using the system" [85]. A higher degree of user satisfaction about a particular information system positively affects the intention of users to use the system [86]. This factor has also been investigated for research into the elderly technology acceptance [8]. The elderly people are generally less innovative and late adopters of technology. Therefore, satisfaction is a prime criterion for them to accept any new technology or service [87]. Hence, we define satisfaction as *"the general evaluation of the elderly users experience in using the smart-home services."* The corresponding hypothesis is framed as:

H_{12}: SF is positively associated with the BI of the elderly people to use the various smart-home services.

I. SUBJECTIVE NORM (SN)

There is a lack of knowledge about the usability of a technology or service, when it is new. This is because there are very few people who have actually used them, and hence the general perception is unknown. In those cases, the user may be influenced by the opinions or suggestions provided by their friends and/or relatives [88], [89]. The relationship between technology adoption and subjective norm specifically for the elderly population has been considered in a few previous researches also [90]–[92]. In the present context subjective norm is defined as *"the perception of the elderly people that most of the people who are close or important to them think that they should use smart homes"*. The relevant hypothesis is:

H_{13}: SN is positively associated with the BI of the elderly people to use the smart-home services.

J. COMPATIBILITY (CP)

Smart homes typically contain devices made from different manufacturers. Enabling these different devices, applications and ecosystem to work in tandem is a serious challenge due to a confusing array of technologies and protocols used (Zigbee, Z-Wave, Bluetooth, WiFi and much more). This is where compatibility comes into play that can affect the user's intention to use the system [6]. In the context of smart-homes, compatibility can be achieved either by adopting universal standards for a communication protocol or by using a specialized device in the home network that acts like an interpreter among the different smart-home devices and protocols [6]. This can be a prime concern for accepting the smart-home services by the elderly people considering their limited enthusiasm in technology and need of stable and smooth services. In this work, compatibility is defined as *"the extent to which the different devices/sensors from the different manufacturers can work and communicate among themselves."* The hypothesis is:

H_{14}: CP is positively associated with the BI of the elderly people to use the smart-home services.

IV. RESEARCH METHODOLOGY

A. DATA COLLECTION

An online survey instrument targeted towards the elderly people has been developed to measure their perception about the smart-home services. The validity and consistency of the developed questionnaire has been checked prior to their administration to the target population by consulting two independent experts in the field of information systems. We have designed the survey questionnaire by separating it into two sections. While the first section gathers, data related to the characteristics of the participants (age, gender, household size, income, etc.) along with a basic question related to the smart-home awareness. This has been used as a screening question. It is used to minimize the response biases from people who absolutely have no idea or prior knowledge about smart-homes. The screening question used was "Do you know what smart-home technologies/services are?" Response options ranged from "no idea," "vague idea," "general idea," "good idea" to "already using some form of smart home technology/service." Respondents who answered "no idea" are filtered out and do not continue the entire survey. For all other respondents they moved on to part two. In order to ensure that the questionnaire reaches out to as many elderly people as possible a snowball sampling technique has been used in which our contacted subjects are requested to further contact their elderly friends or relatives. A total of 254 responses were obtained out of which 15 did not pass the screening criterion. Hence, for the final analysis we have data from 239 elderly people. The relevant descriptive statistics showing the respondents demographic information is shown in TABLE 3.

B. CONSTRUCT OPERATIONALIZATION

In part, two of the survey we have included questions that try to measure the intention of the elderly people to use the smart-home services. TABLE 4 shows the questionnaire details. TABLE 5 presents the descriptive information of the constructs used in the research framework. All the questionnaire items are evaluated on a 5-point Likert scale (1 = "strongly disagree" to 5 = "strongly agree"). In case of certain questions, an additional "don't know" response option has been provided. All the survey questions are developed, iteratively tested, and refined for clarity prior to their implementation. No background information has been provided to

TABLE 3. Descriptive statistics of respondents demographic information.

Characteristics	Number (N)	N %
Age		
55-64	112	44.1
65-74	90	35.4
75 and above	52	20.5
Gender		
Male	167	65.7
Female	87	34.3
Number of family members		
1	62	24.4
2	69	27.2
3	71	28
4	30	11.8
More than 4	22	8.7
Household income		
Less than 15,000	7	2.75
15,001 – 30,000	40	15.75
30,001 – 40,000	139	54.72
More than 40,000	68	26.77
Country of stay		
India	104	40.9
Thailand	85	33.5
Indonesia	29	11.4
Malaysia	36	14.2

the respondents at the beginning of the survey in order to minimize the priming effects on responses. The order of the response options for a particular set of construct has been randomized to minimize the potential ordering effects on responses [93].

C. MATHEMATICAL TECHNIQUE

The data that is collected from the online questionnaire survey is analyzed using a Confirmatory Factor Analysis (CFA) and Structural Equation Modelling (SEM) approach to test our research model. The convergent validity of the constructs is tested by using the CFA. While conducting the SEM, the Partial Least Square SEM (PLS-SEM) algorithm has been used, as it is best suited for exploratory study like ours where there is less of a theoretical backing to the underlying concepts and hypothesis and where the sample size is small to medium [94], [95]. In case of PLS-SEM the error variables are not part of the model at all; hence they are un-correlated and uncovariated.

V. DATA ANALYSIS AND HYPOTHESIS TESTING

In this section, the results of the data analysis and hypothesis testing are presented. CFA has been done by using SPSS version 17.0, while the process of hypothesis testing is done in Smart PLS version 3.0.

A. TESTS OF VALIDITY

Cronbach's alpha measures are used for checking the internal consistency of the questionnaire. The results are presented in TABLE 5. It is observed that all the constructs have high Cronbach's alpha values (more than 0.7). Therefore, a high degree of internal reliability has been achieved [96]. The highest alpha value = 0.84 has been obtained for the enjoyment construct, while the lowest one = 0.73 corresponds to the perceived usefulness construct.

Results for the test of convergent validity have been reported in TABLE 6. Regarding the convergent validity, we verified two conditions

- The factor loading of every item measuring a particular construct was calculated and found to be greater than 0.6. This is the first minimum requirement for the convergent validity test to pass [97].
- The average variance extracted (AVE) value was also calculated for every construct and found to be greater than 0.5, which is the second test for convergent validity [97]. Therefore, the mean variance shared between the latent variable (construct) and its indicators (items) is greater than 50%. When AVE is greater than this threshold, the variance explained by the items is greater than the variance arising from the measurement error.

The discriminant validity of the constructs is also tested, in order to ensure that two measures, which are not supposed to be related, are in fact, unrelated. The result of the discriminant validity test has been reported in TABLE 7. While examining the discriminant validity, the square root of the AVE for every construct should be greater than the correlational values that it shares with the other constructs. This is exactly what happens in our case (the diagonal elements in TABLE 7 represent the square root of AVE). Thus, the discriminant validity is also confirmed.

The Goodness of Fit (GoF) value is calculated with the AVE and R-square values of the structural model as per the formulae given in equation (1):

$$GoF = \sqrt{(average\ AVE) \times (average - R^2)} \tag{1}$$

The recommended GoF value should be greater than 0.36 [99], [100]. We obtain a GoF value of 0.78, which shows the validity of the model.

TABLE 4. Questionnaire details used in the study.

Construct	Item No	Question (responses based on 5 point Likert scale)	References
Intention to use	BI1	I expect to use smart home services in my house	[12,59, 61, 63]
	BI2	I am absolutely determined to use a smart home very soon	
	BI3	In intend to invest and use a smart home service as much as possible	
Attitude	ATT1	Using a smart home is a good idea	[12, 58, 59, 61, 63]
	ATT2	I like using smart devices in my home	
	ATT3	I have a positive feeling towards smart home services in general	
Perceived usefulness	PU1	Using smart home technologies makes my life more enjoyable	[12, 21, 59, 61, 63]
	PU2	Using smart home technologies improve the performance of my daily activities	
	PU3	I can accomplish my daily activities more quickly by using smart home services	
	PU4	There is an improvement in my overall quality of life when using smart devices	
Perceived ease of use	PEOU1	I can operate the smart devices in my home by myself	[12, 59, 61, 63]
	PEOU2	It is not difficult for me to use the smart devices present in my home	
	PEOU3	Using smart home technologies does not require any special mental or physical effort	
	PEOU4	It is easy and clear for me to use the various smart devices present in my home	
Self capability	SC1	I am absolutely confident using smart homes in my daily life	[62, 63]
	SC2	I have sufficient knowledge and ability to use smart homes by myself	
	SC3	Adopting smart home services is entirely within my control	
Automation	AM1	I find it convenient to use the auto-adjusted controls provided by my smart home	[65, 66, 67, 68]
	AM2	I can control the electronic appliances in a smart home through a very simple operation	
	AM3	Smart homes can simplify my daily life as it helps in reducing human intervention	
Universal connectivity	UC1	I find it useful to use smart home services anytime and anywhere	[21, 69, 70, 71, 72]
	UC2	I find it beneficial to use smart home services when I am away from home	
	UC3	It is advantageous to interact with my home environment from anywhere in the world	
Security/Privacy	SP1	I fear to use a smart home service due to loss of my personal data and privacy	[75, 76, 77]
	SP2	I find it risky to disclose my personal information to the smart home service providers	
	SP3	Smart homes provide a strong security and I feel safe about my personal data	
Affordability	AF1	I cost of building a smart home is too expensive for me	[78, 79, 80, 81]
	AF2	I cannot easily afford to use the services provided by a smart home	
	AF3	Purchasing and maintaining a smart home is a burden for me	
Enjoyment	EJ1	I find it fun to use the various smart home features	[32, 83, 84, 85]
	EJ2	I find the smart homes enjoyable and fascinating	
	E3	Using smart home functionalities is so interesting that I don't do anything else when I use it	
Satisfaction	SF1	Overall I am satisfied using a smart home	[8, 86, 87, 88]
	SF2	The services provided by a smart home meet my expectations	
	SF3	Smart homes are beneficial for me to improve my overall life quality	
Subjective norm	SN1	I will use smart homes if media/government encourages to use them	[91, 92, 93]
	SN2	I will use smart devices in my house if my family members and friends do so	
	SN3	I will use a smart home if people whose opinion I value recommend me to do so	
Compatibility	CP1	I am able to use the smart home services with my existing smartphone	[17, 102]
	CP2	Purchasing smart home devices from different vendors do not create any operational problem	
	CP3	The smart home devices can inter-operate with each other	

TABLE 5. Descriptive statistics and internal consistency of the used Questionnaire.

Construct	Mean	Standard Deviation	Cronbach's Alpha
Intention to use (BI)	4.06	0.72	0.82
Attitude (ATT)	4.02	0.81	0.64
Perceived usefulness (PU)	4.13	0.75	0.73
Perceived ease of use (PEOU)	3.95	0.66	0.77
Self capability (SC)	3.76	0.95	0.81
Automation (AM)	3.66	0.86	0.76
Universal connectivity (UC)	3.88	0.78	0.77
Security/Privacy (SP)	4.32	0.80	0.83
Affordability (AF)	3.99	0.57	0.80
Enjoyment (EJ)	4.07	0.85	0.84
Satisfaction (SF)	3.95	1.04	0.78
Subjective norm (SN)	4.01	0.62	0.82
Compatibility (CP)	3.97	0.93	0.79

B. HYPOTHESIS TESTING

The hypothesis testing is done in Smart PLS 3.0. In order to test for the significance level and obtaining the path coefficients, the bootstrapping procedure is followed [103]. In the bootstrapping method, subsamples are created with randomly drawn observations from the original set of data (with replacement). The sub-sample is then used to estimate the PLS path model. The process is repeated until a large number of random sub-samples have been created. For our case, we used a maximum iteration value of 300 that gives an

TABLE 6. Test for convergent validity.

Construct	Item	Factor loading	Composite reliability	Average variance extracted
Intention to use	BI1	0.975	0.967	0.908
	BI2	0.934		
	BI3	0.950		
Attitude	ATT1	0.901	0.935	0.827
	ATT2	0.916		
	ATT3	0.912		
Perceived usefulness	PU1	0.858	0.970	0.845
	PU2	0.948		
	PU3	0.946		
	PU4	0.915		
Perceived ease of use	PEOU1	0.932	0.971	0.726
	PEOU2	0.961		
	PEOU3	0.917		
	PEOU4	0.901		
Self capability	SC1	0.920	0.944	0.849
	SC2	0.945		
	SC3	0.898		
Automation	AM1	0.904	0.932	0.823
	AM2	0.927		
	AM3	0.891		
Universal connectivity	UC1	0.771	0.808	0.584
	UC2	0.769		
	UC3	0.754		
Security/Privacy	SP1	0.887	0.922	0.798
	SP2	0.904		
	SP3	0.891		
Affordability	AF1	0.835	0.875	0.705
	AF2	0.821		
	AF3	0.862		
Enjoyment	EJ1	0.895	0.953	0.872
	EJ2	0.966		
	EJ3	0.939		
Satisfaction	SF1	0.880	0.898	0.749
	SF2	0.863		
	SF3	0.854		
Subjective norm	SN1	0.925	0.954	0.874
	SN2	0.947		
	SN3	0.933		
Compatibility	CP1	0.836	0.859	0.672
	CP2	0.852		
	CP3	0.769		

TABLE 7. Test for discriminant validity (diagonal position contains the square root of ave).

	BI	ATT	PU	PEOU	SC	AM	UC	SP	AF	EJ	SF	SN	CP
BI	**0.953**												
ATT	0.845	**0.909**											
PU	0.799	0.717	**0.919**										
PEOU	0.647	0.666	0.567	**0.852**									
SC	0.664	0.653	0.862	0.525	**0.921**								
AM	0.502	0.489	0.651	0.467	0.710	**0.907**							
UC	0.299	0.248	0.292	0.146	0.122	0.124	**0.764**						
SP	-0.656	-0.602	-0.575	-0.520	-0.567	-0.250	-0.515	**0.894**					
AF	-0.730	-0.729	-0.719	-0.563	-0.633	-0.306	-0.515	-0.588	**0.839**				
EJ	0.261	0.298	0.246	0.132	0.206	0.162	0.248	-0.154	-0.279	**0.933**			
SF	0.455	0.443	0.492	0.451	0.429	0.278	0.471	-0.378	-0.273	0.353	**0.865**		
SN	0.536	0.531	0.446	0.501	0.433	0.324	0.419	0.367	-0.338	0.361	0.544	**0.935**	
CP	0.712	0.619	0.651	0.598	0.619	0.215	0.448	-0.650	0.626	0.135	0.401	0.674	**0.819**

optimal performance [103]. TABLE 8 gives the results of the hypotheses testing, while the final theoretical framework has been shown in Fig. 4.

The results show that all the hypotheses except H_8 and H_{11} are supported. The original TAM constructs i.e. attitude (H_1, $\beta = 0.371$, t statistic $= 4.908$ and $p < 0.001$) and perceived usefulness (H_2, $\beta = 0.231$, t statistic $= 2.953$ and $p = 0.003$) have a significant effect on the elderly behavioral intention. Likewise, perceived usefulness (H_3, $\beta = 0.424$, t statistic $= 5.735$ and $p < 0.001$) and perceived ease of use

TABLE 8. Results of hypotheses testing for the eshtam framework.

Hypothesis no	Hypothesis/Path	Standardized coefficient (β)	T - statistics	P - value	Hypothesis status
H_1	Attitude -> Behavioral intention	0.371	4.908	< 0.001	Supported
H_2	Perceived usefulness -> Behavioral intention	0.231	2.953	0.003	Supported
H_3	Perceived usefulness -> Attitude	0.424	5.735	< 0.001	Supported
H_4	Perceived ease of use -> Attitude	0.330	4.809	< 0.001	Supported
H_5	Perceived ease of use -> Perceived usefulness	0.133	2.757	0.006	Supported
H_6	Self capability -> Perceived usefulness	0.741	11.701	< 0.001	Supported
H_7	Automation -> Perceived usefulness	0.177	3.539	< 0.001	Supported
H_8	Universal connectivity -> Perceived usefulness	0.041	0.729	0.466	**Not supported**
H_9	Security/Privacy -> Attitude	-0.185	2.775	0.005	Supported
H_{10}	Affordability -> Behavioral intention	-0.338	3.270	0.001	Supported
H_{11}	Enjoyment -> Behavioral intention	0.020	0.664	0.507	**Not supported**
H_{12}	Satisfaction -> Behavioral intention	0.454	6.327	< 0.001	Supported
H_{13}	Subjective norm -> Behavioral intention	0.228	2.810	0.005	Supported
H_{14}	Compatibility -> Behavioral intention	0.135	2.076	0.038	Supported

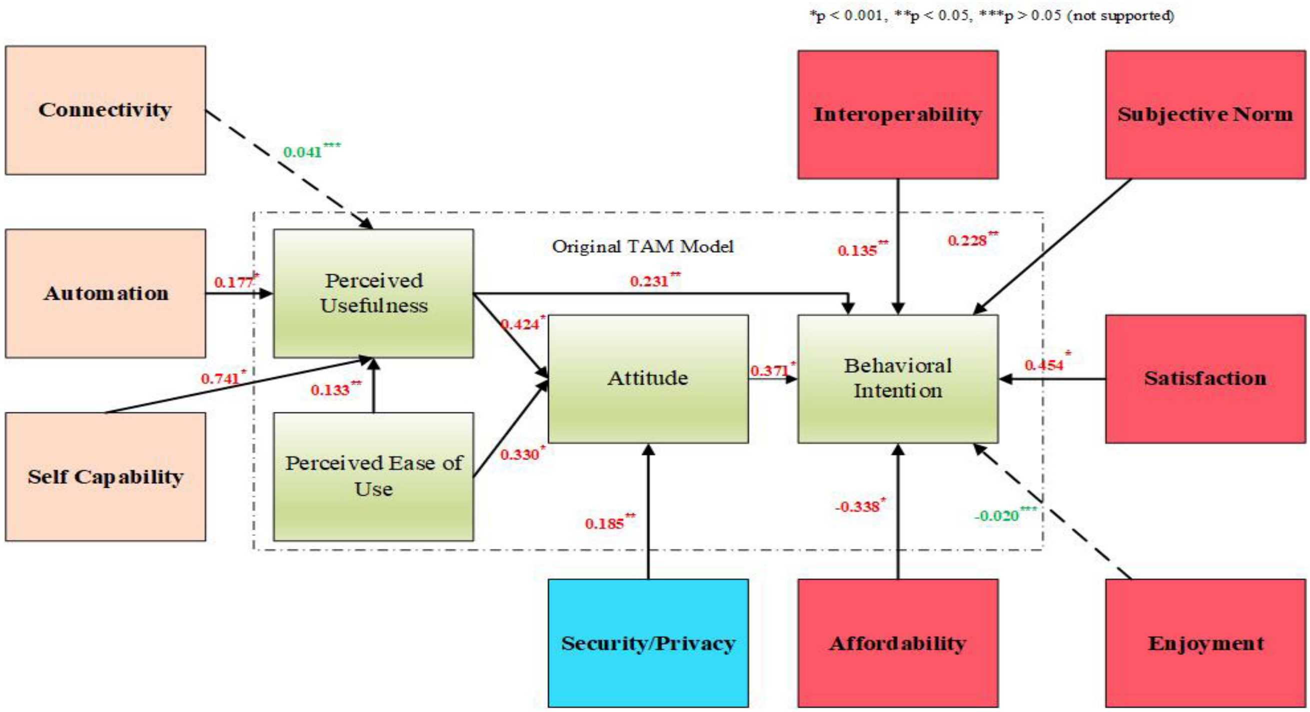

FIGURE 4. Summary of the ESHTAM framework.

(H_4, $\beta = 0.330$, t statistic = 4.809 and $p < 0.001$) also have a significant positive effect on the elderly attitude. The security/privacy construct (H_9, $\beta = -0.185$, t statistic = 2.775 and p = 0.005) has a significant negative association with attitude. The relation between perceived ease of use (H_5, $\beta = 0.133$, t statistic = 2.757 and p = 0.006) and perceived usefulness also hold true. Apart from perceived ease of use, two out of the three constructs that we have defined for our ESHTAM model, self-capability (H_6, $\beta = 0.741$, t statistic = 11.701 and $p < 0.001$) and automation (H_7, $\beta = 0.177$, t statistic = 3.539 and $p < 0.001$) are found to have positive effects on the perceived usefulness. In fact, self-capability is the strongest predictor of perceived usefulness as evident from its β value. However, the proposed relationship between universal connectivity (H_8, $\beta = 0.041$, t statistic = 0.729 and p = 0.466) and perceived usefulness is insignificant. Satisfaction (H_{12}, $\beta = 0.454$, t statistic = 6.327 and $p < 0.001$), subjective norm (H_{13}, $\beta = 0.228$, t statistic = 2.810 and p = 0.005) and compatibility (H_{14}, $\beta = 0.135$, t statistic = 2.076 and p = 0.038) are found to have significant positive associations with the behavioral intention, while it is negative for the affordability construct (H_{10}, $\beta = -0.338$, t statistic = 3.270 and p = 0.001). The relationship between enjoyment (H_{11}, $\beta = 0.020$, t statistic = 0.664 and p = 0.507) and behavioral intention is insignificant.

Affordability, compatibility, subjective norm, satisfaction, attitude, and perceived usefulness together can explain 85.4% of the variance in behavioral intention. Perceived usefulness, perceived ease of use and security/privacy accounts for 63.5% of the variance in attitude, whereas 79.3% of the variance in perceived usefulness is accounted for by the perceived ease of use, self-capability, and automation constructs.

VI. DISCUSSION

A. THEORETICAL IMPLICATIONS

In this work, we have proposed an acceptance model of the smart-home services for the elderly people. For this purpose, we have utilized the basic idea behind the TAM model and extended it by proposing nine exogenous constructs that reflect the unique requirements of the elderly people along with the functionalities provided by smart-homes, which can prove to be beneficial to them. Self-capability, automation, universal connectivity, security/privacy, affordability, enjoyment, satisfaction, subjective norm, and compatibility are the nice exogenous constructs we define apart from the original TAM constructs.

A number of conclusions can be made based upon the results that we obtain. Satisfaction is found to be the strongest predictor of behavioral intention. This is in line with the findings of other researchers in [103] and [104], who confirmed overall user satisfaction to be a key factor that determines the intention of the users to use a system. Thus, the manufacturers of the smart-home devices must come up with new innovative solutions, which are easy to use by the elderly people in order to improve their overall satisfaction level. Specific elderly characteristics like reduced cognitive capacity, a slower learning curve, less enthusiasm in technology, etc. should be kept in mind while designing and providing the smart-services that must be simple, straight-forward and devoid of any complexity in order to raise their satisfaction level.

Subjective norm also affects behavioral intention in a positive way. This can be attributed due to a combined effect of the elderly people and the relatively young age of the smart-homes in place. The elderly people have very little to no experience in using smart-homes and they are less adventurous in trying out a new technology by themselves. Hence, they prefer to rely on the opinion of the people they trust.

Affordability is another major hindrance towards the acceptance of the smart-home services by the elderly people. Currently, the high cost related to the initial set-up of a smart-home proves to be a barrier to its adoption. The psychological mindset of the elderly people is different from the early adopters of any new technology to whom a high price can be a less important factor [105]. Thus, the smart-home device manufacturers must consider cost to be an important factor if they want the smart-homes to be widely used by the elderly people.

The compatibility construct has very little influence on the behavioral intention (β value of 0.135). This suggests that the elderly people do not perceive interoperability among the various smart devices to be an issue. They use only a limited service provided by the smart-homes indicating towards a monolithic environment in which most of their devices are from the same manufacturer. It is difficult for the elderly people to perceive the direct benefits of compatibility due to a lack of commercial smart-home services and the technical problems of standardization across different manufacturers.

The strangest observation is seen for the relationship between enjoyment and behavioral intention, which is non-significant. This is in sharp contrast to the previous studies where enjoyment was a significant determinant of overall user intention [81]–[83]. The elderly people do not perceive smart-homes to be a source of enjoyment. Keeping in mind the various types of physical and cognitive disabilities that these people can suffer from due to their age, the smart-home functionalities that can assist with their overall health problems and enable them to live independently are more important than the enjoyment or recreational facilities that they provide. Thus, while designing smart-homes for the elderly, health and social aspects should be given a priority rather than the hedonic values.

In addition, this study verifies that security/privacy is negatively associated with user attitude. People do not trust brands to handle their personal information appropriately signifying potential privacy issues. The results from our study suggest that the elderly people also acknowledge the risks of privacy and data breach. Thus, the smart-home service providers must give more stress on data privacy and anonymity if the smart-home services are to succeed.

Interestingly, among the four determinants of perceived usefulness (universal connectivity, automation, self-capability and perceived ease of use), self-capability is found to be the strongest predictor with a β value of 0.741. In our survey, around 24% of the elderly people live alone followed by another 27% who have just two members. As a substantial portion of the elderly population, either live alone or is supported by a caregiver, hence they believe in their own capabilities to use any form of technology/service. This is a very crucial factor that the smart-home device manufacturers and service providers must keep in mind while designing such systems for the elderly. The device operation and user interface should be as minimal as possible devoid of unnecessary complexity. Since, with ageing there can be problems with vision; hence voice assistance can be integrated with the smart-homes meant for them.

Automation, which is a primary goal of smart-homes also, has a significant influence on the perceived usefulness. Automating a home environment increases the convenience for the elderly people. Since, this age group people can suffer from various forms of physical disabilities, automating certain tasks can improve their sense of independence and lead to a better QoL.

Universal connectivity is found to be non-significant. This is in contrary to the previous findings by researchers in [49], [67], and [68]. Generally, the elderly people have limited mobility due to physical problems and tend to live in their home as much as possible. Thus, the notion of using the smart-home services from outside their home has little meaning to them. However, the opinion of the general population (other than the elderly) can be different in this regard and needs further investigation.

B. METHODOLOGICAL IMPLICATIONS

This study offers some important insights into analyzing the acceptance behavior of the elderly from a methodological perspective. As pointed out previously there is a lack of theoretical approach in technology acceptance modelling of the smart-homes since studies usually concentrate on a specific technology or service [7]. However, more focus should be given on the general perception of the users' acceptance behavior. Therefore, our study introduces an approach to measure the perception of a service that is in its initial stage of diffusion.

VII. CONCLUSION AND SCOPE OF FUTURE WORK

The concept of smart-homes is still evolving and new, which lacks widespread usage on a commercial basis. In this work, with elderly people as the prime target, we have attempted to propose a theoretical framework based upon the popular Technology Acceptance Model. For model building, an in-depth literature review regarding the usage of smart-homes by these people has been done and five different use-cases are identified [14]. Nine exogenous constructs are proposed to be an integral part of our ESHTAM framework apart from the original TAM constructs. The empirical results show that the ESHTAM framework has a good explanatory power with a R^2 value of 85.4%. This implies that the integration of TAM along with our proposed constructs is able to create a useful theoretical framework to explain the usage intention of smart-homes among the elderly.

A. RESEARCH RECOMMENDATIONS

There are a number of recommendations for the smart-home device manufacturers and service providers from this study. The elderly people belong to a special age group and therefore there are certain factors, which are unique to them. In order to increase the adoption rates, the manufacturers should focus on designing systems that are simple to operate. This can be in the form of easy to understand user-interfaces or simple hardware actions that can trigger a specific function. While designing smart-homes for the elderly, the focus should be on usage simplicity rather than various system functionalities. Also, in order to support more automation, large-scale investments have to be made in the form of data centers and big data analyzing solutions that can track the smart-home residents' lifestyle and provide them with the right type of environment, which will ultimately improve their QoL. Rather than creating a fancy environment for entertainment and recreation purpose, the smart-homes for the elderly should provide more health benefits. Tracking of vital health statistics and assurance of round the clock medical assistance service if needed will increase the adoption rate of smart-homes among the elderly largely. Therefore, the service providers must come up with innovative smart healthcare ideas to satisfy this age group of people.

The compatibility issue of the devices used in a smart environment should also be resolved. Therefore, more research needs to be done towards adopting a universal standard protocol that all the devices can use irrespective of the manufacturer. Alternatively, the manufacturers can develop some form of universal interpreter or gateway that can perform the necessary protocol translations from various heterogeneous devices if needed. In order to promote a standardized platform there have been efforts from many companies like Open Interconnect, Linux Foundation, etc. who are trying to create a proper technical architecture that can be followed by any smart-home service provider. These recommendations should serve as a baseline for the various smart-home stakeholders that will increase its chances of adoption by the elderly people.

B. LIMITATIONS AND FUTURE WORK

One of the current limitation of this work is the geographical distribution of the elderly subjects. All the elderly people are from India, Thailand, Indonesia, and Malaysia. However, more number of elderly people from across the globe should be included in order to test for any significant differences in opinion. In addition, we can extend our current findings by investigating the moderating effects of gender, and cultural background.

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