Hindawi
Advances in Human-Computer Interaction
Volume 2018, Article ID 7249378, 15 pages
https://doi.org/10.1155/2018/7249378

Review Article

Tangible User Interface for Social Interactions for the Elderly: A Review of Literature

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Received 30 November 2017; Revised 20 February 2018; Accepted 14 March 2018; Published 2 May 2018

Academic Editor: Thomas Mandl

The global population is ageing rapidly. The ageing population faces not only the risk of health-related problems but also the challenge of social isolation and loneliness. While mainstream technology is designed to improve daily life, elderly people's unique needs are often neglected. These technology designs can be difficult for older adults to learn and use. Tangible user interface (TUI) gives physical form to digital information, with the aim of bridging the gap between the digital world and the physical world. Thus, it can be a more natural and intuitive interface for the older adults. The objective of this research is to review the existing research on TUI for enhancing the social interactions of elderly people. Results show that very little research has been published, given that the TUI concept was introduced 20 years ago. Our systematic literature review also resulted in several recommendations for future research, which includes getting elderly people involved in the process, from designing to evaluating the prototype and investigating the effect of TUI on older adults' social interactions and health.

1. Introduction

According to DESA, the United Nations Department of Economic and Social Affairs [1], the number of adults who are 60 and above will grow from 901 million to 1.4 billion between 2015 and 2030. This number is projected to grow to 2.1 billion by 2050 and 3.2 billion in 2100. Due to socioeconomic developments, people tend to live better, have better healthcare, and thus, are living longer [2]. Life expectancies are increasing, while fertility rates remain low, and this condition is expected to continue in the coming decades. However, evidence is scarce as to whether these added years are lived in good health and function [3, 4]. Thus, since the world population is ageing rapidly, it is essential to identify determinants of healthy ageing so one can maintain his or her function and preserve health as long as possible [5].

Healthy lifestyles have a strong association with healthy ageing and maintenance of social and physical function [6]. According to World Health Organization (WHO) [7], social well-being is one of the elements required for a person to be healthy. In Europe, at least one-third of the elderly people live alone [8], who tend to be socially excluded. This number is growing according to recent statistics [9]. Being socially active, which means having good social interactions, can contribute to our well-being and feelings of belonging, which makes us happy [10]. Social relationships are found to be a significant predictor of well-being across the course of life [11–13] which is perhaps particularly salient for older adults [14, 15].

While information and communication technologies (ICT) tools designed to improve daily life are expanding widely, the special needs of elderly people have always been neglected in the design of technology tools such as mobile applications and social media [16, 17]. Older adults might not be as good as younger people when it comes to physical and cognitive abilities, and every elderly person is different. As a result, older adults need a better design for interaction while using technology tools.

Tangible user interface (TUI) can be defined as an interface where everyday physical objects play a central role as both physical representations and controls for digital information [18, 19]. In short, TUI makes no distinction between "input" and "output." TUI offers an intuitive design that allows tactile manipulation and physical expressiveness

by coupling digital information with physical objects and environments [20]. It merges physical objects with digital information. By using physical objects to represent digital output, TUI eliminates the need to have intangible output devices such as monitors and speakers [21]. Thus, TUI has been identified by Spreicer [21] as having great potential to improve older adults' acceptance of technology acceptance. This can be a more natural, intuitive, and easier interaction for elderly people, which might also result in less cognitive and physical efforts required from them.

Therefore, TUI has potential to make technology tools more accessible to elderly people. The objective of our review is to gain an overview of the evidence. By conducting this systematic literature review, we wish to summarize the current research evidence where elderly people are involved in TUI design process and TUI has an impact on the social interactions of older adults. We identify possible shortcomings of the current research in this area and suggest improvements. This paper is organized as follows. After the Introduction, we present the background, covering loneliness and social interactions of older adults and TUI. We present methods and process of the literature review in Section 3, from planning, conducting a review, and studying the selection, to reporting on the review. Results are discussed in Section 4. In Sections 5 and 6, we present our recommendations and conclude the paper by reflecting on the process and outcome.

2. Background

2.1. Loneliness and Social Interactions of Elderly People. Loneliness can be defined as a feeling or emotional state of individuals who are dissatisfied with their social relationships. This dissatisfaction occurs when they face a difference between what they expect or want and what they get when it comes to their social lives [22]. Social interaction is defined as "*two or more autonomous agents co-regulating their coupling with the effect that their autonomy is not destroyed and their relational dynamics acquire an autonomy of their own. Examples: conversations, collaborative work, arguments, collective action, dancing and so on*" [23]. Thus, any form of socialization between two or more agents, for instance, between elderly people with their friends and families, health personnel, or even new people who they have never talked to, is considered as social interaction as long as it is done with their own will. Social interaction varies across gender and age [24]. Due to transitions in one's life cycle, for instance, from schooling to working then retirement, from being single to getting married, and so on, the social interaction changes.

Elderly people who are dissatisfied or inactive in their social interactions would feel lonely and socially isolated. Loneliness and social isolation among the ageing population are significant concerns as they have varied negative impacts on elderly people's health [25–31]. Socially disconnected older adults (e.g., having small social networks and infrequent participation in social activities) face the possibilities of having inferior physical and mental health because of being isolated [32]. Studies have also demonstrated associations between loneliness and diseases such as heart disease, hypertension, stroke, lung disease, and metabolic disorders [29]. Being active in social interaction can contribute in less cognitive decline and better physical well-being [24]. Thus, having good social interactions is essential, as active social lives can help maintain a good quality of life, health, and physical functioning [33, 34].

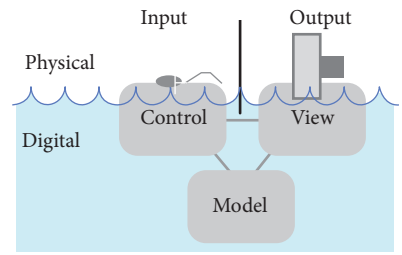

Figure 1: Interaction model of GUI: Model-view-control model from Smalltalk-80 [35].

Many studies have been conducted regarding the use of ICT tools to prevent or reduce the social isolation of elderly people, but the outcomes are ambiguous. Social isolation has been identified by Chen and Schulz [17] as an untested concept in these studies since most studies only evaluated loneliness, social network size, and social support. Thus, the effects of these ICT interventions on the overall perception of social isolation remain largely unknown. They also suggested that the ICT solutions are not "one for all." The benefits of ICT interventions to improve older adults' social interactions can only be maximized if the potential elderly users can be identified.

2.2. Tangible User Interface (TUI). Much of our daily life has become digitalized. From physical walk-in banks to electronic banking (e-banking), from abacus and physical calculator to calculator in computers and mobile phones, more of our physical surroundings are being replaced by the digital world. With the intention of rejoining the richness of physical world in Human Computer Interaction (HCI), Ishii and Ullmer [18] introduced the vision "Tangible Bits." By coupling digital information (bits) with everyday physical objects and architectural surfaces, the interaction between humans and digital information can be enhanced from its traditional Graphical User Interface (GUI).

The traditional GUI obtains input from control and displays the output in the forms of "digital representations" [19]. As illustrated in Figure 1, this interaction model was developed in conjunction with Smalltalk-80 programming language [35]. The difference between the traditional GUI interaction model and TUI is that TUI does not make a distinction between input and output (Figure 2).

According to Ullmer and Ishii [19], TUI has three main characteristics, as shown in Figure 2. They are as follows:

(1) Physical representations *(rep-p)* are computationally coupled to underlying digital information *(model)*.

(2) Physical representations embody mechanisms for interactive control *(control)*.

(3) Physical representations are perceptually coupled to actively mediated digital representations *(rep-d)*.

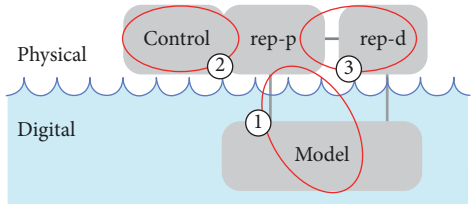

Figure 2: Interaction model of TUI by Ullmer and Ishii [19].

Besides that Ullmer and Ishii [19] suggest five types of tasks which TUI is good for. They are as follows:

(1) Information storage, retrieval, and manipulation.

(2) Information visualization.

(3) Modelling and simulation.

(4) Systems management, configuration, and control.

(5) Education, entertainment, and programming systems.

Tangible Bits aim to eliminate the gaps between the physical and digital world, as well as the foreground and background of human activities. Ishii and Ullmer [18] presented three key concepts of Tangible Bits:

(1) Interactive surfaces: surfaces such as walls, ceilings, doors, and windows are transformed into active surfaces between physical and digital worlds.

(2) The coupling of bits with graspable physical objects: everyday graspable objects such as cups, books, and cards are coupled with digital information.

(3) Ambient media for background awareness: ambient media such as sound, light, airflow, and water movement serve as the background interfaces for digital worlds where a human being can perceive them.

Due to its advantage in using haptic interaction to interact with the digital world, TUI has been used in fields such as learning, problem solving and planning, information visualization, tangible programming, entertainment, and social communication [36]. Urban Planning Workbench (Urp) was developed by Underkoffler and Ishii [37] as the first generation of TUI. Scaled physical models of buildings were used as representations of digital models of the buildings, so users can manipulate them physically to change location and simulate shadow, light reflection, and more.

From Urp, it is clear that collaboration, learning, and decision making though digital technology could be enhanced by having a human being physically touch and interact with the physical objects [38]. Although TUI provides an excellent platform for collaboration and makes users feel "situated" in the real world with digital information, it faces the problem of scalability and versatility [36]. The more digital information users must deal with, the more complex the TUI must be. Digital objects are easy to create and modify, but physical objects cannot be transformed as easily as digital objects.

3. Method and Results

The methodology of this review has been derived by referencing other published literature review and refers to the systematic literature review guidelines by Keele [39]. Our review methodology consists of three main phases.

3.1. Planning the Review. During this phase, we identified the needs for this literature review, which we clarified and presented in our introduction. To identify the gaps and give recommendations for future research directions [39, 40], we reviewed the state-of-the-art existing literature in this area. The research questions were generated accordingly, and they are listed as follows:

(1) How does TUI impact the social interactions of elderly people?

(2) Have elderly people been involved in the process of design and development of TUI prototype, and if so, in which way?

3.2. Conducting the Review. From the research questions, we identified three main search terms, and they were "elderly," "tangible user interface," and "social." Before performing the search, the inclusion and exclusion criteria were defined.

(1) The target group of the paper must be older adults who are generally above 50.

(2) Papers must focus on TUI.

(3) Papers must focus on the social aspect.

(4) Papers where TUI focuses on robot, mobile, computer and tablet-based applications, ambient intelligence, and smart homes are excluded. Our primary focus on TUI is using everyday objects and not a whole environment or unfamiliar object. Robot, mobile, computer and tablet-based applications, ambient intelligence, and smart homes do not fulfil the condition of using an everyday object as TUI. Mobile phones, computers, and tablets also have a certain level of difficulty in use for the elderly people. Both ambient intelligence and smart homes work as an environment and not a single object. Therefore, they are also excluded.

(5) Only published or peer-reviewed works are included. Dissertations and theses are excluded.

(6) Non-English papers are excluded.

The search was conducted from 20 June 2017 to 10 July 2017 by two researchers, separately. Four electronic databases recommended by Brereton et al. [41] and one by Keele [39] were used in performing the search. Combining the main search terms and inclusion and exclusion criteria, the generated search string was *elderly AND "tangible user interface" AND social AND NOT robot AND NOT "smart home" AND NOT "ambient intelligence"*. A supplement search using the same search string was conducted on Google Scholar (also recommended by Brereton et al. [41]) from 29 January 2018 to 31 January 2018.

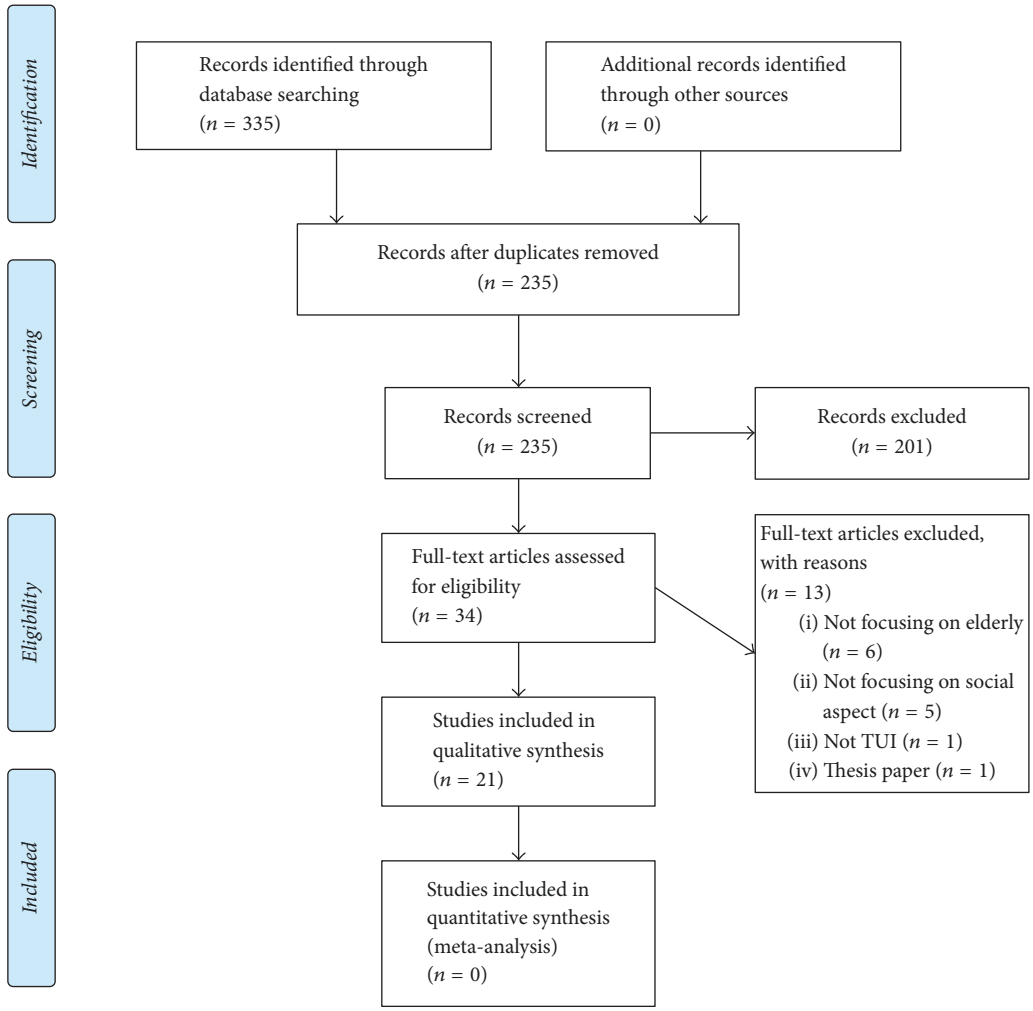

Figure 3: Process of review using a PRISMA flow diagram.

Table 1: Summary of electronic databases and number of search results.

Electronic database	Number of search results
ACM	66
Springer	69
Science Direct	14
Engineering Village	8
IEEE	10
Google Scholar	168
Total	335

We did not exclude mobile, computer, and tablet at this stage because we considered the possibility of researchers using these technologies in developing their TUI prototypes. The results from each electronic database are summarized in Table 1.

Total records identified through database search and other sources from two searches are 335 papers. Records after removing duplicates are 235 papers. After removing duplicates, abstracts of the papers were read, and the content of the papers was screened by both researchers to determine if the papers fulfilled all the inclusion criteria and exclusion criteria.

Synonym terms for "elder" such as aged, old, and senior were searched throughout the papers to check if they fulfilled criteria (1). The papers were also checked to determine if they fulfilled the definition of TUI. A TUI makes no distinction between input and output, just like an abacus [19]. Prototypes that were purely mobile, computer, or tablet-based were also excluded. The screening resulted in 34 papers. 201 papers were excluded at this stage due to the fact that they did not fulfil all of our inclusion and exclusion criteria as stated in Section 3.2.

After screening, the papers were assessed and read in full-text for eligibility, to check if they fulfilled all the inclusion and exclusion criteria. 21 papers were included as relevant papers that use the concept of TUI in enhancing social interactions of elderly people. Figure 3 illustrates the process using a PRISMA flow diagram [42]. There were no studies included in quantitative synthesis due to no common data being measured in the selected papers.

3.3. Studying the Selection and Reporting the Results. The 21 selected papers were studied and reviewed. The research questions guided the review process, and the review was based on the following criteria:

(1) Objective of the study.

(2) Discipline in which the author and coauthors of the papers worked.

(3) Methodology guiding the design and development of the prototype.

(4) Methodology guiding the evaluation processes.

(5) User involvement (user here means elderly people. Involvement means involvement at any stage of the research).

(6) Sample size and demographics (during evaluation).

(7) Evaluation method and data capture.

Most of the papers aimed at designing, developing, and evaluating their prototypes which targeted to address loneliness and social exclusion among elderly people. Most of the authors and coauthors of the papers worked within the technology field, while a few worked in art and design. Regarding methodology for design and development of the prototypes, six papers [43–48] adopted a user-centered approach which involves users in the iterative process of requirement gathering, design, development, and testing. Although other papers did not use user-centered approach, some of them did involve users to identify their requirements. For instance, Zhao et al. [49] conducted interviews with 10 elderly people in their first design study, while Davidoff et al. [50] used semistructured interviews with six email-using elderly participants.

In terms of methodology for evaluating the prototypes, one paper [51] did not present any testing or evaluation of their proposed TUI. The other 20 papers used empirical approach. All 21 papers presented their prototypes and all but two [51, 52] involved users in their evaluations. Four papers [44, 46, 53, 54] reported that they had evaluation but did not present information about their sample. Thus combining the two papers that did not involve users in their evaluation, a total of six papers had no sample. The summary of the review is presented in Table 2.

4. Discussion

4.1. Evidence and Number of Relevant Papers. The review results indicate very little use of TUI to enhance older adults' social interactions. Our search using six electronic databases resulted in 167 search results, and out of these 167 search results, only 21 papers fulfilled all the inclusion and exclusion criteria. The number of papers selected after all screening processes shows the lack of research in using TUI for elderly people's social interactions.

The search results include many research works using touch gestures, such as mobile applications and tablet-based applications since touch gestures are also a kind of "tangible" user interface. However, this review only targets on the TUI that uses Tangible Bits, where digital bits are coupled with everyday physical objects and architectural surfaces [18]. Elderly people do have problems using touch-gesture devices [16, 64, 65]. As a result, researches where the prototype was mobile, tablet, and even computer-based were excluded and we only considered TUI that adopted everyday physical objects in our review.

No time range was applied during the search in order to include as many search results as possible. Although the TUI was introduced by Ishii and Ullmer [18] nearly 20 years ago, our review only managed to identify 21 relevant papers using TUI to improve the social interactions of the older adults. Three out of 21 papers [44, 46, 47] were on same project, kommTui. Thus the number of individual studies was even smaller. The small number of papers indicated little evidence of research work done in this field.

In terms of data capture by the 21 reviewed papers, most of them focused on the usability aspect of the prototype. Only seven papers focused on the social interaction of the elderly people. Foverskov and Binder [43] studied the possibilities for elderly people to have more active interactions and dialogues; workshop series conducted by Ehrenstrasser and Spreicer [47] in 2010 explored on the communication habits of elderly people; Meza-Kubo et al. [56] studied interactions of elderly people within cognitive stimulation sessions and the factors affecting the relationships of them with their family through case study; Huldtgren et al. [58] observed the interactions of the elderly participants with a tangible multimedia book and interactions between people during reminiscence sessions; Marques et al. [53] conducted usability testing to observe how elderly people used tangible objects and interacted with other players while playing tabletop game; using tangible objects and tabletop surface, Murko and Kunze [62] studied the well-being of the dementia patients in terms of social interactions between caregivers and patients; and lastly, Angelini et al. [63] evaluated whether elderly participants managed communicate with the person on the other side of the prototype, a tangible window. The small amount of reviewed papers focusing on social interaction of the elderly people clearly shows the lack of evidence in using TUI to make an impact on the social interactions of older adults.

4.2. The Objectives of the Papers. The majority of the papers in our review focused on usability, accessibility. and user experience, as they effect the elderly people's acceptance of the newly introduced technology. However, some focused more on other aspects. For example, Fu et al. [55] targeted to provide elderly people a tangible self-health management system. In the mean time they acknowledge that health and social interaction are very much related. Thus, the system linked the elderly people with their family, friends, and doctors by cross-media platform and social network.

Meza-Kubo et al. [56] designed a TUI pervasive cognition simulation collaboration system. The system aimed at not only reducing the risks of suffering a cognitive decline related condition, but also addressing the technical, social family networks and illiteracy gaps of the elderly people. Augmented reality cubes were designed by Boletsis and McCallum [57] to

Table 2: Summary of review results.

Paper #	Objective of the paper	Discipline	Design & development methodology	Evaluation methodology	User involvement	Sample size & demographics	Evaluation method & data capture
[50]	To design and conduct a preliminary evaluation of a "the book as user interface"-based email system for elderly people	Human-Computer Interaction	Semistructured interviews with email using elderly participants	Yes. Empirical	Yes	Six participants (five were using a computer for the first time, while one was a complete beginner)	Questionnaire. Perceived ease of use and feelings of independence
[45]	To promote reminiscence and memory sharing activities by explore the suitability of using digital media with tangible scrapbook application	Information Technologies, Computer Science and Informatics	User-centered	Yes. Empirical	Yes	Not elderly participants	User study experiment and questionnaire. Usability in terms of performance results, ease of use, usefulness, and so on
[44]	To better design usable and user-sensitive interaction for the elderly people, with the purpose to increase their acceptance using ICT for communications	Technology Assessment & Design, Inclusive Design and Research	User-centered	Yes. Empirical	Yes	Not mentioned	Workshop. Usability
[49]	To design and evaluate a TUI embedding asynchronous voice message systems to address elderly people's intergenerational communication	Bioengineering, Computer Science and Engineering, Art	Research through study approach with engaging users	Yes. Empirical	Yes	Not elderly participants	Qualitative evaluation. Usability and user engagement
[43]	To study how to create possibilities of interaction and dialogues using tangible social media via the design concept of Super Dots	Centre for Theory & Method/Co-Design	User-centered	Yes. Empirical	Yes	Age was not clearly mentioned. One participant was 82 years old. A total of six elderly participants were mentioned throughout the paper	Workshops. Possibility for interaction and dialogues
[46]	To apply and analyze different multimodality (aural, visual, tactile, gesture, posture, and space) in designing tangible communication systems for elderly, with the purpose to support communication and social interaction among elderly people. Prototypes were implemented and evaluated	Informatics & Design, Inclusive Design and Research	User-centered	Yes. Empirical	Yes	Not mentioned	Workshops with use cases. Observation on how players interacted with the TUI in terms of different modalities

Table 2: Continued.

Paper #	Objective of the paper	Discipline	Design & development methodology	Evaluation methodology	User involvement	Sample size & demographics	Evaluation method & data capture
[55]	To design more accessible and enjoyable chronic disease self-health management system for the elderly people	Information Art & Design, Computer Science and Technology	User research (interview, observation, persona)	Yes. Empirical	Yes	10 participants (only details of seven of them were given). Age ranged from 60 to 90, with different diseases like hypertension, bronchitis, diabetes, and disabilities such as poor memory, visual impairment, motor impairment, and so on	Role-play to access the elderly people's interaction pattern; cord sorting to understand mental model. Visual interface was also tested
[47]	To design accessible, functional and acceptable TUI for elderly people's digital inclusion through user involvement	Informatics & Design, Inclusive Design and Research	User-centered	Yes. Empirical	Yes	Series of workshop were conducted from year 2010 to 2012 but sample size and demographics of the participants were not mentioned	Workshops with interviews, design sessions, focus groups, usability testing, and feedback rounds. Multimodal analysis frames were also used as evaluation tools for redesign process. Workshop series in 2010: focus on the exploration of communication habits of elderly people. Workshop series in 2011: focus on the interaction design. Workshop series in 2012: focus on the usability
[56]	To design and evaluate a TUI pervasive cognition simulation collaborative system, with the aim of addressing technological, social family networks, and illiteracy gaps regardless of physical location for elderly people	Computer Sciences	Case studies (identifying and understanding users, roles, interactions, and identifying factors that affect relationships of elderly people with their family)	Yes. Empirical	Yes	Six healthy elderly participants with one relative each (five adult children, age ranged from 33 to 55 & one grandchildren aged 21)	Observation and questionnaire to study perception of use (ease of use, usefulness, enjoyment, and anxiety) and projected use (intention of use and expected use). Open questions to study communication practices and cognition simulation activities

Table 2: Continued.

Paper #	Objective of the paper	Discipline	Design & development methodology	Evaluation methodology	User involvement	Sample size & demographics	Evaluation method & data capture
[57]	To design a serious game for cognitive training and screening for elderly people by utilising augmented reality and tangible objects	Computer Sciences	Based on design principles, design, and usability suggestion from other studies and collaboration with physician	Yes. Empirical	Yes	Five elderly participants who were 60 years old and above, independently performing activities of daily living, not diagnosed with any kind of dementia, familiar with technology (i.e., using or having used laptop, tablet PC, and smartphone) and video games (i.e., playing or having played video games before) and would be novice augmented reality users	In-Game Experience Questionnaire to evaluate the game experience. System Usability Scale to evaluate the usability and interaction. Open, semistructured interviews to study participants' personal playing experience
[58]	To employ tangible multimedia artifact to support reminiscence sessions	Media, Design, Innovation Sciences	Field research	Yes. Empirical	Yes	Eight people with dementia (7 women and 1 man. Age above 80) suffered from different levels of Alzheimer's with handicaps such as mobility problems, hearing problems, speech impairments (related to strokes), and tremors; and four caregivers	Sound recording for transcripts and observations to study the interactions with a tangible multimedia book, interactions between people, and physical reactions of participants during reminiscence sessions. Focus group to get feedback from caregivers about the reminiscence sessions

Table 2: Continued.

Paper #	Objective of the paper	Discipline	Design & development methodology	Evaluation methodology	User involvement	Sample size & demographics	Evaluation method & data capture
[59]	To design an immersive interface focusing on edutainment contents, with the aim for elderly people to enjoy themselves and improve their health and quality of lives	Internet & Multimedia Engineering, Advanced Fusion Technology, Game Engineering,	Not mentioned	Yes. Empirical	Yes	Experiment 1: 30 people (five age groups (20, 30, 40, 50, and 60) and each age group consists of three men and three women). Experiment 2: 8 subjects (three women & five men. Age ranged from 50 to 70)	Experiment 1: performances of playing the games were evaluated to measure the effects of familiarity to the interaction metaphor. Learning curves of the digitalized game were tested to measure the effects of familiar interaction metaphor. Experiment 2: time required to complete each game was measured to see the effects of believable interaction metaphor. Subjects were interviewed with questionnaire to measure user satisfaction
[48]	To develop a tangible intergenerational collaborative game for elderly people	Embedded Interaction, Informatics	User-centered	Yes. Empirical	Yes	Two elderly women (age ranged from 56 to 65) who did not have grandchildren and described themselves as advanced computer users, and one boy (age 8) who played computer games frequently	Observations and comments from the participants. The acceptance, the handling with the game and suggestions to improve the games and to adapt the players' requirements
[52]	To bridge intergenerational gap between elderly and young people with the aim of engaging elderly people in social media through photos and solving social isolation barrier	Imaging Media	Not mentioned	Yes. Empirical	No	N/A	Comparing with other existing systems (Sound Shot, AudioBoom, and Yappie) and the previous work (audio enhanced paper photos) in terms of functionality and performance of system
[60]	To design and evaluate a tabletop game especially created for senior citizens, with the aim of providing leisure and fun	Industrial Design, Communication and Information Sciences	Field study (observation, interview)	Yes. Empirical	Yes	Eight elderly participants (three women & five men. Age ranged from 65 to 73)	Questionnaire and interview. Game experience of the elderly players

Table 2: Continued.

Paper #	Objective of the paper	Discipline	Design & development methodology	Evaluation methodology	User involvement	Sample size & demographics	Evaluation method & data capture
[61]	To design a tabletop solution that provides a pleasant social cognitive training, with the aim of preserving cognitive functions in elderly people	General Psychology, Bioengineering and Technology	A series of stages including identification of requirements, planning and development of initial concepts, and usability and acceptance analysis	Yes. Empirical	Yes	Usability evaluation: three different groups of four elderly players (age ranged from 64 to 75, mean age 68.083, standard deviation 3.34); trial managers and usability experts. Level of acceptance of the prototype: 107 elderly users in three trial centers (Spain 46%, England 14%, and Norway 40%) and a group of 21 experienced users. Consistency of the monitoring module: 59 elderly players	Usability evaluation: video-analysis and observation for elderly players to identify requests for help. Checklists for trial managers and usability experts to test usability. Level of acceptance of the prototype: questionnaires and focus groups to evaluate acceptance. Consistency of the monitoring module: statistic comparison of the scores by Eldergames with those obtained with the Wechsler Abbreviated Scale of Intelligence to validate the scoring system
[54]	To study the guidelines for making users feel playful and engaged while playing game by developing an application	Computer Sciences	Based on guidelines	Yes. Empirical	Yes	Not mentioned	Observation and comments from participants. The impact of games in terms of user experience
[51]	To present a multitouch social interaction system for elderly people that enables them to engage the benefits of ICT and enhance their social interaction	Industrial Design, Computer Science and Information Engineering	Not mentioned	No	No	N/A	N/A
[53]	To improve the quality of elderly people's life by providing a better and richer gaming experience with the use of real objects while interacting with digital games	Computer Engineering	Not mentioned	Yes. Empirical	Yes	Not mentioned	Observation during usability testing. The use of tangible objects and the interactions of elderly people with them while playing the game

Table 2: Continued.

Paper #	Objective of the paper	Discipline	Design & development methodology	Evaluation methodology	User involvement	Sample size & demographics	Evaluation method & data capture
[62]	To explore the use of surface computing and TUI for people with dementia by developing three prototypes	Human and Technology Interaction	Interviews and workshop with experts, use of personas and referencing books and material collections for occupational therapy in dementia	Yes. Empirical	Yes	14 participants (nine women & five men. Age ranged from 77 to 93) representing all degrees of dementia	Observation, system log, and interview with occupational therapists. User experience and system usability, well-being of the dementia patients in terms of social interactions between caregivers and patients
[63]	To design a system where the technology is hidden behind a well-known metaphor so that system accessibility and user acceptance of elderly people can be improved	Technology for Human Well-being, Hospital & Health Care, Technology	Based on guidelines, feedback from lab users and visitors	Yes. Empirical	Yes	Eight participants (five women & three men. Age ranged from 69 to 100) with different health conditions. Had primary education level and rarely used new ICT. Social interactions varied from weekly visit to yearly visit and from receiving calls from family and friends to no calls	Observation to study task-based analysis (communication task, recognition task, and opening/closing task) and interaction analysis (proximity in terms of distance where people stand from each other while interacting, participants' gestures and actions, and emotions). Semistructured interview to study user experience

use in games for cognitive training and screening for elderly people. They also emphasized the social interaction aspect while studying the game mechanics.

4.3. Study Design and Involvement of Elderly Users. Due to cultural differences, we did not specify the older adults' age since the definition may vary from country to country. Out of the 21 papers, 19 involved elderly user involvement throughout their research while two papers [51, 52] did not mention anything about involving elderly participants.

The study design of these 21 papers did not give enough detail in terms of the elderly user involvement. Spreicer et al. [44], Tellioğlu et al. [46], Marques et al. [53], and De la Guía et al. [54] did not provide much information about their participants throughout the paper. This made it difficult for us to understand more about their study design.

Although Zhao et al. [49] interviewed six women and four men whose ages ranged from 70 to 86 for their design study, they did not include them in testing. Instead, they only had a qualitative evaluation where they involved around 200 people that visited their exhibition and seven instructors from universities. These evaluation results would be able to tell us more about the impact of using TUI in enhancing social interactions of the older adults if the evaluations had been done by their target users, the elderly people. West et al. [45] did the same thing. 14 elderly participants whose ages ranged from 63 to 81 were involved in their design process. However, seven users whose ages ranged from 20 to 40 were asked to evaluate the prototype.

Nevertheless, six out of 21 papers [43–48] used a user-centered approach. These studies showed that involving the elderly users at an early stage, such as gathering input, could determine more specific and precise user requirements while designing the prototype. Elderly people tend to need more time to learn how to use new technology. Thus, taking into the older adults' needs into consideration is vital while designing new technology for them [16, 66].

Another finding is that West et al. [45] and Ehrenstrasser and Spreicer [47] utilised cultural probes to provoke inspiring responses from the elderly participants; they came out with a design that suited the end users. Cultural probes can result in a design process which is more responsive, and they are suitable to be used when target users are unfamiliar [67].

4.4. The Disciplines Where Researchers Worked. In terms of disciplines where the papers' writers and cowriters worked, the review shows that the idea of adopting TUI in improving social interactions of elderly people has not been widely explored in academic disciplines. There were some collaborations between technology and art, but very little with other related disciplines such as health sciences and social sciences. Only three papers [49, 61, 63] demonstrated multidisciplinary collaborations. Collaborations between technology and other disciplines such as health sciences and social sciences might tell us more about the benefits of using TUI to enhance social interactions of elderly people.

5. Recommendations

5.1. Precise Use of the Term "Tangible User Interface". Ishii and Ullmer [18] define TUI as a user interface that augments the real physical world by coupling digital information to everyday physical objects. Not all tangible objects are everyday physical objects. Thus, there is definitely a difference between a user interface that is tangible and tangible user interface. Many researchers quote works which use touch devices such as tablets and smartphones as TUI. However, these devices are not everyday physical objects.

5.2. Elderly Users' Involvement throughout the Whole Research Process. Out of 21 papers in our review, Spreicer et al. [44] Tellioğlu et al. [46], Marques et al. [53], and De la Guía et al. [54] did not provide clear information about their elderly participants, while West et al. [45] and Zhao et al. [49] only involved elderly participants during their design process and not in the testing or evaluation process. Having elderly participants before or during design can ensure more precise user requirements from the actual users: elderly people. Without having them test the prototype, it cannot lead researchers to a more accurate evaluation and validation of the prototype. As a result, we see the importance of involving older adults through the whole research study, from designing the new technology for them to having them test the new technology.

5.3. More Research on Using TUI to Enhance Elderly People's Social Interactions. From this review, we can see that TUI has indeed been adopted to enhance elderly people's social interactions, but only to a minimal extent. The review resulted in 235 relevant papers after eliminating the duplicate ones, and then only 21 papers were selected after all the screening with full-text reading. Out of these 21 papers, three papers [44, 46, 47] presented the same prototype, kommTui. Given that TUI was introduced 20 years ago, our findings with only 21 papers indicate the limited amount of research studies in this field. During our review process, we came across a few papers which only focused on aspects such as learning and training. These papers are not included in our review.

5.4. More Focus on the Social Interaction Aspect in addition to Usability during Evaluation. During the evaluations, usability aspects were studied in most of the papers, and in their evaluation, social aspects were completely neglected. Out of the 21 papers, only seven papers [43, 47, 53, 56, 58, 62, 63] focused on the social interaction aspect during their evaluation. Other papers like Davidoff et al. [50], West et al. [45], Spreicer et al. [44], and Zhao et al. [49] focused on usability aspects, such as ease of use, performance results in using the prototype, and feelings of independence. Because there were so few papers, we decided to include them nevertheless. As a result, we did not define quality criteria, and only presented the works they had done. While introducing a new technology for older adults to improve their social interactions, it is important to evaluate the impact of their social interactions and not just the usability of the prototype. A prototype that scores high

in the usability aspect might turn out to be not useful to the target users, thus not improving their social interactions.

5.5. Interdisciplinary Collaboration. As shown in Section 4.4, there was very little collaboration in terms of disciplines. There is a definite strong relationship between health and social well-being in the elderly population. By using easy, accessible technology tools, the elderly people can benefit from having a more active social life, which leads to better health too. Only three papers [49, 61, 63] showed collaborations with other disciplines. While most of the papers did not emphasize the relationship between technology, health, and social aspects, we would like to highlight the importance of interdisciplinary collaboration, and hopefully, more research studies can be carried out together by researchers with different yet related backgrounds.

5.6. Longitudinal Study on Impact in a Larger Scale. The impact of using TUI to enhance social interactions in older adults is significant; it can be even greater if interdisciplinary research study can be conducted over a more extended period to see its impact from a health perspective, such as the quality of life and health of older adults. A longitudinal study can be conducted. This will be a more precise measure since it can serve as a follow-up after introducing the prototype to older adults. All in all, we hope to see our literature review inspire more research work in this field. This research work can be extended to more collaboration with researchers from other countries. It is certainly worthwhile to see how TUI can improve the social interactions of older adults in both a longer period and a larger geographical picture.

5.7. Guidelines for Developing and Evaluating TUI for Older Adults. Lastly, while we have guidelines for developing and evaluating mobile application such as The World Wide Web Consortium (W3C) Web Accessibility Initiative's (WAI's) accessibility guidelines, we do not have a set of guidelines specifically created for TUI. Needless to say, we do not have the guidelines to design and evaluate a TUI that are targeted for older adults. These guidelines which can be used both in developing and in evaluating can help researchers, designers, and developers to provide TUI that is accessible, usable, and easy to learn and use and keep the elderly users motivated while using it. Lack of guidelines can result in a system that is neither accessible nor useful to users. Some existing guidelines for mobile applications and technology targeted to elderly people could be applicable. However, further study has to be conducted to verify this.

6. Conclusion

With the fast growth of ageing population, lack of social interaction among elderly people is becoming an increasing social and economic challenge in many countries. The objective of our systematic literature review is to gain an overview of the state of the art research and evident effects of TUI as an intervention on social interactions of older adults. This research is therefore timely and important both to the research communities related to elderly, health, and TUI but also have implications for the society.

At the early stage of the review we found out that many researchers referred to their touch screen, mobile-based, and computer-based prototypes as a "tangible" user interface. By adopting the definition of TUI by Ishii and Ullmer [18], we managed to make a clear distinction between user interface that is tangible and tangible user interface. Doing so helped us develop the exclusion criteria used in our search and screening process.

We acknowledge that the quality of the research in the reviewed papers varies. Data captured by the 21 relevant papers were very different, and there were no criteria in common where we could evaluate these papers. All of them focused on very different aspects and thus, it was impossible to come out with a quality score. As a result, we could only present what has been done, and where there is a gap.

Although the papers aimed at designing, developing, and evaluating prototypes to address the loneliness and social exclusion among elderly people, most papers only evaluated the usability aspect of the prototype. Collaborations between technology and other disciplines such as health and psychology have been low among the researchers. There is a lack of user involvement, both in designing TUI for the elderly people and in testing and evaluating the prototype.

The process of this systematic literature review has been fruitful. Referring to the guidance by Keele [39] and referencing other published literature reviews, we have conducted this literature review to address our research questions. The literature review resulted in 21 papers that fulfil all the inclusion and exclusion criteria. As three out of these 21 papers presented the same prototype, this makes the amount of prototypes even fewer. The results from the literature review clearly indicate very little use of TUI in making an impact in elderly people's social interactions, especially since TUI was introduced by Ishii and Ullmer [18] 20 years ago.

We acknowledge that research conducted in different countries defines the age group differently. Some research might have also adopted TUI but did not use the exact term, so they did not appear in our search results. Thus, we might have overlooked some papers. All in all, by conducting this literature review, we hope that more researchers can be inspired to develop and evaluate TUI for enhancing elderly people's social interactions. Our future work will focus on designing and evaluating a TUI system for social interaction among elderly people. We will adopt a user-centered approach. By including the elderly people throughout our design, development and testing iterations, and collaborating with researcher from health sciences, we hope to gain more evidence on how TUI can contribute to enhancing the social interactions among elderly people and consequently improve their general well-being.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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