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Perspective

Digital Twins for Supporting Ageing Well: Approaches in Current Research and Innovation in Europe and Japan

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Abstract: One of the central social challenges of the 21st century is society's aging. AI provides numerous possibilities for meeting this challenge. In this context, the concept of digital twins, based on Cyber-Physical Systems, offers an exciting prospect. The e-VITA project, in which a virtual coaching system for elderly people is being created, allows the same to be assessed as a model for development. This white paper collects and presents relevant findings from research areas around digital twin technologies. Furthermore, we address ethical issues. This paper shows that the concept of digital twins can be usefully applied to older adults. However, it also shows that the required technologies must be further developed and that ethical issues must be discussed in an appropriate framework. Finally, the paper explains how the e-VITA project could pave the way towards developing a Digital Twin for Ageing.

Keywords: digital twin; ageing; Society 5.0; cyber-physical systems; ethical questions

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1. Introduction

1.1. Content and Structure of the Paper

With the project "e-VITA" ("EU-Japan Virtual Coach For Smart Aging"), we as a consortium aim to make a significant contribution to the development of AI for the aging society. In doing so, we are following a preventive approach, corresponding to the concept of "Active and Healthy Aging" of the WHO. A central concern of ours is to make AI accessible for older people (60+) and to let this steadily growing group of people benefit from its potential. In concrete terms, the e-VITA project is about developing a virtual coach for older adults, designed to support wellbeing maintenance. Among other things, the coaching system includes diverse applications for smartphones or tablets, various instruments for recording personal data, such as sensors, and a selection of embodiments (further information about the e-VITA project can be found in Section 5.1).

We are intensively studying innovative technologies in the research area around AI for the aging society. As our research and development processes have progressed, it has become apparent that the coaching system parallels the technology of so-called digital twins (DTs), which enable the digital representation of physical systems. We believe that technologies of this kind offer a promising approach to the concept of Active and Healthy Aging. At the same time, we know that transferring the concept of DT, which originated in the industry field, to people raises several ethical questions. The focus questions are: Under what conditions can the concept of digital twins be transferred to older adults? Which aspects must be considered?

The present white paper explores these questions. It provides a compact and understandable description of DT technology, how a DT for Ageing (DTA) could be designed, which ethical aspects need to be considered, and how the work done in the e-VITA project could pave the way towards developing a DTA. The paper is structured as follows. Below, the problem to which DTAs offer an answer is described: the aging of society. Following this, we introduce terms that are relevant to the discussion of the questions raised, including explanations of the terms "Industry 4.0", "Society 5.0", and "Digital Twins for Ageing". In addition, we give an overview of the current state of research around digital twins for wellbeing. Then, selected findings from the research areas, (1) digital human activity recognition, (2) personalized communication via intelligent conversational agents, (3) markers determining the detection of health, and (4) measurement systems for data acquisition, are compiled. In a further step, we present reflections on ethical issues. Finally, we introduce the e-VITA project and the extent to which the project findings offer indications for developing DTAs. The paper then closes with reflections on the outlook.

1.2. Ageing Society and the Role of Cyber-Physical Systems

Demographic aging is a process that is taking place worldwide. Two trends are decisive for this: the increase in life expectancy on the one hand and the decline in birth rates on the other. The resulting changes in the population structure can be considered one of the most significant challenges for society in the twenty-first century. The challenge is to meet the growing need for care appropriately. Already, today, there is a considerable imbalance between people with care needs and people who can perform care activities. Care deficits are the result.

A critical approach commonly applied to address the challenge of the nursing shortage is the use of technology. There is an arguable tendency to advocate technological solutions without due recognition of alternatives. This article also emphasizes the advantages and opportunities of using technology in (health)care, but it should be mentioned that other solutions must also be considered, such as improvements in working conditions. All-in-all, change must be recognized as fundamentally socio-technical.

Although demographic change can be observed in all industrialized nations, one country in particular stands out: Japan. The process is taking place very rapidly here. The Japanese government is meeting this challenge (among others) with the strategy of creating a "Society 5.0", "a society in which future generations can live in abundance while satisfying the needs of the present generation". To achieve such a society, the Japanese government's sixth "Science, Technology, and Innovation Basic Plan" (2021) envisages "to reform the economic and social systems [. . .] in a manner that addresses the declining birth rate and aging population and changes in the economy and society" [1]. In concrete terms, the idea is to apply the concept of Cyber-Physical Systems (CPS) to society and its members. The approach of developing digital versions of physical systems originates from the industrial sphere. Here, with the help of artificial intelligence, both individual machines and entire companies are digitally mapped nowadays. The terms "4th industrial revolution" or "Industry 4.0" are also used in this context. In principle, the concept of DTs can be applied to all systems, including living ones such as people or societies. This is currently taking place in Japan, and it is conceivable that other countries will follow.

2. Digital Twins

2.1. "Industry 4.0" in Germany and "Society 5.0" in Japan

Digitalization gathered momentum in the 2010s when computing capabilities increased and became powerful enough to process enormous amounts of data from a growing number of sensors installed that collect data about our everyday lives. Humans can no longer analyze this so-called Big Data, but artificial intelligence can now find patterns and draw conclusions. In 2014, Germany was one of the first countries to introduce a dedicated strategy to address digitalization ("High-Tech Strategy"). The strategy covers many fields, like digital economy and society, sustainable management and energy, innovation within the world of work, healthy living, smart mobility, and civil security [2]. Although healthy living was part of the strategy, the digital transformation started first in the industry, which is the economy's most powerful sector and has sufficient resources. Soon, the term 'Industry 4.0' emerged, meaning the 4th Industrial Revolution. This revolution is based on linking physical systems with cyber systems, which use sensors and other network technology to provide connectivity. Together, they constitute Cyber-Physical Systems (CPS). Every asset, from simple machines to entire factories and their value chains, can be represented by an exact digital model with all its functions, the DT [3]. Using the DT, data about the functioning of the physical system are collected and analyzed with AI. This procedure allows the creation of a matching simulation of the real system's functioning, thus enabling better optimization than possible without the DT. A machine, for example, is equipped with several sensors that collect data concerning, for instance, vibrations. The AI system can now detect if some continuous measurements are outside the expected ranges [3]. As a result, the necessity for maintenance can be detected at an early stage. Such "predictive maintenance" reduces machine downtime and is being applied in new business models in which customers pay for the number of parts produced ("Pay Per Use").

DTs can help to simulate processes, make predictions, and avoid malfunctions, for all systems, including living ones such as people or entire societies. With the concept of Society 5.0, the Japanese government is following this approach. The government's sixth "Science, Technology, and Innovation Basic Plan" states the following in this regard: "In Society 5.0, every element of society will be built as a digital twin in cyberspace, restructured in terms of systems, business design, urban and regional development, etc., and then reflected in physical space to transform society".

2.2. Human Digital Twins: State of Research

DT technology uses recent advances in AI. Deep learning techniques, increased computer capability, and cloud computing provide possibilities for platforms and architectures that enable increased accuracy in modeling the functioning and structure of real-world objects in a digital environment. Traditional applications range from models describing jet engines or buildings to more complex entities like factory plants and cities for monitoring and optimization purposes. A DT is an abstraction of any object or process used to achieve a particular goal, and it helps model the operations and functions needed to achieve the goal. From this perspective, it can be said that DTs have been available as long as modeling of the natural world has been conducted in science and society. A new aspect is that DTs transform the power of modeling to a virtual world, where virtual and augmented reality transforms the experience of the natural world, i.e., the model is not only an abstraction of the external world which the user can modify and manipulate, but it is part of the user experience, immersed in physical reality.

The increased power of cloud and data analytics techniques allows simulation of the world beyond the traditional representation of objects, operations, and processes toward modeling and predicting the functioning of complex systems. Interest in DT technology is rapidly growing from typical manufacturing tasks towards areas of humanities, social science, and policy making. Virtual, augmented, extended, and immersive reality applications provide a vast repertoire of tools and platforms to apply the DT concept to various environments and settings. For instance, DT models have been used for fitness management, healthcare, and physical activities. The Singapore Project studies urban planning and policy-making with "city digital twins", while DTs as human workers are also discussed [4–6].

Concerning DTs of humans (HDT), it is clear that an exact simulation of the entire "system" is not yet possible. However, DTs can already store a lot of descriptive data about a person, e.g., sex, age, and weight, as well as medical data, medical history, etc. Since the concept of a human DT is relatively new, there is no uniform definition. Miller and Spatz (2022) [7] suggest defining a human DT as "an integrated model which facilitates the description, prediction, or visualization of one or more characteristics of a human or class of humans as they perform within a real-world environment". They divide the attributes that can be modeled into the following categories: (1) physical, (2) physiological, (3) perceptual performance, (4) cognitive performance, (5) personality characteristics, (6) emotional state, (7) ethical stance, and (8) behavior. Depending on the purpose of an HDT system, different categories have priority. These different conceptual priorities are also apparent in the wide range of terms that are (non-uniformly) used in HDT research, e.g., WDT for wellbeing digital twin or, as in this paper, DTA for digital twin for ageing. Boulos and Zhang speak of different types of human DTs [8]. They elaborate that twins of the whole human body exist, twins of only one body system or function, twins of single organs, and twins designed for specific diseases or disorders. Further, they speak of "composite digital twins" that integrate two or more types of those described and "reference digital twins" or "proto-twins" that serve as templates or archetypes for building more complex, individualized digital twins of each type.

Meanwhile, DT technology is considered an exciting and promising approach for the healthcare field. A key phrase in this context is that of personalized medicine, which focuses on making medical treatments more effective. This is achieved by paying more attention to variables that differ from person to person (such as genetic makeup, lifestyle, and environmental factors). It is not uncommon today to use data collecting and processing technologies to monitor and improve health status. Speaking about this fact, Boulos and Zhang mention activity trackers, diet monitors, and telemedicine services, for example [8]. With the help of DTs, individual personal data of this kind can be combined into larger aggregates, i.e., digital copies of persons, at least in parts. This would not only make treatment for existing problems more effective, but it would also allow prognoses to be made and preventative interventions to be initiated in a targeted manner. Lehrach (2016) even suggests that HDT will be used to compare the expected success of different treatment options and to select the most promising method [9].

In the area of DTs for wellbeing, several applications are presented, including applications for the detection of liver disease [10], ischemic heart disease detection [11], fitness management [4], blood circulation analysis [12], and trauma management [13], for example. Ferdousi et al. (2021) also report on the progress in industrial production of corresponding products. The products/services they list include the following: (1) a 3D Heart Twin from Siemens, (2) a simulation to assist in sensualizing data from multiple sources to generate a DT of a hospital for testing alternatives from GE wellbeing, (3) a patient-centered treatment using DTs of patients from IBM, (4) a 3D model of a live heart from Dassault Systèmes, (5) a testbed (5G connectivity) from NHS, (6) a comprehensive modeling system for treatment simulations from Digitwins and (7) AI-enabled cardiac models from Phillips. The authors note that many prominent companies compete in HDT development [14].

2.3. Digital Twins for Ageing

The term "Digital Twins for Ageing" refers to DTs designed as digital copies of elderly people to help this target group maintain a high quality of life. Even though it is common in science and politics today to view the life phase of (old) age from a positive, resource-oriented perspective, old age also brings complex challenges. Havighurst's (1972) model of age-specific developmental tasks, which has shaped the social sciences' understanding of lifelong development since its publication in the mid-20th century to the present day, holds, for example, that people in the life phase of "later maturity" (61+) typically face the developmental tasks of adapting to decreasing strength and health, coping with retirement, and adjusting to a lower income and establishing satisfactory living quarters [15].

It is plausible to assume that using digital copies will help older adults cope more easily with the challenges typical of their stage of life. The Japanese government expects that AI will make it possible to reduce burdens, predict the onset or worsening of illnesses at an early stage, and enable people to remain in their own homes. Ultimately, these new possibilities are also intended to reduce medical and social costs. Data that are considered helpful to collect for these purposes include realtime personal physiological data (e.g., body weight, heart rate, GPS info, glucose level, blood pressure, temperature, and respiration rate), medical data, and environmental information. Based on the detection of overweight, high blood pressure, and a worrisome cardiogram that today's smartwatches can already record, it should be possible to recognize a person's body's pathological condition and recommend a visit to the doctor, for instance. Today, a DT of a heart can help optimize treatment or find the best location for a cardiac pacemaker.

3. Components for Creating DTA

3.1. Human Activity Recognition and Digital Twins for Smart Homes

Human Activity Recognition (HAR) is the process of monitoring and analyzing the behavior of one or more people to infer their activity. In a smart home context, HAR is about monitoring the daily activities of residents based on a network of devices installed in the home. Thanks to this monitoring, a smart home can offer personalized home assistance services to improve its residents' quality of life, autonomy, and wellbeing, especially for older adults or people with impairments. With the development of the Internet of Things and the rise of powerful and inexpensive smart devices, smart homes based on ambient sensors have become viable technical solutions for providing various services, such as comfort, automation, security, and aging. Activities of daily living (ADLs) are performed as part of daily living to ensure self-care. The information gathered by the smart home helps detect potential drifts, anomalies, and threats to older adults' health, comfort, or happiness, as Soulas (2016) [16] proposed. Beyond the hardware, those services also need algorithms to exploit the potential. However, optimizing HAR in smart homes is a crucial and challenging problem because human activity is complex and varies from one resident to another. Each resident has a different lifestyle, different habits, and abilities. The wide range of ADLs and the variability and flexibility of how they can be performed requires an evolutionary and adaptive approach.

As Bouchabou et al. (2021) [17] note, HAR, in general, has recently progressed in the development of new deep learning algorithms for end-to-end classification, such as convolutional neural networks [18] or fully connected networks [19]. It also benefits from recent sequence learning algorithms, such as long-short-term memory [20]. However, recognizing ADLs in a smart home is a difficult task. Thus, algorithms must analyze sparse and irregular time series to generalize to different situations across houses, equipment, household members, or habits. Training machine learning algorithms to be deployed in test cases on such heterogeneous data is a significant challenge. To address the gap between training data and use case data, generating more realtime data could be a solution.

Thanks to the DT concept, it would be possible to realize this. DTs of this type are termed Digital Twins for Smart Homes (DTHS) in the following. For HAR, a DT could be a digital copy of a target house with the same sensors installed. In this digital environment, one or more avatars could perform ADLs by modeling the complex behaviors of residents. In this way, the DTSH could be used to refine the final algorithms before deployment in the target house. DTSH could also be used to generate data from numerous houses, household configurations, and resident habits, providing the possibility of faster simulations and automatic labeling without the cost of sensors. In addition, DTSH can be used to assess the correct positioning and selection of sensors to recognize a predefined list of activities of interest.

The objective, therefore, could be to create DTSH that can reproduce real homes and the composite activities of residents using programs, i.e., sequences of actions and atomic interactions, and then to play these activities and generate time series of synthetic data similar to those produced by an IoT network in the natural environment. The ability to quickly and efficiently produce a DTSH of the human user's environment can help develop customized assistive solutions. Simulators, such as OpenSSH [21], focus on the interactive simulation of people in houses equipped with home automation sensors, with the limit that it requires a human actor to label activities progressively. Gazebo [22] and V-REP [23] are used for modeling sensors and computer vision systems for robotics. Another notable project is Habitat 2.0 [24], a highly photorealistic and efficient 3D platform that trains simulated robots in interactive environments. VirtualHome [25] is a simulator that has multiagent functionality, thus allowing the scripting of actions to be attributed to the avatar(s) and the reproduction of scenarios. In addition, whole properties can be replicated, including walls, furniture, and objects. The practical and technical aspects of creating DTSH using off-the-shelf available sensors and software need to be investigated to address the high variability of house and household configurations. A DTSH can, on the one hand, be built using a priori information (e.g., architectural plans, comments, and contributions from inhabitants), but on the other hand, sensory input data can also be used (e.g., home automation, IoT, robot sensors, etc.). The corresponding smart house can be scanned with a depth camera (handheld or on a robot), and then a SLAM (Simultaneous Localization and Mapping) algorithm, commonly used for robot navigation [26], can create a dense 3D point cloud of it. Modeling software such as Blender or Gazebo could then build CAD (computer-aided design) models of the house and its objects from the point cloud data. Detecting the categories of objects of interest (e.g., tables, chairs, etc.) and their position could have several advantages in a DTSH context. The YOLO-v3 (You Only Look Once) algorithm [27] enables object detection and recognition and can, therefore, deduce the semantics of scanned furniture and objects.

3.2. Personalized Communication Using Smart Conversational Agents

Virtual agents are widely used in interaction studies, ranging from animated characters on the screen to realistic human simulations. Replication of the whole human in a digital world is still more like science fiction, but development is progressing rapidly in animation and augmented reality. Research in modeling human behavior is being conducted, including various aspects of natural communication skills and their imitation. This involves not only auditory information for automatic speech recognition [28,29] and speaker analysis (also called Computational Paralinguistics [30], but also the use of visual information like multimodal face [31,32], hand gesturing [33], and body movements [34,35], as well as other sensor information like tactile, olfactory, and gustatory [36], as well as artificial neurons [37] and the whole cognition [38].

Virtual agent technology has long been efficiently used to create virtual agents, avatars, and bots for various interactive applications. Such Embodied Conversational Agents can be personalized concerning their appearance but also concerning their interaction capabilities, including multimodal aspects such as gesturing, facial expressions, laughter, etc., to investigate the impact of various communicative signals on the fluency and satisfaction of the human-agent interaction. Similarly, in social robotics, personalized interactions are designed and developed to include multimodality in the advanced dialogue models to address various communicative needs of the users. For instance, Yaghoubzadeh et al. (2013) discusses virtual agents as daily assistants for older adults [39], and Sakai et al. (2012) present a listener robot agent for older adults [40].

Embodied conversational agents, intelligent virtual agents, and social robotics developed for various applications are examples of extensive research combining the virtual world, AI, and communication technologies to create intelligent social agents that could act as companions, counselors, or instructors in real-world applications. Overviews of the research topics, technologies, as well as opportunities and challenges for building applications, are provided by Jokinen and Wilcock (2017) [41] and Wan et al. (2020) [37].

Also, the teleoperation of humanoid robots includes advanced research issues related to integrating human cognitive skills and expertise with the capabilities of humanoid robots. Applications range from robots acting as physical avatars of human workers to robots assisting humans in tasks requiring high accuracy (telesurgery) or communicative capabilities (telenursing). An overview of the technological and methodological advances is provided by Darvish et al., 2023 [42]. The authors also extensively discuss potential applications. A spoken dialogue system allows users to interact with a virtual coach conversationally by taking turns in a dialogue to accomplish a task or engage in a conversation. This type of interaction is potentially more accessible and intuitive for older persons than navigating menus and drop-down boxes on a traditional user interface or typing in text and manipulating objects on a small mobile device [43]. On the other hand, personalized interactive systems are also prone to high expectations of fluent human-like conversational capabilities and various issues in speech-based applications, especially for elderly users, as Young and Mihailidis (2010) [44] elaborated.

With advanced speech technology, personalized interactive systems are expected to be further developed to become more reliable and robust in their speech recognition and generation capabilities. Progress has been made in recognizing speech from various age groups (young, middle-aged, and elderly users) and users with different emotional and physiological characteristics. For example, Luz et al. (2021) present an approach to the automatic detection of Alzheimer's type dementia based on characteristics of spontaneous spoken language dialogue [45], and Cummins et al. (2023) identify different speech markers related to the onset and progress of MDD (major depressive disorder) across speakers of three different languages [46]. Baird et al. (2021) evaluated speech-based markers to analyze stress [47], and Grabowski et al. (2019) surveyed the tools enabled by modern technology for emotional expression research for clinical treatment strategies [48].

Investigations related to effective computing technology are also widely conducted. Many studies deal with mapping facial and paralinguistic parameters to basic emotions. Parada-Cabaleiro (2023) discuss advances in emotion classification, pointing out that "the basic six" (fear, anger, disgust, happiness, surprise, and sadness) may not be feasible when dealing with the wide range of human affective states [49]. When using automatic classifications on real-life data, it is helpful to analyze the confusion between the categories to deal with the intrinsic ambiguities of emotions. In this line, studies on recognizing the user's state of health, like having a cold [50], have been conducted, while Borna et al. (2023) review pain detection based on automatic voice analysis [51]. Other research studies the emotional and physiological reactions of users when interacting with an artificial agent. Consequently, the results are used to design and improve the agent's interaction strategies toward more natural and engaging communication capabilities [52], which can also be helpful in therapy situations [53].

Personalized, automated AI agents have significant potential for assisting humans and supporting daily life activities. However, in the social domain, where humans and their communication are in the focus for developing effective socio-conversational systems and technological applications, this kind of research and development also brings forward various challenging issues related to ethics and trust, which are widely discussed (see for example [54,55]). The same AI technologies can also be applied for the more ambitious task of building digital twins of the users in social health and elder-care domains, and thus ethical questions such as how to best use the digital twins, what kind of functional capabilities are needed, what kind of expectations they raise in the users, etc. need to be carefully considered when developing digital twins.

3.3. Markers Determining the Detection of Health

The use of the concept of a DT in the health sector comes along with the revolution posed by the personalized medicine (PM) approach, as the final aim of any DT is the provision of a plethora of helpful information to depict the person's profile and, thus, to design patient-centric interventions. In 2005, the EU Council defined PM as "a medical model using the characterization of individuals' phenotypes and genotypes (e.g., molecular profiling, medical imaging, lifestyle data) for tailoring the right therapeutic strategy for the right person at the right time, and to determine the predisposition to disease and to deliver timely and targeted prevention" [56]. Prevention, early detection of diseases, and monitoring their progression are the main objectives of the PM approach, in addition to supporting health professionals in making precise diagnoses. By designing and developing DTs for health, it would be possible to put the aims promoted by the PM concept into practice, allowing the identification and reproduction of clinical subtypes of patients, for example, to understand the underlying mechanisms of pathologies, the intercorrelations between the environment and the individuals or to discover innovative pathways for supporting the intrinsic capacity in a preventive perspective.

In the case of aging, DTs may represent a critical factor in making the mechanisms underlying the complexity of aging processes more transparent. For this reason, some authors have suggested addressing the challenge posed by applying DT technologies for the health management of older patients for precision and personalized medicine, along with the realization of real innovative healthcare solutions based on combining clinical needs with the virtual world [57].

A DTA will need high-quality and voluminous data collected from the spectrum of health measurements. Medical imaging technologies can provide one stream of data for the DT. The significant categories of imaging include Magnetic Resonance Imaging (MRI), Computed Tomography (CT), X-ray, Positron Emission Tomography (PET), and ultrasound imaging. MRI has a wealth of research supporting evaluations for aging, especially regarding the brain, and large MRI databanks have been established worldwide [58]. PET imaging has been shown to track the progress of Alzheimer's disease [59]. CT scanning has also been used in the context of brain aging. It can show changes associated with the normal aging of the brain [60]. The taking of X-rays is a routine and low-cost procedure. It has been shown that X-ray imaging can function as a biomarker for the assessment of cardiovascular aging, using a deep learning analysis [61]. Further, in the context of digital twins for hearts, Philips uses ultrasound [62].

Considering that nowadays health analysis takes place at a molecular and cellular level, it is to be expected that genomics tests and cellular-level screening will provide a platform for DT technology. Such tests are already becoming personalized, with direct-to-consumer sales and analysis. Given the complexity of aging, explanations of the leading networks and mechanisms underlying this process are of enormous relevance to the scientific communities. Despite the advances determined by the availability of high-throughput data, the capability of interpreting such evidence remains a significant challenge for research in the field [63]. Although aging-related physiological changes are well-known, their molecular correlates must be thoroughly investigated [64].

3.4. Measurement Systems for Data Acquisition

Measurement systems to monitor health and wellbeing will be essential in developing DTAs. Data can be acquired by sensors installed in the living environment and worn by the user to extract information that covers all aspects of the user's health and quality of life. Nowadays, the number of sensors and systems for monitoring user health and wellbeing in the market is vast, with a growing preference for low-cost, non-invasive, and user-friendly sensors [65]. In addition, mobile sensors are preferred, responding to changes that may occur in the environment. Sensors installed in the environment and wearable sensors are the most used to extract user-related features and parameters. Since seniors spend most of their time in their immediate living environment (more than 90%) [66], remote monitoring with sensors installed in the living environment is more frequently applied to measurement without being invasive for the user. Intelligent environments are usually equipped with PIR sensors (Passive InfraRed sensors) combined with door, light, and energy consumption monitoring sensors to understand user behavior inside the home, respecting the user's privacy [67]. Through the acquisition of these data, it is possible to identify the activities carried out by the user during the day and to extract more detailed information such as ADL (activity of daily living) which, in an extended period, can provide information regarding the variations of user habits and, thus, can be declined with a progression of a disease or an improvement of lifestyle.

Data extracted from wearable sensors could provide a dynamic source of information for developing DTA. Wearable sensors can provide continuous data and signals regarding health status and user activities inside and outside the living environment. Smartwatches, wrist or chest bands, smartphones, etc., are increasingly used to monitor physiological parameters, e.g., heart rate, sleep patterns, level of stress, etc., and activity of the user, e.g., number of steps or distance traveled. Regarding these sensors, it is necessary to consider their measurement properties, which obviously influence the outputs in terms of accuracy [65].

4. Identification of Ethical Issues

It is beyond question that transferring the concept of DTs—originally embedded in industrial contexts—to older adults can bring many advantages for the members of this group. Nevertheless, from an ethical point of view, the endeavor is not without problems. We have already pointed out that humans are more complex than machines, but this is not the (only) point that needs to be discussed. An exceptional context is given regarding the digital mapping of older adults. On the one hand, it concerns a group of people who tend to have increased vulnerability, and on the other hand, the talk is about continuously collecting and processing data of private individuals. In the following, an attempt will be made to identify and explain different ethical issues related to the endeavor, wherein there are certainly some overlaps.

4.1. Strong Focus on Human Performance

Machines are digitally mapped to optimize production processes. It could be assumed that the concept of CPS is transferred to people expecting to increase their productivity. Ultimately, the expectation could be to make the whole of society more efficient. In this context, the question arises of whose objectives are at stake. Developing technologies for older people usually involves different parties, such as scientific disciplines, marketing companies, political actors, and service providers. While it is obvious that companies are primarily interested in increasing the productivity of machines, optimizing the productivity of society would instead be considered a strategic goal of government policy. Indeed, the establishment of new technologies for older people also has other political objectives than increasing their productivity: for example, contributing to their health and quality of life. However, ultimately, the two objectives are inter-related. It is at least not unreasonable to ask whether the aim is the wellbeing of the members of society or to profit from their workforce; it could even be called exploitation.

In principle, the interest in a healthy and productive society is legitimate. It is essential for the functioning of a society with apportionment-financed social security systems that the individual members should contribute to the functioning of their system. However, focusing unduly on the performance of individuals can also have a negative impact on social life. If the performance principle alone provides orientation, competition and outperforming are daily occurrences. At the same time, feelings of solidarity, which are crucial for the functioning of a society, can only be present to a minimal extent. Indeed, modern societies have the problem of being elbow societies. The problem is that transferring a concept designed for optimizing production processes to people or society could promote a strong focus on the idea of performance. This would be utterly contrary to the idea of an inclusive society.

4.2. Becoming "Glass Citizens"

Obviously, the problem also relates to ethical aspects concerning privacy and data protection. One characteristic of Industry 4.0 is the processing of large amounts of data. The state of the machine(s) in question, all processes taking place, and all relevant information from the surrounding systems are continuously digitally recorded and mapped. This makes the machine and the work processes transparent. When considering collecting and depicting data about older adults, the inquiry arises as to whom the information is rendering transparent. It can be assumed that sophisticated AI applications will make it increasingly difficult to understand and correctly interpret the data. It will hardly be possible for older people without the appropriate specialist knowledge. For this reason, the visualization of data for use by older people is an essential design issue.

In general, the collection and processing of data play an increasingly significant role in various domains of social life, particularly in healthcare. Consequently, the system's constituent elements, namely, individuals, are becoming increasingly visible in this context. In other words, by using (digital) services, they become transparent citizens, also called "glass citizens". Social sciences have been critically examining this topic for decades. Foucault's panopticon (see "Discipline and Punish. The Birth of the Prison", 1975) can be cited as an example. Deleuze's continuation of Foucault's reflections concerning digitalization ("Postscript on the Societies of Control", 1990) should also be named in this context.

4.3. (No) Freedom of Choice

Less evident than the first two ethical aspects is the risk that freedom of choice will eventually be eliminated. This applies not only to the use of technologies such as DTs but also to all technologies that prove to be helpful in the maintenance of health or in the implementation of political strategies. Of course, it is a clear advantage that technology can contribute to maintaining health. Many people consider the new possibilities enriching and want to use them; numerous studies have already proved this. From an ethical point of view, there is nothing to be objected to in the fact that people use technology if they want to. Nor is there a conflict with them disclosing their data and allowing it to be processed. However, there are certainly also people who do not want to use technologies of this kind. Negative attitudes may also be displayed in the case of DTs. Be it that individuals do not want to disclose their data, be it that they do not want to be technically imaged (perhaps they feel restricted in some way) or be it because they do not want to know exactly how they would have to organize their everyday lives to stay healthy. Perhaps some people prefer to indulge their weaknesses instead of behaving excellently.

The scientific discourse on age and technology has repeatedly pointed out that there should never be coercion to use certain technologies and that technical products are developed only for those who want to use them. The question of freedom of choice could nevertheless arise in the future, for example, even in cases where services could be provided technologically with lower financial costs than by human hands. It is conceivable that cost savings will be used as an argument for using technology in future times. The issue needs to be discussed urgently. At this point, it should be explicitly stated that any form of coercion would contradict the right to the free development of the personality, regardless of whether direct or indirect sanctions are applied to a refusal of use. People must not be forced to use technology in any conceivable case.

4.4. Transhumanist Approach

Another aspect should also be considered when reflecting on the topic from an ethical point of view. A closer look reveals that a transfer of the concept of DTs to humans is moving in the direction of transhumanist approaches. To make this understandable, a few words should first be said about transhumanism or the idea behind it. The term transhumanism has several meanings. It means (1) a scientistic–futuristic-oriented community, which has its origin in Silicon Valley, (2) a technology-enthusiastic philosophical direction, which also has followers in the academic world, and (3) a stage of mankind, which is to be brought by the unrestricted use of technologies, hence the advocates of the approach. At its core, transhumanism aims to use technology to optimize the human organism with its cognitive, emotional, and moral capacities. Proponents of transhumanism affirm the unrestricted use of technology to advance evolution and optimize humanity purposefully.

The DT approach is about collecting and evaluating data on (among others) vital parameters, detecting (potential) health problems at an early stage, and implementing appropriate interventions. This is intended to maintain health, expand opportunities, and increase quality of life. In other words, the aim is to become "improved" people who, as far as possible, no longer have any illnesses. Even if it is impossible to map the brain with all its information—as some proponents of transhumanist thinking aim—the approach is at least to image everything that is realistically possible to bring improvements.

Indeed, from a technical point of view, realizing the visions associated with transhumanism is impossible in several respects. It may not be possible in 50 years, either. But what about in 100 years? What about 500? Thinking centuries ahead is not common in scientific discourses around age and technology. The main reason for this is most likely because conjecture is the only possibility. The further it must be thought into the future, the more difficult it becomes. There are countless possibilities of what can happen, what developments will take place, and what events will influence them.

On the other hand, the discipline of technology assessments is becoming increasingly meaningful. Even if it is "estimating" and running scenarios, it is still essential that it is done. The fact is that there is an increasing use of technology, and there is also the trend of humans and machines merging more and more. At the same time, alienation from nature is taking place. From a philosophical point of view, one can ask whether humanity has a duty to optimize itself through technology. This is not self-evident and must be discussed; DTs are an example that illustrates this very clearly.

5. "E-VITA" as Starting Point for the Development of DTAs

5.1. Project Description

"E-VITA: EU-Japan Virtual Coach for Smart Aging" is an EU–Japan joint project under Horizon 2020 and MIC funding. In four EU countries (Germany, Belgium, France, and Italy) and Japan, 22 partners are researching new technologies and methods to assist older adults. In Germany, the project is coordinated by the University of Siegen, chair for Information Systems and New Media, and in Japan by Tohoku University, Smart Aging Research Centre (SARC). The project aims to create an innovative coaching system based on the needs and wishes of older adults. The virtual coach will provide personalized recommendations and interventions to improve the quality of life of aging adults. At the same time, it is intended to enable SMEs and NGOs to explore the feasibility of a new ecosystem. It can be assumed that empowering older adults to manage their activities better will positively impact their wellbeing. Socio-technological support is expected to enable them to age "actively and healthily", enhancing their quality of life.

5.2. From a Virtual Coach to a DTA

It must be explicitly mentioned that the virtual coach, developed in e-VITA, is not a DT but rather an assistant for elderly people and, thus, more of a "counterpart" than a twin. It is designed to provide dialogues with the user. Nevertheless, it became apparent during the progress of the project that there are clear parallels between the two technologies and that the coach's development could—at least, to some extent—pave the way for developing a DTA. Even though the virtual coach is not designed for the systematic collection of data, as would have to be the case for a DTA, it is a rough approximation of such a technology. The "user profile" contains much information about the user. Physiological data, as well as data on activities, behavior patterns, and preferences, are collected. Furthermore, the coaching system developed in e-VITA uses the knowledge gained from ambient sensors in the users' homes to understand the inhabitants' activities and provide the most relevant advice possible.

The different components needed to create a DTA are described in Section 3. As part of developing the virtual coaching system, each area is addressed in e-VITA. However, even if e-VITA, with its holistic approach, strongly focuses on older adults' needs, to build a fully working DT-environment that suits complex social systems like a Society 5.0 concept, research must exceed beyond the project. An important point for further research is that ethical aspects are seriously considered. The consortium partners agree on this. Ethical issues that play a specific role in DTA development and use have already been identified in Section 4. In the following section, considerations are given to handling the ethical issues.

The first problem identified in the section on ethical questions was that a strong performance orientation is inherent in transferring the concept of digital twins to people. Fortunately, however, the problem of performance orientation predominating within society has already been recognized by politics, also at the EU level and in Japan. A significant problem that has been (and still is) associated with the orientation on the performance principle is the social exclusion of people with disabilities. To stop this, the Convention on the Rights of Persons with Disabilities came into force. Since then, considerable progress has been made, but inclusion is still far from being realized. Implementing the idea would require perseverance, leisure, courage, and creativity. Abandoning the performance principle and enabling all people to participate in society would mean creating barrier-free conditions, in the physical world and social consciousness. From an ethical point of view, applying a concept like digital twins to people can only be legitimate if the focus is on the individual's wellbeing and not on their ability to perform.

Politics has also intervened regarding the second of the aspects outlined, which concerns privacy and data protection. There have been some changes at the European level in the recent past, and some more are on the horizon. One milestone was undoubtedly reached when the GDPR came into force. In Japan, the GDPR does not apply, but the APPI does, and some adjustments have been made in the recent past. The understanding of data protection is very similar. In Article 5, the GDPR lays down various principles of data protection that must be observed when collecting and processing personal data: "lawfulness", "fairness", "purpose limitation", "data minimization", "accuracy", "storage limitation", "integrity and confidentiality", "accountability", and "transparency". The requirement for transparency is one of the significant changes the GDPR brought, compared to the Data Protection Directive from 1995. One problem with implementing the principle of transparency now lies in how digital services present their information when collecting, processing, and storing personal data. Privacy statements are filled with legal phrases and usually have little relevance for users. In practice, there is still a need for improvement, particularly regarding the requirement for transparency. According to this, for a GDPR/APPI-compliant application of the concept of digital twins to humans, it must, firstly, be guaranteed that collected data are only shared when it is necessary or at least helpful, secondly, only to persons determined in advance, and, thirdly, only those vital parameters may be collected for which informed consent has been given.

Regarding the third aspect, freedom of choice, it is clear that a social system in which citizens are forced to use certain technologies or disclose personal data to minimize the financial burden would not be compatible with current human rights. People must be free to decide whether to use technology and what data they share. Against this background, explicit legal regulations could be helpful.

Finally, the fourth aspect ("transhumanist approach") is worthy of consideration, even if currently speculative. Today, many interventions in the human organism are conceivable, even at the genetic material level, so that future generations will be even healthier. It can be discussed under the term "transhumanism" or simply under the words "expansion of possibilities through technological progress", but it is essential to discuss in general what exactly we (do not) want, across disciplines and nations.

6. Outlook

Whether it is possible to transfer the DT concept to humans can be answered affirmatively. There are already numerous approaches to this in the research areas around public health and wellbeing. The integration of DT technology into the healthcare system is considered promising. Accordingly, well-known companies are already making efforts to develop HDT in the industrial sector. Insofar as the concept of DTs can be applied to persons, it can also be applied to elderly persons. The thought of making aging more comfortable with the help of CPS is an obvious one. During the development of a virtual coach for older adults within the e-VITA project, several insights were gained regarding considerations for developing DTA. Alongside the ongoing development of essential technical components, focusing on the ethical considerations elucidated in the article is particularly important. However, it could be shown that the use of DTA would not only improve the wellbeing of older adults on an individual level, but its systematic use could also make a valuable contribution at the level of society. What is unique about the idea of systematic use of Digital Twins for Ageing (DTA) is that it would not only have to be considered a compensatory solution for the shortage of qualified nurses but also a preventive one. Two main aims can be named: (1) to enable more and higher quality care by using technology and (2) to keep the amount of care needed low even though the population is aging. These aims could, for example, be achieved by early detection of problems such as the onset of disease. Although this approach is promising, there will be some challenges to overcome in terms of designing and developing technology as well as ethical considerations.

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