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RESEARCH PAPER

Imagining digital twins in healthcare: Designing for values as designing for technical milieus

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ABSTRACT

Medicine is increasingly focusing on the prevention of diseases. The digital twin (DT) is considered to be an important technological development for realizing this transition. Broadly speaking, a DT is an *in silico* representation of an individual that dynamically reflects molecular and physiological status, which makes it possible to monitor precisely health status over time. Currently, DTs are more of an abstract ideal than a concrete technological reality, which makes it possible to actively imagine the different ways in which DTs might materialize. This article develops an approach to imagining the different ways in which DTs can be integrated into the lives of people. It focuses on how potential users want to be cared for by means of DTs and how care practices might be changed through the introduction of DTs. The article shows that a shift towards preventive medicine is taking place and situates DT in this context. Then, drawing on the insights of Gilbert Simondon, it suggests that the notion of technical milieu can be a helpful tool for designers to imagine the practices of valuing to which DTs give rise. Subsequently, it explains how our philosophical approach helps inform what kinds of DTs can be imagined. Then, based on interviews with people likely to relate to DTs in the (near) future, it develops six conceptions of DTs and fleshes out some of the implications of our approach for the design of DTs.

Introduction

The healthcare sector is one of the main sites of technological innovation. The ageing population in most of the Western world places a large financial burden on healthcare systems. Technologies are thought to be a key factor in maintaining the quality of healthcare and the health of populations (e.g., European Commission, 2018). Examples of such technologies are health-monitoring applications that enable care at a distance and potentially decrease the number of hospital visits, and self-tracking applications that help individuals live a healthier lifestyle. The digital twin (DT) is considered an important novel health technology for alleviating the burden of rising healthcare costs and is promoted as a technology that will help people take care of their health more independently of existing healthcare systems. DTs promise personalized models of individuals and their biology that are continually updated based on measurements of health and lifestyle parameters as well as the general medical history of the targeted individual (e.g., Brown, 2016; El Saddik, 2018). However, DTs are almost indistinguishable from other efforts to digitalize healthcare processes and it is unclear what kinds of technologies need to be combined to realize DTs in practice (Popa *et al.*, 2021).

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The fact that DTs are still an abstract ideal and have not materialized into a technical object or system makes it possible to imagine the different ways in which they could materialize. This article contributes to the development of such visions. Analysing interviews with potential users of DTs, we investigate what kinds of values are at play in the ways in which potential users want to be cared for by DTs, as well as what kinds of novel care practices might arise in the interaction between future users and DTs. Building on this analysis, we propose different ways in which DTs might materialize.

We suggest that these different potential materializations can be considered different milieus co-constituted around the technology in question. We borrow the notion of ‘milieu’ from the French philosopher Gilbert Simondon, who wrote extensively on how technologies create specific ‘techno-geographical milieus’ that invite particular ways of acting. Furthermore, he developed the figure of the mechanologist to describe someone capable of guiding technological development. The mechanologist needs both a deep understanding of the internal working of technologies and the ability to anticipate what kinds of milieus they help constitute (Simondon, 2017, p.157). The mechanologist does not solely evaluate technologies in terms of their potential uses, but instead has an eye for the cultural significance of technical objects as well as the relations between different technical objects (Mills, 2016, p.136; Lapworth, 2020).

This article complements the work of Simondon with scholarship in the field of responsible research and innovation (RRI) and suggests that his philosophy offers an interesting theoretical starting point for anticipating how emerging technologies materialize. It does so by explaining the different ways in which DTs help constitute different milieus in which specific ways of valuing take place. This understanding contributes to RRI by fostering specific forms of imagination, which makes it possible to cultivate what Simondon calls the ‘openness of technical objects’, namely, their potential to align with different values as well as function in different milieus, which is hindered when technical objects are developed to realize a single predetermined goal. Generally, Simondon’s philosophical project can be considered a critical response to such reductionist views on technical objects.

The remainder of this article is structured as follows. First, we show how a shift in healthcare towards preventive medicine is taking place and situate DT in this context. Second, drawing on the work of Simondon, we suggest that the notion of techno-geographical milieus can be a helpful tool for designers to imagine the practices of valuing to which DTs give rise. Third, we explain how the philosophical approach taken informs which potential materialization of DTs can be imagined. Fourth, based on interviews with potential future users of DTs, we develop six conceptions of DTs and discuss the implications of our analysis for their design.

Predictive, personalized, preventive, participatory (P4) medicine and digital twins

The introduction of DTs in healthcare systems is part of a larger (r)evolution in medicine. Although the cure and treatment of diseases have long been the primary goals of medicine, medicine is increasingly concerned with preventing these diseases from occurring in the first place (Moerenhout *et al.*, 2018). This shift is sometimes captured under the banner of P4 medicine, referring to medicine being predictive, personalized, preventive and participatory (e.g., Flores *et al.*, 2013; Hood, 2013). The goal of medicine should be to predict future forms of biological dysfunction in human bodies before symptoms of disease appear (predictive), to stratify diseases in relation to the genetic make-up of individuals and optimize treatments accordingly (personalized), and to intervene pharmaceutically in biological systems to maintain normal functioning in terms of biomedical parameters (preventive). Obtaining these goals requires the active participation of patients, families, and patient communities as well as their willingness to donate relevant data and use the resources that medicine has to offer to increase health and well-being (participatory).

The shift towards preventive medicine implies that medicine is increasingly focusing on behaviours and lifestyle choices that might be detrimental to a person’s health. This requires a

dynamic understanding of biological systems in which certain behaviours and lifestyles can be singled out as potential risks that increase the likelihood of (future) biological dysfunction. Citizens are then invited to monitor those aspects of their lifestyle considered to be relevant health parameters to identify risk factors and seek interventions. One prominent way of doing this is by using self-tracking technologies that enable the monitoring of daily steps or calorie intake and offering feedback when they fall below a certain standard. Hence, the realization of P4 medicine relies heavily on the willingness of individuals to adopt a healthy lifestyle, the availability of technologies to monitor relevant health parameters and precise measurements of the dynamic interaction between lifestyle choices and biological processes relevant to the organism's ongoing functioning (e.g., Vogt *et al.*, 2016; de Boer, 2019).

Against this background, DTs are promoted as contributing to a novel way of delivering healthcare. It is not yet clear what the term 'digital twin' exactly entails, meaning that it is not possible to speak of DTs as concrete technologies with clear spatiotemporal boundaries (Braun, 2021). DTs emerged in engineering, where they were used to test the functioning of certain artefacts (e.g., a jet engine) by running a dynamic real-time simulation. Such simulations make it possible to engage in predictive maintenance to accurately measure when technical interventions might be needed before anomalies occur. In the context of healthcare, it is imagined that, analogously, DTs can offer real-time simulations of humans (although humans are more complex systems) to predict when anomalies might occur and/or when interventions might be needed.

A distinctive feature of DTs is that they promise to develop dynamic models of objects that are continually updated based on changes in the object they represent (in the context of healthcare, this might be an organ, but eventually also a person as a whole). This dynamism relies on a permanent data flow between the target object and its simulation. At the very least, DTs promise to offer '*in silico* representations of an individual that dynamically reflect molecular status, physiological status and lifestyle over time' (Bruynseels *et al.*, 2018, p.1). In doing so, they seem to embody perfectly what P4 medicine promises, namely to monitor constantly and update health status based on a dynamic personalized model that incorporates the interaction between lifestyle choices and biological (e.g., physiological, molecular) processes such that future diseases can be predicted and actions taken to prevent them from occurring.

A prominent criticism of current healthcare practices related to preventive medicine, which also seems applicable to DTs, is that they threaten to turn citizens and patients into mere sets of data points, such that the person represented is reduced to the model used to represent them (Ruckenstein and Schüll, 2017). Furthermore, P4 medicine may turn healthy individuals into aggregates of risk factors, which might adversely affect their well-being. For example, one can wonder whether the awareness that someone has a genomic disposition for a certain disorder will have a positive effect on the choices they make and on their well-being. In other words, P4 medicine and the development of DTs are thought to turn many people into potential patients, thereby implicitly or explicitly inviting them to understand themselves and their lives through biomedical frameworks. This, in turn, so it is postulated, reveals that current developments in medicine are a potential threat to the autonomy of citizens (e.g., Lanzing, 2019).

Such a negative evaluation of DTs might not do justice to how representations of health parameters can be relevant to the concerns of the individual being represented. Despite the threat that DTs will create a distance between the representation of an individual and the individual being represented such that the amount of control that one has over one's life and body decreases (de Boer, 2020, pp.408–9), this does not need to be the case. Indeed, DTs also offer new ways to understand oneself and relate to one's body. The key question, therefore, is: 'How can it be ensured that the person is represented in a way she decides and still has the opportunity to direct the representation in a way that serves her desires and enables self-determination?' (Braun, 2021, p.6).

This question can be addressed by investigating empirically the concerns that future users of DTs themselves foresee, which is one of the goals of this article. Since DTs in healthcare are not yet an integral part of healthcare systems, there is still room to consider how users want to be cared

for by DTs and how they want DTs to be integrated into their lives. At the same time, however, both biomedical researchers and technology companies that develop DTs foresee that they are a game changer with the potential to disrupt existing healthcare practices (e.g., Croatti *et al.*, 2020). Our empirical work focuses on what kinds of disruptions potential users of DTs would consider desirable and how they would like to be cared for by DTs. As will become clear throughout the article, our empirical study helps imagine new ways in which DTs become part of the lives of users, beyond a narrow biomedical understanding in which they are considered to be mere instruments that allow biological systems to be fixed.

Values, Simondon and a hermeneutic approach to RRI

Understanding the impact of DTs on healthcare practices requires a focus on what users consider desirable ways of taking care of their health. Moreover, it requires understanding how values related to health and care might change with the introduction of DTs into existing healthcare practices. In recent approaches to RRI, it has been argued that identifying the values at stake as well as how these values are affected by the introduction of new technologies requires developing a hermeneutic approach to RRI (e.g., Grunwald, 2014; Groves *et al.*, 2016; Boenink and Kudina, 2020).¹ For example, Grunwald (2020) argues that RRI and technology assessment should focus on identifying the societal meaning of technologies, the narratives that accompany them and the extent to which these match the interests and values of relevant actors. Boenink and Kudina (2020) argue that this process of identification requires understanding values as practices. In this way, values are not understood as concrete or stable entities, but rather as having a lived, interactive and dynamic character. Values then ‘result from, as well as guide human action, and are continuously reshaped in and by the interactions of humans with their material and social environment’ (Boenink and Kudina, 2020, p.466). Therefore, a hermeneutic approach requires focusing on the future practices that users envision and the kinds of interactions with the technology they foresee rather than relying on a set of values identified and/or prioritized beforehand.

As will become clear, our approach shares with prominent ethical approaches in RRI (such as value-sensitive design (VSD) and anticipatory ethics) the ambition to evaluate the social impact of emerging technologies, and to enable discussion about the extent to which these technologies align with societal ideals (e.g., an ideal about what constitutes good care). A main difference from VSD is that we take values as emerging within practices; the dynamics of these practices are not clearly captured when relying on pre-established values. This is where, for example, our approach diverges from what Van Wynsberghe (2013) terms ‘care-centred design’. Van Wynsberghe builds on VSD to develop a framework for caring technologies that can evaluate whether they align with the foundational values of care. VSD shares with anticipatory ethics the idea that it is important to identify the values embedded in technologies early on. In the formulation of Shilton (2015, p.5), anticipatory ethics searches ‘to describe what values are considered [to be] important by designers in early phases of design’. Our approach extends this endeavour by offering new ways for designers to imagine what kinds of values could be considered, based on users’ concerns and focusing on the types of practices that technologies might enable.²

As Groves *et al.* (2016, p.8) argue, technological developments create a specific kind of environment by creating a specific kind of interdependence between humans and technologies. This

¹A specific defence of this take on RRI is beyond the scope of this article. For now, we assume that a hermeneutic approach in RRI is worthwhile and propose a specific way of carrying out this approach drawing on Simondon. For a brief discussion of which issues in RRI and technology assessment a hermeneutic approach addresses, see De Boer *et al.* (2018, pp.300–2).

²In this paper, we intend to clarify how our approach differs from VSD and anticipatory ethics, but refrain from an in-depth discussion of (a) the internal differences between VSD and anticipatory ethics and (b) the advantages and disadvantages of VSD and anticipatory ethics compared with the approach developed in this paper.

interdependence shapes the concerns that humans might have as well as how they care for themselves and others, both in the here-and-now and in the future. In other words, technological developments shape how humans can individuate (i.e., what kinds of agents they become, what kinds of futures they imagine) by offering opportunities, but also by placing constraints on the practices that can be materialized. As the notion of DTs is currently more of an abstract idea than a technological reality, it is still possible to participate in imagining the different ways in which a DT could materialize and which forms of individuation it helps make possible. In this article, we develop an approach inspired by the work of Simondon, which helps imagine future practices around DTs and which ways of individuation are enabled in the interaction with them.

An important tenet in Simondon's work is the idea that technologies – or 'technical objects', as he calls them – partly develop according to their internal logic and that they create a specific milieu around them in the process. Understanding technical objects in this manner can be connected to a practice-based approach in RRI that thinks of values as arising in practices. Simondon's philosophy shows how technologies help constitute a specific milieu that significantly influences the processes of valuing taking place within it. This is not primarily because technical objects embody certain values, but rather because they constitute a particular milieu that offers specific opportunities for, and places constraints on, valuing.

One of Simondon's key ideas is that technical objects have an associated milieu that is a condition *sine qua non* for their functioning and which exists virtually before invention (e.g., Simondon, 2017, pp.63, 68).³ For example, the inventor of the air-cooled combustion engine imagines an associated milieu of air flowing around the engine while the vehicle moves, while the milieu itself is created by the object (Simondon, 2017, p.27). Simondon calls technical objects that have their own associated milieu 'technical individuals'. However, such individuals do not emerge from nowhere, but consist of different technical elements that do not have an associated milieu, but instead can be incorporated into different individuals. In the case of a combustion engine, a typical element is a bolt that is part of the engine, but is not individualized itself. Furthermore, Simondon distinguishes between technical individuals and technical ensembles. Technical ensembles are those objects that do not contain a particular associated milieu, but instead require humans to coordinate different machines (e.g., the connection of an electric guitar to an amplifier and use of certain distortion pedals to modify the sound of the guitar). In these cases, the constellation does not stabilize itself (as in the case of the combustion engine), but stabilization is achieved through human coordination. When combined in a specific way, these different technical elements form a complex system through which they can individuate, either independently as technical objects or as technical ensembles, thanks to some form of human coordination.

For Simondon, technical objects not only carry their technical milieus within them but must also adapt to existing milieus. In doing so, they constitute a techno-geographical milieu, namely, a 'mixed milieu which is simultaneously both technical and geographical' (Simondon, 2017, p.68). According to Simondon, this mixed milieu is constituted because technical objects individuate in a process of adaptation–concretization (Simondon, 2017, p.58); the materialization of a technical object requires an adaptation to a given milieu subject to certain natural laws and sociocultural norms. However, during adaptation, a technical object brings its own technical milieu with it, thereby realizing a new milieu adapted to the technical object in question. Because of this, Simondon maintains, in the interplay between the geographical and the technical, a new mixed milieu arises that allows for the emergence of new technical objects and ensembles, but also offers opportunities and places constraints on human forms of action and evaluation, thereby generating new practices (e.g., practices of valuing). For example, the invention of the combustion engine is not only a development in terms of

³Here we leave out Simondon's general interest in technical evolution as a process taking place over longer periods and which gives rise to different civilizations (Simondon, 2017, pp.53–82; see also Stiegler, 1998, pp.67–81). Rather, we isolate the specific elements of his general philosophy of technical objects and use them as heuristics to propose a way of anticipating the development of specific technical objects.

technical efficiency, but also one that increases mobility, which changes how people value the location(s) where they live.

Simondon was primarily interested in the internal development of technical objects and tended to conceive of the process of adaptation–concretization in purely technical terms (i.e., as the possibility for certain technological functions to be carried out). However, Feenberg (2017, pp.79–80) argues that there is no reason why this process would not be influenced by human, social and ecological conditions. Hence, a mixed milieu can also be considered to be something constituted in relation to societal demands as well as already existing (digital) networks, user preferences, industry demands and the climate in an area. Although this complicates understanding of the process of individuation significantly, there is no principal reason why a Simondonian approach cannot help anticipate the mixed milieus that complex sociotechnical systems – or technological cocktails (Popa *et al.*, 2021) – such as DTs help constitute.

Now that we have established what Simondon takes a technical object to be and how technical objects help constitute new mixed milieus in processes of adaptation–concretization, we can move onto the implications of this conceptualization for RRI. For Simondon, the significant impact of technical objects on the world in which we live requires the presence of individuals capable of coordinating technological developments. He captures this requirement with the figure of the ‘mechanologist’, which has the function of a ‘psychologist of machines, or of a sociologist of machines’ (Simondon, 2017, p.160).

In his paper ‘Technical mentality’, Simondon (2009) hints at what this function could look like by contrasting a technical mentality with a technocratic and industrialist mentality. On the one hand, he states that the mentality suited to technical objects cannot be technocratic since ‘the technocratic attitude cannot be universalized because it consists of reinventing the world like a neutral field for the penetration of machines’ (Simondon, 2009, p.22). This attitude overlooks the fact that technical objects are not entering a neutral field, but instead adapt to an associated milieu shaped anew by their introduction. On the other hand, he laments the industrial mentality that similarly consists of technical objects as if they exist in isolation; this becomes visible in the desire to add non-essential features to technical objects that obstruct successful shaping. Simondon provides an example of cars, which he maintains are characterized by quick obsolescence since they are designed to be seen rather than used. This, in turn, makes them closed objects that eventually fail to adapt to the demands of the milieu in which they function (Simondon, 2009, p.24).

The mentality needed for the successful development and guidance of technical objects involves a mode of knowledge that recognizes the openness present in the interplay between the different elements that constitute a technical object. Technologies have, to a certain extent, an internal tendency that makes particular trajectories of development possible. A technical mentality searches to free technical objects as much as possible from what is inessential to them and make them develop according to their internal tendencies. That is, technical objects embody a certain degree of openness that can be cultivated, which makes different ways of shaping possible. This openness is the result of the possible combinations enabled by the different elements of a technical object as well as the novel technical elements that can be integrated within it. When this openness is cultivated, the number of milieus to which a technical object can adapt and the types of mixed milieus it may virtually constitute increase. Put differently, a technical mentality that recognizes openness enables one to imagine a richer variety of possible materializations than a technocratic or industrial attitude.

However, the possibility that a technocratic or industrial attitude influences how technical objects are shaped already indicates that their development is never free from socio-political concerns (Voss, 2019). The concept of ‘openness’ becomes relevant for RRI at this point. Openness refers not only to the openness of technological functioning, but also to being open to the concerns of a wider set of stakeholders than those implied in industry and/or engineering, such that technical objects enable a multiplicity of practices (Feenberg, 2017). Hence, the technical mentality that Simondon introduces also implies a responsibility to engage the relevant stakeholders in technology development to be able to care for the openness of technical objects.

The example of the addition of a catalytic convertor to existing automotive exhaust systems shows how stakeholder engagement can foster openness. Initially, engineers lamented the convertor as reducing the efficiency of the car's engine (Feenberg, 2017, p.82). However, when linked to the social demand for decreasing car-induced air pollution, the convertor was integrated in most automobiles. This example indicates (i) that stakeholders can help in cultivating the openness of technical objects by proposing the integration of novel technical elements, and (ii) that these technical objects take different shapes when adapting to different demands (e.g., the demand for efficiency versus the demand for clean air) and constitute different techno-geographical milieus accordingly. The critical point here is that the evolution of technical objects (such as DTs) differs when approached with different mentalities, such that different mentalities give rise to different forms.

One of the key questions to be addressed when forging a link between the work of Simondon and RRI is how the above discussion of Simondon's philosophy can inform the practice of design and thus help anticipate the different milieus that technological objects inhabit. In the remainder of this article, we first show how engaging in specific ways of imagining potential formations makes it possible to cultivate the openness of technical objects. Subsequently, we use DTs as a case study to explore how imagining different ways in which DTs can materialize helps designers and future users anticipate how DTs might constitute different milieus.

The entanglement of imagination and invention in design

Since DTs in healthcare have not yet become technical objects, there is still room to develop different ways of imagining how they can materialize. Drawing on Simondon, this section explains how such a process of imagination can be fostered. For Simondon, imagination is not a purely mental or cognitive activity that fully coincides with having in-depth knowledge of the technical working of a given object. Simondon (2014) breaks away from such an understanding of imagination, assigns a relative independence and exteriority to what he calls 'image objects' and compares them with organisms or seeds with their evolutionary path (see Voss, 2019, n.7). Imagination then becomes a process of welcoming existing image objects and receiving, subsuming and shaping them (into a technical object, a work of art, or a scenario) rather than producing images from scratch.

For Simondon (2017, p.60), technological imagination, or more specific invention, includes the anticipation of the associated milieu to which a novel technical object gives rise. This anticipation crucially involves recognition that openness is a condition for any human participation with objects (Simondon, 2017, p.18), for example, in the interaction between humans and DTs. Objects can evolve further towards such a refined level of participation that they become equal in their participation with humans (Combes, 2013, p.60), but as machines are not yet able to develop their openness, there is a role for humans to cultivate such openness. Simondon goes as far as to say that opening the object further and imagining new relations in which it can participate is the right mentality to deal with technical objects (Simondon, 2009).⁴

How designers imagine has recently been studied by Vincent Beaubois, who establishes a close connection between Simondon's theory of imagination and the concrete practice of design (Beaubois, 2019). Beaubois argues that designers pay attention to a schematic materiality that forms the associated milieu of the designer's imagination (Beaubois, 2019, p.316). In his view, the materiality of design work does not primarily pertain to the finishing of a ready-made product, but rather to the creation of a design environment. Materializations, such as sketches, models, prototypes and scenarios, comprise both the design problem and the way to respond to it (Beaubois, 2019, p.323). Beaubois suggests that the imagination of the designer works differently from that of the engineer, who tends to anticipate only the technical aspects of a given object. The engineer overlooks how an

⁴We focus on how new image objects can help designers imagine the milieus constituted around DTs and refrain from examining how these image objects structure the imagination of future users.

object becomes integrated into what Simondon terms a mixed techno-geographical milieu that cannot be reduced to the technical workings of a given technology.

More precisely, it is the operative schema of an existing functioning object or ensemble to which the designer relates (Beaubois, 2019). The notion of operative schema highlights the dynamic interaction between designer and design environment, indicating that how a design takes shape should be understood in terms of the designer's interaction with the objects in the environment, with image objects being crucial. For example, the role and functioning of DTs in engineering is imagined in the context of healthcare and offers an implicit blueprint of how users of DTs are understood; namely, as biological systems that need to be fixed. Our interview study with future users intends to generate novel image objects that allow us to imagine other ways in which users would like to be cared for by DTs.

Six ideal types of digital twins: from a coach to a last will

To explore how potential users imagine a valuable materialization of their bodily functions and health parameters through the representation of a DT, we took an empirical approach using interviews. Our empirical study was guided by the methodology of interpretative phenomenological analysis (IPA), focusing on how people experience and make sense of the phenomena around them (Smith *et al.*, 2009). In IPA, interviews aim to reveal interviewees' personal accounts, which in turn allows researchers to make sense of these personalized accounts and analyse them systematically. However, this systematic analysis does not serve to develop an objective account of the experiences and should be considered as a sense-making process in itself, during which a researcher tries to make sense of the sense-making processes of others (Smith and Osborn, 2015).

Our interviews focused on receiving a diagnosis. Preliminary discussions with potential users, as well as experts from a DT research group in the Netherlands, revealed that this area significantly affects the user's experience of their body. Our objective was to explore people's experiences of receiving a diagnosis and compare how they thought their experiences might evolve in the future, assuming that DTs would become an integral part of the diagnosis process. In line with the methodology of IPA, group samples were kept relatively small, enabling an in-depth qualitative analysis of each interview. Two interview groups with four participants per group were formed, each of which consisted of participants living in Western Europe. The first group consisted of healthy participants between 24 and 28 years old, of which two identified as female and two as male. The participants in this group grew up in the digital age and were less likely to have experienced long-term problems with disease. The second group consisted of healthy participants between 54 and 65 years old (two men and two women). The participants in this group did not grow up in a digitalized world and, by this point in their lives, it can be assumed that they had experienced or were concerned about the effects of long-term or even chronic diseases. All the interviews were recorded with the consent of the interviewees.

The interviews were carried out via a video call in which the general idea of a DT was introduced and a semi-structured interview was conducted. The semi-structured interview guide was divided into six steps. The first step focused on the experience of being diagnosed, the second on the expectations of the future experience of healthcare and the third on the diagnosis. The fourth step introduced the general concept of a DT from an engineering perspective, and the fifth step explored the general perception of DTs in healthcare. The final step sought to uncover the possible effect of a DT on diagnosis. The step helped participants recall past experiences, explore a future vision, eventually evoking their imagination and uncovering a future vision of DTs in healthcare and their impact on the experience of a diagnosis.

The analysis of the interviews was guided by the six steps suggested in IPA (Smith *et al.*, 2009). These six steps consisted of first relistening to the recorded interview and reading the transcript to gain a second-person perspective. This was followed by making initial notes in three ways: descriptive, linguistic and conceptual. Descriptive comments are designed to reflect and organize the structure in which participants provide their answers and thus the activity of sense-making

through the participant. Linguistic comments focus on the tone with which interviewees narrate their process of sense-making; for example, with laughter or using metaphors to describe experiences. During conceptual note-taking, the researcher takes a more distanced role and starts the process of sense-making. In this way, key moments are interpreted through the conceptual comments of the researcher, taking a hermeneutic approach and welcoming novel images. The third step was to identify emerging themes within the transcribed material. The chronological order of the interview is retained as the structure; hence, emerging themes are listed in this order. This step supports a more abstract understanding of the shared experience, but also highlights the importance of not abandoning the profoundness of what is being said. Fourth, we distinguished emerging themes by clustering them under a collective descriptive term (i.e., different ideal types). We then moved to the next interview to search for other emerging themes. The final step of the analysis aimed to compare the overarching themes of each interview and visualize their interplay. Visualization is an important step in iterating and reflecting on the analysis. To reflect reliably the broad range of experiences, all themes were represented in the analysis. This type of analysis aims to uncover the meaning of each experience rather than the number of times they occurred.

During the identification of themes, 415 quotes from both younger and older participants were highlighted as representing the various themes. Once the 415 quotes and their underlying themes were highlighted, we clustered them to arrive at the emerging themes. In this step, 67 themes emerged from the experiences of the younger participant group and 62 themes emerged from the experiences of the older participant group. These themes provided the basis for reflecting on the meanings and shared experiences of a vision for DTs in healthcare.

Based on the detailed six-step analysis above, the interviewees imagine possible materializations that differ significantly from how DTs are often represented in the engineering and healthcare domains. In the latter case, DTs are often envisioned as enabling healthcare professionals to provide better lifestyle advice and more accurate medical assessments. Thus, whereas DTs are often imagined to be dynamic (i.e., constantly updated based on real-time data), their use remains ingrained in a static model of medicine in which healthcare professionals are providers of medical information that is passively absorbed by (potential) patients. Our analysis and insights derived from the interviews suggest that this view does not necessarily reflect how future users want to be cared for by DTs. To move away from the static concept of a DT, we envisioned six conceptualizations of DTs that align better with the practices that our interviewees imagined and their concerns when interacting with DTs (Table 1).

Not all the emerging themes could be integrated into these ideal types and this non-exhaustive list of ideal types is not necessarily examples of best practices based on current technical possibilities. Furthermore, the interviewees included in this study were all raised in Western countries and highly educated. This severely limits the scope of the current exploration, as it does not consider many of the relevant variables (e.g., ethnicity, level of education, socioeconomic status) likely to influence how DTs are perceived and how future interactions with them can be imagined. In short, working with a different group of interviewees would be unlikely to give rise to the same ideal types. These limitations notwithstanding, we believe that the six ideal types outlined below shed light on the kinds of DTs that can be valuable to future users.

Table 1.

User concerns	Type
Support, self-improvement, knowing your body	Coach
Being seen as a whole, knowing your body, emotional data	Diary
Security, efficiency, control	Back-up
Fear of monetary aspect, (data) security	Judge
Location	Last will
Support, acceptance of own faith	Bank

DT as a coach

I think it can be a kind of guide. If it's the one saying giving you feedback and suggestions more than the diagnosis on the problem you already have, maybe having it on a daily basis would be nice, if it's a helping hand more than just a communicator showing all your diseases.⁵

One of the ways in which future users imagine DT is as a coach, which is exemplified in the above quote in which DTs are understood as offering guidance on living a healthy lifestyle. This trend is especially visible in the younger group of participants and is informed by ideas of support and self-improvement. DTs are then understood as providing a new way of knowing one's body and offering feedback based on this knowledge. DTs can support individuals in their daily lives; for example, by helping to change certain habits or supporting a specific diet. The interviewees highlighted that, as a coach, a DT should positively support users to improve themselves without explicitly judging their behaviour. Recommendations can be updated based on parameter changes and relevant scientific findings. Thus, the coach achieves a high degree of personalization and offers the individual relevant information that helps the individual pursue goals, such as losing weight, optimizing athletic performance, adopting healthier behaviours and improving cognitive and physical performance. The dynamic model of one's body was deemed crucial because it made possible correlation of behavioural change with physical change, making users aware of the influence of lifestyle choices. The DT becomes more than just a point of confrontation; rather, it takes on the role of supporter, creating a positive environment that supports the user's individual goals.

DT as a diary

I could imagine that you find earlier things where you say okay, we intervene earlier simply because the digital twin says so. But do you know if the digital twin can really capture everything, including your psyche? Well, I can tell you when I'm excited, you can see that directly from my blood pressure.

Interviewees emphasized that DTs captured the relevant connections between emotional well-being and the physical parameters, which they felt was currently not an integral part of medical diagnoses. They imagined that this connection could positively shape doctor–patient relationships by offering a more complete image of (potential) patients. In this way, a DT could take the form of a diary, making it possible to be seen as a whole by medical professionals. Interviewees foresaw that a DT could help move away from seeing (potential) patients in terms of statistical data and help recognize that health and well-being do not solely consist of physical parameters. DTs were thought to offer new ways for users to get to know their bodies and connect to their emotional status. Additionally, the diary could provide insights into why users might deviate from their normal functioning or why they might meet (or fail to meet) certain goals, thereby offering a novel method of self-evaluation.

DT as a back-up

You can see your body like the time machine on your computer, like different stages for, when you are young, and when you are old, then you can see parts of your body, things that you can predict when you can see red spots, when you have more problems or things that happen in this point, pain somewhere.

Having a DT as a back-up emphasizes that users value security, which can be enabled by a personalized DT giving a sense of control in a medical emergency. In the event of a serious accident or unforeseen event that results in serious physical harm, the DT can step in. By routinely taking full-body back-ups that record the patient's status history as a snapshot, the data can be used to evaluate

⁵These quotes are taken from the transcription of the interviews. The transcription is available on request.

progress in relation to the pre-accident state. This could increase the patient confidence in being restored to the pre-accident state and is considered to be a safety net in daily life. Offering personal body back-ups enabled by DT was thought to enrich the current practice of emergency care.

DT as a judge

Well, . . . I don't know if it would happen but theoretically you could say that . . . the parts of that man are all pretty worn out and now he is 78 years old and needs an artificial hip, so it's not worth it, we [healthcare providers] don't do that anymore.

In this quotation, in which the participant imagines the conversation between an imaginary health-care worker and a patient, the fear that a patient's eventual worth could be based on the information provided by a DT becomes clear. This fear is fuelled by the fact that cost and effort are calculated by direct predictions of, for example, one's life expectancy or chance of illness and might serve as the basis for making decisions. Therefore, an individual's worth might be determined and evaluated solely on physical parameters and economic value, and a DT would not assign worth to a (potential) patient in themselves. There is a second aspect to a DT as a judge: the DT might criticize or provide feedback to a person about monitored behaviour that is detrimental to their health. The analysis of the interviews made it apparent that the participants were particularly attentive to the tone, manner and timing of communication with the physician during past diagnoses. Depending on these criteria, they shared positive or negative experiences when interacting with physicians in the past. Accordingly, this aspect was also thought to be important for their interaction with DTs.

DT as a bank

I would rather have the diagnosis and feedback with an expert at their workplace and not at home. For me, the place is significant.

The ideal type of bank serves to address the significance that the interviewees attributed to where a diagnosis is made. They indicated that the readiness to face a diagnosis is different in a doctor's office or hospital than at home and mentioned that they feared the consequences of receiving a diagnosis at home. It was indicated that the latter would be highly intrusive at home, which is usually a place of privacy and security. It can be assumed that receiving a diagnosis has large and long-lasting effects on the person and the person's future. In the literature, critical life events and news that affect a person's memory are referred to as flashbulb memories (May *et al.*, 2020). Triggered by a surprising or even traumatizing event, flashbulb memories might establish a permanent memory of the event. This memory need not be limited to a diagnosis (in this case), but may include emotions or the location where the memory was triggered. Hence, memories might be triggered continuously in one's home (Brown and Kulik, 1977). Conceptualizing a DT as a bank might counter this in that the DT represents a place that one can choose to visit, a place where data on one's condition can be accessed by asking a doctor about the condition of the DT, similar to visiting a bank to withdraw money.

DT as last will

He could take the medication by knowing what I want in my living will and that I might be asked again and that the digital twin could then facilitate the medication. [The DT] could also say what other things I need or if it is perhaps time that relatives should join, and the son as he is most important . . . He has to be informed so that such information can be provided if the patient cannot say this anymore.

A DT as a last will only appears in the older group of participants and highlights an unexpected potential role of DTs. In this form, a DT acts as a supporter and enables end-of-life decisions by

providing insights into the (future) decrease in certain bodily functions, which, as the interviewees mentioned, could enable a self-determined end of life. A DT could help a person prepare for their death through early confrontation with, among other things, information about living wills and could inform relatives in case of death. Furthermore, in this conceptualization, the DT could support the process of arranging a funeral by collecting relevant information about the deceased's wishes in advance. After the death of a person, the DT could inform a notary about the heir before the DT is shut down. However, this also raises the question of what happens to a DT after a person's death, which needs to be further researched, discussed and reconciled with legal requirements.

Discussion

These six ideal types point to different approaches to how a DT might align with the desires of potential users and enable self-determination in their relations with DTs. Building from Simondon's account of imagination, these ideal types function as novel image objects that embody the potential of DTs. These image objects were grounded in the existing imaginaries of DTs present in current healthcare innovation, after which the DT was introduced to the interviewees. However, the interviews enabled the interviewees to derive their vision of a DT in healthcare and imagine novel schemas of functioning and interacting, thereby envisioning different materializations. In doing so, potential future users constitute novel image objects that are not reducible to the earlier image object, which constitutes a different design environment. These novel image objects can then inform the process of designing DTs and clarify the ways in which future users want to be cared for by DTs and what kinds of agents they want to become in their interactions with DTs.

The different potential materializations of DT presuppose different associated milieus in which DTs play different roles. Let us illustrate this with reference to two of the ideal types identified in this section: DTs as a bank and DTs as a last will. In the ideal type of bank, a DT can be imagined: opening an enclosed space, positioning valuables in that space, closing the space and reopening the space to access the valuables under certain conditions (e.g., a key). This puts to work an operative schema that can be transposed from one situation to another (Simondon, 2009, p.18; Lindberg, 2019). Data (valuable goods) are deposited in a secure digital place (the enclosed space that protects valuable goods) and are disclosed under certain conditions (the key to the space).

In the case of DTs as a last will, another analogy can be made. Developing a last will can be considered a form of anticipating one's own death to highlight what one would like to happen towards the end and what kinds of wishes one has after passing away. Realizing a last will requires the cooperation of the medical field, family members and other loved ones, and other professionals (e.g., a notary or a professional in palliative care). This practice can also function as an operative scheme while simultaneously fulfilling the central aim of design practice, namely, to make objects materialize that create 'synergies between heterogeneous fields' (Beaubois, 2019, p. 323) – in this case, a synergy among the medical field, notary professionals and loved ones.

These two examples illustrate that the different ideal types developed on the basis of interviews with potential future users of DTs can be fruitful for design practices by helping constitute novel image objects within the designer's imaginative environment.⁶ In doing so, they participate in the operative schemas that eventually guide how DTs materialize.

Conclusion

Our non-exhaustive list of six ideal types of DTs serves to approach this technology as a 'mechanologist', what Simondon calls 'a psychologist, or sociologist of machines' (Simondon, 2017, p.160).

⁶The perspective developed in this study fits well with the ideal of interdisciplinarity often prevalent in RRI. However, we leave open the question of whether these studies should be conducted by designers and engineers, by social scientists, or by scholars in (empirical) philosophy.

This approach can be opposed to a view in which DTs are considered only in terms of technical effectiveness and/or feasibility, and remain narrowly understood as instruments that allow biological systems to be fixed. This particular conceptualization of DTs is closely linked to their origin in engineering and explains how their role is imagined in the context of healthcare. It offers an implicit blueprint of how users of DTs are understood. Our article contributes to a hermeneutic approach to RRI by presenting novel imaginations of DTs grounded in interviews with future users. These laid bare how they would like to be cared for in their interactions with DTs. The conceptualizations developed from our interviews suggest directions in which DTs can materialize. In other words, these different ideal types reflect the ways in which users might individuate through their interactions with DTs (i.e., reflect the different agents that users might become and different futures that they might imagine). These potential materializations can inform the practice of design by giving rise to specific forms of imagination, which makes it possible to cultivate what Simondon calls the ‘openness of technical objects’. As a result, technical objects (such as DTs) should be capable of aligning with different ways of individuation and functioning in different milieus. The development of a dynamic DT should not be limited to how it can offer dynamic models of targeted individuals but should also include dynamism in the different milieus and projects within which DTs can function.

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