# The Future of Digital Twins


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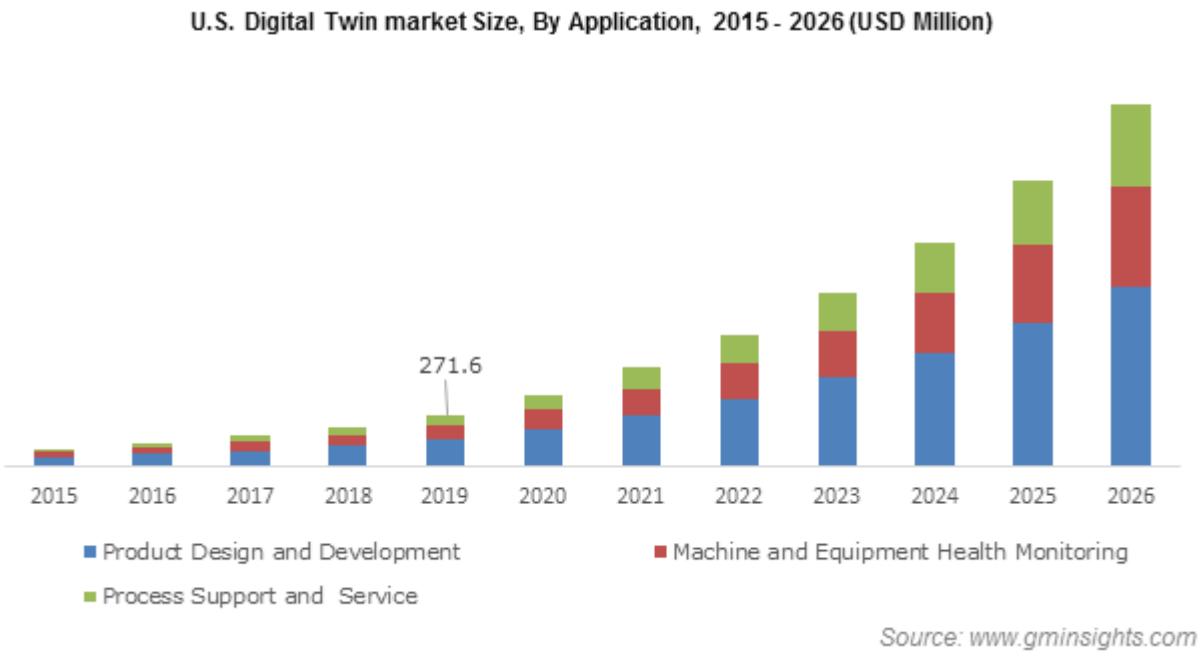
# The Future of Digital Twins




As far as we know, The Digital Twin concept was established approximately 15 years ago. That is quite a long time considering the accelerated evolution of modern digital technologies. Yet it only recently caught the interest and garnered attention from researchers in computer science, probably due to its origins in the manufacturing world.

Only three years ago, one of the authors was asked to name one key technology impacting the evolution of computer science in the 2019-2020 timeframe, and when he suggested Digital Twins, he received negative feedback. Those voicing negative comments against this idea were subject-matter experts from the Computer Society. Yet, in a very short time span (from 2018 to 2019), the dam was broken, and the Computer Society generated several events and publications that marked a 180° change in their attention on the relevance of Digital Twins.

In the last 12 months it has become an avalanche. In a way, we are starting to have doubts on Digital Twins. They are mentioned everywhere, and the topic of discussion is irrelevant—you can rest assured that a speaker, to make a point, will sprinkle his talk with the mentioning of Digital Twins. It has reached the same level of popularity as 5G and AI. Everybody feels the need to mention Digital Twins, quite often, without understanding what they really are.

As a matter of fact, we have been asked to participate in writing a book pertaining to the future of Digital Twins, and, ironically, the first virtual meeting with all contributing authors, including ourselves, was spent trying to reach an agreement on the official definition of Digital Twins.

It is a curious state of affairs when a group of "subject-matter experts" need to spend a substantial amount of time, without success, to agree on, precisely, what they are talking about.

If you look at this from a different point of view, the broad variety of ideas defining Digital Twins and their uses is a clear indication of the rapid evolution and the diversity of application areas. This leads to several ways of defining them since, in a way, they get twisted to fit the specific need of an area, and those needs may significantly differ across diverse application areas such as manufacturing, healthcare, machines, people, etc.

In this eBook, derived from a webinar conducted via the IEEE Digital Reality Webinar Series, we try to address the Future of Digital Twins by looking at the forces that are pushing their adoption, and the adaptations taking place in their deployment.

## 1. Once upon a Time

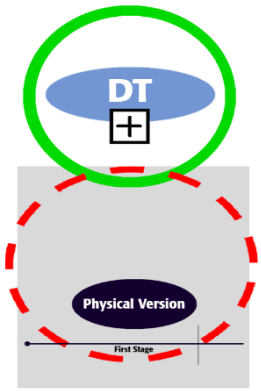



Figure 1: In the design phase we can create a digital twin as a virtual image of the yet to be created physical twin.

Digital Twins derive from Computer Aided Design (CAD), particularly the type used within the mechanical industry to design components. Even for something as mechanical as a cog, the manufacturing industry uses CAD software in the design phase. This simplified the design process because it enabled an accelerated method to exchange documents, and it supported a growing library of components in digital form. The very first Digital Twins were Digital Models, created by leveraging CAD software. Additionally, the CAD system recorded the evolution of that component, making it possible for engineers to access previous design phases, modify some of the details, and produce an updated version. By accessing previous modifications throughout the evolution, we have a tracking of the overall evolution, a Digital Thread. The first Digital Twins were born before their corresponding Physical Twin and this is still the case today in many scenarios, see figure 1.

The increased connectivity (embedding of IoT) in products provides producers with a method to track and analyze a product usage and operation. The Physical Twin, see Figure 2, sends data to update its Digital Twin. This allows the manufacturer, as well as those operating and performing maintenance on the product, to monitor the physical version and be proactive in response. The synchronization of the physical and the digital version of a product, system, or process is called Digital Shadow. This is the third component, along with the Digital Model and the Digital Thread, constituting a Digital Twin.

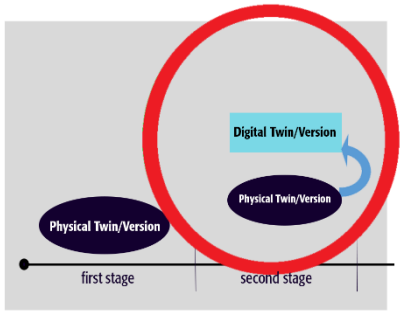



Figure 2 The digital twin is connected to the physical twin using IoT/sensors.

The next step was straightforward, but it started to complicate things: if the Digital Twin can represent the current status of its Physical Twin, and the Digital Twin identifies an error or issue, why can't it notify the Physical Twin to request a modification? For example, if an engine (the Physical Twin) temperature sensors report an higher than normal temperature, the digital twin can simulate the possible evolution and evaluate actions to rectify the issue, basing the solutions on data and specs from previous experiences of that Physical Twin, or from experiences derived from other engines (Digital Twins associated to other engines).

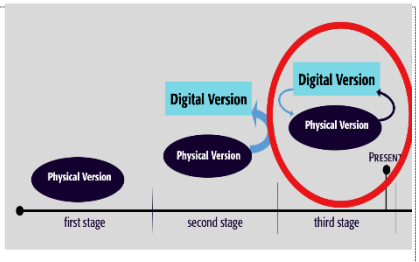



Figure 3 Digital Twins can be connected to their respective Physical Twins, receiving data and sending commands to execute specific actions.

We are now at the so-called Digital Twin stage III, which is when a Digital Twin is "more than a Digital Twin"—it no longer represents only one Physical Twin, it also has the capability to represent future/possible versions of its Physical Twin, and takes action to move its Physical Twin to a new, desired state, see Figure 3.

Digital Transformation is making this possible. It is actually motivating industries and businesses, in general, to conduct more and more activities and tasks in the cyberspace, where everything is more efficient, completed faster, and at a lower cost. Digital Twins are among the most important players in the cyberspace. They are used on "behalf" of their Physical Twin which may or may not exist at that particular time (meaning the physical twin may be at a different state). In other words, the Digital Twin can be made to operate faster than its Physical Twin, and only when a certain, steady state is reached, the Digital Twin will transfer the new state to its Physical Twin.

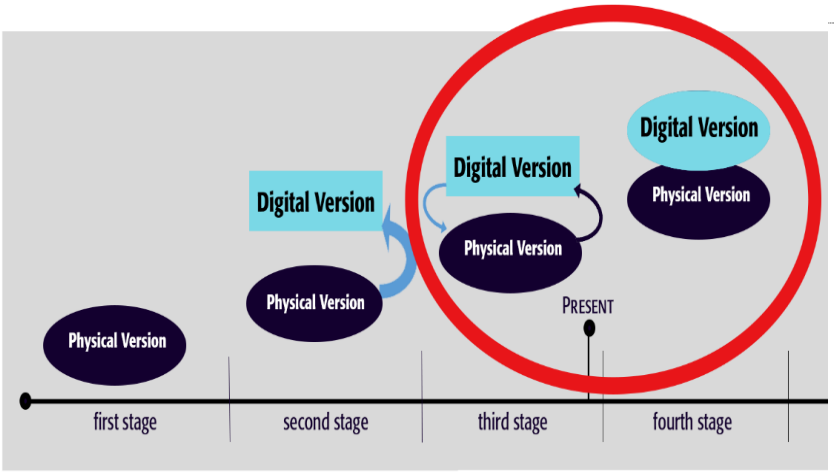



Figure 4 At stage IV the digital twin and its physical counterpart merge into a single behavioral entity, i.e. the functionality we perceive when interacting with a physical object (physical twin) will not be possible without its digital twin.

In this hypothetical scenario, most of the evolution is taking place in the cyberspace, and only once in a while (when absolutely required), it is implemented by the Physical Twin in the Physical space. This means that some of the capabilities exhibited by the Physical Twin are actually features created by the Digital Twin. Although a Physical Twin (an object) may have had an independent life in the stages explained before, this is no longer possible when the Digital Twin moves to stage IV: the non-existence of the Digital Twin would not allow the existence of the Physical Twin as we know it, see Figure 4. That object requires the existence of its Digital Twin to be what we perceive it as.

## 2. The Forces driving the Digital Twin (DT) Evolution

As we have seen, DTs have evolved, as result of the tech evolution, expanding the ways in which they have been used. These same forces are the ones that will be steering, actually accelerating, their evolution.

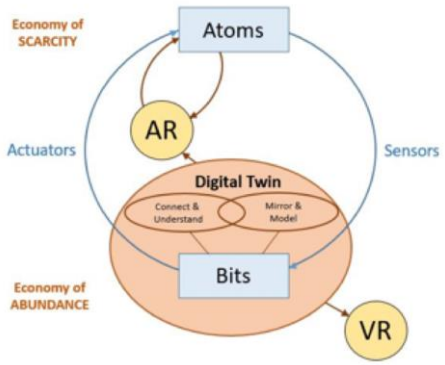



Figure 5 Schematic representation of the Digital Transformation highlighting the role played by Digital Twins.

## Digital Transformation

The Digital Transformation is accelerating, and so is the adoption and extension of Digital Twins in a growing number of areas.

As shown in the diagram, the data (created by sensors) feed the cyberspace representation, and then the model of the physical entity is updated and enhanced. The Digital Twin is becoming an essential component for making use of this data, as well as for monitoring and simulation purposes. Additionally, several activities that were taking place in the physical space could and will take place in the cyberspace. The "actors" performing these actions are the digital twins. Digital Twins can also be seen as a gateway bridging the cyberspace with the physical space of a specific user, supporting augmented reality (AR). In addition, DTs allow the visualization and manipulation of data in the cyberspace, supporting Virtual Reality (VR)—see the graphic in figure 5.

## Communication Fabric

The entire communication infrastructure is evolving towards a fabric where the users are becoming communications nodes. In other words, it is becoming more difficult to distinguish the end points of a network from the network nodes.

Think about the way the cloud has been extended from being somewhere within the network core to reach the edges. Now, we are increasingly going to see the "edge" moving into the devices. This pervasive cloud will consist of a cluster of federated clouds, from the ones provided by the hyperscalers, to the edge in the devices.

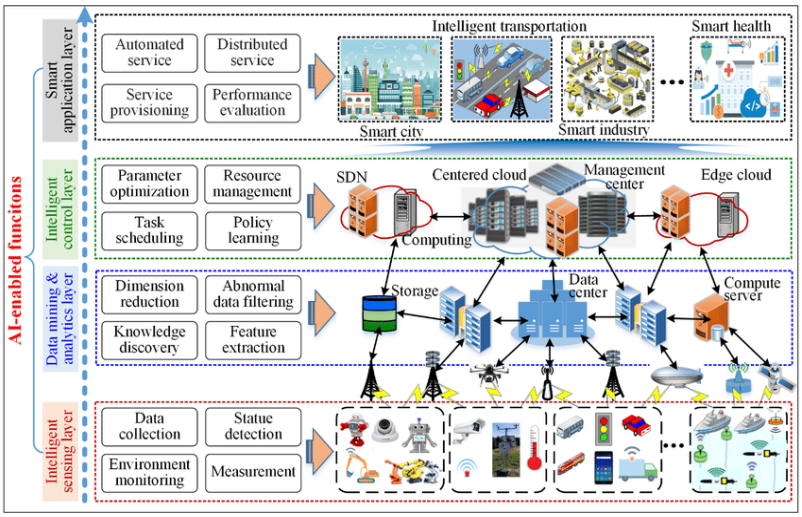


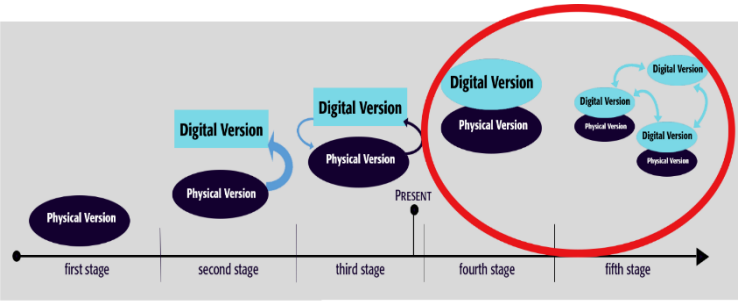

Figure 6 – Distributed AI architecture in future networks. Image credit: Zehui Xiong et al.

The Digital Twins that have been floating in the cyberspace will likely move inside the edge (e.g. in a device such as a smartphone), and will likely self-replicate to have several copies hosted in other parts of the cloud federation and even roaming the cyberspace. This creates a push towards autonomous Digital Twins. Additionally, Digital Twins are hubs of local intelligence and awareness, and Future Networks (see figure 6) will leverage this local intelligence—for example, to size resources. A part of the communications will be happening

through data sharing, and Digital Twins are a technology that can be used for data encapsulation and data sharing (through interactions).

## Artificial Intelligence

The autonomous behavior is enabled by, and simultaneously stimulating the growth of, artificial intelligence embedded in the Digital Twin. This is what we characterize as a Digital Twin at stage V, see graphic on the side. This Digital Twin is not just smart and autonomous, it is designed to become increasingly smarter over time and more enhanced. As a result of the extended set of interactions experienced by roaming the cyberspace, interacting with other Digital Twins, as well as interacting within itself through GAN technology, it can evaluate a huge slate of possible futures, and take decisions on which one to pursue. As a matter of fact, Digital Twins are starting to be considered the "mind of machines."




This Digital Twin is bound to become much smarter than its Physical twin, and that is great... as long as its Physical Twin is not a human being (even worse if it happens to be me!).

This evolution is inevitable, yet it is fraught with issues: who will become responsible for the Digital Twin behavior and for its influence on the Physical Twin? When a Digital Twin was just a faithful model of the Physical Twin, the responsibility was on the lap of its Physical Twin, but now?

## Swarm Intelligence

As Digital Twins become smarter and interact with one another, most of the time in subtle ways, they are influencing one another (for example, Digital Twins mirroring different types of objects—a laptop and a smartphone are different, but much of the internal components are the same). This leads to an emergent behavior, like in swarms of bees, or flocks of starlings (an in-depth discussion can be found in *The Path Towards 6G and Digital Reality*, an eBook by Roberto Saracco). Here, the issues of responsibility become even more difficult to address. Yet, this evolution is extremely likely to occur given the lack of constraints in physical distance and the almost instantaneous communication between the Physical and Digital Twins. So instantaneous, in fact, that it becomes difficult to distinguish before from after or to determine cause and effect!

A swarm of Digital Twins can be modelled as one "Digital Twin," but the data "owned/processed" by the entire swarm of Digital Twins can be seen as a data bank. For example, considering healthcare applications in epidemics—each Digital Twin might mirror a different person, a concept known as Personal Digital Twins (PDTs—Click here to access *PDTs and their Role in Epidemics Control*, a free webinar). All these people, through their mutual

interactions, create a swarm (the behavior of each one is subtly influencing the neighboring ones, resulting in spreading or controlling the contagion). By aggregating all individual "twins" into one Digital Twin to represent the swarm, we can model the epidemic risk in a specified swarm by analyzing and observing the complete data bank while preserving data privacy for individuals (only the mutual interactions and the outcomes of the interacting parties are important).

The extension of Digital Twins to swarms is seen in models of smart cities, in the context of Industry 4.0 we see it in production lines leveraging autonomous robots, and in the behavior of stock markets…

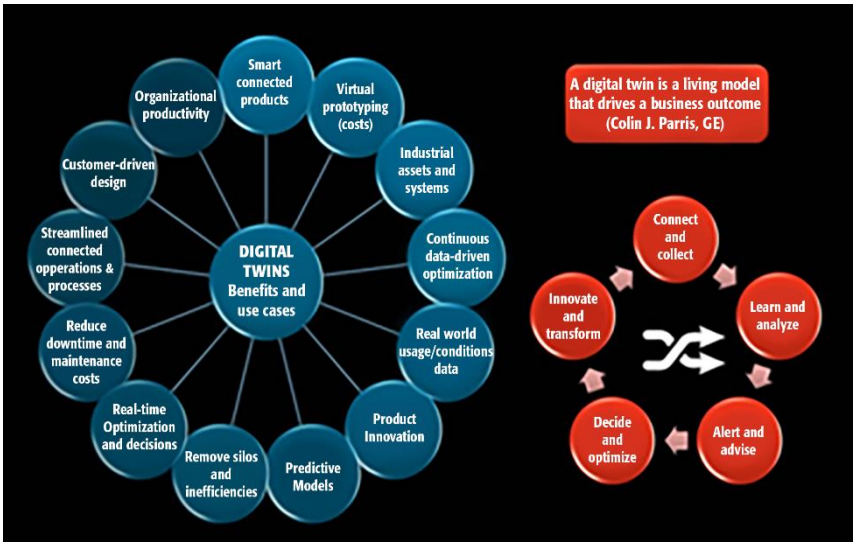



Figure 7 – Broader range of application for Digital Twins
Image credit: Colin J. Parris, GE

## Application Fields

Digital Twins are now being used throughout the entire life cycle of a product (see Figure 7), and in all the fields of applications you can think of, as well as in a few others that you wouldn't have considered!

Digital Twins are extending the depth and sensitivity of their modelling capabilities as more and more characteristics of a Physical Twin are merged with their digital replica, and as they interact more frequently with their Physical Twin. Additionally, their entrance into areas such as Healthcare and Education are extending their impact on people. In the healthcare industry, for example, professionals can use PDTs to test pharmaceuticals and instruments to determine how a patient will be affected by them and to ensure it will result in the desired effect. Education tools, such the ones developed at Loughborough University and Mevea, clearly involve the student and are changing the education paradigm: is it better to educate the student or their Digital Twin? This will be extended in the workspace with companies wondering what would be most effective: training the Digital Twin or its Physical Twin (their employee). Notice that this is not strange as it might seem. Today, and over the past decades, we have developed tools to assist workers rather than improving workers knowledge…

Indeed, we are moving towards a trend of having replicas of ourselves, and as for objects, these replicas may become autonomous, they may potentially even become our proxies. Same questions as before, just bigger and much closer to home.

# 3. What does the Future Hold for Digital Twins?

Having considered the forces that are steering the evolution of the Digital Twin concept, we can now ask ourselves what kind of future can be expected for Digital Twins.

## Capabilities of Digital Twins

In the near future we can expect Digital Twins to proactively search for data, harvest data, and request that sensors capture certain types of data with customized sensitivity.

In addition, as they become smarter, we can expect Digital Twins to develop their own model of the world, in other words, to become increasingly aware of their environment.

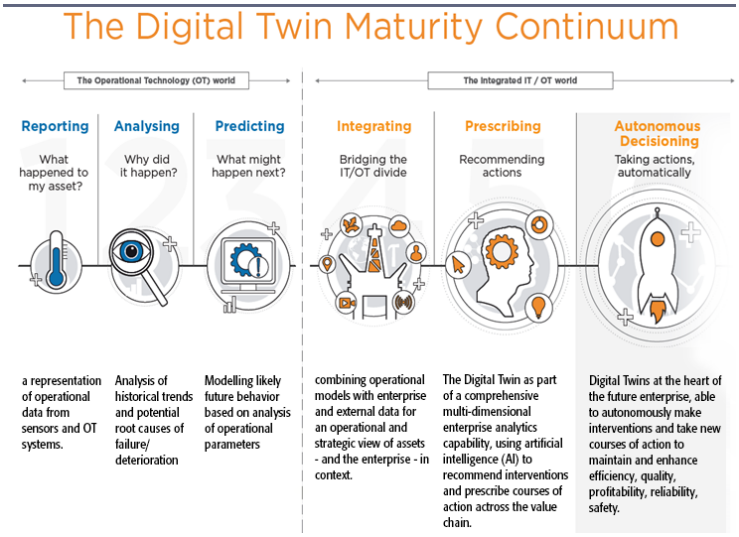



**FIGURE 8** – Expected evolution of Digital Twins capabilities.
**IMAGE CREDIT: SMART ENERGY INTERNATIONAL**

As another major step forward, we can expect them to interact with other Digital Twins and with their Physical Twin at a semantic level, thus getting rid of the need to have predefined syntax (standards) for enabling communications.

Furthermore, we can expect them to become capable of playing a role of proxy in the cyberspace and, through actuators, in the physical space. Additionally, they will be able to replicate themselves in several instances, as a need arises, essentially creating instances that can act in parallel.

Finally, we can expect Digital Twins to learn from their environment and experiences and be able to self-assess the quality of the lessons learned (to determine which ones to retain) – Figure 8 presents the expected evolution of Digital Twins capabilities.

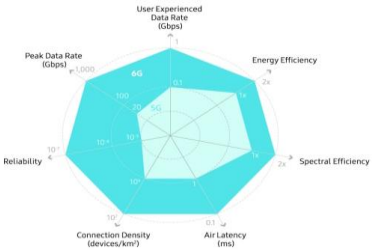



Figure 9 – Planned features of 6G compared to 5G .Image credit: Samsung

## Digital Twins Communication Fabric

Digital Twins can be seen as data banks and, through mutual interactions, can create federated data spaces. For example, the Gaia-X[1] model being developed in Europe with the participation of all major world stakeholders.

Additionally, the local embedded intelligence in Digital Twins will transform these data spaces into semantic hubs, and eventually, 6G will leverage these hubs as communication nodes for the future 6G network fabrics.

6G is still on the drawing board, but the path towards creating mesh networks at the edges through the interaction/cooperation of autonomous systems is already visible. Digital Twins can be the agents having both the semantic awareness of what kind of connectivity is needed at a

[1] https://www.data-infrastructure.eu/GAIAX/Navigation/EN/Home/home.html

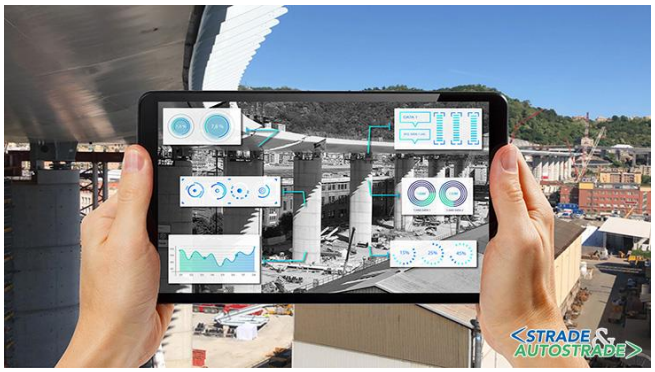



Figure 10 - Genoa, San Giorgio Bridge. Image

specific time, and the ability to coordinate with other DTs, which is required for the dynamic construction of a local mesh network.

## Aggregation of Digital Twins - Meta Digital Twins

We are already seeing examples of aggregating Digital Twins. For example, the recent San Giorgio Bridge in Genoa, figure 10, is a Meta Digital Twin, or in other words, a Digital Twin made up of hundreds of other Digital Twins that represent various aspects of the bridge. This Meta Digital Twin interacts with the Digital Twin of the Harbour urban highway to manage traffic flow across the city of Genoa.

Buildings are other examples of DT clusters (ARUP is using this technology in their new buildings). Cities such as Singapore are being managed through a Digital Twin, resulting from the aggregating of hundreds of DTs.


Figure 11 - Image Credit: Siemens

Even Countries and Continents may, in the future, have their own Digital Twin. Europe is funding a big initiative, Destination Earth[2], with the goal to create a Meta Digital Twin to represent various aspects of European infrastructures as well as its social fabric.
The Spatial web, a 3D representation of the cyberspace will likely make use of meta DTs.

## Digital Twins - A Window on the Cyberspace

The observation on the Spatial Web takes us to the use of Digital Twins as our window to the cyberspace, acting as mediators for contextualized Augmented Reality (AR), taking personal interest, knowledge, and context into consideration.

These Digital Twins will act both on-demand and as proactive intelligent entities. This is important in order to decrease the information load and to make information relevant to the specific context at a particular time.

This is great, however, it raises questions pertaining to the assessment of objectivity and subjectivity since all will be factual, but all will be simultaneously mediated by our DT interpretations. People may interpret the same situation differently, thus resulting in mismatched interpretations of reality. For example, our brain "interprets" the reality, and different brains are likely to develop unique interpretations. To summarize, mediated AR may

[2] https://digital-strategy.ec.europa.eu/en/library/destination-earth

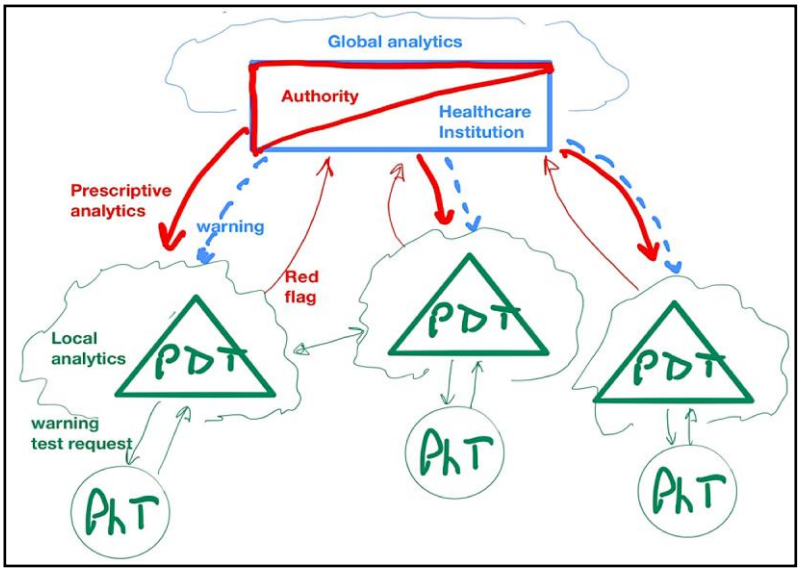



Figure 12 - Schematics of using PDTs to provide personal awareness, as well as for feeding the global data space to assess local and global risk while preserving privacy.

further increase divergence amongst people and introduce an external "bias" to the factual reality.

## Personal Digital Twins in Healthcare

Personal Digital Twins (PDTs) will become an everyday reality in the Healthcare sector. Their capability to mirror "you" will be a crucial tool for your doctor first, and shortly after, it will become a key player for the healthcare services available in the future. A digital doctor, not necessarily the digital twin of a doctor, will be following you … continuously. Actually, your digital twin might obtain a medical doctorate degree by mining the web, allowing it to accrue a tremendous amount of experience about its' physical twin (you), and improve its knowledge! This is actually the future—your personal digital twin will double up as your digital doctor, ready to seek for consultation should the need arise.

More than that, Digital Twins will be (already are) a powerful tool in testing drugs. Future vaccines will make massive use of DTs both in design and testing and, of course, will be monitoring the actual deployment.

In epidemics, a topic we have more recently become very interested, PDTs will create awareness in order to foster appropriate behavior, doubling up as sentinels to mediate between the value of personal privacy and societal benefits (Figure 12).

## Cognitive Digital Twins

The idea of a Cognitive Digital Twin (CDT), a digital representation of knowledge, has been fostered by IBM in connection to the knowledge embedded in machines, processes, and companies. This has been further extended by the Digital Reality Initiative (DRI) with the creation of the Knowledge as a Service tool, KaaS, supporting the creation of a personal CDT used to explore the knowledge space of IEEE, and to provide companies with a tool to compete at the knowledge level in the future.

Cognitive Digital Twins raise new questions, such as:

- Where does the knowledge reside—in my brain augmented by my digital twin? or possibly, if capable to use in a seamless manner, in my CDT?
- My CDT will know everything that I already do, but it can also know something that I don't understand. Things that I will probably never be able to digest. Is this knowledge?

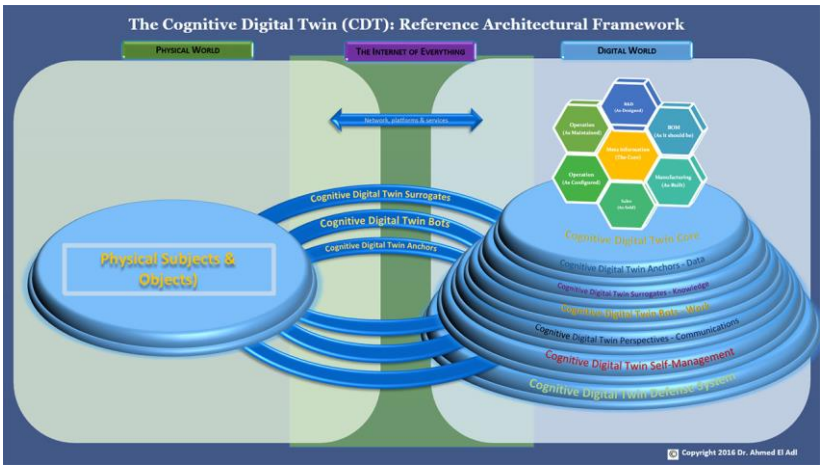



Figure 14 - Architectural building blocks for the first CDTs.
Image credit: Dr. Ahmed El Adl

Within DRI, The Future Directions Committee (FDC) is exploring the possibility of creating CDTs as a tool (KaaS: Knowledge as a Service) to access the IEEE knowledge base at the level of a single individual, as well as at the level of an organization (an IEEE Society, a company, etc.).

This tool will provide services such as knowledge gap analyses and learning reinforcements by helping to select the training materials (available through IEEE) to fill knowledge gaps.

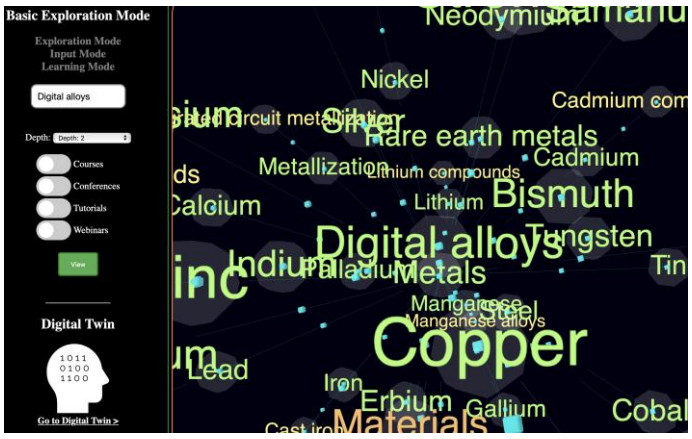



Figure 13 - Screenshot of the KaaS.

The knowledge structure, and the CDT data structure, are open and enable third parties to develop additional services.

## Society of the Future

The Society of the Future will see a continuum with increasingly fading boundaries between the physical and the digital space (the cyberspace). Digital Twins will live in the cyberspace, but at the same time, they will be our bridge to the cyberspace. We are already using them to interact with chatbots

(maybe we hate them!), but a Digital Twin can be seen as a more sophisticated version of a chatbot.

On the left side, figure 14, the Digital Twin layer intermediates between cyber/physical systems (things and humans alike), and displayed on the right is the variety of services through which both humans and things will perceive the world, and through which they will interact with one another.

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## My Personal Digital Twin is already in my Smartphone

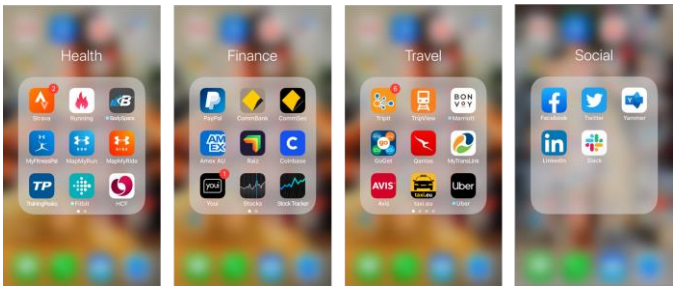


Figure 15 - According to Pieter van Schalkwyk, his smartphone is his Digital Twin

One thing people do not always realize is that their PDT is, more or less, already embedded into their smartphone. Looking at the various categories such as health, finance, travel, and social, you will find that the data keeps growing in addition to retaining the data concerning your recent and past activities. Pieter van Schalkwyk, who put them together, is an engineer (CEO of XMPro Datastream) and claims that his smartphone 'knows' him better than anyone else, including his own wife and employees. However, the beauty of it is that Pieter suggests one thing more—it is possible using, for example, the software from his company to integrate all this data into a single entity that becomes, quite truly, your personal digital twin. On his site[3], he shows an example of how it can be done starting with a rather puny object's data collection (an industrial pumps digital twin) containing various function-monitoring aspects. He demonstrates how the data from your smartphone, each according to its category, can be adapted and applied to the same, separate functions that report on the pumps functioning so that they can contain and integrate the data from a phone. Now, this might take a little bit of programming wizardry, and you probably wouldn't want to risk it, but we can imagine, without a doubt, that some clever soul reading this ebook will have the time to try it, format it for common usage, and make a fortune!

## Critical Issues Raised

As presented in the previous section, there are a few key points that are highly relevant to the present and future of the PDT. For example, the 'shift to cyberspace' that we take for granted since we have been slowly evolving for over a decade, but that doesn't necessarily mean that we are doing it well. In fact, limited as we are to our keyboard and screens, we can only do so much searching, collating, analyzing, and other activities that we are used to performing. This shift presented is more ambitious considering that you and I go right into the cyberspace via our PDT! This would allow us to enact a quantum leap into the usage of the abundant resources, data retrieval, crushing, and sorting that our PDT, knowing exactly what we are looking for, would be able to do. We will have, quite literally, an alter ego—not just in the physical aspect, but also in the data sphere, where it will be able to manage highly complex issues such as if you a student in your last year at university, what career path should you embark on, or, assuming you are in the process of getting a divorce, what arguments are best to invoke in order to deal in the most fair manner with the separation of you and your partner.

[3] https://www.linkedin.com/pulse/my-digital-twin-pieter-van-schalkwyk/

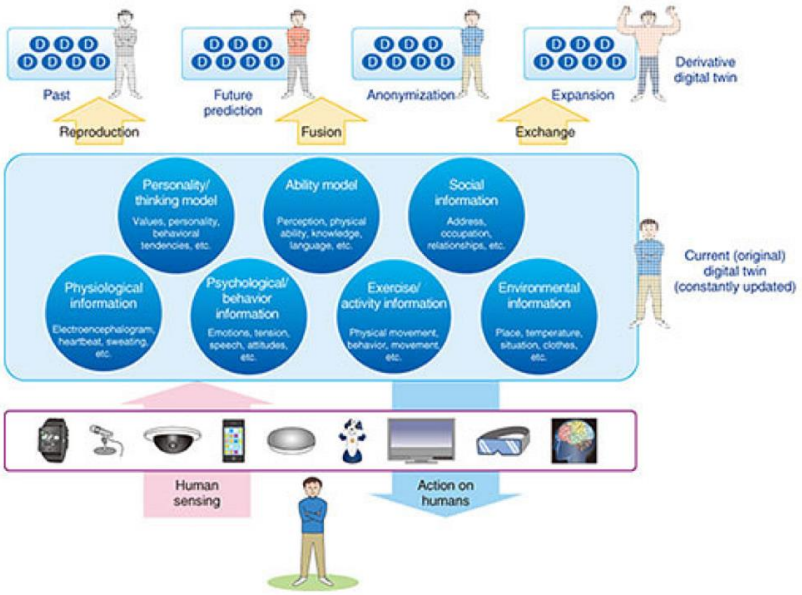


Figure 16

Handling complexity and pertinence, or rather 'hyper-pertinence,' in such cases would be a matter of seconds for your PDT in the cyberspace. In order to be able to do that, your PDT would need to update itself on a permanent basis, for which we suggest that it be equipped with a 'lifelog'—a recording system that stores your every move as you go (such as developed by an ex-colleague, Steve Mann[4], at the University of Toronto). In addition, it will also need to be capable of assessing itself, thanks to a great dose of machine-learning. That said, the key to your relationship with your PDT is a seamless and fluid conversational Q&A ability. This, as suggested, would require sophisticated language prediction systems which are already in development under various technologies including GANs (Generative Adversarial Networks), GPT-3 (Generative Pre-Training-3), or whatever comes up in our lightning-speed future (See figure 16).

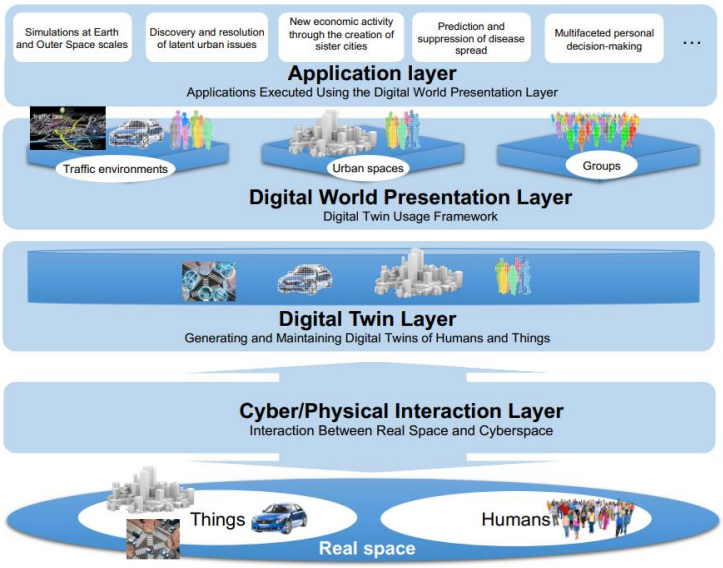


Figure 17 - Image Credit: NTT - https://group.ntt/en/newsrelease/2019/06/10/190610a.html

This last suggestion is both the trickiest and the most predictable addition to any PDT worth the name. Autonomous World Modelling is along the lines of what we have been aiming for in the various White Papers[5] on Symbiotic Autonomous Systems that we have been working on since 2016. At some point, in order to unleash our PDTs with some level of confidence that it won't go astray or get lost, we need to establish guardrails in the connections between context awareness and valuation by the PDT, guaranteed by critical check and balance operations automated by

[4] https://spectrum.ieee.org/geek-life/profiles/steve-mann-my-augmediated-life
[5] https://digitalreality.ieee.org/publications#white-papers

the very environment in which you and your PDT occupy at any given time. As a matter of fact, we have to expect that the more sophisticated our PDT becomes, the more autonomy it will acquire This will result in numerous predictable advantages to negotiate our relationships with both the digital and physical environments, but equally predictable dangers and mishaps, especially provoked from a contraption (our PDT) that is perfectly equipped to simulate, but not to 'know' in any way anything it is required to simulate.

Now, take a look (a close one) to the right side of Figure 17— you can see the first image of a suite from Nippon Telegraph and Telephone (NTT)'s Digital Twin Computing Research Centre (click here to access the original publication). We have selected to present this group in particular because it is the first we found (after a fair amount of Googling) that actually reflects not only on the future of PDTs (that they call Digital Twin Computing, or DTC), but also on the future of society once individual members are endowed with a PDT. The image contains very ambitious suggestions that not only include recording data and activities that an outside observer could examine, but, more intimately, the very personality of the physical (biological) twin, namely YOU. This research groups approach adds modelling the personality, thinking, emotions, psychological behavior, and more deeply seated processes within the physical twin to what is already available, that is, physical and environmental conditions. You may not really want this, but it is possible too that you never really played with Transformers or owned a Tamagotchi!

## Knowledge and Emotion Representation

The NTT group seems to take technologies that grasp the contents of our minds and hearts for granted regardless if they are available to them or elsewhere. They confidently announce digitizing personality, thoughts, sensibilities, and skills. This, they claim, will lead to helping individuals to make decisions—something we can certainly agree with, albeit not requiring such an invasive approach as the one they propose. The newest thing here is the suggestion that, by using associated PDTs, one could expect to develop group intelligence. This is quite typical of Japanese and other Asian cultures propelling on community over individuals, which is more of a characteristic of western sensibility. That said, let's take their claims one by one and see what technologies are, indeed, available today (or at least in the works) to support them. Mind-reading is indeed on the way, but rather timidly so far.

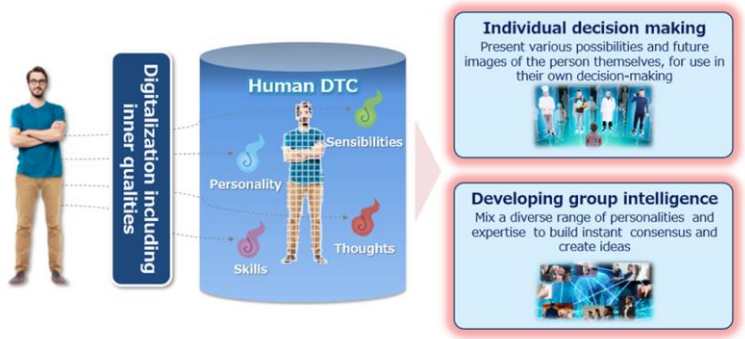


Figure 18

Neurological studies and localization in cognitive brain imaging have been growing consistently over the last 5 years. There has been real progress enabling researchers to identify clusters of concepts, and even spot what events or contexts such images are about. It is also possible to 'read' someone's linguistic mental constructs sentence by sentence, albeit with unwieldy probing

equipment and clinical conditions[6]. However, AI is beginning to change that by making it possible to 'hear' subvocalization sufficiently well enough to guess at and complete missing bits. "Carnegie Mellon University research has found ways to read "complex thoughts" based on brain scans, and output text accordingly. The university's study demonstrated that complex thinking could enable its A.I. to predict the next "sentence" in the thought process"[7]. We are not quite at the point of Whole Brain Emulation, but it already has a name and initials (WBE). WBE is the theoretical technology of modelling a human brain in its entirety on a computer—thoughts, feelings, memories, and skills intact. It is a staple of science fiction. Recently, proponents of WBE have suggested that its potential will be realized in the next few decades[8]. However, there is a long track record of work centered around BCI (Brain to Computer Interaction), and several technologies that allow you to command computer response from thought alone have been available on the market for years, starting with IBVA (Interactive Brainwave Visual Analyzer) developed by Masahiro Kahata in 1983 (and still available online), as well as MUSE and eMOTIV, similar systems also available online.

The other way around is called CBI (Computer to Brain Interfacing), but CBI is not quite as developed as the previous groups of technologies (to the effect that people still confuse the two directions). It recently made headlines in Mindball, a game that, instead of requiring you to get excited, you can only win if you remain calm or settle down. In this game, your headset can transmit your state of mind to the parameters of the game, and then it invites you to go zen[9]. The immediate question is, of course, what does that indicate about worldwide technological culture today? It brings the Spanish Inquisition to mind, which used less sophisticated techniques (in fact torturing the body to get into the heretic's mind) to obtain the same result. Yes, the WBE may convey value for us in our PDTs, but even more so for those investigators who, for whatever reason, have been restricted to the questionable efficacy of lie-detecting machines. More about group intelligence in the following.

[6] http://www.ccbi.cmu.edu/reprints/Wang_Just_HBM-2017_Journal-preprint.pdf

[7] https://www.computerworld.com/article/3268132/mind-reading-tech-is-here-and-more-useful-than-you-think.html

[8] https://www.researchgate.net/publication/269477453_The_Prospects_of_Whole_Brain_Emulation_within_the_next_Half-_Century

[9] https://blog.fluidui.com/the-computer-brain-interface-products-of-today-and-tomorrow/

## Living with Digital Twins

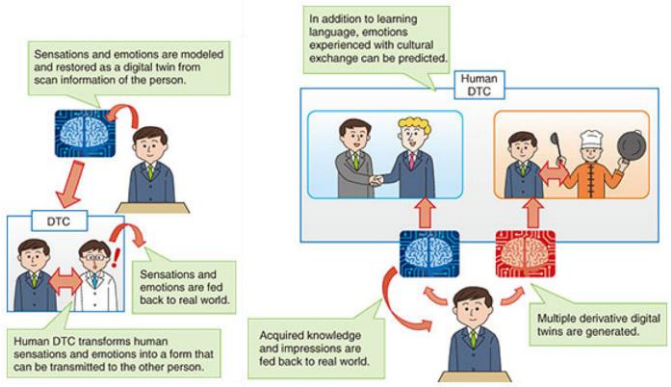


Figure 19

According to the NTT group, there are five examples of what it would be like to live with a PDT. In the first example, they explain using the digital twin as an interface to allow users to navigate the enormous cyberspace. However, it can do something much more complicated: it can deal with other digital twins or with people to inquire specified information, such as asking the digital twin to find suitable transport, especially in these difficult times. Similarly, they can act as travel agents that work with people who are selling tickets for various activities. In another use case, leveraging them as personal agents to work on a user's behalf—for example, when a person has too many meetings, they would love to have a digital twin that could run the meeting for them. At that point, it would be helpful to have one that does not look like a cell phone.

Nevertheless, we think the most exciting example was the enabling of a fictional dialogue. You may have heard about GPT-3 and Replika. Today, it is becoming a rather common occurrence to reuse conversations we have had online, such as emails you have sent or social media interactions that you've had, and then combining this data to create a character. For example, as portrayed in the Black Mirror episode called "Be right back." In this episode, a man who had died from an accident comes back to his wife as somewhat of a digital twin of himself. It is all based on the possibility that artificial intelligence will connect all of the data that came out of previous exchanges and recreate a similar conversation. Replika is the first example of this, and it began with a tragic story. Eugenia Kuyda's friend, Roman Mazurenko, passed away in a 2015 street accident. Roman was her emotional backbone, her comfort zone, and her friend. She was already working with AI experts, so she thought about all the email exchanges between her and her friend, she figured why not use this data and reconstitute him. She created not only created a PDT to keep her company, she also established a company—Replika, adaptable to anybody else's experiences, and now it has millions of users. You can check Replika online, and you will see what people do with the extraordinary capability to create a character for

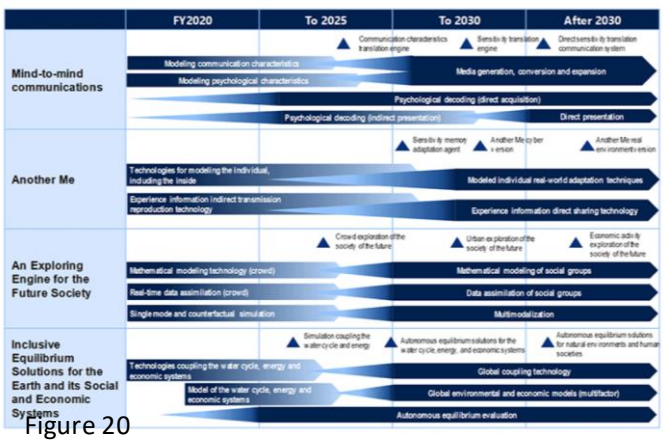


Figure 20

yourself. It would also be fascinating to apply this app to PDTs, particularly in the context of enabling a conversation. GPT-3 is the sum, for the moment, of language production systems, called generative pre-training issue number three. Elon Musk has invested millions of dollars into it. It is a bit like a Wikipedia, but it wouldn't have to find the answer to your question, instead it would create one on the spot. It does all kinds of things, such as serving as a chatbot with the characteristics you want, and all it requires is five-six words, or sentences, to guide the creation. It is a new genre of electronic fiction— an extraordinary idea or vision that has only been considered for use in novels, theatre, or poetry. Today, we have many new platforms and clever software to create various things, such as literate creation.

## Digital Twin Society of the Future: Symbiotic Autonomous Environment

The NTT Group is the first association found in our research on Digital Twins with a long-term vision of what they will do. This vision includes four basic segments, for example, *mind to mind*, where they translate one's sensitivity and decode psychology. All kinds of systems and data show that technology is progressing extremely fast when it comes to building a digital twin. A variety of new software allows researchers to get into people's minds, but not yet very successfully, or (more to the point) smoothly. Still, one could use Replika's method, record different thoughts or ideas a person has, and integrate them into Mindbank. You can teach it all kinds of things, and Mindbank creators utilize it to gain wisdom and insights (a type of psychological decoding of) into your personality.

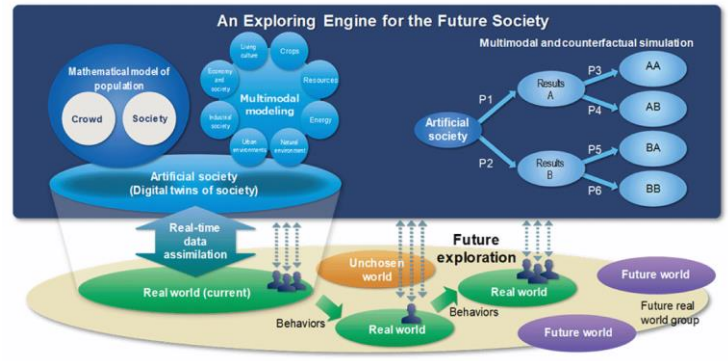

Figure 21

The second segment is *another* me—the digital twin with an adaptive memory agent. It would have a lifelog device, and it would be capable of integrating current information while simultaneously using all the experiences that a person had is the past to make it increasingly integrated with how one would want the 'other them' to represent. However, the fascinating thing is that NTT researchers want to move beyond the individual and into the whole social setting. The equivalent, perhaps in the western world, would be the exciting aspect of relating, for example, a smart city and everyone's personal Digital Twins. In this case, they want to pursue it much further, and have Digital Twins of the city's' population congregate and decide, without any tension and while resolving their differences, to come up with an agreement or consensus on how to build the city. This would require using large–scale computations, such as IOWN Photonic Disaggregated Computing. This is very similar to the symbiotic autonomous systems that have the additional presence of Digital Twins, which is equilibrium stimulation— coupling water-sourced energy with the overall creation of an

autonomous economic system. We know now that many decisions are made by algorithms and by a specific AI-driven software that can analyze and influence diagnostics, prognostics, verdicts, military decisions, financial advising, and so on. There is so much that is already automated in the background that, according to the NTT team, to a certain point, an entire automated community can be created. They haven't tested whether people worldwide would adopt it. However, it's a good question for the global environmental system.

## A More Sober Vision

According to the NTT group, the autonomy of the global environment's social and economic system is not adequately aligned with the autonomy of the Earth's environment. This results in environmental changes that are destructive to humankind. Thus, they combined various areas that they were concerned about and created a multimodal model. This model includes crops/agriculture, water (that, as we know, is becoming perhaps more precious than petrol), energy, resources, natural environments, urban environments, economy, and society, etc. It combines them into a single environment that includes the real world and the digital. It appears that the group is ready to welcome an automated future. That said, some people in the west might wonder—if all of this is automated, what purpose would humans serve? Excellent question! Thus, we want to reiterate and revisit our previous statement, with the added thought that IBM smart cities initiative proposes a sober vision.

In our opinion, the NTT project is pushed to extremes. However, it is clearly presented in a manner more feasible in the western context, for example, by the addition of sentiment analysis. It is an interesting method interpret and grasp the mood of the citizens, which can already be done to a certain extent. Perhaps it brings us to a more grounded vision of a smart city, and to the idea of having twins for various urban and general life aspects.

## Final Considerations

All the above is fair and good, but it can't be authenticated without a critical review. This was provided by Nina Panina, a member of our research group (associated with a team focusing on PDTs), from the faculty of Engineering at the State University of Novosibirsk in Siberia. Her first question is—how can anyone pretend to simulate personality? Not only in terms of what technology can do, but also in how 'personality' is defined, to what extent is cultural conditioning known or unknown, and does it depend on how could computers assess a person's self-image (mentally and physically), etc.? In her own words: "Due to the fact that the personality is a phenomenon to the highest degree of complexity, the question arises as to how its imitation, or 'copying,' is possible at all—after all, it is necessary to take a large number of situations, attributes, and other factors into consideration. It is assumed that this can be done using lifelogging—the scanning of a person's entire life in real time." However, according to Nina, lifelogging is simply not enough. It is too 'superficial' to produce reliable inferences about

someone's personality. More than that, the fact that PDTs, albeit the capability of evolving thanks to machine-learning, cannot self-reflect— principally, they are entirely devoid of 'reflection' and have no consciousness of any kind, or about anything. Unless in the case of malicious or careless programming and data inputting, they cannot make mistakes on their own, or create anything "consciously." The Digital Twin would not be able to model the two most important attributes of personality–self-reflection and freedom. Freedom implies the possibility of making irrational decisions, the right to make mistakes, and the right to blame." My answer to those valuable critical comments is that, while they are absolutely deserving of being kept in mind in any venture regarding PDTs, there may not be a real necessity to represent the personality of the user. At least not now, and not in real-time fashion. As the example seen above with the data contained in one's smartphone, all people would initially need (without precluding on the likely modifications of human character that technology always brings with itself) would be a kind cursor assisted by AI in cyberspace. In other words, they would need to understand the way, designed by the PDTs specific characteristics, the physical twin would ask questions and conduct online searches. In other words, it would be like Google's practice of tracking search patterns to get to know the user, but only at-large so to speak. Other issues are commonly discussed about AI in general and apply to PDTs as well. For example, ethical concerns regarding a PDT's behavior in social encounters with physical or digital 'people,' access to various categories of data (for example, the "dark space" of cloud or c-space), etc. Therefore, legal (and perhaps constitutional) provisions should be devised and put in place regarding ownership of one's twin, the resources it has borrowed in C-space, as well as in regards to the privacy and security of data, etc.

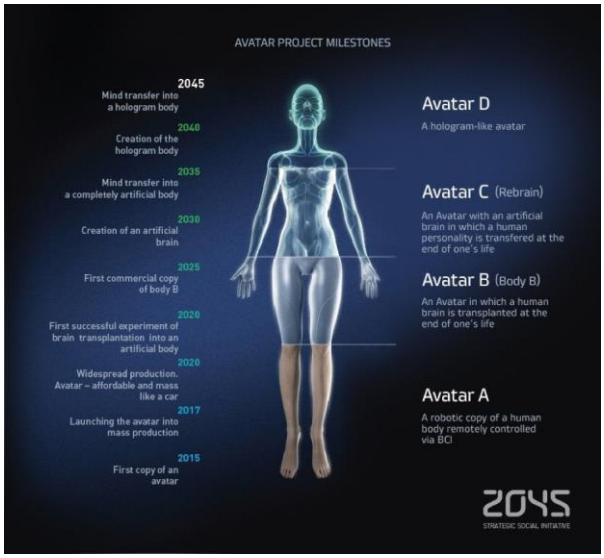


Figure 22

By the way, Figure 22 is included to demonstrate the extreme speculations about the future of humanity. It proposes to imagine the evolution of PDTs (here still called 'avatars' from the first elaboration in 2015), to the WBE (or complete 'mind transfer') capabilities to a holographic representation of YOU in 2045. The dating of various technological advancements is understandably approximate, and by 2020, it appears that we should already be further ahead than we are. But never mind, it is an interesting 'thought experiment' if anything else.

## What Next?

We would like to conclude with the following statement:
"Avatars are bound to become a more and more faithful representation of their physical counterpart. Embedded with a person's Digital Twin, they may share memories and character traits of the persons they are impersonating." This is why we research this

topic—we both agree that the PDT is actually on the way. On the other hand, we must consider that if the Digital Twin is here to stay, perhaps it will be referred to as something else. In any case, it is already somewhat present in digital assistants, and these are taking over certain tasks for us, to a point. It might turn out that suddenly, instead of you calling Alexa to do something for you, you get called by the lonely Alexa who would like to talk. "Come on, answer me!" says Alexa[10]. Considering our internal self, this here is the key in terms of how technology changes our psychology. We all know that we make decisions from inside our body—it could be in our head or within our heart, but it's undoubtedly something inside. However, once you have a digital twin that decides for you and implements a decision without correctly assessing its pertinence, automation takes over, and suddenly something that used to be internal to you is automatically integrated into cyberspace. Do you really want that? Hence, there is a danger of our personal digital assistants, later Digital Twins, becoming our masters.

[10] https://cmte.ieee.org/futuredirections/2021/05/17/come-on-answer-to-me-said-alexa/