Digital Twins as Part of Building Automation Systems

Dimitar Mankov, Docho Tsankov

***Abstract* — In the essence of industry 4.0 and the growing demand of digitization, this paper gives a representative view of the modern trends and correlations between the building automation systems and the digital twins, mainly keeping focus on the predictive maintenance and future decision making processes. Different approaches and methods of classification are included as main part of the defining process of the Digital Twins technology, mainly in the area of Smart Buildings and occupants.**

***Index Terms*— digitization, digital twins, IoT, Building Automation Systems**

I. Introduction

In the era of 4.0 Industry it is quite difficult to distinguish the real-time parameters from the virtual values. In the terms of sustainable usage and credibility the cyber-physical systems took over the hardware world in predominant way, which has never been investigated that further. For that sake very often we can use the so called Digital twin technology manages and control entities from the physical world. It is often able to predict future behavior of the system or it's components or to analyze deeply the already existing events from the past. And while most of the techniques already exists as an stand-alone ones, the main advantage of the digital twin is that it provides all of them combined and this is it's unique value proposition. The Digital Twin (e.g. DT) can be considered also as forefront part of the industry 4.0 stream which can be described as trend that includes quite advanced data analytics and Internet of Things connectivity (so called IoT). IoT is trend to increase the volume of total usage of internet traffic and data from different industries, such as healthcare, manufacturing and last but not least smart infrastructures, including smart cities and smart homes. This environment bonded with data analytics is the perfect tool for predictive maintenance purposes and early fault detection in complex environments, mainly concerning big cities and buildings. As a leading example of this emerging technology comes the effortless integration between subsystems and services, which is and will be the main reason to look after such concept in big entities. The main subject of this abstract will be the focus on Digital Twin technology for the most vital technical applications that exists currently and in will penetrate the technology world in near future, together with the challenges in automated building environment.

Dimitar Mankov is with the Faculty of Automatics at Technical University of Sofia, 8 Kl. Ohridski Blvd, 1000 Sofia, Bulgaria. (e-mail: mitakus91@abv.bg).

Docho Tsankov is with the Faculty of Automatics at Technical University of Sofia, 8 Kl. Ohridski Blvd, 1000 Sofia, Bulgaria (e-mail: d_tsankov@tu-sofia.bg).

II. Digital Twin

A. Definitions

Digital twin technology was mentioned first by Grieves in a 2003 presentation and then documented in different scientific journals. Some organizations describe it as:

a: NASA 2012 [1] "A Digital Twin is an integrated multi-physics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin."

b: CHEN 2017 [2] "A digital twin is a computerized model of a physical device or system that represents all functional features and links with the working elements."

c: LIU et al. 2018 [3] "The digital twin is actually a living model of the physical asset or system, which continually adapts to operational changes based on the collected online data and information, and can forecast the future of the corresponding physical counterpart."

B. Digital twin misconceptions

1) Digital model

The main point of distinguishing is the fact that there is no mechanism for data exchange between digital and physical systems. In other words, once the DM is created a change that occurs on the physical model has no impact at all on the digital one. The DM is illustrated on Figure 1.

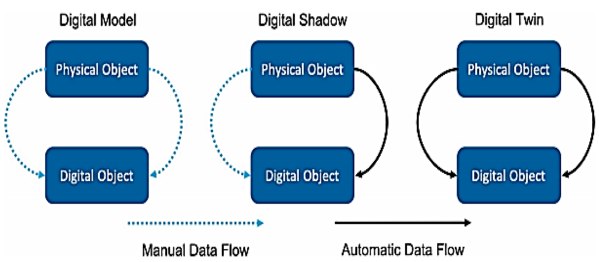

Fig. 1. Model flows and categorization

2) Digital shadow

This approach represents a model, where the flow is only one-way and it is between the physical and the digital object. The important fact here is that any change made on the physical object leads to a changed in digital one. This approach is strictly following the lead-shadow concept of data transfer between different properties. Figure 1 illustrates a Digital Shadow.

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2) Digital twin

When the flow of data is between an existing physical object and a digital such one and they have native full integration which works in both directions. This concept is proven to be the right definition of a Digital Twin. Of course in total correspondence to the mentioned above, a change made on the primary (Physical) object automatically leads to a change in the secondary (Digital) object. Figure 2 illustrates a Digital Twin.

C. Digital twin applications

In the following few sections of this research focusses on the variety of applications of Digital Twins. For the moment the term and concept of a Digital Twin are growing across academia, and the advancements in IoT and artificial intelligence (AI) are enabling this growth to increase [4]. At this stage, the primary areas of interest are smart cities.

1) Smart cities

As it can be seen during the last few years, the interest and potential benefits in terms of usage are obvious when it comes to the so call Smart cities. The main reason for that is hidden in the extremely fast developments within the connectivity field basically thanks to the Internet of the Things approach. With an drastic increase in the amount of total connected devices and even more dramatic trends for the upcoming years. The use and the potential for Digital Twins to be dramatically effective within a smart city is increasing year on year due to rapid developments in connectivity through IoT. The more growing smart cities, the bigger the volume of connected devices. And this also means more usage of Digital Twins in different environments. And that's not all, as we grow faster on connectivity and as long as the AI takes over some critical structures and services this will be the ice breaker for more complex algorithms in near future [5], [6], [7]. The information which is gathered from different sensors and in general, connected devices is suppose to help to the main city services and infrastructure to provide more accurate and consistent analytics and monitoring of data [8].

2) Manufacturing

When it comes to delivering visible results and effective production, the manufacturing ground is definitely one of the major industries. The biggest challenge, which we addressed is the optimization of the process price per unit or cost for production. This has much to do with digitization in general and proper usage of resources. One way to track better the production process and to be able to enter in a simulation mode for all kind of subprocesses is to turn to Digital twins as technology. This will ensure good, accurate results and sustainable vision for the production process. The application of Digital twins are countless and the amount of time and money spent in operational phase are evaluated differently.

3) Healthcare

Imagine how many connected devices each one of is carrying on a daily base with himself. This includes even the smart watches on our wrists, which are collecting health care information 24/7. If we have to conclude the current and the shortly upcoming state of this industry, for sure we will have to mention how heavily impacted by the digitization, especially regarding personal electronics, different health monitoring and preventive smart apps and devices in general. Also economically, the devices are getting cheaper and cheaper, which means that the number of connected devices will and is rising rapidly for a very short period of time. And if we add to that the cloud services and central collection of data, the algorithms and AI interventions are drastically increased [9], [10]. This increased connectivity only grows the expectation of potential mass-practical application of Digital Twin use within the healthcare sector. One future application is a Digital Twin of a human, giving a real-time analysis of the body. A more realistic current application is a Digital Twin used for simulating the effects of certain drugs.

III. Digital Twin for Building Management

Depending on the type of building the lifecycle may vary from 5 to more than 40 years or even more. Nevertheless each of them begins with an idea and a project submitted by a team of designers or other visioners about how to adapt the building to the trending digital transformation or to create something new as a concept straight out of the scratch. And the whole process starts right at that point, and from this moment on, the involvement of architects on conceptual level which is then transferred to design level and then to realization and built, in respect commissioning and then operations, hopefully with the right mindset and approach for the longer possible period of time. And this continues again and again, until someone decides to close the whole process again, but the main difference is that the second, third and each other consecutive time this period will take less and less time, because of the improved level of digitization and the demanding AI. In order to unlock some powerful capabilities such as integration on high level, a Digital Twin approach must be considered as strictly mandatory and powerful tool in the hands of the developers. And it is valid basically for all steps of the building lifecycle.

An important factor about the Digital Twin is that it may goes thru many changes and variations before it reaches it's final version. And also many simulations can be made, including millions of changes. And all of that before it is eventually used to navigate the construction of it's physical sibling. Of course there are some other cases, where the Digital Twin is born way after the physical object and placed into use. In that case the first version (the virtual ones) could be considered as very coarse approximation of the physical model as it is shown on Figure, where us the comparison between the virtual and physical lifecycle of the building. It is clear that the DT can take place at each step of the lifecycle in both physical and virtual aspect. Something else, which is also very important is the consideration of Digital Twins in comparison with the Building Information Modeling. Must be very punctual on the difference between those two techniques. One crucial misconception is the difference between the Digital Twin and the Building information modeling, or the so called BIM. The main differentiator turns out to be the fact that while the DT is a real-time, yet virtual, model of the building, the BIM is a process which involves a lot stakeholders in it. The BIM represents equally the physical and the functional characteristics which can cover a huge and broader scope of the building automation systems and subsystem, including neuron and sensor networks in that count.

More and more it is proven that the Digital Twin runs in parallel with IoT technology and trends as well as the AI which ends up in common challenges for both areas if considered together with the impact of the Digital Twins.

The first step in this research is to investigate the common challenges mainly in the area of predictive maintenance and digital services optimization. Some of the shared challenges might affect the data management and storages procedures as well as the network architectures and validation. Of course the risk of cybersecurity issues is always on the table.

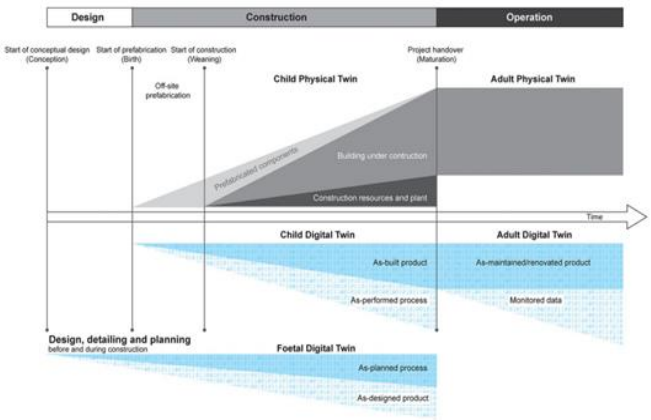

Fig. 2. Lifecycle of the physical and digital building twins

A. Data analytic challenges

As part of the research, some main challenges within the field of Digital Twins creation for Building Management Systems are listed below:

1) It infrastructure

The known rule of doubling the CPU and GPU power is generally known as technology challenge. This means that in order to provide sustainable DT model, the IT infrastructure must be compatible with the latest requirements of the network infrastructure. Let's not forget to mention here the drastic need and usage of AI as software and hardware specialized platforms.

2) Data

What is really unique characteristic of the data is it's relevance and accuracy. More relevant data means better understanding and this leads to better decision making. In terms of quality of the data, a verb such as timing, value transfer interval, segmentation and clearness of the data must be seriously considered as primary factors in the process of providing data, especially to the Artificial Intelligence infrastructure.

3) Privacy and security

As long as the world is connected this will always remain a topic for consideration. Unfortunately solid laws and regulation procedures are yet to be established, but the good outcome of the movement would be even superior to our initial imagination and business requirements. As we all know, privacy has been turned out as priority number one for us as individuals, but it's even more important when it comes to business world. And especially in the terms of management of sensitive assets as we are moving from controlling equipment to controlling whole infrastructures, as small hole in the ship of cybersecurity might cause significant damage to the whole business unit.

4) Trust

In the beginning of each relation is always the trust. Trust always comes first and this is also valid for the Digital Twins when they are managed by AI. Mainly and most recently because it is relatively new technology trend. As every new trend there is a major dose of resilience among the users and the market. Managing this point would be easy if the affected side is focused more on the positive outcome than the negative ones, such as AI taking over whole infrastructures or/and businesses all over the world. And as closing statement here, can be mentioned the fact that the trust in Digital Twins as technology is relatively higher that the trust in robots an AI, even knowing that DT is a form of automated system, which can make decisions and take actions based on collected data, analytics and deep learning approaches.

5) Expectations

Last but not least stands the challenge for the DT that it can solve literally all building management related problems. This can be true, in case the system is huge enough and it covers all possible inputs, like sensors, actuators, field controllers, customer interfaces, HMI's, trends, graphics, alarms, events and etc. But that's not the case with the most nowadays systems, where we can see a form of segmentation between the different subsystems. For example very often the Management of the electrical network is not part of the building management system, instead the Power management software is responsible for the reports generations, billing and dashboards. In order to create fair expectations related to the DT there must be a clear vision about the scope of the functions that this technology can handle. And of course as step number one, always remains the pure fact that still these systems require a physical inputs in order to gather relevant data. So in that terms, for example if we are experiencing a problem with our printer service in the office, there is no way for the Digital Twins to handle that if the printers are not part of the monitored sub-systems via SNMP or different protocol for example. The more relevant data inputs, the more accurate and data driven system outputs will be generated.

IV. APPLICATIONS AND DATA COLLECTIONS FOR DIGITAL TWINS

As it was mentioned in the previous section, the more relevant data is received, the more accurate decisions about all our assets will be made by the Digital Twins. In this section of the research, a brief list of data sources will be taken upon investigation. It's not a secret that a good Digital Twin must contain a set of systems or in other words to represent a "system of systems" integration:

1) Embedded sensors

Their main role is to create digital twins of individual equipment (for example an HVAC unit) or a larger system. Embedded sensors transmit field data from equipment to operators who monitor the system and control it remotely.

2) Wireless sensor networks

Mainly installed in buildings to collect data on tempera-ture, humidity, CO_2, lighting, occupancy, and other factors. Their main advantage comes from the easier system expansion, flexibility to relocate sensors as space needs change, and more seamless installation.

3) Digitized building lifecycle data and systems

This includes mainly BIM data, connected and smart HVAC systems, smart plugs, and smart elevator controls are all ways to channel data and build a digital twin.

4) Integration with other cloud services and data providers

It's a known fact that different data sources, such as ERP's may be integrated into the digital twin from outside sources, in this category we can include also weather data or from 3rd party "cloud to cloud" integrations.

V. The Impact of Digital Twins

Overall the usage of Digital twin (DT) seems to be quite promising in terms of implementation in complex cyber-physical building automation and in general connected infrastrcutures. Their service-oriented structure could expand the functions of DT. It' quite interesting how the DT functions can be encaplsulated and presented to the main stream as services. This abstract is just an entry point to all of this, but it touches the glimpse of it by sharing another, more uncommon opinion on DT technology application in the form of services specifies. There is still a huge amount of researches to be done in this field, but the implication whici is given in this context should be followed and later further investigated. As we as society are changing slowly our mindsets from product orientated to solution orientated society, the logical step further would be the adoption of the DT technology as complementary service in a specific given context. Standard visual representation of the Digital Twin layers can be seen on Figure 3 down below. It gives a view on the coordination and interventions between different layers and constructions in this field.

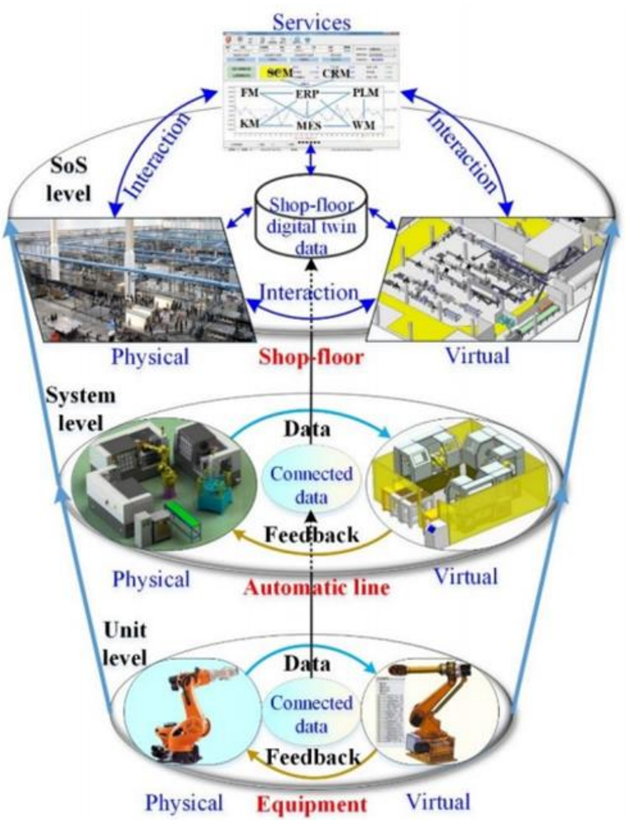

Fig. 3. The until-level, system-level and SoS-level digital twin and five dimensional model

Once the services encapsulation is finished properly, the DT services are transferred or shared with the so called services pool and management platform, where they are getting prepared for sharing with different users. The visual and logical structural representation of this process is shown in Fig. 4, digital twin services consist of the equipment services, technology services, test services, data services, knowledge services, algorithms services, models services, simulation services, etc. In addition, there are many auxiliary services, such as financial services, logistics services, training services, equipment repair services and others.

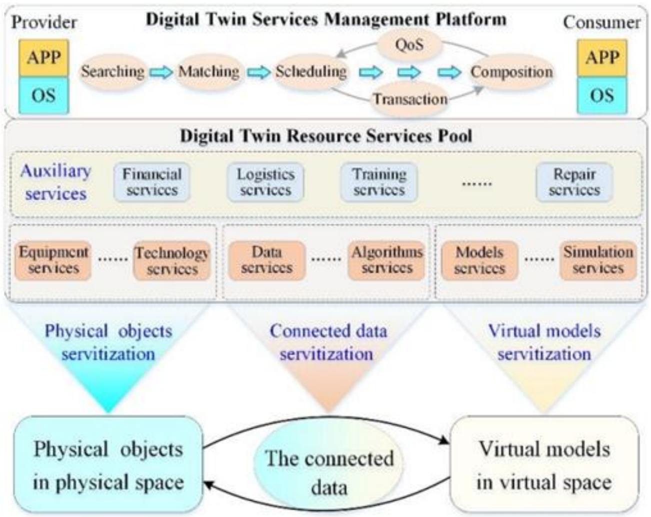

Fig. 4. The digital twin service management and applications

As of the most important part of the services, different functions such as combinations, scheduling, searching and similar can be distinguished and prioritized according to the user or application requests. The whole structure then fall apart in the so called subfunctions or sub-encapsulations which basically are translated as subtasks, If we follow the low level architecture. The reason for this is to somehow transfer the complex tasks to a single actions or a set of actions, which can be handled by single service. In product design, it is the process of back-and-forth interactions between the expected, interpreted, and physical worlds [11]. The digital twin driven design is to turn the expected product in the designer's mind into the digital representation in interpreted world based on the existing physical products. To innovate product, designer have to study plenty of data to acquire valuable knowledge [11]. Service is an answer to above problems.

Designers just simply submit their needs to the services management platform. Services managers will match the data services which designers need and the models and algorithms services that are used to process the data.

VI. Conclusion

This content is much on how the Digital Twin technology will establish itself as leading technological and standardized tool for various of projects and applications. What could be considered as real focus of the research is the practical application of the Digital Twin technology mainly in the context of Smart buildings and if we have to scale it up – smart cities in respect. Such practical implication could be considered to be the combination of the Digital Twin technology with the existing 3D models or in combination with some parts of the BIM models in the vast majority of buildings in order to optimize the preventive maintenance and the post-operation period, these two period of the lifecycle are considered to be enough economically toxic as the investment in infrastructure itself, that is why it is highly important for the affected persons or organizations to see the practical usage of the DT technology at very early stage in every project, from the idea and design phase up to the services phase. As it was proven during the research the importance of pre and post operation DT technology or in other words modeling and services should be considered with equal level of importance. Then the next step should be the standardization and putting the whole approach into practical frames, which includes different technical conventions, rules, standards and etc. This is extremely valid also in terms of the AI and it's algorithm application in regards to the Digital twin technology. This need is well described by [20] and [21] with the idea of more standardized models which are taking into account different components form the smart cities and smart buildings world.

Quite interesting and important conclusion is the lack of standardization in the area of Digital Twins. If addressed properly this can ensure the further development of the concept and will avoid any wrongly defined concepts.

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