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Digital Twin Technology: A Review of Its Applications and Prominent Challenges

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Abstract: Digital twin is a virtual representation of physical product that is used as benchmark to evaluate, diagnose, optimize and supervise operational performance of products before venturing into mass full production in accordance with global standard. Digital twin merges virtual and physical objects together via sensors and IoT to transmit data and keep traces of objects interactivity within present environments. In virtual model environment, digital twin permits product troubleshooting and testing to minimize rate of failure and product defects during product manufacturing to enhance effectiveness and customers' satisfaction. Digital twin is utilized throughout product life-cycle to simulate, optimize and predict product quality before final production is financed. Digital twin is beneficial to modern digital society because attitude of modern factory workers can be boosted to improve motivation to work. Digital twin has come to stay, future product suppliers may be required to put forward digital twin of their products beforehand for virtual lab testing before making order while suppliers that fail to comply may be left over. With emergence of digital twin, virtual testing can be conducted on proposed products before finding their ways into physical marketplaces. Business sector remains most beneficiaries of digital twin to predict present and future state of physical product via digital peer analysis. Today, digital twin application can support enterprises by improving product performances, decision making and customers' satisfactions on logistic and operational workflow. However, in this survey of digital twin research, efforts have been made to review in detail about digital twin, its impact and benefits to modern society, its architecture; security challenges and how solutions are proffered. It is believed that ICT experts, manufacturers and industries will leverage on this research to improve QoS (Quality of Service) for new and future products to take full advantage of profits on investment returns via digital twin.

Keywords: Digital twin, technology, applications, architecture, challenges, industries.

1.0 Introduction

1.1 Overview of Digital Twin

Advent of innovation in information technology has caused emergence of multifarious technologies like digital-twin. Digital twin is emerging technology that replicates image of physical device virtually in order to get deeper knowledge about its operation performance. Today, digitization has operation of physical products before final mass production or implementation are performed in-line with QoS (quality-of-service) for universal best practices. Digital twin has intelligent components like IoT, sensor network, pervasive-computing and AI (artificial-intelligence) that are employed in digital system with other devices to perform fault tracing, product testing, rate of failure and product defect detection system. According to Bop (2017), stated that digital twin is quickly coming up as future big-technology that assists enterprises and industries to forecast current and future status of physical products and emerging inventions. Its capability to merge IoT and machine learning together as unit makes it possible for many companies and innovators to weigh up their inventions and products to spot impending errors before full roll-out implementation into markets commence

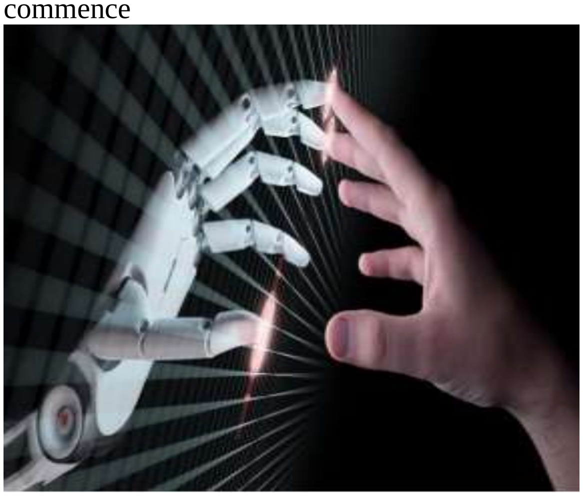

Figure 1.1: Typical Virtual Digital Twin and Physical Digital Twin Models (Tao, 2017)

taken over; higher proportion of digitization development will surely come from manufacturing sector because many industrial equipment are now controlled via IoT (internet-of-things) to heighten equipment monitoring and make emergence of new products related to digital twin become possible Knapp (2018). Digital twin is virtual-modeling of real-product that is used as benchmark to evaluate, diagnose, optimize and monitor performance

Digital Twin is adopted to perform design for control unit in simulated virtual environment in order to carry out series of tests before taking it to production level where products are produced in real-life at minimal cost. It permits lots of tests to be performed within virtual surroundings until it gets to virtual-production stage to ascertain how production of real-life will be carried out Cheng (2017). Digital twin is no longer restricted to manufacturing only; it has joined forces with IoT, AI (Artificial Intelligence), 3D-simulation, blockchain, 4G/5G network, cloud computing, big-data analytic and sensors to observe continuous data flow in virtual environment before running with real-time data that will assist in bringing product concept into reality Clair (2019). Digital twin links virtual and physical objects together via sensor and IoT technologies on digital lane to exchange data and keep record objects interacting with physical and virtual environments. Virtual simulation assists in product testing to minimize occurrence of product failure and defects ahead of time during product manufacturing lifecycle to improve effectiveness and customers' satisfaction

In law of digital twin, every physical entity must have digital equivalent within virtual environment; modeling behavior of physical object by using its digital equivalent is possible by attaching sensors on such physical object for information exchange to digital environment. Any physical entity like factory, car, airplane and human-being can utilize sensor to transmit information to its digital twins at real-time while feedback is conveyed back to physical entity. Digital twin permits collective synchronization between physical and virtual entities on real-time basis for organizations perform analytical and diagnostic analysis on mock-up products Zhang (2017). Emergence of IoT (Internet-of-Things) for 3D-internet, industrialized designs and connected network devices for organizations are fast boosting market development for digital twins. Digital twin has come to stay because inventions and products can now be optimized and improved upon through their digital twins in virtual environment; product setbacks can be detected ahead of time before they happen in physical world while new discoveries can be tested in virtual environment for future handy implementation.

Today, digital twins are utilized throughout complete life-cycle of any digital product to simulate, predict and optimize before financing its final fabrication. Another inspiring factor about digital twin is that factory employees can be modeled (digital-twinned) to boost motivation and increase attitude to work Roland (2017). In nearest future, product suppliers may be informed to tender digital-twins of products for testing purposes from manufacturer's virtual-lab before order can be placed while any supplier that fails to tender digital-twins of their products may be ignored. Many unrealistic applications for human can now be realized through digital-twin technology. With digital twin technology in place, performance of new invention or products can be tested before finding getting to marketplaces

Figure 1.2: Digital Twin Application in Industry (Roland, 2017)

In current era, growth of digital twin is decided by many factors like IoT, security and cost reduction. Data security is one major threat that limits market development of digital twin due to integration with IoT and cloud computing services. According to Rosen (2018), development of digital twin is viewed from three perspectives like:

i. Hi-tech need: As IoT-devices increase, billions of linked IoT devices are broadcasting huge data daily to physical environment. As quality of data increases, there is need to drive market growth using hi-tech

ii. Business enterprise need: Every enterprise looks out to future to fine-tune performances for future business market growth while being aware of situation on ground at moment
iii. Fiscal need: As market growth for digital-twin is envisioned, there is urgent need to lower operating cost to safeguard business operation during predicted failure and downtime

Digital twin emergence offers support to users by formulating quality decisions about future products within virtual environment

1.1.1 Characteristic of Digital-Twin

There are many characteristics of digital twin; some of them are: modularity, homogenization, connectivity and digital trace which are shown below. Embedded and connectivity systems are fundamental to digital twin because of their impacts in growth of digital environment.

Table 1.1: Key-technology characteristics of digital twin (Cheng, 2017).

Table 1.1: Key-technology characteristics of digital twin (Cheng, 2017).

Connectivity	Connectivity is important characteristic of digital twin because physical product and its digital twin must be linked via sensors, 4G/5G and IoT network. Without connectivity, there is no digital twin; connectivity also exists between product and customer in supply chain
Homogenization	Homogenization of many data sources and decoupling into physical component is permitted in digital twin. In accordance with Moore's law; increase in computing power decreases overall future cost of computing; literally, marginal cost of implementing digital twin will go down to permit future users to perform product test, solve current problem and foretell future about targeting products
Programmability	Digital component of physical product is programmable via sensors to alter its functionalities. Digital twin of each product can collect data relating its performance via embedded sensors or can be reprogrammed to create another version of engine
Digital-Tracing	Digital twin leaves traces that are used by engineers to diagnose and troubleshoot defective product engines. Digital traces are used manufacturers to proceed design products to avoid defect in final physical products
Personalization	Digital-twin is flexible, it adapt to individual need by carrying out product adjustment

Adaptability	Digital-twin can modify product to meet individual needs by using deep learning technology
Context-Awareness	Digital-twin has ability to spot individual product component via context-awareness sensors
Embeddedness	Network devices and objects are installed into virtual surroundings via sensor communication with physical environment

At moment, digital twin products are not yet available in large quantity within our common environments, they are currently found in educational research areas where digital twin is still found under experimental products for future testing purposes David (2018). Many researches on digital twin are centered on intelligent and automation.

1.1.2 Understanding How Digital Twin Works

Modeling software and CAD (Computer Aided Design) can be used to create digital twin; these software are used by product designers and engineers during initial life-cycle of product implementation. Sensors are embedded on physical products to transmit data at real-time to virtual product that is known as digital twin. Transmission of data between virtual and physical products can improve life-cycle of product performances Jerry (2017). Business owners that want to test-run digital twin software, standalone early version can be installed and run on desktop computer while Android and IOS mobile versions can be installed via their respective stores. Application must be installed after license purchase to commence digital twinning immediately by connecting physical-object to virtual-twin for product evaluation and monitoring purposes.

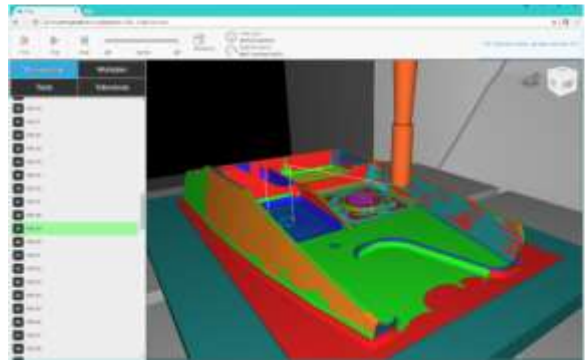

Figure 1.3: Digital Twin in Operation (Jerry, 2017)

Once data regarding physical object is collected, developer can make virtual replica (digital twin) based on data collected. Simulation works on data transmitted from physical object to simulate its performance within virtual environment on habitual basis. Simulation has capability to add/remove components to decide how physical object will react to alterations in order to understand cause of product defect or performance. Once adequate data has been collected, developers can carry on with diagnosing digital twin from virtual environment without upsetting processes that leads to decision making response on the product Winner (2017). Digital twin will influence business world positively to perform product diagnosis, testing, inspection and last production without compromising QoS (Quality-of-Service)

LITERATURE REVIEW

2.1 Historical Background of Digital Twin

Underlying concept behind digital twin first emerged in 1960s from NASA during space programming mission. NASA made replica of physical model about earth in order to utilize its virtual model version in space programme. Digital twin was later designed by NASA to replicate board behavior of Apollo-spacecraft used for space mission. After Apollo-13 commenced in 1970, Apollo-spacecraft oxygen tank got exploded before reaching space; emergency rescue mission was considered necessary to proffer solutions to technical difficulties that were two hundred thousand miles away from planet earth. Digital twin was utilized by NASA engineers to carry out repairs and troubleshooting faulty spacecraft tanks remotely from planet earth. According to Kamal (2017), pointed out how concept of digital-twin had been in practice since 1998 before application of digital-twin recorded first usage. Digital twin was always called "digital copy of actor Alan" during this time. However, same technology was called "pairing tech" during NASA Apollo-space missions. In 2002, "digital twin" was first used at University of Michigan in documented research journal papers by Michael Grieves. Despite commencement of digital twin concept in 2002, IoT-innovations and related technologies made it possible and affordable for digital twin to come into lime-light

Usefulness of digital-twin in 21st century is just fast emerging to help out organizations boost up customer understanding by driving digital innovation for emerging modern businesses Thomas (2017). Digital-twin and IoT integration began on international scene about 2yrs ago; blending both technologies will assist software developers, researchers and manufacturers to acquire useful knowledge required to construct many innovative technologies associated with digital twin to model digital behavior of legacy and emerging products via progression of information technologies. Acceptability of digital twin or related technology is still low on global scale, about 98% of humans on earth today have not comprehended idea underlying digital twin not to talk of patronizing existing products related to digital twin. Many programmers and automation engineers are now coming out with different kinds of innovations interconnected with digital twin Lehmann (2018). There are still many grounds to cover in term of innovations and productivity in digital twin, researchers must come out with authentic theoretical research information that will assist engineers and developers to gain relevant knowledge required for implementing useful products related to digital twin and related technologies to support humanity.

2.2 Reasons for Digital Twin Acceptability

Societies are advancing in population and getting industrialized which are becoming essential parts of emerging economy. There have been sharp increases on manufacturing of fake and sub-standard products recently within our present physical environments. For existing product model to be redesigned to prevent fake or sub-standard products, digital twin remains viable solution to industrialized sector because it merges many technologies like AI, Mobile application and IoT together to attain efficient service delivery. Remodeling of physical product via digital twin is realizable if physical product can interact with digital twin (virtual product) via IoT and contact sensor devices Ezekiel (2018). Standard of product can be improved with digital twin by performing diagnosis, inspection and testing to correct inconsistency traces found on product before final manufacturing of products in physical environment commences. Digital twin plays vital responsibility in manufacturing sector by making interaction with other systems becomes possible within virtual environment. According to Kellington (2017), highlighted below are diverse reasons how and why digital twin is necessary as modulated system:

i. **Minimizes Downtime with Time Saving:** Digital twin thwarts downtime processing and detects faults in product through virtual and real-sensor swap before real production commences. On long run, digital twin saves precious time which contributes to improved productivity

ii. **Cost:** Digital twin is needed to minimize implementation cost on long run if adopted

iii. **Safety:** Digital twin minimizes occurrence of accident via product fault-tracing and detection capability before commencing mass production of products. Digital twin products are integrated with AI to figure out best option to decide when product defect is detected during inspection of product to avoid looming disaster. These precautions are centered on safety to minimize injury effects on human after production of mass digital twin products in real-life environment

iv. **Plasticity:** Digital twin is flexible due to its simple integration with emerging intelligent technologies like sensor, IoT, AI and 3D-Objects

v. **Quality:** Introduction of digital-twin, internet-of-things and other intelligent systems can boost QoS (quality-of-service) and improve efficiency within digital-twin product manufacturing sectors. Digital twin is capable of improving quality service delivery via enhanced product testing and production platforms

vi. **Improved Economy:** On yearly basis, processing downtime contributes to loss of billions of naira. With digital twin, efficiency becomes higher due to decline in processing time

2.3 Challenge and Limitation of Digital Twin

Digital twin is virtual model that is required to aid psychological analysis and monitor of physical surroundings. Concept of digital twin commenced in industry where it was applied to monitor and analyze things like windmill and industrial farm. By adopting system dynamics and agent-based modeling, digital twin can be used as fault-detection system and diagnosis of any product. In nearest future, digital twin will proffer solution to many challenges facing humans. Hennek (2017) stated that even though there are lots of benefits derived from digital twin, many challenges are still facing digital twin which include:

i. **Security:** this is serious challenge issues that require solution to benefit from digital twin. Security challenges are enormous due to big data transmission between virtual and physical objects. Whenever data is exchanged, potential-risks become elevated; every digital twin user must bring up to date security setting. Enhancement revolution taking place in digital twin will help resolve security vulnerability issues arising from poorly constructed digital devices or hacked digital twin devices. Homogeneity can blow up potential effect of any security vulnerability with sheer-number of devices that have identical characteristics. Collaborative technique to security current challenges is required to protect digital-twin

ii. **Standardization Problem:** Interoperability becomes issue of concern in manufacturing environment because of lack of industrial standardization which may hamper digital twin growth. Single product designed from digital twin may not require standardization because it is simple to create while complex products with multiple modular parts may require standardization to realize enviable result

iii. **Privacy:** Digital twin creates exclusive challenge to privacy which emanates from integration of physical and virtual digital model together from smart environments without willfully use them. Digital twin must discern appropriate time to interrupt privacy to save human-life and know appropriate time to bring under control itself from interrupting user’s privacy Groth (2017). Voice recognition feature in digital twin can be hacked secretly or implanted into another digital twin product in order to listen to private conversation or observe how data is transmitted secretly to cloud service against users’ privacy. This information Compilation exposes regulatory and legal challenges facing digital twin data privacy and protection law during implementation

iv. **Regulation:** There are many legal and regulatory issues around digital twin environments that require deliberate considerations. Legal issue on digital twin relating to security breaches, data-destruction and retention policies and privacy lapses may violate digital twin regulation. Digital twin is growing faster than associated regulatory and policy environments; however, regulatory analysis of digital twin is being viewed from techno-neutral perception of legal scope to avoid deceptive and unfair practices against digital twin users to keep physical and virtual surroundings safe from abuse

v. **Digital Twin Reliance:** This is one of the challenges that future technology can cause; there is over reliance on digital-twin to execute every task that relates to product prediction and inspection and alert about product defects before going into mass production. Human can be over dependent on digital twin which may have negative impacts on human lives especially if embedded program is hacked as witnessed in movies like iRobot, Matrix, and smart transportation films

vi. **Human-Feeling:** Digital twin is artificial; users think they can't get intimate closeness like human-touch, togetherness, warmness feeling and emotional perception of human closeness they obtain from physical-product model. Digital twin doesn't have ability to feel human- closeness that many users love to experience in virtual model of product. Digital twin may become irrational in service delivery if it becomes hacked and re-programmed to carry out negative evil acts against manufacturers' aspirations within virtual surroundings

vii. **Low Esteem:** Human beings may feel inferior to digital twin counterpart later in future as information technology matures because digital twin will be able to execute every task that is higher than what human can do. If digital twin handles all re-modeling jobs accessible to human in real-environment, it can initiate job loss for product supervisors or feel inferior or useless to digital twin which may result into mental-illness associated problems down to joblessness

viii. **Mishandling:** If digital twin technology gets into wrong hands, it may be misused to hurt humanity or cause annihilation of life. Digital twin may be hacked, re-programmed and re-modeled from virtual environment to instigate attack against humanity. Digital twin software may also get infected with virus to cause malfunctioning of digital products or violent incident that human wisdom and logic may not be able to handle promptly

Architectural Model

3.1 Architecture of Digital Twin

In digital twin architecture framework, every physical object contains its virtual equivalent which is usually referred as virtual model or mirror counterpart. Virtual model has ability to predict, monitor, evaluate and analyze physical objects. Digital twin architecture establishes efficient communication mechanism between virtual and physical objects that blends synchronously to produce close-loop. Idea behind digital twin created CPS (Cyber-Physical System) architecture within computing domains. Before one can understand technicality behind digital twin, one must be acquitted with CPS architecture. CPS is technical convergence of virtual and physical domains which forms core architecture of embedding computing and communication capability into physical component that can be monitored, coordinated and controlled through virtual object.

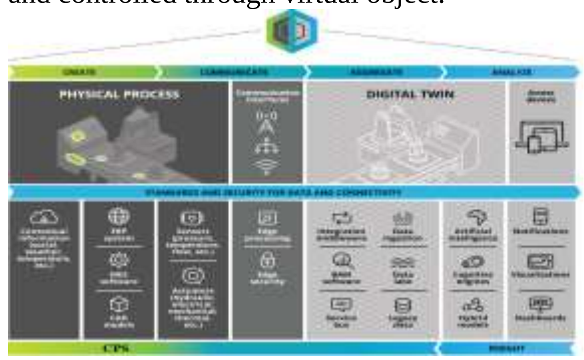

Figure 3.1: Technologies underlying Digital Twin (Thompson, 2017)

CPS merges together physical computing, networking and processing as one embedded object that can be utilized in different digital appliances like car, medical device, toy, scientific instrument and fitness cloth. CPS needs architectural modeling and abstraction which can be utilized to construct computation power, application integration and data monitoring of physical objects like humidity, velocity, heat and motion. CPS can become component part of IoT ecosystem integration due to architecture flexibility

3.2 Underlying Technologies behind Digital Twin

Digital Twin merges IoT, 3D-objects and artificial intelligence together to generate replica model of physical object to bring digital twin into existence. One big challenge facing researchers is on how to invent technology that works flawlessly and astutely between physical and virtual environments. There are many underlying technologies working behind digital twin development which must be tackled. Thompson (2017), highlighted below some underlying technologies that contributed to introduction of digital twin; some of these underlying technologies are: Pervasive-Computing, 3D-Mouse, Vision-Station, Google Glass, Context Awareness, Ubiquitous-Computing and Embedded Digital System, even though initial concepts behind them were different:

Figure 3.2: Technologies underlying Digital Twin (Thompson, 2017)

i. **Modeling:** is virtual mirror image model of physical world object which can be visualized for defects during digital product inspection. This is one reason behind underlying existence of digital-twin to generate digital replica model of any physical object. Using sophisticated 3D-modeling software can produce digital model version of physical objects for digital exploitation in public views. Modeling is likely not exact copy of physical-object down to principle following its production

ii. **Sensor:** is vital component that speed up materialization of digital twin; sensors connected to physical objects gather valuable data regarding product condition, status and context before broadcasting data to digital twin within virtual world environment. Sensors are becoming cheaper day-by-day in term of pricing, but increasing in many kinds which favor digital twin positively

iii. **3D-Mouse:** This input device permits 3D-modeling application software users to navigate across computer screens to move digital-twin as 3D-object to any preferred locations within virtual surrounding. Its introduction increases the likelihood of bringing digital twin into certainty. 3D-mouse is more engaging and interactive when measure up to 2D-mouse because 3D-controller allows access to three-dimension navigations from up-down, forward-back and left-right directions. It can rotate around each-axis at 6-degree of liberty down each-axis within a virtual environment. 3D-mouse remains idyllic input device for CAD camera movement and construction in virtual surroundings; inherent controller contains cap element that makes it simple to navigate to and fro across computer screen without proper adjustment to 3D-environment

iv. **Vision-Station:** This technology also aids materialization of digital twin, it is meant for one user that tries engaging in 180^0 immersive view. It is 2-meters with resolution size of 1920 x 1080; it is low cost multi-projector technology that has high-feel of immersion that is simple enough to setup in short period. It becomes ideal model solution for multiple project-areas like building-reviewing, aero-spacing, automotive-design, building low cost driving and military simulators because of minimize cost of usage and maintenance. It can house many integrated components like task trainers, cockpits, mission-rehearsal system and UAV-operator console

v. **Artificial intelligence**: This is capability of machine to resolve problems that requires human intelligence to solve or capacity of a system to become accustomed to its immediate surroundings via intelligent learning system. It covers how to make computers act like humans to execute tasks that ordinarily necessitate human-intelligence for speech-recognition, visual-perception, decision-making and speech translation

i. **IoT (Internet-of-Things):** This is one more technology underlying digital twin emergence; IoT connects every object, device, sensor, appliance and move application into virtual environment. IoT applications bring together huge volume of data from many sensors and devices for automation and control reasons. 5G is propose for adoption as capable and efficient wireless network system for Internet-of-Things due to its plasticity, cost reduction, unused available spectrum and resourceful network control

Figure 3.3: IoT – Connects Everything (Thompson, 2017).

i. **Virtualization:** This technology also forms basis of digital twin materialization. Due to tremendous needs for receiving and transmitting signals within smart virtual surroundings to exchange few bytes asymmetrically and huge boost in data for various usages create cordial tie to virtualization for network functions. Virtualization offers many benefits in term of cost reduction for network plasticity and operations

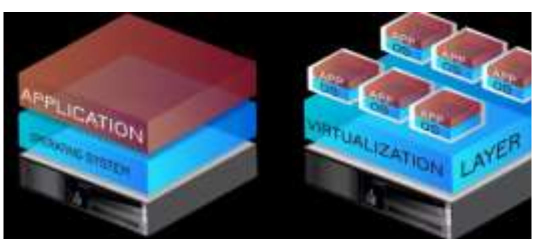

Figure 3.4: Virtualization Technology (Thompson, 2017)

Many operators are migrating to virtualized IP based networks because packet core-side of wireless 3NodeB and internet can be virtualized. Splitting between lower-layer and central core protocols are presently being decided by industry stakeholders at NEMs (network equipment manufacturers) so that sliced and virtualized networks can be suitable to various user devices.

4.1 Application of Digital Twin

Digital twin is more beneficial to business environment to predict present and future conditions of physical products to determine analysis of digital twin (its digital peer) within virtual environment. Application of digital-twin helps enterprises to boost product performances, customer contentment and aid decision making on tactical workflow. Digital twin is fast altering how manufacturing technologies are handled in contemporary digital environment. With huge digital computational power in modern society, it is now possible to utilize digital twin to spot and troubleshoot defects in manufactured product before going into full and final production in order to improve QoS (quality of service) at real-time in-line with global standard. Digital twin's impacts are here with us as many sectors of societies are turning to smart environments where digital twin applications are mandatory. According to Kreger (2018), highlighted many areas where digital twin applications are being applied:

i. **Manufacturing Sector:** Digital twin is used to conduct tests about newly manufactured products to forecast their operation performances and prevents future product failure in physical environment. It permits organizations to test-run new inventions for experimentation purposes before committing huge resources to its final production and implementation. Digital twin has become indispensable manufacturing mechanism in product designing, troubleshooting and maintenance services. Relevance of digital twin in business application aids downtime reduction via regular predictive maintenance procedures.

Figure 4.1: Manufacturing Sector (Kreger, 2018)

i. **Healthcare:** Digital twin plays significant role in medical areas to perform patient monitoring and surgery. Surgical operation and diagnosis can be conducted on patients from virtual environment before physical surgical operation is performed to determine if outcome of surgical operation will remain successful if carried out in reality. Healthcare medical centers can utilize digital twin to enhance health care system, handle emergency medical cases and perform health-prediction analytic based on bio-medical information gathered via sensor fitted digital twin on real-patients to determine current medical condition of patients. Digital twin is capable of collecting information and data like patient blood pressure, temperature, and make remote patient monitoring simple. Digital twin is utilized to support clinical decision system regarding medical diagnosis of EMR software Sandel (2018)

ii. **Automobile:** This is other application area where digital twin helps to construct virtual models for connected vehicles via sensor based data that is transmitted from physical-model to digital-twin in order to evaluate vehicle performances for improved service delivery for consumers

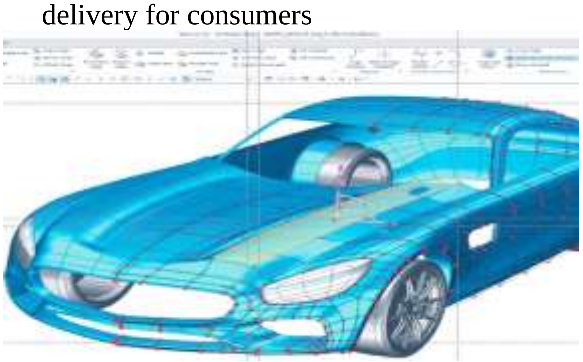

Figure 4.2: Digital Twin Application in Automotive (Thompson, 2017)

iii. **Asset Management at Real-Time:** Digital twin is used to monitor daily regular operational flow to diminish machine's wear and tear. It can also alert business owners to make adjustment to save cost and aid organizations to perform maintenance and repair to boost efficiency. It can be utilized in customer prediction, supply-chain and inventory monitoring system; digital twin can be used to order raw materials for procurement purposes from regular suppliers on behalf of organizations and has capability to forecast impending causes of shipping-delay. Digital twin can supervise stock-level from warehouse to determine when order should be placed in favor of organization

iv. **Plant Layout:** Digital twin can help construct entire plant layout for proposed organization setup. All machines and equipment needed for proposed company's operation are fed into software to build virtual plant layout with full simulated operation of physical plant in virtual environment to boost efficiency of plant layout. With digital twin, companies can forecast, monitor future plant's shortcomings and remotely control entire plant operation as well as carry out configuration process. Digital twin with integrated CAD-modeling software can demonstrate inclusion of virtual office bulbs, utilities, staffs in the office and determine if available resources will be adequate for their use.

Figure 4.3: Plant-Layout (Kreger, 2018)

v. **Remote Assistance:** Technicians can use digital twin to perform remote troubleshooting and diagnosis from virtual environment irrespective of locations. Consumers can be offered assistance to repair or collect vital information that can aid future product growth. Digital twin can alert technicians by making chronological data available to resolve machine problem since statistic has revealed that many consumer requests remain unresolved at first attempt until more attempts are carried out. Visual inspection on machine products can be performed by digital twin before technicians are available with appropriate skills, repair-tools and knowledge required to resolve present issues

vi. **Self-Driving Car:** This is another area where digital twin is applied, self-driving cars are built for smart cities; digital twin is required to improve safety around smart cities. Designer of self-driving cars require training computer about handling major components of driving via AI rather than human's senses within virtual environment. NAVLAB-11 is latest self-driving autonomous Jeep; many car industries are currently performing different researches in areas of digital twin to enable cars that are capable of tasks like pre-collision detection, traffic-congestion control and car-parking assistance system.

Figure 4.4: Self-Driving Car (Kreger, 2018)

vii. **Earthquake Forecast:** Harvard scientists utilized digital twin to achieve visco-elastic computations used in earthquake forecasts of sites from virtual surrounding. Earthquake computations were problematic before digital twin came into existence to develop computation time and speed by 50,000% via sequence of virtual testing. Timing is vital while handling earthquake calculations to protect human-life from one position to another

4.2 Future Trends in Digital Twin

Many researchers and stakeholders are excited over digital twin performance within virtual environment monitored.

Figure 4.5: Future of Digital Twin (Schröder, 2017)

Due to massive benefits digital twin offer, lots of IT-users are enthusiastic to have knowledge of what future holds regarding digital twin

According to Schröder (2017), highlighted below are comprehensive lists of future trends required to offer support to future advancement of digital twin in many sectors of modern societies:

i. **Urbanization and Digital Twin:** Few years ago, an increase in population and urbanization growth was observed globally. Recently, there have high-demands for quality products than ever before. To avoid sub-standard products in future, digital twin will be needed to remodel industrialized sectors for future development and merge contemporary technologies like IoT, AI, 3D-modeling and process automations to provide solutions to future challenges. World population is expected to jump to 9.6 billion by 2050 which may cause congestion that may result into lacking quality products across many urban cities. Digital twin will become mandatory option to move forward digitization of standard products

i. **IoT and Digital Society:** IoT advancement will extend to AI, 3D-modelling and big data in future digital society; more than 50-billion devices that include industrial equipment will get connected to internet via 5G-technologies by 2025 in readiness for digital-twin integration compared to 15-billion in 2018 that utilized 4G/3G technologies. In future of digital twin, societies will logically be forced to adopt digital twin to keep away from being left behind as every focus will center on digital twin

ii. **Improvement in Automotive:** In the nearest future, improvement in automotive will help digital twin applicable in fault-tracing, diagnosis, inspection and component manufacturing. In the automotive sector, fuel based vehicles may go into extinction while battery-powered or hybrid vehicles fight for relevance in digital twin environment. Digital twin in future will become viable in information sharing between V2G (vehicle-to-grid) and V2V (vehicle-to-vehicle) which will make it become prominent in future ventures in design and energy reduction model

iii. Network Capsule: This is another kind of neural network with capability to execute visual information like human-brain. With network capsule, future of intelligent digital twin will provide accurate recognition and identification system for each future product with minimal error. Use of network capsule is expected across different manufacturing domains as digital twin becomes unfold within virtual environment

iv. Reinforcement Deep Learning (RDL): Digital twin is capable of relating with users to proffer solution to business problem. RDL is neural network that learns via interaction with virtual environment via reward, observation and action. It was used sometimes ago to learn game-tactic like Atari and Go of which AlphaGo beat best human-champion in chess game Porter (2019). RDL is well known learning techniques that are useable in many business applications because it needs small amount of data to train its model compared to many other learning techniques available. RDL can get trained via simulation to remove needs for using data label in digital twin

v. Machine-Learning: Development of machine-learning model for digital twin is time consuming due to workflow procedure involvement like feature-selection, model-selection data preparation and training. Machine learning automates workflow using many deep and statistical learning techniques that are parts of digital twin components that permits users to advance transportation model without deep programming setting. Machine-learning will speed up time for data engineers to model contemporary digital societies. In future of digital twin, many more integration of machine-learning should be expected.

CONCLUSION

5.1 Conclusion

Digital twin is fast growing to where many virtual and physical innovations can come together to support humans to get exciting feeling via association with IoT to unlock thrilling world of monitoring, real-time control and communication with virtual-space to replicate virtually anything before it is reproduced in physical-world. Before public acceptance of digital twin commences, there are still many deficiencies in human-computer interaction, algorithm and infrastructure development that must be resolved. Achievement in digital twin has not attained its climax; it will soon become mature for societies to enjoy. Current challenges facing digital twin will be prevailed over in nearest future especially as it merges with new sets of IoT-devices that contain embedded security features. As ICT-technology progresses, digital twin will proffer solutions to multiple tasks autonomously via virtual environment and provides digital twin related jobs Samuel (2018). Risks and benefits abound in future digital twin, human beings must determine on what use and purpose digital twin be utilized as intelligent future technology. Humans must have clear goals to reach optimum target in future usefulness of digital twin especially as it blends with IoT to realize many enviable performances. According to Brachman (2017), digital twin works together with sensors and human to proffer solutions to many looming problems in the future which may result into job swapping that every inventor, developers and IT-expert must be ready to sail through future digital environment. Human must get prepared for looming negative effects that may relate to vulnerability issues, bugs and virus-attacks targeting digital twin. Security firewall must be advanced to have capabilities to secure digital twin and associated networks. Digital twin has become reality, re-modeling is required on regular basis to stay relevant in 21st century environment and beyond. Computer security experts must get set to safeguard digital twin against nefarious future activities. Digital twin is promising technology that target big and small-organizations to alter how product lifecycle will be handled. Every small and medium organization must align into digital twin which is certainly adopted as future technology

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