

Introduction to Industry 4.0

Digital Twins and 3D Printing

Emerging technologies and their impact on products, organisations, society and the planet

MSc Industry 4.0 Advanced Manufacturing (I4W)

Module Code: ACPA7004

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Date- 28th May 2022

Digital Twins and 3D Printing

(Different technologies of the Industry 4.0)

Emerging technologies and their impact on products, organisations, society and the planet

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Introduction-

The Fourth Industrial Revolution or Industry 4.0 (I 4.0) is one of the significant set of changes in our human experience/humankind so far. We've already lived through three major industrial revolutions that have changed the world in each aspect.

Fuelled by advanced telecommunications, microchips, and the Internet of Things, the world has become hyper-connected and increasingly digital.

With the recent wave of digitalization, the latest trend in every industry is to build systems and approaches that will help it not only during the conceptualization, prototyping, testing, and design optimization phase but also during the operation phase with the ultimate aim to use them throughout the whole product life cycle and perhaps much beyond (Rasheed and San and Kvamsdal, 2020, p.1)

In addition, old industries have been destroyed or reinvented, and many new game-changing products, technologies, ideas and services have been introduced. In each of these revolutions, the world prior to them looked different than the world after them. Many nations and people prospered, but unfortunately, many also lost out. Now, as we are in the first decades of the 21st century, a fourth revolution is upon us. It is at the top or peak of all the revolutions that have come before it. It is a convergence of the digital, physical, and biological world. In the Fourth Industrial Revolution, new innovation has greater scope, impact, and speed to market. It is defined by new expectations, far-reaching technological innovation, and disruption at a moment's notice. As one example, remarkable automation and artificial intelligence will not only bring higher-quality, lower-cost products and services to market, but may also displace millions of workers and change the nature of work. It is in this context that organizations are placing a greater emphasis on how we design, build, and support the world around us, including all the items we use and consume.

Moreover, a transformation is happening in how things are being designed and built that is called Industry 4.0. In this era, as technological capabilities, digitisation particularly in design, manufacturing, and data analytics have grown and costs have continued to drop, we now have better tools, technology to build and support results that meet and exceed 21st century market expectations.

- The current essay will highlight
- What is a Digital Twins?
- How the Digital Twins work?
- Is digital twin a new concept or has it existed with different names in the past?
- What is the process for the Digital Twins and their advantages?

- What are the applications/uses of the Digital twins in the aerospace?
- What values are expected out of the digital twin concepts?
- What is a 3D printing and their advantages?
- What are the applications/uses of the Digital twins in the aerospace?
- What are the disadvantages of these technologies?
- What are the Government's plans and strategy?
- What are the impacts on society and on our planet?

Digital Twins

The qualities and context of the Fourth Industrial Revolution (Industry 4.0), is the environment, safety and accuracy in which digital twins will prosper and contribute, and it's why their value is so essential (Reichental, 2020).

Now the boundaries between the digital world and physical products are fading and this is what we recognise as the Fourth Industrial Revolution, or Industry 4.0. At the front line of this revolution are “smart” technology applications such as Internet of things (IoT), global connectivity, big data, machine learning, and virtual reality. Digital Twin technology combines all these applications and has become a key component of Industry 4.0. This technology presents significant opportunities for the Aviation sector (Rolls-Royce, n.d.).

A Digital Twin (DT) is a virtual representation of a real entity or world or system or process. This is really simple definition of the digital twin. In other words, a digital twin is, basically, a computer program that uses real world data and information to create simulations that can predict how a product or process will perform. Different software manufacturers and developers have their own visibility or clarification/words to explain digital twins.

Digital twin is a vital tool, concept, or process to help engineers and operators understand not only how their products are performing , but also how this product and they will perform in the future. Data collection from the real operation or from the real operating system (in near real-time), analysis of this data from the Internet of Things (IoT) and connector sensors, combine with real time factors, relevant data, conditions and with other sources of information, allows engineers to make these predictions (Armstrong, 2020).

Using a digital twin, engineers can accurately determine the life of structural components and this information can be used to improve performance, generate savings or increase operational flexibility.

The life of a digital twin begins with experts in applied mathematics or data science researching the physics and operational data of a physical object or system in order to develop a mathematical model that simulates the original.

The developers or engineers who work on the digital twins, they always want that the virtual computer model should be connected with the real world version that means the virtual computer model should receive all required information, data, feedback from sensors which are connect or installed on the original version. All these assemble data, information allow digital version mimic and simulate what is actually scenario and situation of the original version in real time, in real condition and in real circumstances, creating opportunities to collect insights and intuition into performance and any potential barriers and problem (TWI, n.d).

A digital twin can be as simple as possible or it can be as compound/complex and critical as one's required, it all depends on the data, amount of data, precise and accurate data provide to the model and how precisely model simulates the real world physical version. The uses and applications of the digital twins are different and depend on the users.

Digital twin technology has been implemented for some time now across organisations. NASA has been using software replicas of its spacecraft for decades. It is believed that the successful return of the 1970 Apollo 13 mission after the oxygen tank exploded was orchestrated by the agency's use of "mirrored systems" back on earth (Singh, 2021).

Process, application advantages

In engineering terms, the use of Digital Twins reduces the need to rely on probability-based techniques to determine when an engine might need maintenance or repair. Our Engineers create a Digital Twin of an engine, which is a precise virtual copy of the real-world product. They then install on-board sensors and satellite connectivity on the physical engine to collect data, which is continuously relayed back to its Digital Twin in real time. The twin then operates in the virtual world as the physical engine would on-wing and will determine how the engine is operating and predict when it may need maintenance. This also allows us to enact preventative engine maintenance, which can greatly reduce aircraft downtime and, in turn, enhance reliability (Rolls-Royce, n.d.).

In addition, the data analysis used by the Digital Twin allows us to model a greater number of potential circumstances than physical engine tests would ever allow, which results in a greater understanding. Using a Digital Twin, Rolls-Royce can study and predict the physical behaviours that an engine would exhibit under very extreme conditions. This allows us to model potential operational scenarios entirely digitally (Rolls-Royce, n.d.).

A fully operable, usable and workable digital twin offers comprehensive and predictive analytics. For example, an aircraft integrated with digital twin technology would be able to predict future problems, errors or failures of the engine with help of previous data which has been collected or assembled from original aircraft in real time. It would allow the creators and engineers to look into the future potential problem prior to any danger whether it would involve completely re-testing the airframes of an aircraft, testing its engine or doing any further security checks to ensure the

safety of the people onboard. The traditional control rooms also have various predictive analytics, however, the integration of the digital twin would enhance the efficiency to deal with any looming in the nearer future. In short, this technology allows engineers/creators to not only operate effectively, reducing testing cost but also to maintain and repair systems when they aren't within physical proximity to them (Miskinis, 2019).

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The aerospace industry has been using technology that is similar to Digital Twin for years now. However, it has mostly been used to develop digital models of commercial aircraft in airports and air force jets in order to find ways on how to improve the machine and achieve optimal performance. Moreover, they've successfully used the tracking aspect of digital twins to track aircraft across the world in order to ensure the success of their day to day travels by heavily relying on Challenge.org knowledgebase. However, as this technology grows and continues to evolve, more opportunities will start to present themselves that will allow aircraft engineers to be more productive in terms of executing new model tests and when it comes to the commercial aspect of flying, the final user experience of travelers will be more pleasant and safer than it ever was before (Miskinis, 2019).

USE CASES

The digital twin of the Lockheed Martin Block IIR GPS satellite, known as a SatSim, was built in 2018 for the Air Force Space and Missile Systems Center. The SatSim has enabled the vulnerability scans and penetration tests to be conducted on the whole GPS system, including the satellite, its ground control station and the radio frequency link between them. Digital twin technology also has been used to train AI to fly autonomous aircraft. AI pilots can get thousands of hours of flight time on a digital simulation in a fraction of that time and learn in days than what it takes, a human pilot, months to experience (Singh, 2021)..

GE has already built digital twin components for its GE60 Engine family and has helped develop the world's first digital twin for an aircraft's landing gear. Sensors placed on typical landing gear failure points, such as hydraulic pressure and brake temperature, provide real-time data to help predict early malfunctions or diagnose the remaining lifecycle of the landing gear.

At Boeing digital twins are used to design aircraft. Simulations are run that predict the performance of various aircraft components over the lifecycle. As a result, Boeing engineers can predict when components are expected to fail. According to the company they have achieved a 40 per cent improvement rate in the first-time quality of parts by using a digital twin. The company plans to digitise all of its engineering and development systems in the future and also plans to share this information with its supply chain.

Another use case being explored for Boeing aircraft is using a digital twin to achieve a perfect cargo load balance. For example, a Boeing 737-800 has a maximum cargo load of 80,000 kilograms but many planes fly with less cargo as weight figures are calculated manually. By using IoT sensors on a digital twin, a precise and yet safe cargo load can be determined thereby increasing cargo revenue per flight (Singh, 2021).

The ability to map complex, real-life scenarios on a virtual platform allows Rolls-Royce to improve and adjust operations as well as maintain our highly complex aero engines even more effectively. Digital twinning is part of a comprehensive suite of digital models that underpin the Intelligent Engine, our vision for the future.

As well as designing, testing and maintaining engines in the digital twin environment, the Intelligent Engine vision sets out a future where an engine will be increasingly connected, contextually aware and comprehending, helping us deliver products that are more reliable and efficient (Rolls-Royce, n.d.).

Overall, a Digital Twin will continuously learn and update itself using data from sensors that monitor various aspects of the real-life product's environment and operating conditions. Digital twins are vital, effective and very important for aerospace industry as well as all domains. This is a big deal that we can repair the systems/error when aircraft is in the air. Using a digital twin, engineers can accurately determine the life of structural components and this information can be used to improve performance, generate savings or increase operational flexibility. If aeroplane are on ground then it is a huge loss for airline/owner it should be in the air as maximum time as possible. Digital twins give us a glimpse into what is happening, or what can happen, with physical assets now and far into the future. A digital twin can be used to save time and money whenever a product or process needs to be tested, whether in design, implementation, monitoring or improvement.

3D Printing

Three-dimensional (3D) printing is an additive manufacturing process that creates a physical object from a digital design. The process works by laying down thin layers of material in the form of liquid or powdered plastic, metal or cement, and then fusing the layers together.

3D printing can create intricate and complex shapes using less material than subtractive manufacturing processes, such as drilling, welding, injection moulding, and other processes.

Making prototypes faster, easier, and cheaper allows for more innovation, experimentation, and product-based start-ups.

The Aerospace industry was one of the earliest adopters of 3D printing technology with initial use recorded back in the late 1980's. Nowadays it is still considered the industry which has the highest rate of adoption of 3D printing technologies.

3D printing is implemented at all stages of the design workflow for applications in the aerospace industry, such as, early design or concept design/models, design communication, validation stage, pre-production, production, tastings,, validations and customisation.

Parts can be made as per requirement to a specific aircraft or the different type of aircraft such as cargo, passenger or helicopter as well. 3D printing also provides part consolidation and topology optimization of many custom aerospace components.

There are many different ways where 3D printing can use. And there are different cases where 3D printing already used. Some common 3D printing use-cases in aerospace are Here are few examples from top-level companies using 3D printing (Hodson, 2021),

USE CASES

In April 2015, GE Aviation received permission from the FAA to use a 3D-printed part in a commercial jet engine. The part produced, a sensor housing, is now being used in more than 400 GE90-94B engines on Boeing 777 jets.

The Boeing Company is an American global organization that plans, produces, and sells planes, rotorcraft, rockets, satellites, broadcast communications gear, and rockets worldwide. Boeing is working on using 3D printing to make parts for its 787s.

Airbus made history in 2014 when the first commercial airliner took to the skies with the first 3d printed metal part, a simple titanium bracket. Airbus found that every kilogram saved prevents 25 tons of CO2 emissions during the lifespan of the aircraft. Since then, Airbus SE received the most orders in 2019 and surpassed its rival Boeing.

NASA has entered into a \$73.7 million agreement with Made in Space to collaborate to produce parts. 3D printing is solving a number of logistical and repair challenges that NASA faced onboard the international space station and provides an excellent case study for future trips to the moon and beyond.

The most important thing of 3D printing particularly in aerospace is, 3D printed parts and tools are very light weighted without compromising the strength. Those parts and tools can be 50% or more light and stronger than the parts which are made up of traditional or conventional methods and material.

The aeronautics industry produces around 2% of all human-initiated carbon dioxide (CO2) emissions worldwide. Aeronautical flights are liable for 12% of CO2 emissions from all vehicle sources, contrasted with 74% from street transport (Hodson, 2021).

Therefore, anything which reduces weight without compromising requirements that will much appreciated in the aerospace industries because it improves the fuel efficiency and reduce CO2 carbon dioxide emission (The Essentium Team, 2021).

Disadvantages of Digital Twins and 3D Printing technology

Digital twins

Digital twin is totally depends on the IoT Internet of Things and it should have full internet connectivity, without IOT we can not manage this technology. As it is fully internet connectivity and dependability, it is very vulnerable. Security and the data management are a big concern. It is big setup with sensors and full of technology requires high capital investment. Also require highly skilled staffs, software, and sensors.

3D printing

The lack of legislation and regulations regarding the 3D printing. For example, there can be printed guns, weapons, parts for aircrafts, military parts, counterfeit parts for commercial or defence operations, drugs or chemical weapons.

3D printer is the fact that children could print out dangerous items. In order to prevent this, one can employ software limitations and parental control. 3D printing is its high cost. Limited materials are listed for 3D printing. Some time finishing will be the issue.

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Many 3D printers currently in operation are still relatively slow when compared with other manufacturing processes. This limits 3D printing's ability to compete in the mass-production space.

The cost of materials is generally the largest cost component of 3D printing.

3D printers are still relatively expensive when compared with other traditional manufacturing machines. Depending on the size of the machine, functionality of the machine, and type of raw materials to be used, 3D printers can cost anywhere from \$10,000 to \$100,000 or higher (Claconnect, 2020).

Government and policy makers supports

By looking at benefits from Industry 4.0 and from their technology government really wants to support manufacturers. UK government has several plans and strategies to support new innovations, technologies and in the development of Industry 4.0.

The UK Government has put many efforts to support business and individual during pandemic. They put in place unprecedented economic package, providing businesses and individuals support and certainty, spending hundreds of billions to support people's jobs, businesses, and public services across the UK.

Moreover, UK Government has planned to support three core pillars of growth those are Infrastructure, Skills, and Innovation.

UK government also has Innovation strategies and plans with finance, investments. They have four pillars to support Innovation; those are Unleashing Business, People, Institutions & Places, and Missions & Technologies. In these strategies they are investing £200 million through the British Business Bank's Life Sciences Investment Programme, new talents- scaling-up visa route and Allocating £127 million through the Strength in Places Fund to develop R&D capacity and support local growth across the UK. They are delivering in public sector R&D investment, as part of ambition to raise total investment in R&D to 2.4% of GDP by 2027 (GOV.UK, 2019).

Conclusion

In this digitalisation world many industries such as manufacturing, automotive, aviation, energy, utilities, healthcare, logistics, retail, and other industries have adopted digital twins to augment productivity and efficiency. By 2029, the global digital twin market size is forecast to reach \$96.49 billion from \$6.75 billion in 2021 and exhibiting a CAGR (Compound Annual Growth Rate) of 40.6% during this forecast period, 2022-2029 (Fortune Business Insights, 2022).

Digital Twins and 3D printing are the technology of Industry 4.0 Both offer great opportunities in various sectors of the product and engineering process. Despite of some challenge in these technologies we can achieve as required result because it has so many advantages over the disadvantages. Over the time, those challenges can be reduced and we will have many solutions on it. The market is global and growth will be particular rapid in all sectors. Implication of these technologies has already had a massive impact on the world's economy. In terms of employment, these technologies offer new technology, software, and advance process to learn and upgrade the skills to go further.

A digital twin can be used to save time and money whenever a product or process needs to be tested, whether in design, implementation, monitoring, or improvement.

Each coin has two sides similarly each industrial revolution comes with pros and cons By definition, revolutions are dramatic and highly disruptive.

Impact on our Society, Environment, and our Planet

Preparing and responding to change

Taking actions: organisation-

Many jobs will disappear while we will gain a lot of new jobs. Technology is continuously changing and it will be like this. All industries are going to adapt new technology to cope and survive in the new digitisation world. Industry need to upgrade their instruments, infrastructure, way of working whenever they will adapt new technology. Similarly, Industry should look into their staff skill, knowledge and techniques as well. Instead of replacing staff, organisation should invest money in their staff. Learning is essential for long-term organizational development.

Taking action: Individual-

The rapidly industrializing and urbanizing world of the 21st century has largely continued to produce enormous amounts of new opportunities, new roles. Employment, despite growing ranks of illegible workers, has remained high on average. More, skilled and latest education will be required for jobs that have greater technical skill requirements. Everyone should take a further step by keeping these things in mind. Take education which having practical knowledge and which having new technology in it

In summary, these technologies have enormous potential in many areas. Everything is changing so fast and transformation is going on so everyone should take care of it and move forward according to the predictable future. Future and priorities are different for everyone but there will be a common thing - they will demand high level of flexibility, adaptability, and lifelong learning.

Digital twins offer great opportunities in various domains of the product engineering process. Presented examples, linking product and production twins into digital production twins, show first approaches for the integration of production knowledge or product twins into the respective other domain. The continuous linking of digital twins is the key to achieve further improvement of the operational excellence and maintaining the competitiveness within the industry of precision products. The main future challenge is to define a consistent framework for the holistic use of digital twins in the entire product engineering process, which covers the topics of common understanding interfaces and standardization, as well as efficient information flow. This particularly requires the integration of product designers and production planner concepts in future research (Fortune Business Insights, 2022).

Impact on our Environment, and our Planet

In this era, we can see the boom of many technologies of industry 4.0. This is the transition phase where we are moving towards fully digitisation world. With this transition mode we need to think for our society, environment, and our Planet

As we have seen above, 3D printing reduces more than 50% of weight of parts as a result, it improves the fuel efficiency and reduce CO2. And this is the positive effect on environment.

3D printing technology reduces the scrap. It also allows us to optimize raw materials, because we use only the amount we need to build a product. Most of the product we can use as a single part where as with conventional methods we can't manufacture those part as a single entity.

3D printing also has a positive effect on the carbon footprint. Because it does not rely on complex manufacturing and assembly supply chains, it facilitates localized production and reduces the need to transport goods manufactured in third countries.

It does this in two ways. Firstly, it is becoming increasingly popular to manufacture printing filaments from recycled materials, which adds value in the eyes of more environmentally aware consumers. Secondly, consumers will be able to repair broken products by self-manufacturing spare parts on home printers or at 3D printing centres. These two practices lengthen the useful life of original products, either by transforming them into a new raw material or by repairing and reusing them (Sanchez, 2019).

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