Digital twin in epidemic: How does a smart city cope with novel challenges through digital simulation, automation and visualisation

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ABSTRACT

At the beginning of the 21st century, as rapid urbanization becomes a global phenomenon, smart city becoming more and more a future-proof solution for cities with rising unprecedented challenges of congested infrastructure, population density, energy inefficiency and global public health. In this context, digital twin was initially introduced by Dr Michael Grieves in 2002 as a key enabler technology to improve product manufacture and complex systems, and later bloomed as a new concept to promote better design, system integration and troubleshooting of the physical city through simulation, automation and visualisation. This paper, in aiming to understand how digital twin was rapidly adopted by a number of pioneer entrepreneurs, cities and nations, provides a narrative and categorical perspective of digital twin appearance in literature and explores the extents where a real-time cyber presentation of the city can support mediating urban issues within the context of global pandemic. In result, a longitudinal section of digital twin and smart city development has been introduced, including the evolvement of digital model, digital shadows to digital twin, as well as the rising interest of academia and private sector to the technology.

Keywords: *Smart city, Digital twin, Smart infrastructure, Global epidemic*

INTRODUCTION

Since the first industrial revolution in Britain 250 years ago, there have been three industrial revolutions in the history of mankind. Each revolution brings breaking waves of technology by placing innovation as the catalyst for the revolution. From the first appearance of steam-powered engines that replaced animal power in the first revolution, the mass production thanks to electronic power in the second, and the appearance of information technologies in the third, our agrarian and handicraft economy has continuously transformed to embrace industrial and machine manufacturing technologies (Allen, 2009; De Vries, 2013; Kelley & Williamson, 1984).

By the early 20th century, under the umbrella of smart city and the fourth industrial revolution, powerful technologies are introduced such as the internet of things, artificial intelligence and digital twin, allowing urban objects to communicate and connect while imitating the cognitive functioning of humans in perceiving the surrounding environment (Nilsson, 2014; Russell & Norvig, 2016) for better decision making without human interaction. These technologies enable key accessibility to seamless data flow, machine intelligence through data training and cyber representation of the physical world. According to M. Grieves (2019); Xu et al. (2019), the idea of digital twin was first introduced by Dr Michael Grieves in 2002 as a concept for product lifecycle management. In principal, digital twin represents a real-time digital replica of a process, product, or service (Grieves & Vickers, 2017). However, one does not simply perceive descriptive three-dimensional model, but a cyber representation capable of dynamically synchronizing physical entities in actual time. Digital twin can be empowered using IoT to populate and collect real-time data, and use AI to learn, interpret, and simulate the decision-making process of the physical model. The significance of the technology therefore lies in its capacity for continuously learning and updating itself from the original physical model and the data sources accumulated in the past and present, and has the capacity to simulate and predict possible faults and issues before they arise (Mohammadi & Taylor, 2017).

Under emerging challenges of urban density, infrastructure congestion and especially the unprecedented occasion of global pandemic in 2020, digital twin becomes more and more a rational and pragmatic approach in providing a comprehensive action plan through simulation, automation and visualisation. The technology can be utilized as an effective tool for city governance in any of the design, building, and operation stages of a city, including dealing with unprecedented occasions such as terrorist threats or national epidemic. From urban surveillance, infrastructure optimisation to land-use management, digital twin enables the ultra-realistic and real-time simulation of city from the micro dwelling level to the macro metropolitan level. Ultimately, digital twin is entitled for a broader and more comprehensive solution when saturate with data automation technology such as Internet of Things (van der Heide et al., 2017) and data analysation and simulation technology similar with artificial intelligence and machine learning. The birth of digital twin marks a generation of combining and symbiotic smart technologies which opens the door to a more sophisticated, reliable, and data-driven city governance decision-making process that significantly encourages the construction of a new generation of smart and sustainable cities (Petrova-Antonova & Ilieva, 2019; Wakil et al., 2019).

This paper, in introducing a new technology for smart cities development, is an effort aligned with the Sustainable Development Goal (SDG) 11 which been announced by the United Nations in 2015. The insights of this paper can contribute positively to the achievement of target 11.a – Strong national and regional development and target 11.6 – Reduce the environmental impacts of cities.

METHODOLOGY

The chosen research approach to investigate the development of digital twin is a qualitative approach adopted from narrative literature review. This approach involves a systematic way of collecting and synthesizing previous research to generate a firm foundation to advance knowledge and facilitate theory development for further studies. To such an infant technology like digital twin, narrative literature review can address the research question by integrating findings and perspectives from many empirical studies with a power that no single study has. A literature review can also help to provide an overview of areas in which the research area is novel, disparate and interdisciplinary (Snyder, 2019; Tranfield et al., 2003; Webster & Watson, 2002).

Compare with the other types of literature reviews, in specific qualitative systematic reviews and quantitative systematic reviews (meta-analyses), narrative literature review is more helpful in presenting a broader perspective. In many of the cases, narrative literature review is mostly used to describe a history or development of a problem, phenomenon or subject. Because of its simplicity approach, narrative literature review is often easily to update and accessible for both novices and experts. To this extent, narrative literature review is an excellent method to report the development of a young technology like digital twin in empowering smart cities.

Nevertheless, narrative literature review also possesses a number of weaknesses. In this unsystematic approach, the selection of collective data and primary literatures is usually subjective and lack of explicit criteria for inclusion. Thus, the methodology depends on author's interpretation and synthesis of analyses rather than following rigid and disciplined research protocols. To mitigate possible bias and fault conclusion, this paper will take into account the methodologies, research design and sample sizes of each literatures in the collective databse. Alternatively, it will focus on reporting the development of digital twin technology, rather than a prompt conclusion of digital twin contribution to smart cities.

RESULT AND DISCUSSION

The birth of digital twin

As reflected in literature, the most remarkable predecessors of digital twin who can work as an insight-provider for the other physical counterpart in history can be named NASA's Apollo program and aircraft industries' Iron bird simulation. According to Rosen et al. (2015), the twining experiment from NASA's Apollo program was to construct two identical space vehicles to allow the operational monitoring of one space vehicle during its space mission while the other twin remaining on earth with mirrored artificial conditions. At the same time, Iron Bird was a ground-based engineering tool to construct a replicated, on-land installation of the actual configuration of an airplane using integrated computing, electrical and hydraulic systems to simulate the flight session under the most realistic conditions for training purposes. Using this tool, the computer was responsible to create a digital world by calculating aerodynamic model, weather conditions and airplane situations for future pilots and additional simulation to allow engineers to discover potential malfunctions of the aircraft in development stages. As both integrated systems became so successful, they were used extensively and introduced in different disciplines and purposes, simulating different scenarios, testing not-yet-available physical models and providing a decision-making supporting process to all level of users (Boschert & Rosen, 2016).

In 2002, digital twin concept was first coined by Dr Michael Grieves as a model for product lifecycle management without being named. In 2005, the concept was first named Mirror Spaces Model and later renamed to Information Mirroring Model in 2006. Only until 2011, under John Vickers of NASA's recommendation, Dr Michael Grieves had finally named the concept as Digital Twin like what we know today. Originally, the first aim of the model is to extend the product lifecycle by providing insights to the design, test and manufacture (Rosen et al., 2015). Later, Grieves and Vickers (2017) have observed a broader potential of the technology in different industries and application, hence extended the scope of digital twin to a larger scale of *'digital twin for complex system'* where different networks of components and communication channels were co-existing (Glaessgen & Stargel, 2012; Tuegel et al., 2011; Zhuang et al., 2018).

Under the hyper advancement of simulation and computing technologies which provide a more and more precise simulations, the cost to build up a physical model of complex system such as aircraft, spaceship, infrastructures, building and even city has become a remarkable disadvantage comparing with building a virtual model, not to include intransigence, time-consumption and resources-consumption. Thus, the diffusion of digital twin into different industries and business, including smart city development, soaring. Figure 2 below illustrates the model of digital twin or the synchronized co-existence between digital and physical twin by stressed two continuous data flows: from physical to digital twin to develop digital capacity and from digital to physical twin to provide well-informed answers as a platform for better intervention-making process.

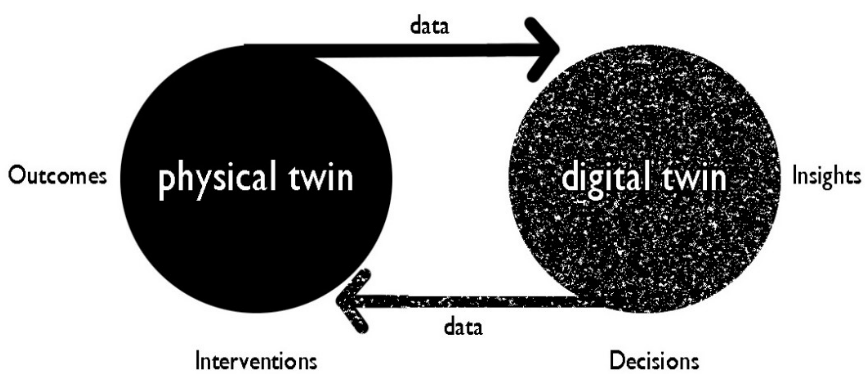

Figure 1 – The digital twin model (Grieves, 2019; Mott Macdonald, 2018)

Defining digital twin

Despite the potentials, digital twin is a developing technology and still very much at an infant stage. Besides Grieves and Vickers (2017), different definitions and conceptualizations have been composed by different scholars, such as Grieves (2014), Dietz et al. (2019), Boschert and Rosen (2016). Therefore, the interdisciplinary nature of digital twin has reflected vague in the rapidly growing literature due to the lack of a sound and common conceptual comprehension. Scholars, practitioners and nations have defined different frameworks that suit their own particular practical perspectives and goals, rather than drawing a common outline to eliminate the complexities, buzzwords and links of various applications to digital twin. Outlined in Table 1 are a number of digital twins terminologies, from the NASA's concept of a simulation of a vehicle (Boschert, 2016) and a physical-entity based system (Glaessgen, 2012) to a more modern concept of intelligent manufacturing in different scale and complexity by Xu (2019).

Although each concept can be interpreted differently in alternative contexts, there are remarkable milestones in the evolvement of digital twin in academic literature. The first generations of concepts introduced by NASA and Glaessgen have acknowledged the significance of digital twin in a complex system such as flying vehicle. However, the technology is perceived towards a simulation tool rather than a comprehensive and automate parallel process. In this sense, digital twin is a technique to imitate the behaviours of some situations or processes by means of a suitably analogous situation, especially under the purpose of study or personnel training. Thus, the first digital twin terminologies were presented more under a supplemented technology to enhance the performance of complexed system rather than a system itself. Recent studies from Dietz et al. (2019); Xu et al. (2019) have interpreted differently.

	Digital Twin terminologies	Author
1	The digital twin is the information constructing of the physical twin. The intent of the digital twin is that it can provide the same or better information than could be obtained by being in physical possession of the physical twin. The incorporation of digital twin is intended to mitigate system complexity by providing more and better information about the Physical twin. Digital twin is a model, which asserts that all systems are dual in nature. There is the physical version of the system and a digital/virtual version or the information version of the system.	(M. W. Grieves, 2019) (Grieves, 2014)
2	Digital twin is no longer a descriptive three-dimensional object, it represents physical entities with their functions, behaviours and rules dynamically. Nowadays, Digital twin is a new paradigm for promoting the development of intelligent manufacturing. It stimulates and maps the entire product life cycle through ultra-realistic and dynamically optimized simulation models, thus reducing the cost of design and maintenance, while enhancing the efficiency and quality of manufacturing. The properties of digital twin are hyper realism, computability, controllability, and predictability.	(Xu et al., 2019)
3	Digital twin is the technology of choice for virtualizing the physical world. The original purpose of digital twin is to enable people to study problems more easily, get to the point, understand, and proceed pragmatically and rapidly. The three main weak points of digital twin are: • Model semantics of digital twin is mostly geometry driven. • Analytics are aligned but not embedded into the model • Simulation and user-interaction are offline.	(Dietz et al., 2019)
4	Digital twin is realistic digital representation of physical things. It unlocks value by enabling improved insights that support better	(Mott Macdonald, 2019)

	decisions, leading to better outcomes in physical world. What distinguishes a digital twin from any other digital model is its connection to the physical twin. Based on data from the physical asset or system, a digital twin unlocks value by supporting improved decision making, which creates the opportunity for positive feedback to the physical twin.	
5	Digital twin is an endeavour to create intelligent adaptive machines by generating a parallel virtual version of the system along with the connectivity and analytical capabilities enabled by IoT.	(Mohammadi & Taylor, 2017)
6	A digital twin is an integrated Multiphysics, multiscale simulation of a vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin. The digital twin is ultra-realistic and may consider one or more important and interdependent vehicle systems, including propulsion/energy storage, avionics, life support, vehicle structure, thermal management, etc. Manufacturing anomalies that may affect the vehicle may also be explicitly considered.	NASA's interpretation (Boschert & Rosen, 2016)
7	The digital twin is an integrated multi-physics, multi-scale, probabilistic simulation of a complex product and uses the best available physical models, sensor updates, etc., to mirror the life of its corresponding twin	(Glaessgen & Stargel, 2012)

Table 1 : Definitions of Digital twins

First, it is the continuous connection between the physical entity and digital twin that leverages the concept beyond a simulation tool. Digital twin, by Grieves (2017) and Mott Macdonald (2018), can exchange data and information seamlessly with physical twin, to become a real time copy of the blueprint entity and parallelly exist in the digital world. The transmission of data also will be used to the greater purpose of machine learning which enables the copy to automatically learn and improve from experience without being explicitly programmed. When the amount of data is sufficient, and the model is considered mature, digital twin will be able to provide '*same or better*' feedbacks of the system operation and predict development scenarios without compromising any potential of the physical entity. This way, the physical entity itself will be benefited by simulated experience of potential risk, hazards, failures or success of the process as a result of million simulations of the digital twin in the virtual world, without any prominent hazard from the physical test. The process of decision making from possible manual operator, therefore, will also be significantly improved and become more efficient.

Second, with the increasing hyper development speed of technology, digital twin enables the vast integration of disruptive technologies as a primary link from virtual to the physical world. Technologies such as Internet of Things, Deep Learning, Artificial Intelligence are supplemented technologies to ensure the gradual exchange of information between two worlds and new data analysis methodologies that automates the learning process from data and make decisions with minimal human intervention.

According to Mohammadi's (2017) and Glaessgen (2018) researches, digital twin has the incredible potential of virtualizing the physical world through mirroring the life of each and every physical entity.

Conceptual relatives or the three generations of digital twin

In comparison with the previous developed technologies in digital modelling such as CAD (computer-aided design) or BIM (building information modelling), digital twin has proved its flexibility and accessibility, based on the variety of spatial and temporal scales provided (M. Grieves, 2019; Mohammadi & Taylor, 2017). Additionally, the continuous connection between digital twin and physical entities (including the original model and its relative peers) also differentiates digital twin from traditional digital modelling tools. While in BIM and CAD, the digital model is a 'one-time' copy, which is disconnected from and can only illustrate the physical entity in one specific point of time, similar to a painting or a photo which captured the model at one specific period of life. Digital twin, on the other hand, is not only able to provide recommendations within the concept and design phase of the product, but it also can reflect the host model in any point of its life where information and experiences can be utilized to eliminate any potential risks of damage to the physical system. Digital model, therefore, distinguishes itself with digital twin by the lack of an automatic data exchange between physical and digital subjects. Any possible data links between the two entities are manually built and represent for the independent model itself with no impact to the physical object and vice versa.

Digital shadow, on the other hand, is the next version of digital model where the data flow from the physical entity to the digital copy is not entirely a manual process, or can be described as an automated one-way data flow from the existing object to the digital object. As a result, '*a change in state of the physical object leads to a change of state in the digital object, but not vice versa'* (Fuller et al., 2019) as represented in Figure 5 below. According to Gassmann et al. (2019), digital shadow has the potential to become an essential constituent of every service in modern cities as well as a prerequisite for smart city development in providing the six major smart domains under Giffinger's definition (Giffinger & Pichler-Milanović, 2007).

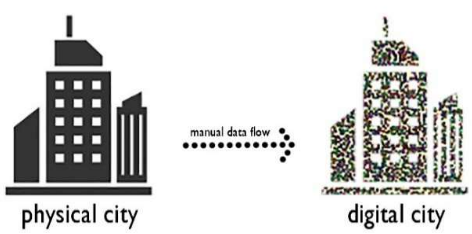

Figure 2 - Digital model

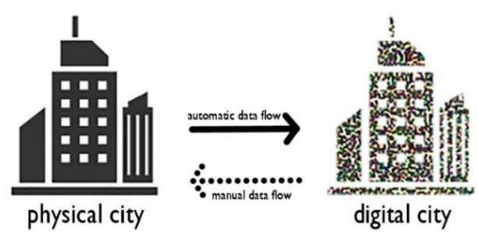

Figure 3 - Digital shadow (shadow twin)

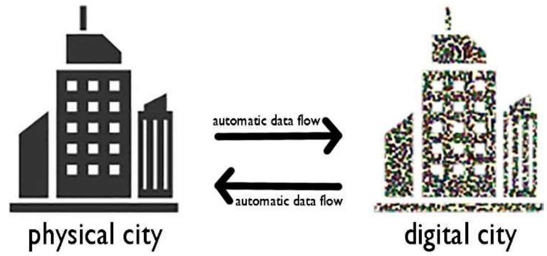

Figure 4 - Digital twin

In case data flows between physical and digital entities autonomously as the information is exchanged and fully integrated to both directions, scientist considers it as Digital Twin (Kritzinger, 2018; Fuller, 2019). This feature is the key to differentiate digital twin with other technologies, as the digital model of the object will continuously develop as a replica to provide platform for simulation, training, management and strategic planning to serve better decision-making. In comparison with former twin versions, digital twin excels in term of cost-effectiveness and flexibility. The technology can be implemented using different modelling approaches, such as binary, geospatial, aerodynamic air modelling, etc. It can be applicable in multi scale projects from building, community, city to national level. More impressive, digital twin extends the human research capacity by providing experiment in any point of time in product lifecycle from beginning to end, from design blueprint to operation, as long as the data flows are provided. The bigger and more complex the physical object is, the more digital twin excels in providing information for better decision making from lessons of the past, scenarios of the future and optimization of the present day.

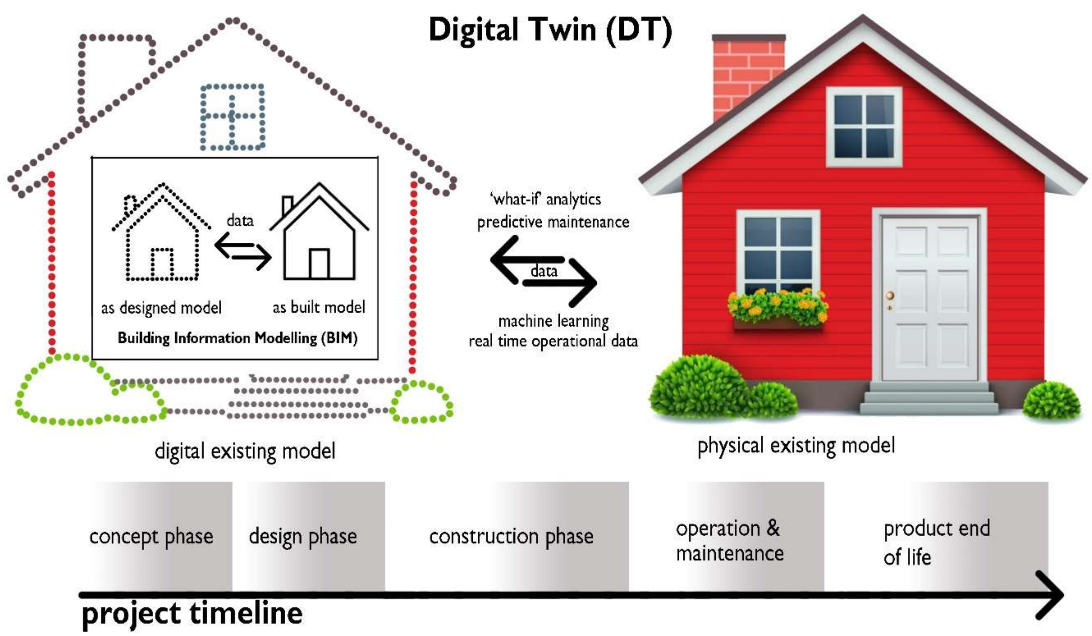

Figure 5 – BIM technology versus Digital twin technology

CONCLUSION

Under the context of the global pandemic in 2020, digital twin is being related as a powerful technology to construct an emergency management and response system for cities. Researchers such as Zhihong et al. (2020), Saracco et al. (2020) have brought up evidence-based discussion of how information can be utilized in a timely manner despite different administrative levels to control, prevent and mitigate the impacts of the epidemic. In a context where information is insufficient with limited public health resources, the importance of a well-informed decision-making process between local and state government is the key to improve a nation's survivability. Therefore, the contribution of this paper is a recommendation of a cutting-edge technology for the planning of a smart city which allows better response to contingencies as well as optimally managing available resources in a unprecedented context. Although digital twin is still at the very infant stage of development, the paper underlines the importance of exploiting digital technologies in building future-proof cities and *'make cities and human settlements inclusive, safe, resilient and sustainable'*.

REFERENCES

Allen, R. C. (2009). *The British industrial revolution in global perspective*: Cambridge University Press.

Boschert, S., & Rosen, R. (2016). Digital twin—the simulation aspect. In *Mechatronic futures* (pp. 59-74): Springer.

De Vries, J. (2013). *European Urbanization, 1500-1800*: Routledge.

Dietz, M., Putz, B., & Pernul, G. (2019). *A Distributed Ledger approach to Digital Twin secure data sharing.* Paper presented at the IFIP Annual Conference on Data and Applications Security and Privacy.

Fuller, A., Fan, Z., & Day, C. (2019). Digital Twin: Enabling Technology, Challenges and Open Research. *arXiv preprint arXiv:1911.01276*.

Gassmann, O., Böhm, J., Palmié, M., Gassmann, O., Böhm, J., & Palmié, M. (2019). Smart Cities. In *Smart Cities* (pp. 25-66): Emerald Publishing Limited.

Giffinger, R., & Pichler-Milanović, N. (2007). *Smart cities: Ranking of European medium-sized cities*: Centre of Regional Science, Vienna University of Technology.

Glaessgen, E., & Stargel, D. (2012). *The digital twin paradigm for future NASA and US Air Force vehicles.* Paper presented at the 53rd AIAA/ASME/ASCE/AHS/ASC structures, structural dynamics and materials conference 20th AIAA/ASME/AHS adaptive structures conference 14th AIAA.

Grieves, M. (2014). Digital twin: manufacturing excellence through virtual factory replication. *White paper, 1*, 1-7.

Grieves, M. (2019). Virtually Intelligent Product Systems: Digital and Physical Twins. In (pp. 175-200).

Grieves, M., & Vickers, J. (2017). Digital twin: Mitigating unpredictable, undesirable emergent behavior in complex systems. In *Transdisciplinary perspectives on complex systems* (pp. 85-113): Springer.

Grieves, M. W. (2019). Virtually Intelligent Product Systems: Digital and Physical Twins. *Complex Systems Engineering: Theory and Practice*, 175-200.

Kelley, A. C., & Williamson, J. G. (1984). Population Growth, Industrial Revolutions, and the Urban Transition. *Population and Development Review, 10*(3), 419-441. doi:10.2307/1973513

Mohammadi, N., & Taylor, J. E. (2017). *Smart city digital twins.* Paper presented at the 2017 IEEE Symposium Series on Computational Intelligence (SSCI).

Mott Macdonald. (2019). *Digital twins - Better outcomes from connected data*. Retrieved from https://www.mottmac.com/download/file?id=37140&isPreview=True
Nilsson, N. J. (2014). *Principles of artificial intelligence*: Morgan Kaufmann.
Petrova-Antonova, D., & Ilieva, S. (2019). *Methodological Framework for Digital Transition and Performance Assessment of Smart Cities.* Paper presented at the 2019 4th International Conference on Smart and Sustainable Technologies (SpliTech).
Rosen, R., Von Wichert, G., Lo, G., & Bettenhausen, K. D. (2015). About the importance of autonomy and digital twins for the future of manufacturing. *IFAC-PapersOnLine, 48*(3), 567-572.
Russell, S. J., & Norvig, P. (2016). *Artificial intelligence: a modern approach*: Malaysia; Pearson Education Limited.
Saracco, R., Autiosalo, J., de Kerckhove, D., Flammini, F., & Nisiotis, L. (2020). Personal Digital Twins and their Role in Epidemics Control. An IEEE Digital Reality White Paper.
Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research, 104*, 333-339. doi:https://doi.org/10.1016/j.jbusres.2019.07.039
Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a methodology for developing evidence-informed management knowledge by means of systematic review. *British journal of management, 14*(3), 207-222.
Tuegel, E. J., Ingraffea, A. R., Eason, T. G., & Spottswood, S. M. (2011). Reengineering aircraft structural life prediction using a digital twin. *International Journal of Aerospace Engineering, 2011*.
van der Heide, J., Grus, M., & Nouwens, J. (2017). Making Sense for Society. *International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences, 42*.
Wakil, K., Nazif, H., Panahi, S., Abnoosian, K., & Sheikhi, S. (2019). Method for replica selection in the Internet of Things using a hybrid optimisation algorithm. *IET Communications, 13*(17), 2820-2826. doi:10.1049/iet-com.2019.0345
Webster, J., & Watson, R. T. (2002). Analyzing the past to prepare for the future: Writing a literature review. *MIS quarterly*, xiii-xxiii.
Xu, Y., Sun, Y., Liu, X., & Zheng, Y. (2019). A digital-twin-assisted fault diagnosis using deep transfer learning. *IEEE Access, 7*, 19990-19999.
Zhihong, T., Shirui, P., & Xianyong, Z. (2020). *Research on the Construction of Smart City Emergency Management System Under Digital Twin Technology: Taking the Practice of New Coronary Pneumonia Joint Prevention and Control as an Example.* Paper presented at the 2020 4th International Seminar on Education, Management and Social Sciences (ISEMSS 2020).
Zhuang, C., Liu, J., & Xiong, H. (2018). Digital twin-based smart production management and control framework for the complex product assembly shop-floor. *The International Journal of Advanced Manufacturing Technology, 96*(1-4), 1149-1163.