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SMART CITY DEVELOPMENT WITH DIGITAL TWIN TECHNOLOGY

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Abstract Growing urban areas are major consumers of natural resources, energy and raw materials. Understanding cities´ urban metabolism is salient when developing sustainable and resilient cities. This paper addresses concepts of smart city and digital twin technology as means to foster more sustainable urban development. Smart city has globally been well adopted concept in urban development. With smart city development cities aim to optimize overall performance of the city, its infrastructures, processes and services, but also to improve socio-economic well-being. Dynamic digital twins are constituted to form real-time connectivity between virtual and physical objects. Digital twin combines virtual objects to its physical counterparts. This conceptual paper provides additionally examples from dynamic digital twin platforms and digital twin of Helsinki, Finland.

Keywords: smart city, digital twin, urban development, technology, bled e-conference.

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1 Introduction

According to UNEP (2013) cities globally are responsible of over 75 percent of the world´s energy and material flows and consumption. Cities thus have salient role in controlling resource and material intensity. It is emphasised that understanding of cities´ urban metabolism is fundamental when developing more sustainable cities and communities (Kennedy, Pincetl & Bunje, 2011). Urban metabolism refers to the production and usage of diverse natural and non-renewable materials like water, energy, food and waste in urban area (Gandy, 2004; Kennedy, Pincetl & Bunje, 2011). With urban metabolism it is also referred to the process of material use in the city, import and export of material flows, recycling, waste management (Bahers, Barles & Durand, 2019) and principles of circular economy.

Cities globally benefit advanced digital technologies to reach their sustainability goals. Digital technologies like sensor and Internet-of-Things (IoT) technologies, artificial intelligence (AI) and data analytic solutions are used to improve energy and resource efficiency and waste management within the city. Investing in digital technologies cities aim to strengthen overall monitoring and governance of the city. Novel digital technologies also enhance the development of the cities critical functions and infrastructures like energy, water and transportation. With novel digital technologies, the city may synchronise its processes and attract citizens to attend urban development activities. By doing so cities make city operations more transparent and less bureaucratic for the citizens. (Gabrys, 2014; Lea et al., 2015; Olivares, Royo & Ortiz, 2013; Sánchez et al., 2013; Zanella et al., 2014.)

This article addresses the concepts of smart city and digital twin technology as means to overcome cities´ sustainability and urban metabolism issues. Smart city denotes the usage of digital technologies like IoT, big data and (AI) to improve socio-economic and environmental outcomes of the city (ITU-T Focus group, 2015; ISO, 2013). Digital twin technology illustrates both virtual and physical representation of an object. With IoT and sensor technologies, it is possible to form dynamic connectivity between virtual replica and its physical counterpart. Dynamic connectivity of digital twin enables combining data and observing digital twin in its real and virtual world. (Enders & Hoßbach, 2019.) Furthermore, the article brings out an example of digital twin of Kalasatama district in Finland and presents commercial dynamic digital twin platforms in the smart city context. This article is organized as follows: after the introduction in Section 1, Section 2 summarizes article´s data sources. Sections 3 and 4 review the concepts of smart city and digital twin. Section 5 covers digital twin platforms in smart city development. Section 6 discusses digital twin of Kalasatama smart city district. Sections 7 summarizes the work and section 8 concludes the paper.

2 Methodology

The theoretical background is based on literature of smart city and digital twin technology. Data from the digital twin of Kalasatama district was collected from written final project report available at city of Helsinki website. Materials for dynamic digital twin platforms were collected from public data sources like company´s product presentations and websites. Further, data was acquired by interviewing representatives of commercial digital twin platform providers Cityzenith and Platform of Trust companies.

Table 1: Data sources

Subject	Source
Theoretical background	Existing literature
Digital twin of Kalasatama district	Kira-digi project – final written project report received from Helsinki city website
Smart World Pro platform by Cityzenith	Phone interview with Business Development Manager, 3.2.2020 Product presentation materials Company website
Platform of Trust	Onsite interview with Chief Impact Officer 5.2.2020 Company website
Open Cities planner platform by Agency 9 & Bentley	Company website

3 Smart city

Smart city concept has played significant role in cities´ digital transformation. Simplistic and narrow definition of the smart city means that city utilizes modern digital technologies to improve city services, infrastructure and quality of citizens' lives. However, a broader definition complement socio-technical perspective and observes smart city from economic and environmental perspectives. For instance, Caragliu, Del Bo and Nijkamp (2011) consider city is smart "when investments in human and social capital and traditional (transport) and modern ICT communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory government". In European settings, European Commission considers smart city as "a place where traditional networks and services are made more efficient with the use of digital and telecommunication technologies and that "a smart city goes beyond the use of information and communication technologies (ICT) for better resource use and less emissions" (European Commission).

In Europe European Commission has created a specific policy to foster urban development with digital technologies. To strengthen smart city initiatives, European Union has directed investments towards smart city development and has offered funding for information and digital technologies to renew and upgrade power grids, buildings, public transportation and waste management systems in European cities. European cities have actively responded to European Union´s call and established partnerships with industries and academia to make necessary changes in cities. As a result, new models and solutions for more sustainable urban development have emerged. (European Commission.)

4 Digital twin

Digital twin has taken foothold in product and manufacturing design, but recently also other industries like aerospace, automation, marine, healthcare and energy sectors have benefited digital twin technology (Enders & Hoßbach, 2019). Reason for more widespread utilization of digital twin technology is that virtual simulation technologies have evolved along with advance digital technologies like data collection and virtual manufacturing technologies (Zheng, Yang, Chen, 2019). Foundations for digital twin lays in computer aided design (CAD), which enables static three-dimensional (3D) product design and representation (Grieves & Vickers, 2017). Whereas CAD designed product is static digital twin provides more dynamic representation of 3D designed product or solution. It is suggested that in the most optimal cases digital twin represents the same features and provides the same information as its physical counterpart. (Grieves & Vickers, 2017.) Most commonly digital twin is utilized for simulation, monitoring and control purposes (Enders & Hoßbach, 2019), but also to calculate and regulate the system status and processes (Zheng, Yang, Chen, 2019). As digital twin is a simulation of the system itself (Negri, Fumagalli & Macchi, 2017), it extends possibilities to explore e.g. behaviour of 3D designed solution in virtual space. Digital twin enables also to explore and test how physical forces influence on designed object. (Enders & Hoßbach, 2019; Grieves & Vickers, 2017.) For monitoring purposes, digital twin enables to represent and interpret properties and current state of a physical and virtual object. Novel digital solutions like IoT and high-speed connections like 5G extend real-time monitoring and synchronizing capabilities of virtual and physical objects. Control aspect covers applications, where digital twin directly influences products or manufacturing assets and enables controlling physical objects remotely in real-time. (Negri, Fumagalli & Macchi, 2017; Enders & Hoßbach, 2019.

One very essential part of the digital twin is the connectivity of the virtual and physical counterparts (Enders & Hoßbach, 2019). One-directional connection refers to a physical object, which has one-way connectivity to its virtual counterpart (Enders & Hoßbach, 2019). One-directional data flow and connection is also referred as digital shadow (Kritzinger et al., 2018; Zheng, Yang, Chen, 2019). Digital shadow refers as "a change in state of the physical object leads to a change of state in the digital object, but not vice versa" (Kritzinger et al., 2018). Bi-directional connection refers to a digital twin that forms mutual connection between physical and its virtual object. Bi-directional connectivity is built on distributed computing devices and data systems that utilize data and real-time connectivity. Bi-directional connectivity enables digital twin to control its physical counterpart without human intervention. (Enders & Hoßbach, 2019; Zheng, Yang, Chen, 2019.) Bi-directional connection consists of different layers e.g. multiple data sources, physical and virtual devices, sensors, data connection and cloud-based environment (Redelinghuys, Kruger & Basson, 2019).

4.1. Benefits of the digital twin

It is argued digital twin is a key enabler of digital transformation (Kritzinger et al. 2018) and organizations may receive multiple benefits from digital twin technology. Compared to static 3D models, real-time connectivity and data from both virtual and physical objects enables real-time system product design, simulation and testing with less time and expenses. Further real-time virtual representation of physical object minimizes design errors resulting less failures of physical system in manufacturing or in actual use. (Grieves & Vickers, 2017.) Digital twin is also prominent technology to bridge multi-stakeholder teams. Real-time virtual simulation environment extends accessibility of diverse stakeholder groups like global product designers, research and development teams, final users and customers to collaborate jointly in virtual environment. With digital twin technology vendors may easily educate and train stakeholders in value networks and provide more extensive customer support for clients. (Alaei et al. 2018.) As virtual and physical objects together with data form the core of the digital twin (Tao et al., 2017; Zheng, Yang, Chen, 2019) digital twin is notable technology to assist organizations with decision making. Real-time connectivity of virtual and physical objects allow organizations´ to detect anomalies and make analysis based on the data received from both virtual and physical objects. Real-time virtual representation of physical systems extends possibilities to make predictions of the conditions of the complex physical systems allowing organization to consider alternative scenarios for the probable outcomes of the cyber-physical system. (Grieves & Vickers, 2017; Negri, Fumagalli & Macchi, 2017.)

5 Smart city digital twin platforms

Cloud-based digital platforms have been commonplace when developing and integrating IoT elements like connected devices, gateways and applications to digital platform. Cloud-based platforms enable to manage IoT service development, distribution and ecosystems evolution. (Mazhelis & Tyrväinen, 2014.) In the smart city context digital twin platforms are established to integrate both virtual and real-world elements of the smart city. Platforms like Smart World Pro, Open Cities planner and Platform of Trust are examples of cloud platforms that integrate data from diverse smart city data sources. Smart World Pro aggregates visual 3D models of the city, building and geospatial information, IoT devices and other data sets and simultaneously create virtual replica of the real-world smart city entities. The dashboard feature of the Smart World Pro collects smart city projects under project portfolio and provides visual view for the smart city entities. (Agency9 & Bentley, Cityzenith, Platform of Trust, 2020.)

Open Cities planner platform enables smart city developers to integrate data sets like 3D models, images, documents geographic and vector data. Open Cities planner works in any web browser and is scalable augmenting possibilities to outline and explore city from street level to a broader city level perspectives. Platform of Trust is a platform that integrates data from diverse data sources and providers. With harmonized data Platform of Trust improves data interoperability and trust among data providers. Platform is scalable and enable data integration from small to large-scale needs. (Agency9 & Bentley, Platform of Trust, 2020.)

5.1. Stakeholder integration on digital twin platforms

Smart city digital twin platforms are virtual meeting points for multi-stakeholder groups within the smart city. The Smart World Pro and Open Cities planner platforms enable smart city developer or project owner easily to integrate heterogeneous stakeholders like architects, engineers, constructors, property owners and managers into the platform. The smart city digital twin platforms thus augment the co-development and collaboration among the smart city stakeholders. As an example, the stakeholders like architectures, urban designers and engineers may easily simulate and test different scenarios and evaluate how changes in certain city parameters like speed limits influence air quality, noise levels and people flow in certain area (Ruohomäki et al., 2018). Digital twin and visual 3D environments also assist integrating citizens to urban development. The Open Cities planner platform has been an environment for local citizens to share their knowledge and expertise. It is also used to crowdsource idea generation within the city. From the city governance perspective, the virtual replica of the city and digital twin platforms improve the governance and outcome of smart city development initiatives. (KIRA-digi project report, 2019.)

6 Smart city development with digital twin – Case Kalasatama digital twin

3D modelling techniques are commonplace in modern urban design and development. 3D modelling tools are utilized e.g. in transportation, land use, town and regional planning. In the smart city development novel digital technologies like Internet-of-Things (IoT), data analytics and artificial intelligent solutions are exploited in diverse city verticals to support smart city development. Dynamic digital technologies together with static 3D modelling and digital twin technologies extend city to understand its spatiotemporal fluctuation (Mohammadi & Taylor, 2017) and improve observing and testing smart city scenarios in multiple levels. Digital twin also supports co-creation of smart city with diverse stakeholders. (Ruohomäki, 2018.)

The capital city of Finland, Helsinki, executed its first urban digital twin initiative in Kalasatama district. Kalasatama district is a strategic smart city development area in Helsinki city. Primary objectives of Kalasatama digital twin initiative were to produce high quality 3D models and publish them as open data for public. Other objectives concerned integrating digital twin model to existing urban development projects and experimenting new digital technologies with high quality 3D models. Kalasatama digital twin initiative aimed also to exploit digital twin in the future design of the city processes and services. (KIRA-digi project report, 2019.)

The first digital twin project objective was actualized by creating and using semantic city data models and reality mesh models of the Kalasatama district. For semantic city data models, a global CityGML standard was applied. CityGML is an open standardized data model to store and exchange virtual 3D city models (Open Geospatial Consortium). For reality mesh models, data from existing aerial photos, point cloud datasets and laser scanning was utilized. Finally, both reality mesh models and semantic city data models were released as open data for public use. By doing so, the city seeks especially to attract construction and real estate operators to benefit digital twin of Kalasatama. (KIRA-digi project report, 2019.) Long-term vision is to support city processes and overall local service development, innovation and businesses in the region with city level digital twin virtual platform (Helsinki city, 2019).

Integrating Kalasatama digital twin to other Smart Kalasatama projects complement the overall development of the region. A specific application called "Open Cities planner" was developed to integrate other Smart Kalasatama projects into virtual digital twin environment. Open Cities planner enabled to visualize, test and experiment the other Smart Kalasatama initiatives in virtual environment before final execution. Kalasatama digital twin was also beneficial for implementing simulations like wind and solar simulations in Kalasatama district. (KIRA-digi project report, 2019.)

6.1. Digital twin restrictions in smart city settings

Creating virtual replica of the smart city contain some restrictions. Visual 3D models and data from other smart city sources engender large amount of data, which set demands for computing power. In the case of Kalasatama digital twin project, generating the 3D mesh model required computers with high computing capacity as 3D mesh model contained large number of data from aerial photos, point cloud datasets and laser scanning. The 3D mesh model was finally created by ContextCapture application. (KIRA-digi project report, 2019.) Additionally, the study by Ruohomäki et al. (2018) show that generating high quality 3D models may be laborious as the data used for 3D model may need manual cleaning and preparation.

7 Discussion

Ubiquitous digital infrastructures with fast telecommunication connections, IoT and sensor technologies have enabled real-time data collection from real-world entities. Concept of digital twin is used to represent and illustrate how dynamic virtual object operates with its physical real-world counterpart and vice versa. Digital twin technology is well adopted in manufacturing industry, but technology has taken foothold also in other industries like aerospace, automation and energy.

In the smart city settings, digital twin platforms are emerging to assist smart city planning and development. Digital twin platforms enable to aggregate static city data sets like visual 3D models with dynamic real-time city data. This extends urban developers´ possibilities to outline the city, explore and experiment diverse scenarios in virtual environment before final implementation. In the case of Kalasatama district, the purpose of Kalasatama digital twin was to observe whole lifecycle of district´s built urban environment, but also to provide a platform for smart city design and testing, application and service development. As an example, the developers used Kalasatama digital twin to simulate and observe how changing weather conditions like wind and solar light impact on district and its built environment over the time. Urban developers utilized both historical and actual data when implementing the simulations in Kalasatama. Based on the results urban designers and researchers´ were able to evaluate e.g. solar energy potential in the area and analyse how storm winds will influence area´s buildings and their surroundings.

Digital twin platform allows low threshold access for smart city stakeholder collaboration. In virtual digital twin environment stakeholders may easily interact and participate urban development process, which enhance transparency and trust among the stakeholders. In Kalasatama district dynamic digital twin platform enabled to bring together diverse smart city stakeholders like urban designers, constructors, city authorities and citizens to change ideas, explore and experiment alternative scenarios and find optimal solutions for real-world city development projects. As an example dynamic digital twin extended stakeholders to consider e.g. impacts and risks of climate change like draught, storm winds, sunlight emissions and floods on current and future built urban environments. (KIRA-digi project report, 2019; Ruohomäki et al., 2018.)

Considering the urban metabolism, the usage and flow of natural and non-renewable materials, evidence of digital twin´s applicability and benefits in urban metabolism design need further research. Dynamic digital twin may be a valid technology to optimize urban metabolism and to explore alternative choices for raw material flows and consumption in the city. With digital twin the city may develop more resource intensive solutions e.g. in the areas of circular economy and industrial symbiosis. In optimal case, digital twin technology may assist city developers to design industrial and city ecosystems so that less raw materials are used, and no waste is produced.

Dynamic city level digital twin is thus a viable tool for urban planning in changing circumstances. However, dynamic digital twins with visual 3D models require high computing and data processing capacities. Generating high quality dynamic digital twins may also need manual cleaning and preparation of data, which may be laborious and time consuming. These factors may hinder digital twin technology´s usage and implementation is smart city development.

8 Conclusion

Smart city development is prominent concept to manage sustainability matters within the cities. Advanced digital technologies like sensor and IoT technologies, data analytics and AI are viable tools to assist cities in their efforts to enhance urban metabolism and the design of more sustainable cities. This article addressed, in addition to the concept of smart city, a digital twin technology as a mean to foster holistic urban development. Dynamic digital twin opens possibilities to explore city´s infrastructures and processes in virtual environment. Urban designers may analyse e.g. changing climate parameters´ impacts on the city, build and simulate probable scenarios under diverse circumstances. Dynamic digital twin might also assist urban designers to optimize urban metabolism of the city and shed light on more efficient and intensive resource and material use in cities. Further research is needed to investigate digital twin technology´s applicability for the design of circular economy and urban metabolism in the cities.

This paper also addressed digital twin platforms for multi-stakeholder collaboration. Dynamic digital twin platforms are feasible environments to combine heterogeneous urban stakeholders like architectures, urban designers, constructors and citizens. Digital twin platforms strengthen transparency and communication, but also trust among diverse urban stakeholder groups. Digital twin platforms are low threshold environments to design and analyse probable scenarios and evaluate risks caused by factors like climate change. With digital twin technology, cities may optimize and improve overall performance of the city, its infrastructures, processes and services, but also socio-economic well-being.

This conceptual paper contained data from prior literature of smart cities and digital twin technology. Project report of Kalasatama digital twin and interviews from smart city digital twin platform providers complemented the study. Applying digital twin solution to specific smart city domain would enrich the future study and extend understanding of the digital twin technology´s relevancy in smart city settings.

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