PhD in Information Technology and Electrical Engineering
Università degli Studi di Napoli Federico II

PhD Student: Manfredi Napolitano

Cycle: XXXIX

Training and Research Activities Report

Year: First

Manfredi Napolitano

Tutor: prof. Nicola Mazzocca

Date: December 28, 2024

1. Information:

- **PhD student: Manfredi Napolitano**
- **DR number: DR997199**
- **Date of birth: 07/09/1996**
- **Master Science degree: Computer Engineering University: Università degli Studi di Napoli Federico II**
- **Doctoral Cycle: XXXIX**
- **Scholarship type: PNRR - DM 118/2023 Mis.: I.3.4 Dottorati Transizione Digitale**
- **Tutor: Nicola Mazzocca**

2. Study and training activities:

Activity	Type[1]	Hours	Credits	Dates	Organizer	Certificate[2]
HOMINIS	Seminar	5	1	21/02/2024	Prof. Carlo Sansone, Eng. Stefano Marrone	Y
Edoardo Giusto – Research past, present and future	Seminar	1	0.2	26/02/2024	Prof. Nicola Mazzocca	Y
Analytic center selection of optimization-based controllers for robot ecology	Seminar	1	0.2	09/04/2024	Prof. Bruno Siciliano	Y
Exploring the Frontiers of Modern Cryptography	Seminar	1.5	0.3	12/04/2024	Prof. Simon Pietro Romano	Y
IEEE Authorship and Open Access Symposium: Tips and Best Practices to Get Published from IEEE Editors	Seminar	1.5	0.3	07/05/2024	IEEE	Y
Sustainable IT: Strategies and Best Practices for a Green Engineering Future	Seminar	5	1	27/05/2024	5G Academy	Y
Generative AI for Software Engineering: Strategies, Impacts, and Pratical Applications	Seminar	5	1	29/05/2024	5G Academy	Y
Social Network Analysis: Methods and Applications	Seminar	2	0.4	07/06/2024	Prof. Giancarlo Sperlì	Y

Introduction to Large Language Models: Evolution and the current state	Seminar	2	0.4	10/06/2024	Prof. Giancarlo Sperlì	Y
On the Single Allocation hub location problems: New formulations and Solving Methods	Seminar	1	0.2	26/06/2024	Prof. Claudio Sterle, Prof. Maurizio Boccia, Prof. Adriano Masone	Y
Real-time Resource Management for Adaptive Embedded Systems and Applications	Seminar	1	0.2	26/06/2024	Prof. Marcello Cinque	Y
Resource management and orchestration for mixed-criticality cloud/distributed systems	Seminar	1	0.2	27/06/2024	Prof. Marcello Cinque	Y
Topological Signal Processing and Learning	Seminar	1	0.2	17/07/2024	Prof. Antonia Tulino	Y
From ACE Technologies to Sustainable, Accessible and Equitable Urban Mobility: An Optimization Journey	Seminar	2	0.4	16/09/2024	Prof. Stefania Santini	Y
FIWARE Tech Training	Seminar	5	1	18-19/09/2024	FIWARE Foundation	Y
Learning in nonstationary environments	Seminar	2	0.4	15/10/2024	Prof. Carlo Sansone	Y
Shaping robustly control loop: look into stability margins & uncertainties	Seminar	1	0.2	05/12/2024	Prof. Ciro Visone	Y
QUIC: the secure protocol shaping the future of real-time communication over the Internet	Seminar	4	0.8	09-11/12/2024	Prof. Simon Pietro Romano	Y
Mathematical and algorithmic foundations of Neural Networks	Seminar	1	0.2	10/12/2024	Prof. Flora Amato	Y
Infrastructure Security: Threat- and Mode-based Automated Penetration Testing	Seminar	1	0.2	10/12/2024	Prof. Massimiliano Rak	Y

Virtualization technologies and their applications	Course	24	5	08-10-15-19-24-25-29-31/01/2024, 05-07/02/2024	Prof. Luigi De Simone	Y
Using Deep Learning Properly	Course	12	4	21-25-30/01/2024, 01-06-08/2024	Dr. Andrea Apicella	Y
IoT Data Analysis	Course	20	4	15-19-21-23-27-29/02/2024	Prof. Raffaele Della Corte	Y
Statistical data analysis for science and engineering research	Course	12	4	15-19-21-23-27-29/02/2024	Prof. Roberto Pietrantuono	Y
Innovation and Entrepreneurship	Course	16	4	12-14-19-21-26/06/2024, 11/07/2024	Prof Pierluigi Rippa	Y

1) Courses, Seminar, Doctoral School, Research, Tutorship
2) Choose: Y or N

2.1. Study and training activities - credits earned

	Courses	Seminars	Research	Tutorship	Total
Bimonth 1	**5**	**1.2**	**4**	**0**	**10.2**
Bimonth 2	**8**	**0.5**	**1.5**	**0**	**10**
Bimonth 3	**0**	**3.7**	**6**	**0**	**9.7**
Bimonth 4	**8**	**0.2**	**2**	**0**	**10.2**
Bimonth 5	**0**	**1.8**	**8**	**0**	**9.8**
Bimonth 6	**0**	**1.4**	**9**	**0**	**10**
Total	**21**	**8.8**	**30.5**	**0**	**60.3**
Expected (1st year)	**20 - 40**	**5 - 10**	**10 - 35**	**0 – 1.6**	
Expected	**30 - 70**	**10 - 30**	**80 - 140**	**0 – 4.8**	

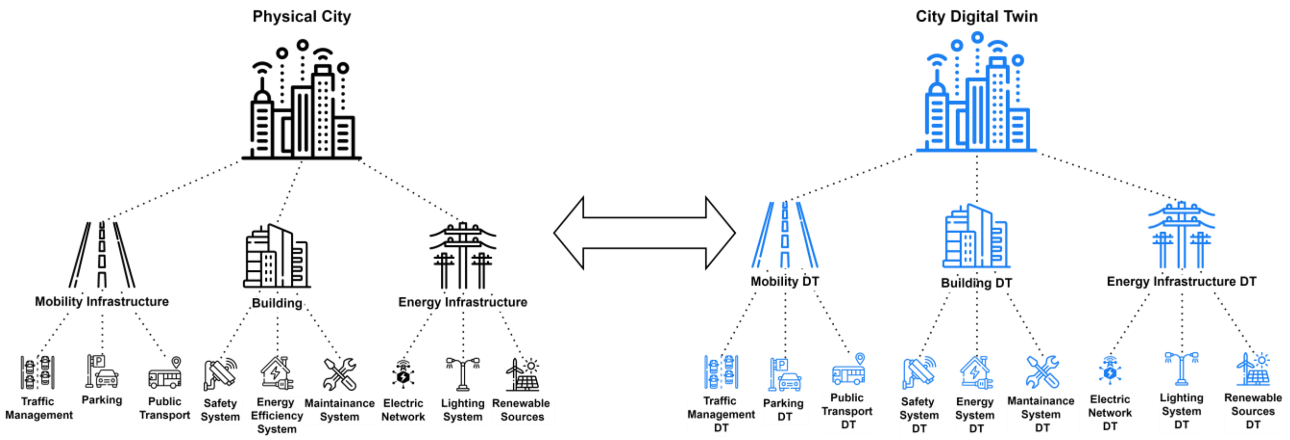
3. Research activity:

Research Topic

In my first year of research, I focused on studying the concept of the Digital Twin (DT), which can be broadly defined as "a virtual representation of a physical system (along with its environment and processes) that is continuously updated through information exchange between the physical and virtual systems" [1]. Digital Twins have a wide range of applications across various domains, including manufacturing, healthcare, freight logistics, and smart cities. They offer several benefits, such as real-time monitoring of physical asset status and the ability to predict future states to identify potential issues. Additionally, by tracking the behavior of their physical counterparts, DTs can be leveraged for system lifecycle management and optimization, helping to reduce costs and production time.
During this first year, I explored the role of DTs in the context of smart cities from three perspectives: studying the application of DTs in the Smart City (SC) domain, reviewing the most widely adopted standards and technologies for DTs, and designing a digital twin system specifically for urban mobility.

Study of Digital Twin in the Smart City domain

The research began with an exploration of DT concepts, focusing on their application within the domain of Smart Cities. A Smart City is defined as an environment where the essential components of urban infrastructure—such as environmental management, emergency response, traffic systems, and energy networks—are interconnected to promote sustainability, enhance citizen well-being, and drive the economic growth of the urban area. This framework represents a cohesive integration of these elements,



which are further structured into multiple interconnected components.

Consequently, the Digital of a SC can be described as a system of interconnected Digital Twins, each representing specific aspects of the city's functioning and development [2]. Within the diverse areas encompassed by the SC domain – such as energy efficiency, urban planning, and smart buildings [3] – I concentrated my research on smart mobility. This focus came from the numerous challenges and opportunities inherent in this sector, including traffic management, air pollution mitigation, and transportation optimization.

Designing a Mobility Digital Twin presents several significant challenges [4]. The hierarchical structure of a city introduces complexities that must be addressed. The first challenge lies in modeling individual DTs, each with distinct characteristics and behaviors. Developing a Mobility DT model requires meticulous modeling of individual components to ensure they integrate into a cohesive framework, accurately capturing their unique features without oversimplification or omission. Another challenge arises from the interconnected nature of a city's DTs. These Digital Twins, representing different aspects of urban life, must collaborate to ensure the city functions effectively. For instance, the traffic model must interact with the traffic light system, which, in turn, may need to interface with the energy management system. Managing these intricate interactions and ensuring seamless data exchange between systems is a considerable hurdle. Furthermore, cities often operate legacy systems that must be integrated with new digital infrastructures, creating compatibility and interoperability challenges that can complicate system interactions.

Scalability is another critical issue tied to a city's hierarchical and dynamic nature. A smart city system must accommodate both growth in scale—managing vast amounts of data and devices across extensive areas – and complexity – handling an increasing number of services and interactions as the city evolves. For instance, a traffic management system initially designed for a specific city district may encounter latency, reliability, or efficiency problems when expanded to cover new areas. Addressing scalability requires solutions that ensure systems can adapt to added devices, data, and technologies without sacrificing performance.

Data integration poses yet another challenge. Information in smart cities is often gathered from heterogeneous sources, stored in disparate systems utilizing different technologies and formats. This leads to compatibility issues and increases the complexity of data management, particularly as the volume of exchanged information grows due to the diverse activities managed by city entities. Furthermore, the geospatial and temporal nature of much of this data requires specialized processing and management to unlock its full potential and ensure effective service delivery.

These challenges highlight the importance of careful planning and problem-solving during the design and definition of the Mobility Digital Twin to create a system that is robust, scalable, and interoperable.

DT standards and technologies analysis:

The standards for Digital Twins (DTs) are still in the process of consolidation, but several initiatives already provide valuable guidance for their design and implementation. The ISO/AWI 23247 standard outlines a general framework for DT design, focusing on real-time architectures, though it primarily targets the manufacturing sector. Meanwhile, the ISO JTC1 SC41/WG6 standard emphasizes the interaction between IoT devices and DTs, along with related technologies. Another evolving standard, ISO/IEC DIS 30173, seeks to define the core requirements of DT systems, addressing aspects such as synchronization, data management, and the integration of physical and digital components. Despite these efforts and the emergence of architectural proposals gaining broader acceptance, there remains a notable gap in standards that can be universally applied across different domains.

The implementation of a DT presents further complexities. Unlike other technologies with clearly defined tools linked to specific functionalities, a DT involves an intricate ecosystem requiring the integration of diverse technologies. This lack of a one-size-fits-all solution necessitates the selection of platforms and frameworks capable of ensuring interoperability, scalability, and real-time data processing. Several frameworks support DT development, including Microsoft's Azure Digital Twin, Amazon's AWS IoT TwinMaker, and open-source options such as Eclipse Ditto. Among these, I opted for the FIWARE framework, which is built on the NGSI-LD standard. FIWARE comprises a collection of software components known as Generic Enablers (GEs), offering functionalities ranging from IoT interfacing to monitoring. At its core lies the Context Broker, the central GE that enables decentralized and large-scale context information management. Solutions leveraging this component earn the designation "Powered by FIWARE," highlighting its foundational role in the framework.

Design of a Mobility DT System

The design activity began with a requirements analysis phase for the Mobility Digital Twin (DT) system. Considering the hierarchical nature of a system of interconnected DTs, the research focused on identifying services within the mobility domain, delving into the fundamental components defining the infrastructure. Subsequently, an analysis was conducted to determine suitable data models that could effectively represent the environment and exchanged information while addressing the highlighted data-related constraints and challenges. In this context, the Smart Data Models (SDMs) proposed by the FIWARE Foundation provided a solid foundation for the unambiguous definition of data. Based on the NGSI-LD standard, SDMs enable the management and communication of domain-specific data while ensuring interoperability.
For the practical implementation, the initial focus was on structuring a single constituent element of the Mobility DT, specifically designing and developing a DT system for traffic management. By leveraging NGSI-LD and SDMs, the chosen enabling technologies for the Digital Twin were clearly those from the FIWARE Catalogue, particularly the Context Broker for managing digital representations of system components and processes, and the IoT Agent for interfacing with physical devices such as traffic sensors, street units, and traffic lights. However, these technologies alone did not fully address the behavioral modeling of the physical twin being represented. To fill this gap, Eclipse SUMO (Simulator for Urban MObility), a widely used urban traffic simulation software, was integrated. Experiments with this system were conducted using data provided by the Municipality of Bologna, available through its Open Data portal.

3.1.References

[1] Botín-Sanabria DM, Mihaita A-S, Peimbert-García RE, Ramírez-Moreno MA, Ramírez-Mendoza RA, Lozoya-Santos JdJ. Digital Twin Technology Challenges and Applications: A Comprehensive Review. Remote Sensing. 2022; 14(6):1335. https://doi.org/10.3390/rs14061335

[2] S. Ivanov, K. Nikolskaya, G. Radchenko, L. Sokolinsky and M. Zymbler, "Digital Twin of City: Concept Overview," *2020 Global Smart Industry Conference (GloSIC)*, Chelyabinsk, Russia, 2020, pp. 178-186, doi: 10.1109/GloSIC50886.2020.9267879.

[3] Faliagka E, Christopoulou E, Ringas D, Politi T, Kostis N, Leonardos D, Tranoris C, Antonopoulos CP, Denazis S, Voros N. Trends in Digital Twin Framework Architectures for Smart Cities: A Case Study in Smart Mobility. *Sensors*. 2024; 24(5):1665. https://doi.org/10.3390/s24051665

[4] Binyu Lei, Patrick Janssen, Jantien Stoter, Filip Biljecki, Challenges of urban digital twins: A systematic review and a Delphi expert survey, Automation in Construction, Volume 147, 2023, 104716, ISSN 0926-5805, https://doi.org/10.1016/j.autcon.2022.104716

[5] Dasgupta S, Rahman M, Lidbe AD, Lu W, Jones S. A Transportation Digital-Twin Approach for Adaptive Traffic Control Systems. arXiv [physics.soc-ph]. Published online 2023. http://arxiv.org/abs/2109.10863

[6] Jacoby M, Usländer T. Digital Twin and Internet of Things—Current Standards Landscape. Applied Sciences. 2020; 10(18):6519. https://doi.org/10.3390/app10186519

[7] G. Mylonas, A. Kalogeras, G. Kalogeras, C. Anagnostopoulos, C. Alexakos and L. Muñoz, "Digital Twins From Smart Manufacturing to Smart Cities: A Survey," in *IEEE Access*, vol. 9, pp. 143222-143249, 2021, doi: 10.1109/ACCESS.2021.3120843

4. Research products:

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5. Conferences and seminars attended

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6. Activity abroad:

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7. Activity in partner companies:

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8. Tutorship

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