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Hanoi, Vietnam, July 1–4, 2024
Proceedings, Part X

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Preface

These 11 volumes (LNCS volumes 14815–14825) consist of the peer-reviewed papers from the 55 Workshops of the 2024 International Conference on Computational Science and Its Applications (ICCSA 2024) which took place during July 1–4, 2024 in Hanoi (Vietnam). The peer-reviewed papers of the main conference tracks are published in a separate set consisting of two volumes (LNCS 14813–14814).

The conference was held in a hybrid form, with some participants present in person, hosted in Hanoi, Vietnam, by the Thuy Loi University. We enabled virtual participation for those who were unable to attend the event, due to logistical, political and economic problems, by adopting a technological infrastructure based on open source software (jitsi + riot), and a commercial Cloud infrastructure.

ICCSA 2024 was another successful event in the International Conference on Computational Science and Its Applications (ICCSA) conference series, previously held in Athens, Greece (2023), Malaga, Spain (2022), Cagliari, Italy (hybrid with few participants in presence in 2021 and completely online in 2020), whilst earlier editions took place in Saint Petersburg, Russia (2019), Melbourne, Australia (2018), Trieste, Italy (2017), Beijing. China (2016), Banff, Canada (2015), Guimaraes, Portugal (2014), Ho Chi Minh City, Vietnam (2013), Salvador, Brazil (2012), Santander, Spain (2011), Fukuoka, Japan (2010), Suwon, South Korea (2009), Perugia, Italy (2008), Kuala Lumpur, Malaysia (2007), Glasgow, UK (2006), Singapore (2005), Assisi, Italy (2004), Montreal, Canada (2003), and (as ICCS) Amsterdam, The Netherlands (2002) and San Francisco, USA (2001).

Computational Science is the main pillar of most of the present research, industrial and commercial applications, and plays a unique role in exploiting ICT innovative technologies, and the ICCSA conference series have been providing a venue to researchers and industry practitioners to discuss new ideas, to share complex problems and their solutions, and to shape new trends in Computational Science. As the conference mirrors society from a scientific point of view, this year's undoubtedly dominant theme was the machine learning and artificial intelligence and their applications in the most diverse economic and industrial fields.

The ICCSA 2024 conference is structured in 6 general tracks covering the fields of computational science and its applications: Computational Methods, Algorithms and Scientific Applications – High Performance Computing and Networks – Geometric Modeling, Graphics and Visualization – Advanced and Emerging Applications – Information Systems and Technologies – Urban and Regional Planning. In addition, the conference consisted of 55 workshops, focusing on very topical issues of importance to science, technology and society: from new mathematical approaches for solving complex computational systems, to information and knowledge in the Internet of Things, new statistical and optimization methods, several Artificial Intelligence approaches, sustainability issues, smart cities and related technologies.

In the Workshops proceedings we accepted 281 full papers, 17 short papers and 2 PhD Showcase papers. In the Main Conference Proceedings we accepted 53 full papers, 6 short papers and 3 PhD Showcase papers from 207 submissions to the General Tracks of the conference (acceptance rate 30%). We would like to express our appreciation to the workshops chairs and co-chairs for their hard work and dedication.

The success of the ICCSA conference series in general, and of ICCSA 2024 in particular, vitally depends on the support of many people: authors, presenters, participants, keynote speakers, workshop chairs, session chairs, organizing committee members, student volunteers, Program Committee members, Advisory Committee members, International Liaison chairs, reviewers and others in various roles. We take this opportunity to wholehartedly thank them all.

We also wish to thank our publisher, Springer, for their acceptance to publish the proceedings, for sponsoring part of the best papers awards and for their kind assistance and cooperation during the editing process.

We cordially invite you to visit the ICCSA website https://iccsa.org where you can find all the relevant information about this interesting and exciting event.

July 2024

Osvaldo Gervasi
Beniamino Murgante
Chiara Garau

Welcome Message from Organizers

After the very hard times of COVID, ICCSA continues its successful scientific endeavors in 2024, hosted in Hanoi, Vietnam. This time, ICCSA moved from the Mediterranean Region to Southeast Asia and was held in the metropolitan city of Hanoi, the capital of Vietnam. Hanoi is a vibrant urban environment known for the hospitality of its citizens, its rich history, vibrant culture, and dynamic urban life. Located in the northern part of the country, Hanoi is a bustling metropolis that combines the old with the new, offering a unique blend of ancient traditions and modern development.

ICCSA 2024 took place in a secure environment, allowing for safe and vibrant in-person participation. Combined with the active engagement of the ICCSA 2024 scientific community, this set the stage for highly motivating discussions and interactions regarding the latest developments in computer science and its applications in the real world for improving communities' quality of life.

Thuyloi University, also known as the Water Resources University, is a prominent institution in Hanoi, Vietnam, with a strong reputation in engineering and technical education, particularly in water resources and environmental engineering. In recent years, the University has expanded its academic offerings to include computer science, reflecting the growing importance of technology and digital skills in all sectors. This year, Thuyloi University had the honor of hosting ICCSA 2024. The Local Organizing Committee felt the burden and responsibility of such a demanding task and put all necessary energy into meeting participants' expectations and establishing a friendly, creative, and inspiring scientific and social/cultural environment that allowed for new ideas and perspectives to flourish.

Since all ICCSA participants, whether informatics-oriented or application-driven, realize the tremendous advancements in computer science over the last few decades and the huge potential these advancements offer in coping with the enormous challenges of humanity in a globalized, 'wired,' and highly competitive world, the expectations for ICCSA 2024 were high. The goal was to successfully match computer science progress with communities' aspirations, achieving progress that serves real, place- and people-based needs and paves the way towards a visionary, smart, sustainable, resilient, and inclusive future for both current and future generations.

On behalf of the Local Organizing Committee, I would like to sincerely thank all of you who contributed to ICCSA 2024.

Nguyen Canh Thai

Organization

ICCSA 2024 was organized by Thuyloi University (Vietnam), the University of Perugia (Italy), the University of Basilicata (Italy), Monash University (Australia), Kyushu Sangyo University (Japan), the University of Minho (Portugal), and the University of Cagliari (Italy).

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Evaluating Inner Areas Potentials (EIAP 2024)

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Econometrics and Multidimensional Evaluation of Urban Environment (EMEUE 2024)

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Environmental, Social, Governance of Energy Planning (ESGEP 2024)

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Ecosystem Services in Spatial Planning for Resilient Urban and Rural Areas (ESSP 2024)

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Ethical AI Applications for a Human-Centered Cyber Society (EthicAI 2024)

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14th International Workshop on Future Computing System Technologies and Applications (FiSTA 2024)

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Toshihiro Yamauchi	Okayama University, Japan
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Geographical Analysis, Urban Modeling, Spatial Statistics (Geog-An-Mod 2024)

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Andreas Fricke	Hasso-Plattner-Institut für Digital Engineering, Germany
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Geomatics for Resource Monitoring and Management (GRMM 2024)

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International Workshop on Information and Knowledge in the Internet of Things (IKIT 2024)

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Regenerating Brownfields Enhancing Urban Resilience Appeal (INFERENCE 2024)

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International Workshop on Territorial Planning to Integrate Risk and Urban Ontologies (IWPRO 2024)

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MaaS Solutions for Airports, Cities and Regional Connectivity (MaaS 2024)

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Martina Sinatra	University of Cagliari, Italy
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Development of Urban Mobility Management and Risk Assessment (MAINTAIN 2024)

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Multidimensional Evolutionary Evaluations for Transformative Approaches (MEETA 2024)

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Building Multi-dimensional Models for Assessing Complex Environmental Systems (MES 2024)

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Models and Indicators for Assessing and Measuring the Urban Settlement Development in the View of Zero Net Land Take by 2050 (MOVEto0 2024)

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4th Workshop on Privacy in the Cloud/Edge/IoT World (PCEIoT 2024)

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Scientific Computing Infrastructure (SCI 2024)

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Downscale Agenda 2030 (SDGscale 2024)

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Maria Ronza	University of Naples, Federico II, Italy
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Socio-Economic and Environmental Models for Land Use Management (SEMLUM 2024)

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Paola Amoruso	LUM, Italy

Ports of the Future - Smartness and Sustainability (SmartPorts 2024)

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Marco Petrelli	Roma Tre University, Italy

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Maria Ronza	University of Naples, Federico II, Italy
Massimiliano Bencardino	University of Salerno, Italy

Smart Transport and Logistics - Smart Supply Chains (SmarTransLog 2024)

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Enrico Dagostini	University of Malta, Malta
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Luca Toneatti	University of Trieste, Italy
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Smart Tourism (SmartTourism 2024)

Workshop Organizers

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Massimiliano Bencardino	University of Salerno, Italy

Sustainable Evolution of Long-Distance Freight Passenger Transport (SOLIDEST 2024)

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Luigi Dall'Olio	University of Cantabria, Spain
Antonio Russo	University of Enna Kore, Italy

Sustainability Performance Assessment: Models, Approaches, and Applications Toward Interdisciplinary and Integrated Solutions (SPA 2024)

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ICCSA 2024 took place on the main campus of Thuyloi University in Hanoi, Vietnam.



Plenary Lectures

Harnessing Artificial Intelligence for Enhanced Spatial Analysis of Natural Hazard Assessments



Prof. Dr. Biswajeet Pradhan

Director - Centre for Advanced Modelling and Geospatial Information Systems (CAMGIS), School of Civil and Environmental Engineering, Faculty of Engineering and IT, University of Technology Sydney, Australia

Abstract. In the realm of natural hazard assessments within spatial domains, the advent of Artificial Intelligence (AI) represents a paradigm shift, revolutionizing the way we conceptualize, model, and interpret environmental risks. This keynote address illuminates the profound impact of AI technologies, particularly machine learning algorithms and data-driven approaches, in reshaping our understanding and prediction capabilities concerning natural disasters.

By assimilating and scrutinizing vast spatial datasets, AI-driven models offer unparalleled accuracy and efficiency, facilitating timely and precise hazard assessments. Real-time processing of geospatial information not only enables rapid predictions but also forms the cornerstone of proactive disaster management strategies. Furthermore, AI's capacity lies in its adeptness at deciphering intricate spatial patterns inherent to natural hazards, unraveling subtle cues and previously unnoticed correlations within the data fabric.

This keynote delves into how AI's nuanced interpretation, coupled with advanced algorithms, elevates hazard modeling, providing deeper insights into the spatial dynamics of environmental risks. By augmenting traditional methodologies and revealing hidden patterns, AI fosters comprehensive risk assessments, fostering informed decision-making processes. The fusion of AI and natural hazard assessments in spatial domains heralds a more resilient approach to disaster preparedness and response.

Join us in embracing this transformative era, where AI's sophisticated modeling techniques and precise spatial interpretations converge, heralding proactive and effective mitigation strategies amidst the ever-evolving landscape of environmental challenges.

Short Bio. Distinguished Professor Dr. Biswajeet Pradhan is an internationally established scientist in the field of Geospatial Information Systems (GIS), remote sensing and image processing, complex modelling/geo-computing, machine learning and soft-computing applications, natural hazards and environmental modelling. He is the Director of the Centre for Advanced Modelling and Geospatial Information Systems (CAMGIS) at the Faculty of Engineering and IT at the University of Technology, Sydney (Australia). He was listed as the World's Most Highly Cited Researcher by the Clarivate Analytics Report for five consecutive years, 2016–2020, as one of the world's most influential minds.

He ranked number one (1) in the field of "Geological & Geomatics Engineering" during the calendar year 2021–2023, according to the list published by Stanford University Researchers, USA. This list ranks the world's top 2% most highly cited researchers based on Scopus data. In 2018–2020, he was awarded as World Class Professor by the Ministry of Research, Technology and Higher Education, Indonesia. He is a recipient of the Alexander von Humboldt Research Fellowship from Germany. Between 2015–2021, he served as "Ambassador Scientist" for the Alexander Humboldt Foundation, Germany.

Professor Pradhan has received 58 awards since 2006 in recognition of his excellence in teaching, service and research. Out of his more than 850 articles (Google Scholar citation: 70,000, H-index: 129), more than 750 have been published in science citation index (SCI/SCIE) technical journals. He has authored/co-authored ten books and thirteen book chapters.

Software Engineering Research in a New Situation



Prof. Carl K. Chang

Professor Emeritus, Iowa State University, USA

Abstract. With the rise of Generative Artificial Intelligence (GAI), epitomized by Large Language Models (LLMs), a profound shift has unfolded in software engineering research. In this presentation, I will traverse my four-decade journey in software engineering research, focusing on situational awareness in the era of the Internet of Things (IoT). I have witnessed the turbulence brought forth by the AI community that demands changes in our approaches. Meanwhile, owing to the pervasiveness of services computing, services became the first-class citizen in modern-day software engineering methodologies.

I argue that situational awareness must permeate the entire lifecycle to consistently deliver software services that align with the dynamic needs of users and the ever-evolving environments. I will elucidate this argument by reviewing the Situ framework, offering a comprehensive illustration of my perspective. Furthermore, I will outline my vision regarding the formidable research challenges considering the rapidly shifting landscape dominated by an irresistible and profoundly disruptive generative AI tsunami.

Short Bio. Carl K. Chang is a former department chair and Professor Emeritus of Computer Science at Iowa State University. His research interests include requirements engineering, net-centric computing, situational software engineering and digital health. Chang was the 2004 President of the IEEE Computer Society. Previously he served as the Editor-in-Chief for IEEE Software (1991–1994), and as the Editor-in-Chief of IEEE Computer (2007–2010). He was the 2012 recipient of the Richard E. Merwin Medal from the IEEE Computer Society. Chang is a Life Fellow of IEEE, a Fellow of AAAS, and a Life Member of the European Academy of Sciences (EurASc).

Interpretability and Privacy Preservation in Large Language Models (LLMs)



Prof. My Thai

University of Florida (UF) Research Foundation Professor
Associate Director of UF Nelms Institute for the Connected World

Abstract. Large Language Models (LLMs) have transformed the AI landscape, captivating researchers and practitioners with their remarkable ability to generate human-like text and perform complex tasks. However, this transformative power comes with a set of critical challenges, particularly in the realms of interpretability and privacy preservation. In this keynote, we embark on an exploration of these pressing issues, shedding light on how LLMs operate, their limitations, and the strategies we can employ to mitigate risks. We begin by examining the interpretability in LLMs, which often function as enigmatic "black boxes." Their complex neural architectures make it challenging to understand how they arrive at specific outputs. This lack of transparency raises questions of trust and accountability. When deploying LLMs in real-world applications—whether for chatbots, content generation, or decision-making—it becomes crucial to demystify their decision paths.

We will use explainable AI (XAI) to offer faithful explanations, from the black-box to white-box models, and from feature-based [1, 2] to neuron circuits-based [3, 4] explanations. By visualizing attention mechanisms, feature importance, and saliency maps, we empower users to comprehend LLM predictions. XAI not only fosters trust but also encourages responsible utilization of LLMs.

We next turn our attention to one of the utmost concerns and challenges: data privacy. LLMs process vast amounts of data, raising risks of data leakage, model inversion, the right to be forgotten, and inadvertent exposure of sensitive information. Furthermore, the integration of LLMs into diverse applications also significantly brings these challenges to the next level [5]. This talk explores strategies to protect privacy, including differential privacy, federated learning, and data encryption.

Short Bio. My T. Thai is a University of Florida (UF) Research Foundation Professor, Associate Director of UF Nelms Institute for the Connected World, and a Fellow of IEEE and AAIA. Dr. Thai is a leading authority who has done transformative research in Trustworthy AI and Optimization, especially for complex systems with applications to healthcare, social media, critical networking infrastructure, and cybersecurity. The results of her work have led to 7 books and 350+ publications in highly ranked international journals and conferences, including several best paper awards from the IEEE, ACM, and AAAI.

In responding to a world-wide call for responsible and safe AI, Dr. Thai is a pioneer in designing deep explanations for black-box ML models, while defending against explanation-guided attacks, evident by her Distinguished Papers Award at the Association for the Advancement of Artificial Intelligence (AAAI) conference in 2023. At the same year, she was also awarded an ACM Web Science Trust Test-of-Time award, for her landmark work on combating misinformation in social media. In 2022, she received an IEEE Big Data Security Women of Achievement Award. In 2009, she was awarded the Young Investigator (YIP) from the Defense Threat Reduction Agency (DTRA), and in 2010 she won the NSF CAREER Award. She is presently the Editor-in-Chief of the Springer Journal of Combinatorial Optimization and the IET Blockchain Journal, and editor of the Springer book series Optimization and Its Applications.

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Smart Tourism (SmartTourism 2024)

Smart Tourism and Platforms. Italia.It, the Italian Tourism Digital Hub

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Abstract. Digital technologies have become a fundamental part of daily life, with the tourism industry consistently at the forefront of adopting new technological advancements and platforms. Smart tourism is essential for the industry's development, as it significantly leverages these platforms to enhance tourism services. The research explores smart tourism's transformative potential, emphasising platform-mediated tourism's impact. It examines the platform "Italia.it", the Tourism Digital Hub, promoted by the Italian government. The case study highlights the extensive implications and opportunities when governments create appropriate framework conditions for the digital transformation of tourism business models and the wider tourism ecosystem.

Keywords: Italia.it · Smart Tourism · e-participation · Italian Digital Agenda

1 Introduction

Digital technologies have become a fundamental part of daily life and can be considered ubiquitous. Society is increasingly digitized and interconnected, constantly permeating every aspect of citizens' lives [10, 16].

Emerging technologies herald the advent of the Fourth Industrial Revolution, reshaping society in unprecedented ways, necessitating a collective and individual approach to harness its universal benefits [36].

The development and the integration of digital technologies are significantly changing lifestyles, work habits, travel practices, business practices and operations, revolutionising and redefining the tourism industry [29]. Tourism emerged as a trailblazer in digitalising business operations worldwide by being among the first to introduce online flight and hotel bookings. With the worldwide expansion of information and communications technology (ICT), the tourism industry has consistently been at the forefront in embracing new technological advancements and platforms [37].

The COVID-19 pandemic significantly impacted the tourism sector, with travel and accommodation restrictions dampening international tourism [21, 41, 19]. However, the sector gradually recovered as restrictions eased in 2021 [15]. In 2023, the international tourism sector recovered 88% of its pre-pandemic volume globally, with international

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arrivals close to 1.3 billion. The sector generated about 1.4 trillion U.S. dollars in revenue, accounting for 93% of 2019 figures. Additionally, the comprehensive export revenues from tourism, including passenger transport, amounted to nearly USD 1.6 trillion, representing 95% of the amounts tallied before the pandemic [39]. Despite this recovery, challenges such as inflation, volatile oil prices, and geopolitical tensions persist, influencing tourism trends and consumer behavior. Future challenges remain regarding sustainability, adaptability, and managing workforce shortages to address the evolving landscape effectively [12].

In the third quarter of 2023, the platform-based tourism sector demonstrated significant growth, overwhelming previous records and markedly surpassing the pre-pandemic benchmarks set in 2019, registering a collective growth of 13.4% in platform tourism with 309.4 million nights booked. This period continued and intensified the recovery that began in 2022. Data from online booking platforms[1] revealed unprecedented activity levels, with July alone recording 115.7 million nights booked—an increase of 10.7% compared to the same month in the previous year.

The outbreak of the pandemic accelerated the digitalization process, prompting industries, including tourism, to adopt digital solutions and data-driven approaches for administrative and operational continuity. Consequently, there is a growing trend towards smart tourism in Europe and globally[13].

The rest of the paper is organized as follows: Sect. 1: Tourism and digitalization, Sect. 2: Italia.it. The Italian Tourism Digital Hub, Sect. 3: Discussion, Sect. 4: Conclusion.

2 Tourism and Digitalization

According to the UNWTO, tourism is a social, cultural, and economic phenomenon that entails the movement of people to countries or places outside their usual environment for personal, business, or professional purposes. These people are called visitors (tourists or excursionists, residents or non-residents), and tourism has to do with their activities, some of which involve tourism expenditure [44].

The widespread availability and integration of technologies such as the Internet of Things (IoT), mobile applications, location-based and geo-tagging services, Virtual Reality (VR), Augmented Reality (AR), social media, blockchain, and smart devices provide a wealth of opportunities for those in the tourism industry to promote services and access large volumes of data for a variety of applications. These tools and applications are crucial in enhancing the tourist experience, boosting destinations' competitive edge, and fostering sustainability improvements [40].

Incorporating novel technologies in tourism, such as augmented reality (AR) and artificial intelligence (AI), indicates a transformative shift in the user experience, cognitively and emotionally. These technological instruments provide innovative means of

[1] Airbnb, Booking, Tripadvisor, and Expedia. The European Commission has reached a landmark agreement with four collaborative economy platforms – Airbnb, Booking, Expedia Group and Tripadvisor – on data sharing.

interaction with the surrounding environment, enhancing the touristic journey with virtual information and content that superimposes physical reality, thereby elevating travel's interpretive and affective dimensions [3].

Social media and various GIS-related platforms have recently become vital data sources for tourism research. The growing relevance of combining tourism with geospatial technology is gaining considerable attention, particularly in the study and use of 'neogeography' or 'volunteered geographic information [34].

Geography and tourism are interconnected, with tourism responding to digital geography by leveraging digital technologies to enhance experiences and increase self-organisation of activities. Digital technologies are progressively permeating the domain of excursions and autonomous tourism, significantly contributing to the substantial expansion of independent tourism within the regions covered by the "*infrastructures oecumene.*" [31].

2.1 Smart Tourism

In 2009, Assistant Secretary-General Geoffrey Lipman of UNWTO defined "smart tourism" as clean, green, ethical, and offering high-quality services at all levels of the service chain [23].

UNWTO Secretary-General Taleb Rifai declare, "'*Smart tourism' is not a trend, but the future of tourism development"*[38]. Smart tourism is not just one of the many forms of tourism [35] but is a component that integrates with all types of tourism toward a more sustainable perspective.

Gordon Phillips described smart tourism as adopting a comprehensive, forward-looking and environmentally friendly strategy for creating, managing and promoting tourism services and businesses [30]. Smart tourism is driven by two main strategies: the smart management of customer demand and access to facilities and targeted marketing techniques designed to reach specific groups of consumers with personalized messages [23].

Chuang describes smart tourism:
Smart tourism refers to the provision of Smart tourism service through Internet devices on mobile devices combined with the evolution of information and communication technologies (ICTs), as well as timely access to tourism information and the convenient use of various travel methods (Xiao et al., 2019). Focusing on the individual personal experiences of tourists, smart tourism attempts to integrate high-quality services at the industry level and meets the growth of tourists' needs (Gretzel et al., 2015c). The tourism ecosystem will be able to obtain and use relevant tourist information in a timely manner to realize intelligent service and business management. Therefore, STS is empowered through the connection of smart technology, smart tourism experiences, and smart business ecosystems (Gretzel et al., 2015b). Objectives include consumers (tourists), industry (tourism service providers), and the government (local public tourism agencies)[10].

Smart tourism integrates Information and Communication Technology (ICT) into the travel industry, signalling a shift towards more technologically enhanced tourism. It represents a collaborative approach at travel destinations to gather and interpret data.

By leveraging cutting-edge information technologies, the aim is to enhance the travel experience, making it richer, more streamlined, and sustainable[22].

As the European Commission suggests, smart tourism adapts to the rapidly evolving tourism sector by embracing advancements in digital tools, products, and services. It ensures equal access and opportunities for all tourists, promotes the sustainable growth of local communities and bolsters creative sectors, local skills, and cultural heritage [13].

Gretzel, Sigala, Xiang, and Koo have identified three key elements that define smart tourism: the smart destination, the smart experience, and the smart business. A smart destination, often associated with smart cities, offers improved mobility, efficient resource distribution, and a sustainable living environment for its inhabitants. Additionally, it enhances tourism by providing an interconnected smart environment that amplifies visitors' experiences. The smart experience *focuses on technology-mediated tourism experiences,* involves enriching the interaction and engagement of tourists with their surroundings. Lastly, smart business pertains to the intricate network of tourism stakeholders who actively exchange information and collaborate to create and share tourism-related resources and services [16].

The European Commission has launched initiatives such as the European Capital of Smart Tourism and the European Green Pioneer of Smart Tourism to recognize and promote sustainable tourism practices within the EU, under the umbrella of Smart Tourism[2].

2.2 Smart Tourism Destination

Smart tourism destination (STD) has received growing recognition among scholars [4–6, 18, 28]. SMD is a crucial element of smart tourism [7]. Its meaning is directly derived from the literature on smart cities [19].

One of the most relevant definitions defines the smart tourism destination as: "*an innovative tourist destination, built on an infrastructure of state-of-the-art technology guaranteeing the sustainable development of tourist areas, accessible to everyone, which facilitates the visitor's interaction with and integration into his or her surroundings, increases the quality of the experience at the destination, and improves residents' quality of life"*[24].

STD can be split into 4 subcategories: Cutting-edge technology, governance, quality of life and sustainability [33]. STD represent a holistic approach to tourism, combining technology and innovation with sustainability, accessibility and inclusiveness throughout the entire travel cycle, before, during and after the trip. STD employ continuous data analysis and integration, improving the travel experience through simplified decision-making and effective resource management. Smart destinations incorporate inclusive tourism governance by involving all community stakeholders, tourists and residents, thus ensuring accessibility to sites, products and services and simplifying mobility. Data use helps understand and manage the impacts of seasonality on tourism and sustainability, facilitating the forecasting and regulation of tourism flows and leading to more efficient and effective destination management [42].

[2] https://smart-tourism-capital.ec.europa.eu/index_en.

2.3 Sharing Economy and Tourism Platform

The sharing economy has significantly restructured the tourism industry, with its growth largely facilitated by the rise of digital platforms. These platforms offer alternative traditional services, creating a more dynamic tourism ecosystem [1].

The phenomenon of platform tourism, also known as platform-mediated tourism, has been studied and explored, especially in the urban context [9]. It often has meanings that highlight the negative impacts that the short-term rental of properties produces in the city, such as the financialisation of housing, gentrification, touristification, and deterioration of working conditions [27].

Over the last ten years, digital platforms for services like short-term rentals, transportation, and social dining have fostered a new wave of entrepreneurs in the tourism and mobility sectors. Initially, these platforms were seen as part of a sharing economy dominated by no-professional providers but have since evolved into a form of capitalist speculation [28]. Although the expression platform tourism mainly refers to short-term rentals [45], it includes goods or services private individuals offer to visitors through digital platforms [17]. The platformization of tourism is gradually expanding [8]. Digital platforms in the tourism industry facilitate travel, reducing search costs and providing travellers with more information about a given destination; digital platforms reduce the monetary and non-monetary costs of traveling [25] (Fig. 1).

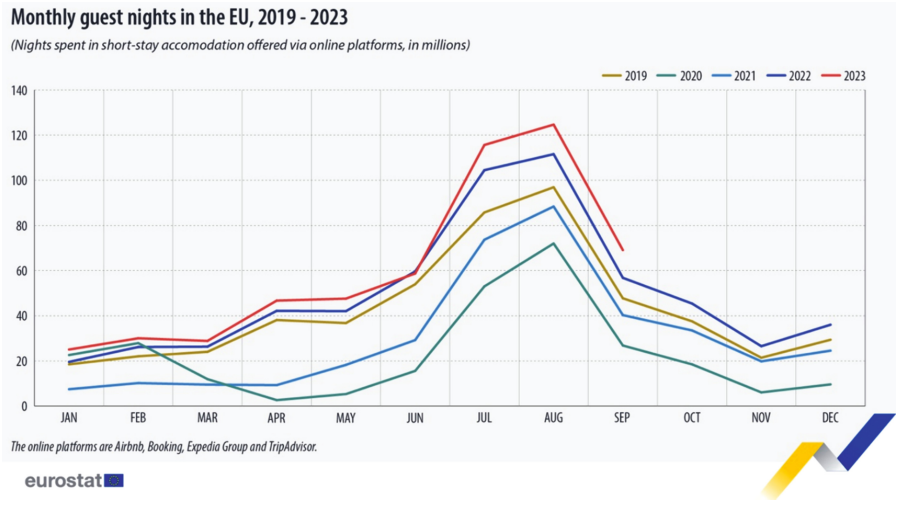

Fig. 1. Monthly guest night in Eu 2019–2023 via online platforms. Source: Eurostat

3 Italia.It. The Italian Tourism Digital Hub

The Italian government's National Recovery and Resilience Plan, called Italia Domani, allocates 27 per cent of resources to digital transition. This strategy is structured around digitizing Public Administration and implementing access to technologies for small

businesses ultrafast networks. The 7 investments planned by the NRP to digitise access to technologies for small businesses and improve connectivity for rural and remote communities.

This framework will guide digital-related actions, setting measurable goals regarding connectivity, digital skills, and digital businesses; the PA is made available through 14 measures, totalling more than 6 billion euros.

The European Digital Decade aims to equip everyone with technological skills, facilitate access to technologies for small businesses, and improve connectivity for rural and remote communities. This framework will guide digital-related actions, setting measurable goals regarding connectivity, digital skills, digital businesses, and public services. In addition, the strategic program defines four main objectives: digital education, infrastructure security, digital transformation of businesses, and digitization of public services.

3.1 Italian Tourism Digital Hub

The Italian government's Tourism Digital Hub represents the web platform, funded with an investment of 114 million euros from the National Recovery and Resilience Plan (PNRR), aimed at revolutionizing the Italian tourism ecosystem by implementing advanced digital infrastructure and adopting artificial intelligence-based technologies. Aiming to promote integrated and homogeneous management of information, promotion and marketing in the tourism-retail sector, the project aims to stimulate territorial economic recovery.

The concept of the Tourism Digital Hub does not find much traction within the scientific debate. The Hub's guidelines for intervention include the modernization of the Italia.it portal, which aims to improve the user experience and enrich the informative content by integrating new data sources. This will expand the portfolio of services available to tourists, including health support and essential information, and enhance professional figures in the sector, such as guide and tour leaders. At the same time, predictive models will be used to analyze tourist flows and identify areas of strategic interest, both established and emerging, to personalize the visitor experience and incentivize locally distributed and conscious tourism. Another key aspect is developing an information system for the promotion and management of tourism-related activities, with a focus on small and medium-sized operators in less developed areas.

Specific goals of the TDH include personalizing travellers' experiences, supporting more than 20,000 tour operators within two years, creating an automated bidding system through AI, and co-constructing detailed customer profiles by integrating different data sources. This will make it possible to connect each visitor with the content, providers and services best suited to his or her needs, thus promoting greater visibility of lesser-known places and improving the coordination of promotional actions at the national level. Finally, the focus is on cross-media dissemination of content through mobile apps, chatbots, and social media development to ensure a wide range of communication and interaction with the public (Fig. 2).

The expected outcomes of TDH are:

- *Increasing flows, destinations and spending, by increasing the quality of the offer and the related exposure of the Italian Points of Interest for Tourism (POI);*

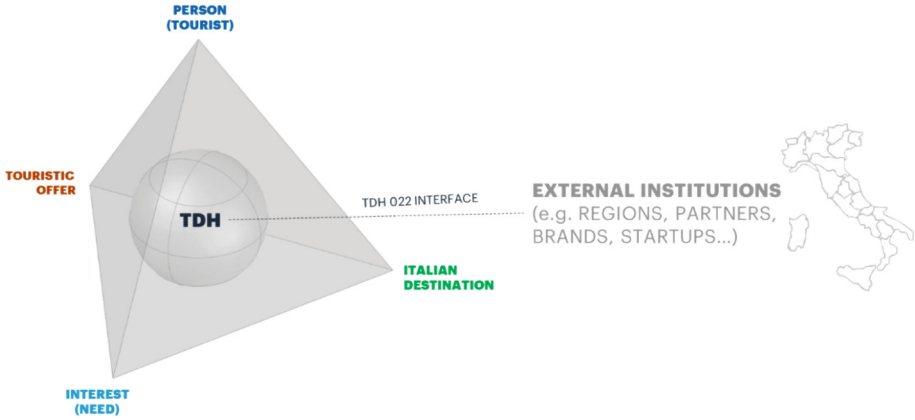

Fig. 2. TDH ecosystem and external connection through TDH022 Source: Italia.it

- *Enhancing the existing framework of digital assets - e.g., regional portals - without any overlapping, while also offering cost saving solutions;*
- *Strengthening the role of TDH's digital assets, defining them as real institutional reference points for searching for POI-related information with respect to an audience of national and international tourists;*
- *Involving the entire Italian tourism system through an open-source approach that collects input and generates output for all stakeholders;*
- *Retaining users (and therefore potential tourists) through tailored proposals based on their needs and preferences, offering a bespoke portal experience;*
- *Favoring the development of a platform that provides timely and correct information on POIs across Italy, and whose data will be used by external tracking platforms such as Google My Business, Bing Places, Apple Maps and so on - thus bringing an additional benefit in terms of visibility on the most common search engines.*

Italia.it will offer content with a triple relevance:

- *Content of Interest: editorial content enables the TDH to infer the Person's interest when reading it. It enables the description of one or more destinations, one or more offers and/or any event related to the tourist experience in our territory (e.g.: an editorial article that talks about the Palio of Siena, if read by the tourist, suggests interest for Siena and its historical pageants);*
- *Destination: local attraction related to a point of interest (x, y coordinates) or to a geographical area («geometry») that persists in the medium-long term (e.g., Colosseum, Trevi Fountain, the city of Rome, etc.);*
- *Offer: a touristic item that can be consumed/booked/seen for a fee (e.g., a hotel room, a museum entry)* [26] (Fig. 3).

3.2 The Platform Italia.It

The Italia.it website, beyond its homepage, is delineated into four primary sections, namely: (I) Where to Go, (II) What to Do, (III) Plan Your Trip, and (IV) Information.

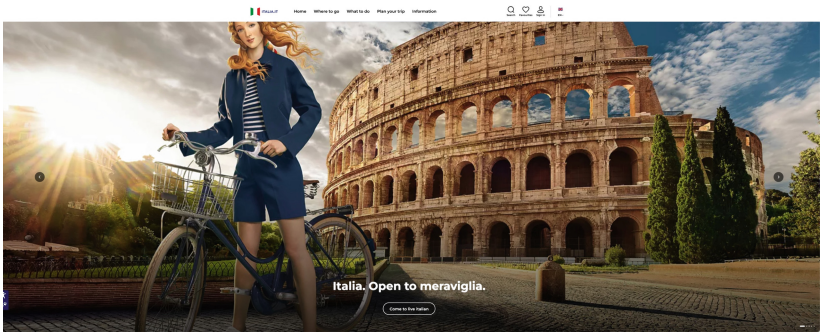

Fig. 3. Home page Italia.it source: www.italia.it

There are 3 languages available Italian, Spanish and English.

The "*Where to Go"* section organizes travel destinations into categories such as: regions, cities, seas, mountains, UNESCO World Heritage Sites, villages, and countryside.

This section underscores the extensive geographical and cultural heterogeneity of Italy, providing travelers with a deep dive into a multitude of destinations. Every part of the page is meticulously curated to showcase Italy's allure through vivid imagery and detailed narratives, designed to inspire journeys and discovery throughout the nation (Fig. 4).

The *"What to Do"* section systematically arranges activities into themes, including Interesting ideas, Seasons, Travel ideas, and Magazines. Interesting ideas are structured as follows: nature, Art and Culture, Food and Wine, Sports, Leisure, Events, Relaxation and Wellness, Spirituality, Shopping and markets, Luxury Experiences, Itineraries, Excursions, and Seasonal Activities. Season is divided into: Spring, Summer, Autumn and Winter. Travel ideas is organized: Solo holidays, Couple holidays, Family holidays, Young people holidays. Each category is complemented by articles about specific attractions or activities, ranging from cultural institutions like museums and historical landmarks to outdoor pursuits and gastronomic expeditions.

The "*Plan Your Trip"* section is further segmented into three subcategories: "Where to Eat", "Where to Eat in Italy", agency.

The *"Where to Eat"* guides to the Italian gastronomic realm, showcasing an array of dining locations such as pizzerias, trattorias, country houses, taverns, and wine bars.

The section provides a search tool complemented by a series of filters. The offer are categorized Region, Kitchen Type, Price Level, Occasion, Services, Bookable.

This page accentuates the variance within Italian gastronomy and endeavours to cater to every culinary preference, assisting tourists in pinpointing the ideal gastronomic venue that aligns with their palate. It furnishes practical tools for exploring menus, pinpointing precise locations, verifying operational hours, and arranging dining reservations online. As of the current update, the Italia.it database includes 19,929 registered accommodation structures.

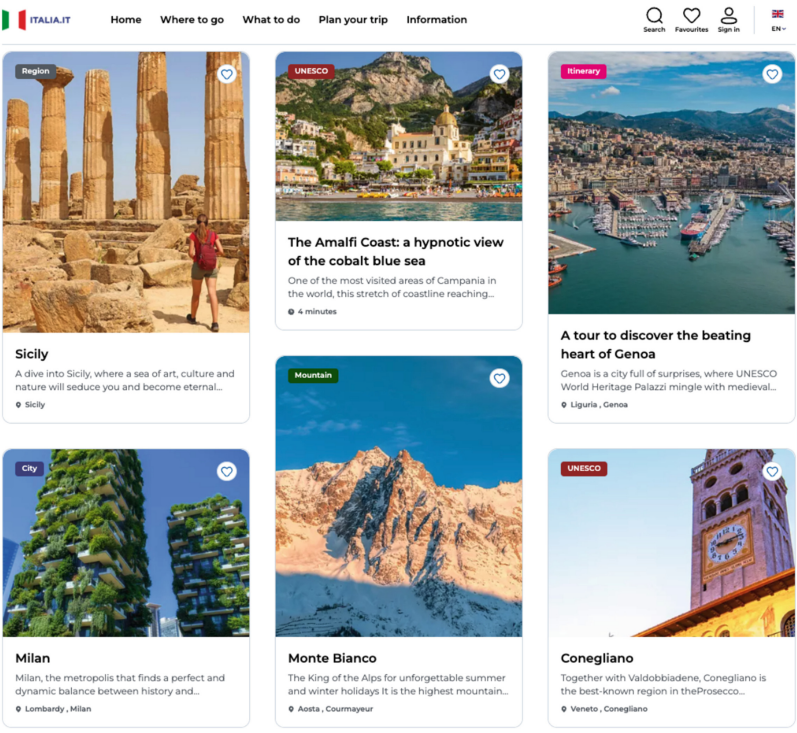

Fig. 4. Where to go page Italia.it. Source:www.italia.it

The *"Where to Sleep"* sub-section categorizes lodging options in Italy, providing a search tool complemented by a series of filters: Region, Services, Structure Type, and Stars. The accommodations are categorized by type, including, but not limited to, guesthouses, agritourism lodgings, farm stays, apart-hotels, apartments, bed & breakfasts, bungalows, campsites, cottages, glamping, hotels, hostels, pensions, and villas. Each category is detailed, facilitating informed decisions based on individual travel requirements, location preferences, and budget constraints. Currently, there are 3,091 registered lodging structures.

The travel agencies sub-section offers a comprehensive directory and insights into travel agencies and tour operators throughout Italy. It provides robust tools for search and filtration, enabling travelers to identify agencies tailored to their unique travel requirements, whether they seek individual, group, luxury, or specialized tours. Presently, there are 672 travel agencies registered.

The Section *"Information"* of Italia.it is a repository of travel information for visitors to Italy. It encompasses pragmatic advice, guidelines for necessary documentation, options for transportation, emergency contact information, and strategic counsel for easily navigating the country.

4 Discussion

The assessment of the Italia.it portal must consider its recent relaunch and the ongoing implementation phase, including the engagement of businesses aiming to reach a target of 20,000 affiliations by June 2024.

Currently, the platform is in a preliminary phase of experimentation and initial deployment, providing a basis for early-stage analysis and evaluation.

Italia.it is the official government portal for Italian tourism, evolving from an existing site created in 2007. In the nearly two decades since its inception, it has seen limited evolution, characterized by significant governmental investment on the one hand and by continuous interruptions and even suspensions of service on the other.

It is important to acknowledge the presence of numerous official websites that promote tourism within various European nations, Italia.it being one example.

Examples of such websites include VisitBritain for the United Kingdom, Germany.travel for Germany, Spain.info for Spain, France.fr for France, VisitPortugal.com for Portugal, Holland.com for the Netherlands, VisitSweden.com for Sweden, VisitNorway.com for Norway, Croatia.hr for Croatia, VisitGreece.gr for Greece, Austria.info for Austria, VisitCzechRepublic.com for the Czech Republic, Switzerland.com for Switzerland, VisitIceland.com for Iceland, and VisitDenmark.com for Denmark.

The structural and organizational framework of the original site is not significantly different from the current portal. The initial version of the site featured sections such as (I) what to do, (II) itineraries, (III) events, and (IV) plan your trip, which in terms of organization and content correspond to the current categories (Fig. 5).

The current redevelopment of the Italia.it portal, intended to transition it from a simple website to a comprehensive portal and platform, is in a nascent phase. Despite its official unveiling, it remains a work in progress, with several functionalities not yet operational. The new Tourism Digital Hub incorporates several notable innovations.

Foremost among these is the direct interaction with local businesses, which now can register on the portal. Another significant feature is the added functionality for users to make reservations. The individual pages for businesses allow users to explore the characteristics of these enterprises, such as hospitality or dining options, complete with service descriptions, product offerings, and location. They also offer the possibility to make reservations, specifically for dining establishments. The reservation function is facilitated for restaurants by integrating the Fork platform within the site. As for lodging facilities, while they do not currently possess an internal booking function on the portal, prospective guests can make reservations via the individual hotel's website linked from their page on Italia.it.

Asadullah [2] identifies some characteristics of digital platforms: reductions in transaction costs, including distribution, search, contracting, and monitoring costs, help organize and coordinate the technological development of complementary products through modularity and appropriate governance structures. Tourism aggregation platforms compile and consolidate travel data from various providers into a single interface, thereby diminishing the expenses associated with seeking information and employing the services of intermediary brokers. Despite having features characteristic of a Tourism aggregation platform, Italia.it cannot be considered a true aggregation platform.

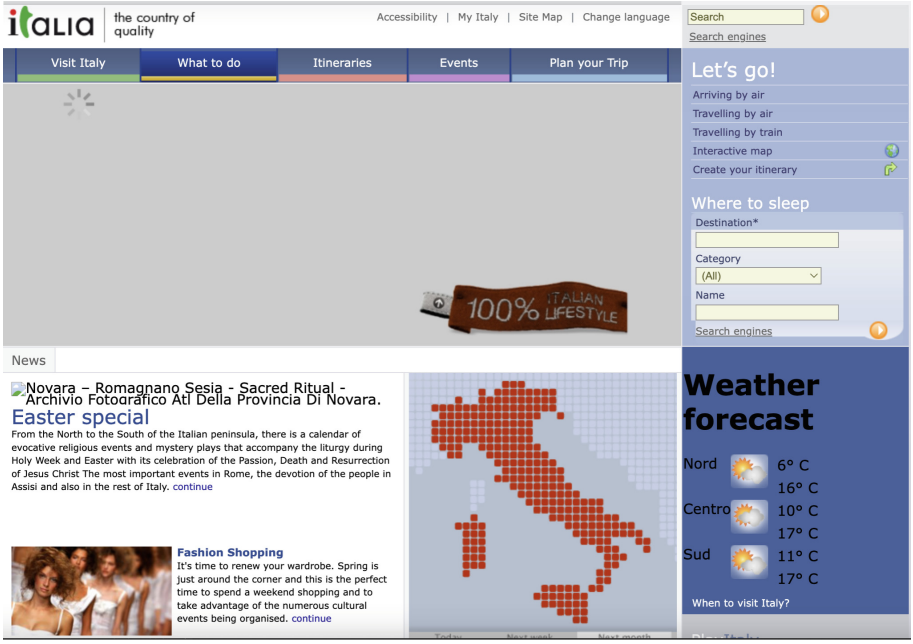

Fig. 5. Home page Italia.it 2007 source: web archive

5 Conclusion

Governments have an important role to play in creating the right framework conditions for the digital transformation of tourism business models and the wider tourism ecosystem. Integrated and coherent policy approaches are needed to leverage the opportunities of digitalisation while also addressing challenges and minimising any negative consequences that may emerge. Policy work can also be positioned across a spectrum of tourism businesses (e.g. digital natives, hybrids and tourism SMEs with low levels of digitalisation) [29].

Within the framework of Europe's Digital Decade strategy, the EU promotes the digital transition of the tourism sector, focusing on four key areas: Improving the digital skills and education of the workforce ("skilling and upskilling"). Developing secure and sustainable digital infrastructure. Encouraging the digital transformation of businesses. Advancing the digitalization of public services [43].

The impact of Italia.it on digitalization can be categorized based on its beneficiaries: the digital transformation of businesses, the implementation of digital solutions for the public sector and tourism managers, and the provision of digital solutions for visitors.

Digital solutions for business. Italia.it play a role as a catalyst for new start-ups by providing a complimentary ecosystem where they can present their businesses, while also aiding existing companies in better aligning their offerings with market demand. For local governments and Destination Management Organizations (DMOs), the platform facilitates the digital transformation of tourism destinations. Moreover, Italia.it could

act as a valuable instrument for tracking and analyzing trends, supplying data that can help formulate sustainable tourism strategies across various levels.

Digital solutions for the public sector and tourism managers. Italia.it supports digital innovation in public sector tourism by offering tools and services that assist in managing and promoting tourist activities. The platform serves as a digital ecosystem to aid tourism managers in optimizing the visitor experience, engaging with tourist demands, and enhancing the accessibility and dissemination of information.

Digital solutions for visitors. Italia.it facilitates visitor experiences through digital solutions for visitors by providing a centralized portal that aggregates travel-related information and resources. Features such as interactive maps, a booking system, downloadable guides, and real-time updates are designed to support and enhance the travel planning process, ensuring visitors can access a wealth of information to plan their trip to Italy efficiently (Italia.it). The experience is not 100% customised experiences, and does not consider before, during and after a visit.

The digital transition planned by the Italian government with the PNRR has an approach aimed at public administrations, specifically through an orientation related to implementing the infrastructural part of access to digital services. There is a lack of a digital transition-oriented vision with an approach related to the culture of digitization aimed at citizenship and the uses of digital in people's daily lives. Digital pervasiveness in people's lives must be an element central to public policies to enable the individual to experience its potential and be an active element of this process in terms of user and policy co-construction.

In the context of the PNRR, Italia.it and digital facilitation centers represent distinctive actions that diverge from the predominantly infrastructure-focused initiatives for digital transition. Unlike many projects within the PNRR that primarily concerned with enhancing digital infrastructure, these initiatives aim to facilitate digital transformation by improving citizens' experiences and competencies. Italia.it as a Vanguard Platform: Italia.it stands out as a pioneering government platform, not by replacing existing popular tourism platforms, but by complementing and integrating with them.

This approach allows for a more cohesive and comprehensive tourism experience, leveraging the strengths of various platforms to provide rich, accessible information and services to tourists. The platform exemplifies how government-led digital initiatives can enhance, rather than supplant, existing digital ecosystems in sectors such as tourism.

The exploration of artificial intelligence (AI) utilization within the Italia.it platform and its direct or indirect benefits to tourists remains an area suitable for investigation.

Several features could be integrated into Italia.it, including tourism data management and the facilitation of data sharing.

The Italia.it platform has the potential to strategically direct its services towards promoting slow tourism[4], prioritizing sustainable experiences that emphasize the intrinsic value of the inner areas [14].

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City, Tourism, and Food. The Italian Street Food Experience as a Connecting Resource and Local Identity

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Abstract. The current competitive environment, dominated by complexity and dynamism, sees territories and, cities, competing to attract capital, residents, businesses, and tourists. This competition is developed through strategies and policies aimed at highlighting local peculiarities to become more attractive. In an era marked by globalization, there is a growing appreciation of local identities and productive traditions. These elements are considered distinctive, as they shape and enrich the tourism offerings of different places. Food, understood as a social and cultural phenomenon, takes on an important evocative role of the territory of origin. In countries such as Italy, associated in the collective imagination not only with art and culture but also with good and healthy food, where the wine and gastronomic offer is extremely varied and widespread, food becomes a strong element of tourist appeal. Food and wine tourism, which is growing steadily according to UNWTO data, attracts postmodern, slow, and green tourists who are interested in local specialties and want to connect with the local area. Hence one aspect of particular interest is street food, a global phenomenon that involves about 2.5 billion people every day. In Italy, this ancient gastronomic practice finds great acceptation, especially in cities, and becomes an experience through which tourists interact with terroir values. In an innovative context, where personalization and sustainability are drivers for the development and growth of the restaurant industry, street food, if made with local and sustainable ingredients, could help strengthen the competitiveness of the urban-rural system and create 'new' itineraries for responsible tourists.

Keywords: Food tourism · Street Food · Slow tourism · City · Italy

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1 Introduction

In an era characterized by strong globalizing forces, the rediscovery and valorization of local identities and productive traditions play a fundamental role. These elements are not only perceived as essential in shaping and enhancing the range of various tourist-territorial products, but also as distinctive features deeply rooted in the regions, capable of generating added value (economic, social, cultural, and political).

One of the consequences of this appreciation in the political arena is the formulation and execution of policies that encourage and enhance, or even delineate, local identities and distinctive elements [1].

That's why socioeconomic development policies implemented at different levels strive to accentuate the unique factors that propel destinations forward, often attributing much of their distinctiveness to symbols of environmental and cultural heritage, local knowledge, vocational skills, and excellent cuisine. In many instances, this culinary tradition takes on the guise of a genuine "gastronomic heritage".

For this reason, numerous countries adopt a gastronomic policy with the aim of positioning the nation as a culinary and gastronomic leader, supported by a range of inputs including traditional foods and cultural elements, which must align with market demands.

This is because food, being seen as a social and cultural phenomenon, carries with it an evocative essence of its place of origin, particularly when the qualities and benefits of the supply chain are emphasized. Moreover, when food is distinctive, deeply rooted in the local culture, and associated with healthy values, it can serve as a powerful draw for tourism. According to the World Tourism Organization (UN Tourism), the different segments of food and wine tourism are growing steadily. Even when food isn't the primary reason for travel, specific food-related experiences are increasingly sought after, particularly by tourists described as postmodern, slow, and green, who are keen on engaging with the local area and its various stakeholders. In this context, a particularly noteworthy mode of food consumption is street food, a phenomenon that engages 2.5 billion people worldwide daily. Italy, especially its cities where it originated and continues to evolve, demonstrates significant acceptance of this trend [2].

The tradition of street food has a rich history and is now seen as both a trend and an authentic gastronomic experience through which tourists engage with the local area. The individuals who prepare and sell street food, mostly locals, serve as ambassadors for the region's resources. They don't just sell a meal; they also share the story behind it. Despite its transient nature, conveying these stories is a challenging task due to the values they embody. In an innovative setting, where customization and sustainability are catalysts for the advancement and expansion of the restaurant industry, street food crafted with locally sourced ingredients from nearby agricultural regions or urban gardens could enhance the competitiveness of the urban-rural system. This could lead to positive outcomes benefiting both urban centers and rural areas, turning them into 'new' destinations for conscientious tourists.

Hence, this paper seeks to undertake a literature review concerning the definition and progression of street food, with the intention of analyzing its role within the Italian urban context as a fundamental component for comprehensive socio-economic development of the territory. Apart from the Introduction, the article comprises four subsequent

sections: 2. Related Works, 3. Objectives, Materials and Method, 4. Street Food in Italy: Perspectives for Integrated Development, and 5. Conclusions.

2 Related works

Drawing a clear distinction between activities inherently associated with Street Food and those that are not is, in some cases, a complex task. Street Food doesn't just concern how food is consumed - typically on the street - but also its production and distribution.

Regarding the preparation and sale of street food, the FAO clarified any uncertainties in 1995 [3] by noting that "The food might be cooked at home and distributed or alternately prepared on the spot depending upon the space available. There are fixed stalls, a variety of types of push-carts, roadside stands, hawkers with head-loads, and other arrangements depending upon the ingenuity of the individual, resources available, the type of food sold, and the availability of other facilities either acquired officially or appropriated from the city".

Thus, Street Food activities include those practiced in traditional stands and carts as well as those that take place with food trucks. These latter types have spread mainly in America, following the economic crisis of 2007 that led many vendors to close their fixed locations in favor of itinerant, less tax-intensive modes of sale.

Indeed, one of the distinctions among various countries lies in the formalization and oversight of street vending. For instance, in many cases across the Latin American region, vending food on the streets is not regulated or formalized to the extent that it involves tax obligations.

Although street food has gained considerable traction recently, particularly in Western countries where it has become a trend, the practice of eating food on the street dates back to ancient Roman times. Evidence of this can be found in the *tabernae* and *cauponae* of Pompeii, establishments overlooking the streets where patrons of that era were accustomed to consuming food, often while standing [4]. This mode of consumption has endured through the centuries, as evidenced by various artworks created between the Middle Ages and the modern era. These artworks attest to the widespread practice of street food consumption, even among the wealthier classes, who engaged in it to avoid visiting taverns [5].

Street food evolves over time and across different geographical locations, adapting to new contexts such as industrialized and globalized settings, which inevitably bring about significant changes in lifestyles and the sourcing and consumption of food. Consequently, it is a dynamic phenomenon that finds its niche within urban systems, with a portion of their tourist appeal linked to this form of food consumption [2]. For instance, in certain major cities across Latin America, Africa, and Asia, street food represents a tradition and often the primary means of accessing food for lower-income groups. Furthermore, it's important to recognize that in these countries, challenges extend beyond food consumption and include difficulties accessing education services and water resources. The absence of clean water and proper education, in some instances, makes it impractical to prepare food under optimal conditions. As a result, some tourists may choose to avoid street food when visiting these countries. Nevertheless, in response to these challenges in Latin America, it's estimated that there could be as many as three million such

businesses, although precise data is unavailable due to the absence of defined licensing regulations for such enterprises [6].

In other Countries, like the United States, street food is viewed as a flexible business tool, whereas in many European and South-East Asian cities, it's seen more as a trend. Food, being the core element of street food, holds strategic importance concerning the competitiveness of territorial systems. It intertwines across various dimensions crucial for evaluating the progress of territories in achieving specific development objectives. Considering, for instance, some of the Sustainable Development Goals outlined in the 2030 Agenda, it's believed that ethically and responsibly conducted street food activities, with a focus on the supply chain, can contribute to tackling poverty and hunger, promoting health, well-being, dignified employment, economic growth, and combating climate change.

Hence, the food challenge is a genuine one that demands the commitment of urban-rural territorial systems and must prioritize the promotion of smart and sustainable production, consumption, and post-consumption practices. In cities, where food supply and consumption methods differ, it's beneficial to analyze the role played by street food activities, which often enrich the tourist offerings and enhance the consumption experience, contrasting the antithetical model represented by fast food chains.

3 Objectives, Materials and Method

In this research, the central objective was to carry out a review of the literature on the definition and evolution of Street Food in order to analyze this practice in the Italian urban context as a key element for an integrated socio economic development of the territory. The research began with a global overview of street food practices and their urban connections, before narrowing its focus to the Italian context. Here, emphasis was placed on the ability of urban systems to establish experiential street food circuits, thereby integrating with rural areas.

To achieve the study's objectives, qualitative methodology was employed. This research paradigm enables not only the examination of qualitative qualities or entities, but also the analysis of the context in which they occur [7]. Within this qualitative approach, analyzing the context is feasible through a range of techniques or methods such as interviews, life stories, case studies, or documentary analysis. Researchers can blend their observations with those provided by others [8]. Thus, for this study, it was considered preferable to understand street food within the urban context and explore how its positive impacts might extend to the rural context through the promotion of local products (Fig. 1).

3.1 The Urban Dimension of Street Food: Between Definition and Localization

More than thirty years since the FAO's official definition of Street Food, it remains intriguing to see how the phenomenon has maintained a strong connection with the urban environment that fostered its emergence and facilitated its development over time. Street Food remains closely associated with cities, particularly thriving in the most urbanized regions, including metropolises and megacities, where it manifests in various

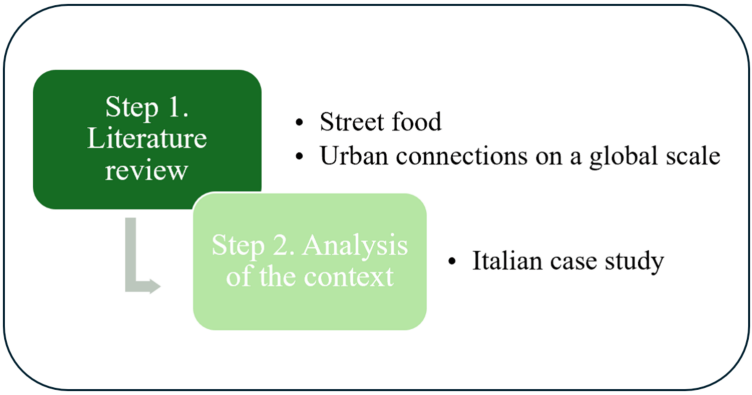

Fig. 1. Methodological process. Source: Own elaboration

forms: serving as a basic means of sustenance, enhancing the diversity of tourist and culinary experiences, and providing a more or less sustainable alternative to other dining options.

Street Food is given by that set of activities that "… are ready-to-eat foods and beverages prepared and/or sold by vendors and hawkers especially in streets and other similar public places" [9]. The FAO's widely acknowledged definition places particular emphasis on street vendors, associating them with specific locations such as streets or other public spaces like squares and markets where food is both sold and consumed, as well as with the processes involved in food preparation and sale [10–12]. This connection is not incidental, considering that historically, squares have been pivotal locations for commercial activities. These spaces were vibrant hubs, animated by the presence of vendors and frequented by urban dwellers and nearby rural residents who gathered there to purchase various goods and foods. Examples such as the Agorà of ancient Greece, the souqs of Islamic cities, Persian and Indian Bazaars, and the Roman Forums illustrate how these marketplaces served not only as places of trade but also as spaces that fostered the development of social interactions [13].

As socio-economic development conditions have shifted, driven by processes of industrialization and extensive urbanization accompanied by significant population growth, particularly evident in the twentieth century, cities have undergone numerous transformations affecting their size, structure, and functions [14–16].

One of the most significant phenomena contributing to recent urban changes is globalization, alongside technological advancements and transportation revolutions. Consequently, the perception and experience of urban space by residents, visitors, tourists, and other city users have evolved. Urban space is now viewed not merely as physical but also as a realm of flows and social interactions [17, 18]. Consequently, perceptions of the city, its functions, uses, and even its culinary spaces have changed, especially those related to consumption, which are often the most visible aspects.

Indeed, deep relationships have always existed between urban space and food, such that some authors point out that "urban evolution is influenced not only by whatever taste demands but also by the behaviors, expectations, and actions that descend from

this demand… and the growing demand for relational spaces, places to sit down to eat, terraces, and dehors is changing public spaces" [19, pp. 109–110]. Fast food chains have proliferated across the globe, embodying a standardized model of production and consumption. However, there has been a resurgence of interest in local cuisine, accompanied by a renewed emphasis on the food production and marketing process [20, 21]. Concepts such as quality, traceability of products, locally sourced ingredients, and sustainability of production cycles have gained traction, driven by increasingly conscientious consumers. These trends have had a direct impact on traditional modes of food distribution in urban areas, including those of street food [22, 23].

However, it's evident that street food activities manifest differently across various cities. They take on specific forms influenced by the geographical, historical, economic, cultural, or religious attributes of their respective locations, which in turn shape how street food caters to diverse needs. Regarding the positioning of street food activities, there is a notable emphasis on their presence in city centers and, increasingly, in revitalized neighborhoods and suburbs. In this context, as demonstrated by some urban regeneration initiatives, street food plays a significant role in the revitalization and renewal policies of areas known as "Food Deserts," particularly prevalent in many American cities [24–26].

3.2 City, Tourism, and Food

Cities, throughout the world, exercise many functions (trade, industry, government, education, health, justice, etc.) to meet the needs of various actors, internal and external to the urban system, sometimes configuring themselves as specialized cities or as multifunctional cities [13].

Cities compete to attract resources, capital and businesses and do so by implementing useful strategies to foster their optimal positioning in markets of interest [27, 28]. The competition that is established between cities and territories pushes each reality to want to be the leader in terms of improving the living and settlement conditions by highlighting peculiarities [29, 30].

Among the issues for which cities compete, tourism holds a prominent position being a growing phenomenon worldwide. According to statistics highlighted by the UNWTO, international tourists in 2022 were 965 million and 62 percent chose to travel to Europe, followed by the Americas and Asia-Pacific. Within this scenario, Italy ranks fifth among the most visited countries in the world with 61.6 million international arrivals preceded in order by France (89.4 million arrivals), Spain (82.8), the U.S. (79.7) and China (62.9). An examination of data on the distribution of tourist arrivals in Italy shows that among the most popular locations are the art cities of the Center-North (Rome, Milan, Venice, Florence, and Turin) confirming the important weight of urban tourism [31].

Urban tourism today must come to terms with the changing tastes of consumers/tourists who elect the city as the destination for their 'slow walk' holiday to enjoy the authenticity of the visited places [32, 33].

Tourists/travelers decide on their travel destination either based on the natural attractions or climate of a location, but also and especially because they are attracted by the local food they can taste [34–37]. For this reason, food is considered a social fact and a cultural element [38]: it is configured as a real reminder of 'geographical eating' [39]

which at the same time allows individuals to live an 'educational' experience by retracing the history and identity of a territory [40, 41]. These assertions are also supported by the study carried out by the World Food Travel Association (WFTA) called 'Food Travel Monitor' [42] which identifies a percentage of around 90% of individuals who choose their travel destination not on the basis of place, but on the basis of food, wines and craft beers and because want find satisfaction from the interaction existing between space, events and native people [43, 44].

4 Street Food in Italy. Perspectives for an Integrated Development

Food consumption is an essential part of any vacation experience. Among the ways that allow tourists to save time, contain spending and at the same time enjoy local specialties produced with zero-kilometer ingredients and in respect of local production traditions, Street Food could be an effective solution. This is true if we refer to the so-called 'traditional Street Food' practices where the focus shifts from the logic of consumption to that of preparation. As Carlo Petrini, founder of the Italian slow food association, observes, 'traditional Street Food' is the demonstration that the slowness and slow values of a food do not lie in the way it is enjoyed but rather in the ingredients, in the link with tradition, in the stories about its diffusion and creation, in the people who prepare it and in the conviviality that develops where it is sold and consumed' [45].

It is also possible to find this concept in the decalogue drawn up by the National Street Food Association, according to which, with ethical and responsible characteristics, it should 1) Respect history and traditions; 2) Use typical and traditional ingredients; 3) Adopt ethics in carrying out the profession and respecting handed-down knowledge and know-how; 4) Respect the link with the territory to which the Street Food belongs; 5) Use artisanal tools; 6) Respect hygiene regulations; 7) Make genuine combinations; 8) Respect the environment both during the process of production, administration and consumption and in the management of premises; 9) Promote the territory (of origin); 10) Promote a Street Food network.

Therefore, Street Food is recognized as having a precise value in terms of tourism, and in the specific Italian case, talking about Street Food means firstly referring to a broad type of activity that falls under the heading of retail trade practiced outside fixed establishments.

It is known that the crisis following the Covid-19 pandemic has affected several product sectors that have suffered a significant decline in recent years. According to the data produced by the Observatory of the Ministry of Economic Development, "retail trade outside fixed establishments has been registering in recent years not only a hold, compared to that in shops, but a real growth trend in almost all its forms (with the exception of mail-order trade progressively replaced by internet trade). As of 2021, the National Institute of Statistics counts 1,791 local units involved in street food services with a total number of employees of 3,528.63 (annual average value) [46]. In particular, Lombardy has a significant presence of itinerant food services (228 local units) followed by Sicily (189), Apulia (184), Veneto (159), and Emilia Romagna (153) (Table 1).

In the last two years, Street Food activities have grown by about 13%, also favoured by the multiplication of festivals and food promotion initiatives in tourist destinations.

Table 1. Local units and employees in street food service by region in 2021

Region	Number of local units of active enterprises	Number of employees of local units of active enterprises (annual average value)
Abruzzo	63	98.3
Basilicata	18	25.53
Calabria	34	47.62
Campania	138	232.7
Emilia Romagna	153	357.23
Friuli Venezia Giulia	23	46.35
Latium	145	346.31
Liguria	20	47.09
Lombardy	228	434.88
Marches	44	79.44
Molise	10	13.61
Piedmont	123	215
Apulia	184	319.42
Sardinia	71	137.45
Sicily	189	311.94
Tuscany	128	301.46
Trentino Alto Adige	39	63
Umbria	16	34.53
Aosta Valley	6	5.94
Veneto	159	410.83
ITALIA	**1,791**	**3,528.63**

Data from the study carried out by Deloitte called 'Foodservice Market Monitor' (2023) [47] also confirm that in Italy in 2022, of the 75 billion relating to the food service market about 1% concerns the Street Food segment: 7 out of 10 Italians on holiday choose street food to taste typical recipes, in particular 83% look for traditional food from the territories visited, 13% ethnic food and 5% fast-food [48].

However, the increase in Street Food activities in the different Italian regions is countered by a 'standardization' of the offer: especially in the historical centers there is little diversification of local gastronomic offerings (the sandwich with *lampredotto* in Florence, *pani ca' meusa* in Palermo, *cicheti* in Venice, *arrosticini* from Abruzzo etc.) which gives way to the sale of 'globalized' food (Kebab, falafel, hot-dog, sushi etc.). In the long run, this trend could lead to a loss of competitiveness of the food supply for the urban tourism system and a loss of attraction for 'glocal' tourists interested in eating typical Street Food.

In Italy, the basket of agro-food goods spread across the twenty regions is varied and ranks first at the European level for the highest number of certified Denomination of Origin and Geographical Indication products: 890 products of which 326 are food and 526 wine (PDO, PGI, TSG), and 35 Spirit GI beverages [49]. The sale of these specialties as street food represent 'gastronomic deposits' [50] capable of conveying the values of a destination beyond urban borders.

In 2016, with a view to defining a quality itinerant gastronomic offer, the Qualivita Foundation (a non-profit organization founded in 2000 to valorize the agri-food sector) drew up a 'Manifesto of Italian Street Food' [22] in which the concepts of territoriality, accessibility, socialization, handicrafts, tradition, innovation and cheapness are strongly connected to motivate a sense of place and tourist diversification. In order to support these new cultural routes of taste in 2018, 'agricultural street food' was defined at the legislative level as one of the ways of direct sale of farm produce. Hence the creation of a network of Italian street food promoted by Coldiretti that, by stopping in squares and markets or as itinerant tours, allows fresh, certified and zero km products to be served. The sale takes place thanks to the use of modern Food Trucks, with all the equipment and comforts of traditional cuisine, which represent essential and innovative elements for the success of the urban-rural connection. This represents an important signal to give a specific type of Street Food that could contribute to strengthening the gastronomic offer of cities consolidated as destinations for tourists who, more and more frequently, love to admire the heritage while tasting local products purchased at low cost. In addition to this, there are the many initiatives promoted at municipal level, such as the Municipality of Milan, which since 2018 has been issuing five-year authorizations (renewed in 2022) for the itinerant street vending of food and beverages to be practiced on ecological vehicles in the city center, or the International Street Food event which, for its eighth edition, will stop in 150 Italian locations from March to November 2024, involving around 30 food trucks and offering not only local food, but also international specialties. These could be some different and alternative solutions capable of conveying conscious behavior, getting more in touch with vendors who become in a certain sense ambassador of the territory.

5 Conclusions

As has been demonstrated in this research, the practice of Street Food has a long history and is currently a trend and a true gastronomic experience through which tourists interact with the territory.

However, only if this Street Food offer is prepared by local inhabitants and made with local and sustainable ingredients, can it be a great economic asset that affects the competitiveness of the urban-rural system by creating "new" itineraries for responsible or green tourists. Therefore, it is essential that the public policies of the States are designed in favor of the offer of Street Food and not transnational franchises that standardize consumption models.

In Italy, Street Food can represent a competitive element in tourism, especially in cities. Indeed, it allows tourists the opportunity to taste local foods often prepared in a traditional way.

Street Food stalls and dedicated spaces can become real tourist attractions where it's possible to interact with local vendors who become ambassadors of the territory. Through the sale of regional and local specialties via Street Food, interest in the culture and history of a specific city can be increased. In this case, the role played by the organization of events and festivals where street food becomes an integral part could also be very important.

Finally, Street Food conducted sustainably and attentive to the specificities of the territories, in addition to contributing to the local economy and job market, is able to strengthen the bond between city and countryside with positive impacts on the entire supply chain.

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Experimental Campaign on the Application of Fast Falling Weight Deflectometer for Possible Rapid Bridge Condition Monitoring

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Abstract. The following paper describes the possible applications of the Fast Falling Weight Deflectometer (Fast-FWD) as a tool for quantitatively characterizing the performance and condition of bridges by measuring the stiffness of the deck and embankment. The FWD is already widely used by transportation agencies for pavement evaluation programs and airfield pavement testing campaigns. This paper reports the testing campaign conducted on eight bridges in which the efficacy of using a Fast-FWD, a controlled excitation device for impact dynamic testing, on short to medium span reinforced concrete bridges.

There are many testing methods available, capable of monitoring and evaluating the performance and condition of bridges. Full scale testing consists of static load and dynamic testing methods using either controlled or uncontrolled dynamic excitation. Although each method has advantages and disadvantages in terms of the experimental campaign, logistical purposes and data analysis are also time consuming. This research establishes that the testing campaign, involving the measurement of local deflections of bridge structures to obtain stiffness values, resulted in rapid, accurate, and cost-effective assessments with minimal impact on traffic flow, providing a valuable alternative to traditional testing methods. Further validation and integration efforts are necessary, to fully exploit the potential of Fast-FWD in bridge assessment practices.

Keywords: Fast Falling Weight Deflectometer · non-destructive test · bridge monitoring · reinforced concrete bridges

1 Introduction

Bridge monitoring is a crucial preventive action for the safety of infrastructure. Deterioration due to aging, material degradation, poor maintenance, and also increasing traffic volume can induce a significant modification in the static and dynamic response of the infrastructure. In some cases, bridges have already exceeded their service life [1]. The methods used to investigate bridge vulnerability aim to predict potential collapses. Factors such as fatigue, corrosion of reinforcement, and aging are critical to evaluate the residual life span of each bridge structure [2]. Visual inspections [3], while simple, low-cost,

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and commonly used, may not be always totally adequate to detect impending collapse phenomena. On the other hand, monitoring through dynamic response identification is a more complex approach that demands substantial computational resources.

The collapse of the Morandi Bridge in Italy in 2018, shown in Fig. 1, which resulted in international attention and prompted a significant call for improved monitoring of road infrastructures, triggered widespread attention to the formulation of specific guidelines by the Italian Ministry of Infrastructure and Transportations [4, 5]. These guidelines were developed to outline comprehensive monitoring procedures aimed at preventing similar tragedies from occurring in the future.



Fig. 1. Morandi Bridge collapse, Genova, 2018 (source commons.wikimedia).

In this paper, we analyze the development of a non-destructive, rapid, repeatable over time, and highly efficient procedure (low cost and high precision) using the Fast Falling Weight Deflectometer (Fast-FWD) on road reinforced concrete bridges. The FWD, classified by the testing methods used, falls into the category of equipment known as Impact Load Devices (ILD), which evaluate the reactions of a structure in various areas of transport. Typically used in road pavements and airport runways, by applying an impulsive load through the dropping of a mass with known characteristics. The utilization of FWD for assessing stiffness values of pavement structures [6] was introduced in the late 1970s, allowing the evaluation of degradation curves and related maintenance actions.

The instrument records, through specific sensors (geophones), the deflection, understood as temporary deformation in the vertical direction, of the investigated surface. The particular arrangement of the geophones relative to the center of the mass drop

allows for the detection of deflection at various points on the surface at varying distances from the load center, thus enabling the evaluation of a deflection basin. Analysis of the shape and characteristics of the deflection basin allows, through accurate and complex back-calculation models, the determination of the characteristics of the underlying layers including material stiffness. In the literature, there are cases in which the FWD for assessing bridge condition was used. In 1996, a study conducted in Virginia, USA, utilized the FWD to measure deflections on the decks of two bridges [7]. This application likely aimed to assess the structural integrity and performance of the bridges by evaluating their deflection behavior under load. Another case study, conducted in 2001, involved measuring the natural frequency of a bridge using the FWD [8]. This study compared the obtained natural frequencies with previous test results to identify any potential damage or changes in the bridge's structural properties over time. Additionally, there's a suggestion in the literature to employ large impulse sources like the FWD for locating natural frequencies during preliminary vibrating testing of bridges [9]. This indicates a potential application of FWD in the initial assessment stages of bridges to identify their dynamic characteristics.

In 2019, a study was conducted in Sardinia, Italy, focusing on a short single-span bridge exhibiting visible structural damage. Subsequently, in 2021, another study was carried out on a multiple-span bridge in the same region. Both studies employed Fast-FWD technology to assess bridge stiffness, aiming to provide engineers with valuable insights into bridge performance and conditions [10, 11].

This research aims to apply this technology, which is well-established in the field of rigid, semi-rigid, and flexible pavements, to evaluate bridge stiffness across various types of reinforced concrete bridges divided into single-span and multiple-span bridges. There is a need to gather data to gain a better understanding of the potential application of FWD in bridge monitoring, aiming to rapidly assess the degradation status of bridges and viaducts. The paper is divided into five sections. Section 2 elaborates on the proposed methodology, while Sect. 3 demonstrates its practical implementation through a case study. Section 4 presents data analysis based on the obtained results. Lastly, Sect. 5 concludes this study, providing insights into the importance of FWD applications in Structural Health Monitoring (SHM) of bridges, and their potential influence on infrastructure monitoring practices.

2 Methods

2.1 Falling Weight Deflectometer

The Fast-FWD, shown in Fig. 2, is a device used to assess the bearing capacity of pavements, roads, and airport runways. It's particularly useful for evaluating the stiffness and resilience of pavement materials and identifying any structural issues. The operation of the FWD relies on the principle of applying a dynamic load to the pavement through a falling weight. When the weight drops onto the pavement, it creates a localized deformation. Sensors mounted on the deflector measure the pavement's deflection caused by the load. This deflection is directly related to the material stiffness and its ability to support the load [12]. In other words, the stiffer the pavement, the less deflection there will be under the load. The testing process typically involves dropping a known weight from a

specific height onto the surface of the pavement under examination. Geophones measure the speed and extent of the pavement deformation during contact with the falling weight and subsequent rebound.

The information collected by the FWD is used to calculate important parameters such as the pavement's modulus of elasticity, bearing capacity, presence of structural defects, and the depth of the supporting material. These data are crucial for the design and maintenance of road infrastructure, as they help identify pavements that require repairs or replacements.



Fig. 2. Fast-Falling Weight Deflectometer, used in the testing campaign.

In this paper, Fast-FWD is analyzed as a non-destructive and quick test procedure to evaluate the efficiency of short to medium span bridges. The Fast-FWD is an instrument that can produce a broadband dynamic force up to an impact value of 120 KN [13]: the impact is constant and replicable, providing accurate action measures of bridge stiffness in a truly short period (30 ms). The testing campaign involved the investigation of 8 concrete bridges. Figure 3 shows the Fast-FWD in action during bridge monitoring.

Figure 4 displays a typical deflection basin recorded by the geophones following the application of an impulsive load. The profile of deflection is shaped by the characteristics inherent to each layer of the pavement, as well as the magnitude and frequency of the loading [6]. The maximum deflection occurs at the loading point, as measured by the D_0 geophone. In total, 12 geophones were employed throughout the testing campaign.

2.2 Data Acquisition and Analysis

In the evaluation performance of road or airport pavements performance, Fast-FWD results play a crucial role. These assessments often hinge on Deflection Basin Parameters (DBPs), commonly referred to as the "Basin Index" (BI). These indices, namely the Surface Curvature Index (SCI), Base Damage Index (BDI), and Deep Layer Index (DCI), are derived from the maximum deflection values measured at designated distances from



Fig. 3. Fast-FWD performing bridge testing campaign, bridge on road SP 87.

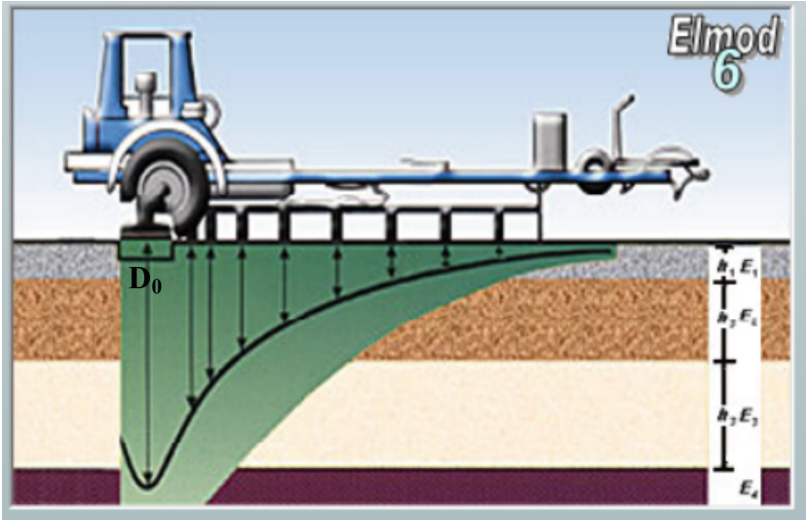

Fig. 4. Deflection Basin and schematic geophones position (source Dynatest operation manual).

the loading mass (expressed in millimeters). They offer valuable insights into the condition of the underlying pavement layers, aiding in the identification of potential issues and guiding maintenance decisions.

The calculation of these indices involves specific formulas:

Surface Curvature Index (SCI):

$$SCI = D_0 - D_{300} \tag{1}$$

Base Damage Index (BDI):

$$BDI = D_0 - D_{600} \tag{2}$$

Deep Layer Index (DCI):

$$DCI = D_{900} - D_{1200} \tag{3}$$

where D_0, D_{300}, D_{600}, D_{900}, and D_{1200} represent the maximum deflection values at respective distances in mm from the loading mass.

These indices serve as quantitative indicators, allowing for a comprehensive assessment of pavement conditions and facilitating informed decision-making regarding maintenance and rehabilitation strategies.

In this paper, the methodology employed to analyze stiffness (K), obtained from the ratio between the maximum applied load (F) and the maximum axial deflection (D_0), which served as a direct measure of local stiffness [10, 11]:

$$K = F/D_0 \tag{4}$$

The tests are conducted at fixed station points strategically chosen to thoroughly assess both the deck, the approach ramp of the bridge, the abutment, and also in correspondence of the beams. The alignment of the support structures of the deck is carefully selected to accurately evaluate the actual constraints experienced. Testing on the approach ramp provides a valuable basis for comparing results obtained from the pavement, without the confounding effects of the bridge deck. This approach allows for the identification of an appropriate survey grid for each specific bridge.

Each station point requires testing in both directions to determine the orientation of the geophone bars effectively. Conducting at least three measurements at each station point, with varying degrees of falling load, is crucial for discerning the mechanical properties of the bridge. Deflection data should be cross-referenced with pavement information gathered through methods such as core drilling and visual inspections with micro-cameras, aiding in the detection and assessment of pavement layer types and thicknesses.

3 Case Study

The testing campaign was conducted, on eight reinforced concrete bridges located in the southern region of Sardinia, Italy. The testing campaign took place over two days. Figure 5 illustrates the precise location of the tested bridges. During the testing campaign, a visual investigation of the structural components was performed and a report was generated detailing any observed defects.

Table 1 provides information regarding the tested bridges. The first column specifies the type of bridge, followed by geometric details such as total length and width. Additionally, the table includes the name of the road to which each bridge belongs, with "SP" denoting a provincial road followed by a number. The initial four bridges feature multiple spans, with lengths ranging from 80 to 98 m, whereas the remaining four are

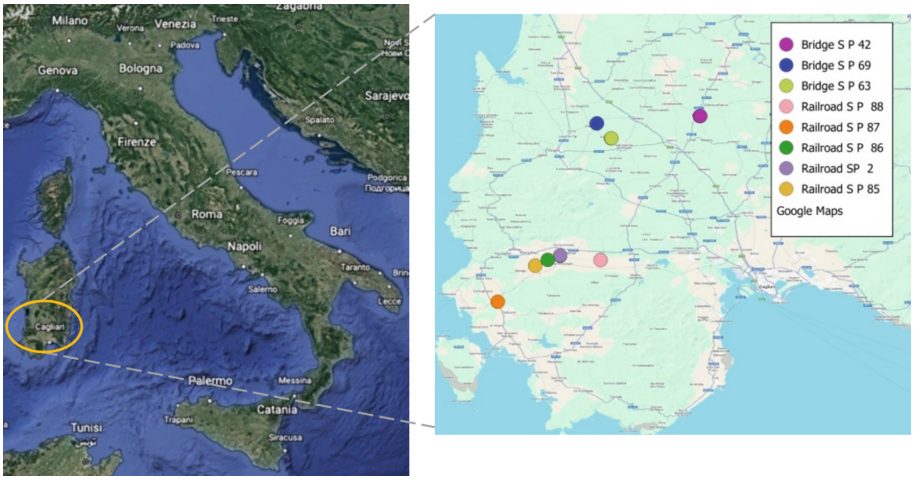

Fig. 5. Position of the eight tested bridges (source Google Maps and QGis).

Table 1. Geometric characteristics and locations of the tested bridges.

Bridge Type	Length (m)	Width (m)	Additional information
n°1. Multiple span beam bridge	80	6.5	Three span bridge road SP 63
n° 2. Multiple span beam bridge	80	5	Three span bridge road SP 69
n°3. Multiple span beam bridge	98	7	Five span bridge road SP 42
n°4. Multiple span beam bridge	90	8	Five span bridge road SP 87
n°5. Single span Arch bridge	11	7	Railway overpass arch bridge road SP 86
n°6. Single span Arch bridge	9	7	Railway overpass arch bridge road SP 85
n°7. Single span beam bridge	11	9	Railway overpass bridge road SP 2
n°8. Single span beam bridge	16.5	9	Railway overpass bridge road SP 88

single span railway overpass bridges. Gathering and comparing data from bridges with different structures is crucial.

Before the testing campaign started, a schematic grid of testing points was established for each bridge, considering the geometrical structure. An example of this can be seen in Fig. 6 regarding bridge n°2. Tests were conducted alternatively on both lanes without the need to close the bridge. Where possible, testing was also performed in the center line. However, conducting tests in the centerline sometimes necessitated the suspension of traffic, which was not always possible due to the volume of traffic. The difference in color of the testing points reported in Fig. 6 considers different testing elements. Tests conducted on the deck are marked in purple, those in correspondence with the beams in

red, and those on the approach ramp in green, for a total of 45 testing points. For each testing point, three load impulses were applied with increasing vertical stress levels of 900, 1200, and 1600 kPa. Also, a view of bridge n°2 can be seen in Fig. 7.

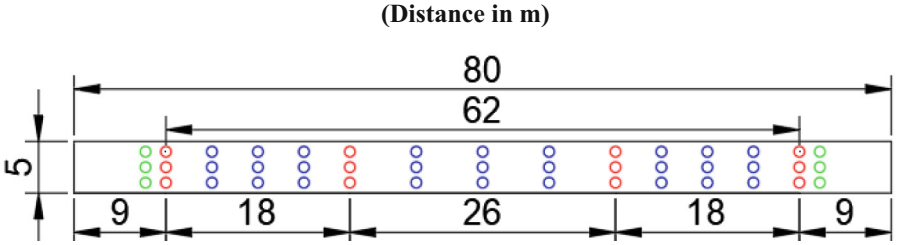

Fig. 6. Schematic positioning of testing points on Bridge n°2 along SP 69 road (Cad.Drawing)



Fig. 7. View of bridge n°2 on road SP 69 (source Google Earth).

Table 2 reports the number of testing points conducted on each bridge and the number of alignments performed, specifying the locations of the alignments, encompassing both lanes and, when possible, on the centerline.

4 Data Analysis

A summary of the stiffness values for the first four multiple span bridges is reported in Table 3. Reporting both average values and standard deviation for each of the tested elements. Stiffness values were calculated using equation n°4, where F represents the maximum applied load of 1600 kPa and D_0 denotes the maximum deflection measured in μm.

Table 2. Testing procedure information.

Bridge Type	Tested points N°	Alignments N°	Position
n°1.Multiple span beam bridge	45	3	2 lanes and centerline
n° 2. Multiple span beam bridge	45	3	2 lanes and centerline
n°3. Multiple span beam bridge	81	3	2 lanes and centerline
n°4. Multiple span beam bridge	46	2	2 lanes
n°5. Single span Arch bridge	14	2	2 lanes
n°6. Single span Arch bridge	14	2	2 lanes
n°7. Single span beam bridge	14	2	2 lanes
n°8. Single span beam bridge	15	2	2 lanes

Table 3. Stiffness (K) values for each tested element of multiple span bridge.

Bridge	Deck mean K (GN/m)	Deck STD K (GN/m)	Beam mean K (GN/m)	Beam STD K (GN/m)	Approach Ramp mean K (GN/m)	Approach Ramp STD K (GN/m)
n°1	0.41	0.08	0.61	0.38	0.26	0.03
n° 2	0.32	0.07	0.61	0.28	0.24	0.06
n°3	0.46	0.25	1.13	0.60	0.09	0.02
n°4	0.33	0.10	0.67	0.28	0.30	0.04

To better understand the variation of the mean stiffness values, they have been graphically depicted for each element of the four bridges, see Fig. 8. Upon initial examination, it becomes apparent that the mean stiffness values for the beams are higher compared to those of the deck and approach ramp, which exhibit lower stiffness.

Also to better understand the variability of the data the ratio between the standard deviation and the mean values was calculated and is reported in Table 4.

The variability in data is significantly higher for the beams in comparison to the deck, whereas the approach ramp displays the least variability along with the lowest stiffness values.

A similar analysis was conducted for the remaining four bridges detailed in Table 5, with the first two being arch railway overpass bridges and the remaining two being single span bridges.

To better analyze the trend of mean stiffness values, for each element of the four bridges they have been depicted on a chart in Fig. 9.

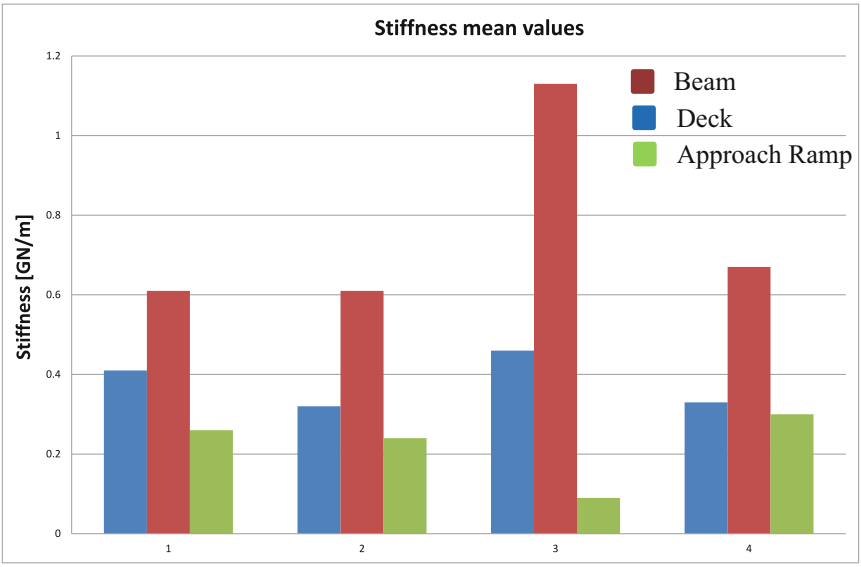

Fig. 8. Average stiffness values for each element of the four tested multiple span bridges.

Table 4. Variability of the data.

Bridge	Deck STD/mean K (GN/m)	Beam STD/mean K (GN/m)	Ramp STD/mean K (GN/m)
n°1	0.19	0.63	0.13
n° 2	0.21	0.45	0.26
n°3	0.55	0.53	0.27
n°4	0.32	0.42	0.14

It can be seen how the higher values of stiffness are those of the abutment of the single span bridges while the arch bridges have much lower values. Overall mean values for each of the tested elements are higher in the single span bridges. In Table 6 the variability of the data is reported and compared. In most cases, it can be seen that for each element the variability is quite similar in the four bridges.

Comparing stiffness variability between multiple span bridges and single span ones reveals that multiple span bridges often display significantly greater variability in data.

Attention was focused on the stiffness values of single span bridges, analyzing the deck values and the exact testing positions marked in purple. The following figures: Figs. 10, 11, 12, and 13, illustrate the test positions on the deck along with the corresponding stiffness values reported in GN/m.

Table 5. Stiffness (K) values for each tested arch and single span bridge.

Bridge	Deck mean K (GN/m)	Deck STD K (GN/m)	Abutment mean K (GN/m)	Abutment STD K (GN/m)	Approach Ramp mean K (GN/m)	Approach Ramp STD K (GN/m)
n°5	0.27	0.09	0.20	0.04	0.17	0.03
n°6	0.23	0.04	0.21	0.04	0.39	0.07
n°7	0.33	0.08	1.08	0.23	0.37	0.07
n°8	0.37	0.04	1.32	0.33	0.54	0.22

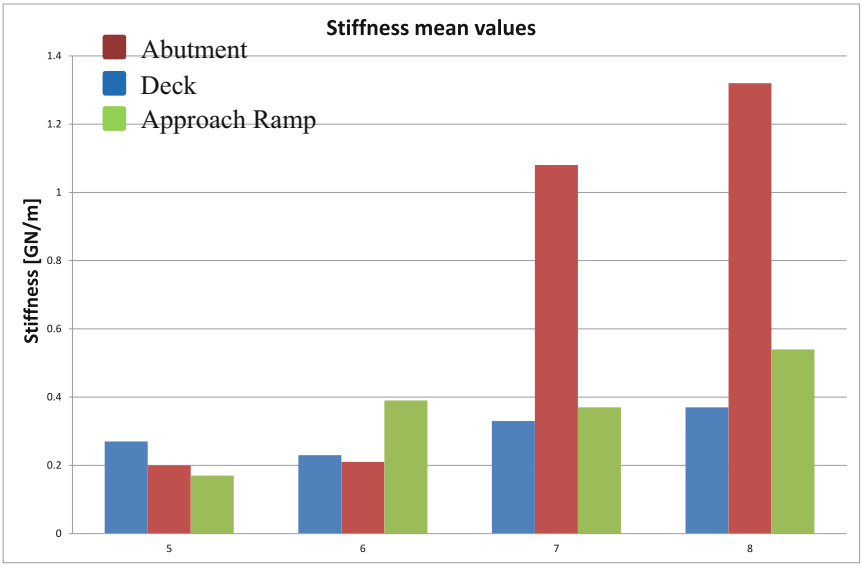

Fig. 9. Average stiffness values for each element of the four bridges.

Table 7 summarizes the values of stiffness measured on the bridge deck of the remaining four tested bridges.

Table 6. Variability of the data.

Bridge	Deck STD/mean K (GN/m)	Beam STD/mean K (GN/m)	Ramp STD/mean K (GN/m)
n°5	0.33	0.19	0.19
n°6	0.19	0.20	0.19
n°7	0.24	0.21	0.19
n°8	0.10	0.25	0.42

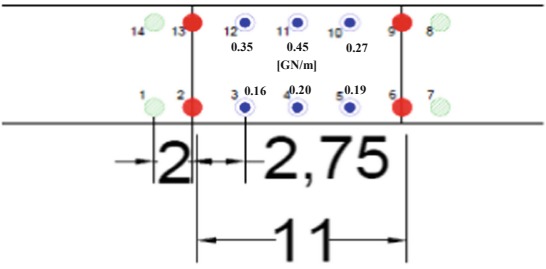

Fig. 10. Single span arch bridge n°5 (Cad Drawing).

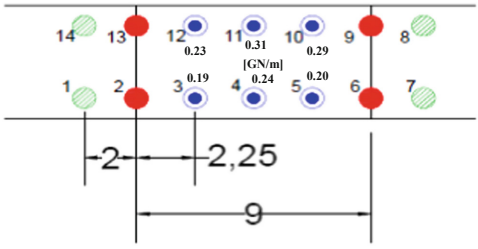

Fig. 11. Single span arch bridge n°6 (Cad Drawing).

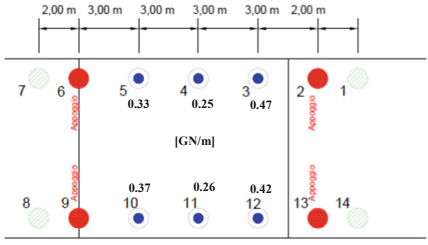

Fig. 12. Single span bridge n°7 (Cad Drawing).

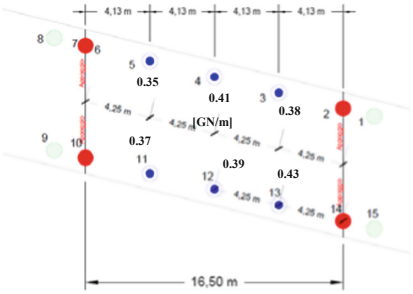

Fig. 13. Single span bridge n°8 (Cad Drawing).

Table 7. Stiffness values of the deck by position.

Bridge	Deck Left K (GN/m)	Deck Center K (GN/m)	Deck Right K (GN/m)
n°5	0.16	0.20	0.19
	0.35	0.45	0.27
n°6	0.19	0.24	0.20
	0.23	0.31	0.29
n°7	0.33	0.25	0.47
	0.37	0.26	0.42
n°8	0.35	0.41	0.38
	0.37	0.39	0.43

It is feasible to assess how the two types of bridges respond differently to the applied load impulse. The arch bridges at the center of the deck demonstrates higher stiffness values if compared to those on the left and right sides. Conversely, this consistent trend is not observed in the single span beam bridge; furthermore, an opposite behavior emerges with higher values noted on the left and right sides of the deck when compared with the center.

5 Conclusions

In this preliminary analysis of the obtained data, it can be concluded that the utilization of Fast-FWD for screening existing reinforced concrete bridges offers a promising method for quickly evaluating their vulnerability. Its primary advantage lies in the minimal disruption it causes and the brief duration needed to gather both static and dynamic structural data. This suggests the potential use of Fast-FWD tests for regular monitoring of bridges and viaducts. Monitoring changes in parameters such as deflection basin and

stiffness over time provides valuable insights into how aging or other factors affect the structures.

The data analysis comparing multiple span bridges to single span ones clearly shows that multiple span bridges display greater variability in stiffness values across each tested element. Specifically, multiple span bridges exhibit higher stiffness values in the beams, and expected structural response, while the deck and approach ramp indicate lower values, with the approach ramp displaying the lowest values and minimal variability. Hence, to gain deeper insights into this behavior, it's essential to test as wide a range of bridge types as possible, underscoring the importance of case studies.

However, single span bridges display different behaviors. In the case of the two single span arch bridges, stiffness values are higher in the central portion of the deck, while they are lower on the left and right sides. Conversely, in the two single span beam bridges, one bridge exhibits larger stiffness values at the left and right sides and smaller values in the central portion of the span, while the other bridge does not demonstrate this type of behavior.

Further examination of the acquired data is imperative to gain a deeper understanding of the behavior of the tested bridges. This involves analyzing not only the obtained stiffness values but also assessing linearity behavior to identify any notable structural degradation. Due to the complexity of bridge structure behavior, it's crucial to broaden our scope by conducting multiple testing campaigns across a diverse range of bridge types. By doing so, we can ensure a more thorough understanding of bridge performance under various conditions.

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Evaluation of Utility Cut Patching on Pavement Structure

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Abstract. Utility Cut Patching (UCP) typically involves cutting road pavement, often with subsurface excavation, and patching works related to utility pipeline maintenance. UCPs disrupt the static behavior of pavements, causing cracking and altering their impermeability and adherence. Generally, there is poor quality control of UCPs, leading to rapid degradation of pavements within a few years, which has severe impacts on traffic quality and safety. This paper presents a case study of a bidirectional urban road where a water pipeline has been constructed in one of the two lanes. The rapid deterioration of the lane was investigated using in-situ nondestructive FWD deflectometric testing, comparing its structural quality with the adjacent pavement not affected by the works. A total of 312 tests were conducted at 80 locations, 40 for each lane, with a 20.0 m pitch by repeating the measurements for 3 stress levels. The analysis results show how the pavement subjected to UCP increases its deformability by about 25%, with less homogeneous and highly variable values. The coefficient of variation is 40% for all layers of the pavement without UCP, while in the one with UCP it is increased by 116% in the HMA, 73% in the foundation, and 58% in the subbase. Further analysis was performed using FE simulations to investigate the effect of the load position with respect to the UCP. Similar maximum deflection values occur in a large range of position while highest horizontal tensile stress peaks occur in the granular foundation when the load is located outside the UCP.

Keywords: Utility Cut Patching · pavement · FWD · maintenance · superstructures evaluation

1 Introduction

The influence of Utility Cut Patching (UCP) on pavement is a complex issue with significant implications for pavement integrity and performance. Maintaining the pavements structural integrity is essential for ensuring safe and efficient traffic flow.

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However, routine maintenance and repair activities, such as UCP, can significantly influence pavement structure and its performance. UCP involves cutting road pavements to facilitate subsurface excavation for utility pipeline maintenance, followed by patching to restore the pavement surface. These activities disrupt the static behavior of pavements, leading to cracking and alterations in impermeability and adherence [1].

Despite the importance of UCPs in utility infrastructure maintenance, several studies report lack of quality control in their execution [55–58]. These studies highlight that often the frequency and type of inspections are inadequate, especially regarding the material compaction. This deficiency often results in rapid degradation of pavements within a few years, with adverse consequences for traffic quality and safety [2]. The UCPs can accelerate pavement deterioration in urban area, increasing maintenance costs for municipalities [3]. Some researchers highlighted the need for a management system to address this problem [4]. Jensen in 2005 identified factors contributing to settlement in and around utility cuts, including fill material and construction practices.

Recommendations include the need for greater control of the moisture content of the remnant material, which should be similar to the natural material to avoid the phenomena of swelling and shrinkage. It is also indicated that the material should be compacted with the relative density greater than 65%. In addition, compaction should be done with a vibrating plate, both in the excavated and cut area [5]. Some studies using FWD (Falling Weight Deflectometer) have analysed pavement deterioration, finding that the deflection value at the patch centre is critical, resulting $\approx$ 1.8 times the average deflection at existing pavement. Moreover, the deflection depends on trench geometry and pavement condition and, as the width increases, the deflection decreases at a diminishing rate [6]. This effect's magnitude depended on climate, traffic loadings, pavement patching procedure, and pavement condition at the time of patching [7]. Others investigation pointed out how a way of reducing the negative impact on traffic networks can be achieved harmonization design, development and operations for attaining sustainable improved movement and safety, for easier maintenance and minimize relocation cost of users and road authorities [8]. These reasons many road authorities have investigate how control and reduce the UCPs impact on pavements [9, 11–13].The systematic literature review, conducted according to PRISMA [59] methodology, returns 260 relevant studies on UCP of pavement. The Fig. 1 summarizes the results of the most pertinent studies.

The 63 most relevant ones were analyzed in detail [1–58]. The review identifies key factors influencing UCPs, evaluates its impact on pavement performance, examines assessment methods, explores mitigation strategies, and highlights directions for future research. In a recent paper [14], the finite element method (FEM) has been employed to analyze the mechanical response of superficial asphalt pavements patched with different shapes of patches (rectangular, stair, and trapezoidal). Pavement with rectangular patches was found to be the most vulnerable to Top-Down and Bottom-Up crack propagation, while stepped and trapezoidal patches can effectively mitigate stress-induced cracking of the asphalt surface layer. Opposite behavior concerns thermal FEM simulation where cracking is less critical for rectangular patching. The study remains limited to the surface bituminous layers, and it would be interesting to extend it to the lower layers (base, foundation and subgrade) as well.

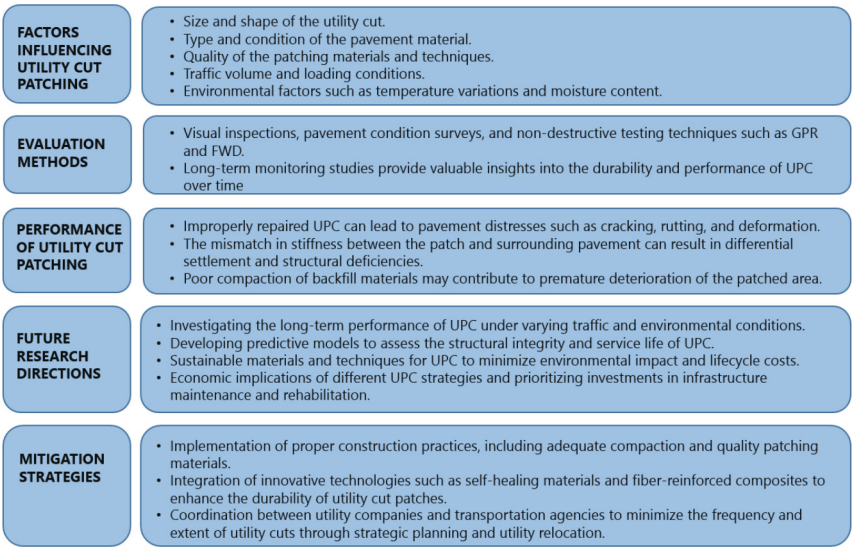

Fig. 1. The findings of the PRISMA systematic literature review

This paper present a case study of an evaluation method of before/after UCP on pavement structure through a FEM simulation and FWD tests in situ. The research was conducted under the specific geographic, climatic, and traffic conditions of the site but can be easily implemented in other contexts. An extensive campaign in a variety of other situations would be highly beneficial for network managers in defining thresholds and parameters of acceptability in quality control procedures. In this perspective, the FHWA (Federal Highway Administration USA) developed a comprehensive manual in 2018 [9] addressing UCP issues in an integrated manner. The document was created to provide information to managing entities aiming to protect and control their infrastructures. On the policy side, various types of policies and regulations are presented, along with case studies and standard regulations. The technological part of the manual offers a brief overview of various trenchless technology methods, their advantages and disadvantages, and other relevant information on implementing this technology in UCP construction. The FHWA views the manual as a starting point for a comprehensive investigation into the types of policies and technologies available to control and reduce UCP-related issues, encouraging researchers and professionals to implement, experiment with, and develop their own policies, regulations, and specifications.

2 Case Study

In the year 2019, a 3.8 km segment of the provincial road SP17 was subject to construction activities for the installation of a water pipeline (Fig. 2).

At a depth of 140 cm within the excavation, a 15 cm layer of sand bedding was laid, serving as a foundation upon which a pressurized pipeline with a diameter of 25 cm was positioned. The excavation, measuring approximately 70 cm in width, was reinstated in

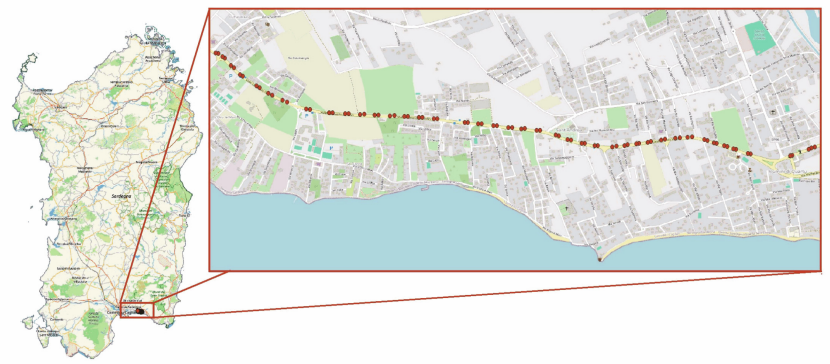

Fig. 2. Provincial road SP17 in Sardinia (Italy) subject to UCP for the installation of a water pipeline

the subgrade using the same material as that excavated. Simultaneously, the pavement underwent reconstruction employing identical thicknesses and materials as the original structure detected during excavations: 20 cm of unbound granular mix and 20 cm of Hot Mix Asphalt (HMA), consisting of a 10 cm base layer and 10 cm surface layers.

Compaction of both the subgrade and granular layers was achieved through the use of a vibrating plate, while the asphalt conglomerates were compacted using a small roller weighing 600 kg and with a width of 60 cm. Figure 3 depicts the cross-sectional view of the excavation and FWD position tests over and outside of the UCP.

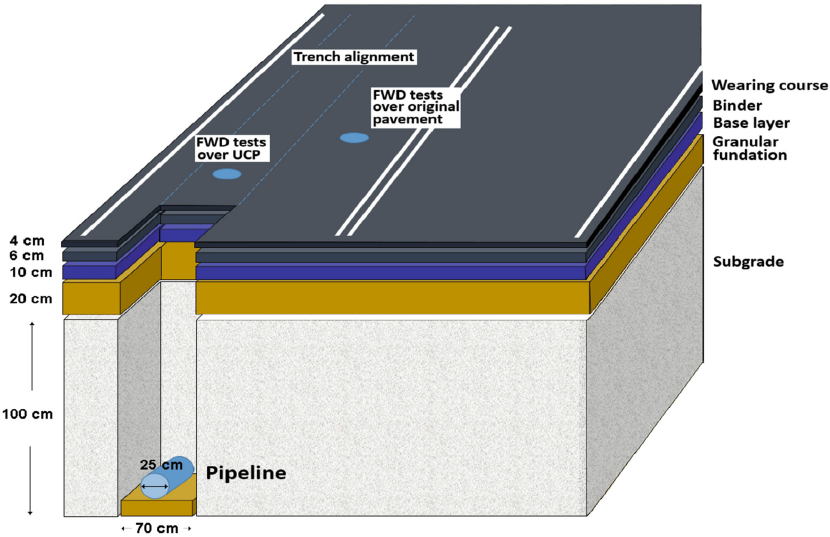

Fig. 3. The cross-sectional view of the excavation and FWD position tests over and outside of the UCP.

3 Research Methodology

First, a series of tests were conducted using the Falling Weight Deflectometer (FWD) to evaluate whether and how a pavement loses structural capacity following the construction of a road cut. The same tests have been used to validate a finite element simulation. The model was subsequently modified to verify the effect of the transversal position of the wheel path respect to UCP.

FWD deflection tests.
The Falling Weight Deflectometer (FWD) is commonly utilized for the investigation of road and airport pavement structures (see Fig. 4). It consists of a falling mass that can be adjusted within the range of 50 to 350 kg, imparting a load impulse spanning from 40 to 120 kN. This load impulse is transmitted through a circular steel plate, measuring 300 mm in diameter, which is strategically divided into four circular sectors to ensure optimal conformity with the pavement surface. Ten geophones are positioned in a line over the pavement, automatically preceding the mass drop, to measure the deflection basin. The impulse duration is 30 ms, while the geophones record within a range of 60 ms with an accuracy of 0.05 μm. The measurements, repeated at 900, 1200 and 1500 kPa, are very fast since the procedure requires about 1 min for a single station point. The shape and slope of the deflection basin are well correlated with the stiffness of the material in each single layer, and numerous parameters have been proposed and investigated to understand pavement response. For these reasons, many road and airport authorities adopt specific techniques and deflection parameters in the process of quality assurance (QA) of the pavements construction and maintenance.

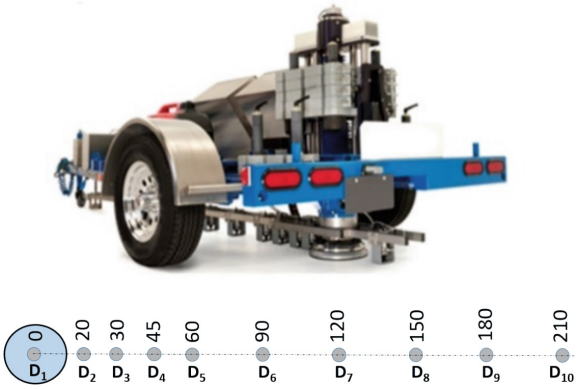

Fig. 4. The fast-FWD and the ten geophones positions

The measurements were analyzed using ELMOD6 software for inverse backcalculation analysis, estimating pavement layer stiffness and thickness from deflection data obtained from FWD testing. Initially, deflection basin data, pavement temperature, and loading conditions are input into the software. It iteratively adjusts pavement layer properties until calculated deflection closely matches measured deflection, employing algorithms like layered elastic theory or finite element analysis.

Output includes estimates of layer stiffness, thickness, and other pavement properties crucial for design, rehabilitation, and management decisions. Backcalculation provides a non-destructive, cost-effective method for accurately assessing pavement structural condition in pavement engineering. In particular, through backcalculation, the elastic moduli of materials were evaluated. For this purpose, the pavement was schematized as composed of three layers: 20 cm of HMA, 20 cm of granular mixture foundation, and subgrade. In addition, from the raw FWD data acquired, it is possible to obtain particular indices, called Basin Indexes, which are well correlated with the stiffness of the layers. Those considered relevant for the trials were:

- Base Layer Index BLI = D_0 –D_{300} correlated with bituminous layer stiffness
- Middle Layer Index MLI = D_{300} –D_{600} correlated with granular fundation stiffness
- Lower Layer Index LLI = D600 –D900 correlated with subgrade stiffness

The measured and backcalculated data allowed for the validation of a 2D finite element model in the elasto-plastic field.

FEM simulations

The Finite Element Method (FEM) is a widely employed numerical technique for intricately evaluating the mechanical response of structures. Initially, the system is discretized into small and simple elements. This is followed by solving the corresponding partial differential equations and connecting them through common nodes. This approach, coupled with graphical modelling of results, effectively visualizes the mechanical behaviour within materials. Consequently, FEM is universally acknowledged as an effective tool in pavement design, facilitating detailed analyses without excessive labour or high costs. The predictive quality of simulations hinges on the accuracy of the model, particularly the size of finite elements, which exponentially increases computational cost. Furthermore, accurately describing the constitutive behaviour of the materials is crucial. Considering elastic road materials may suffice only if material stress levels remain far from plasticity and load application times are rapid. The Drucker-Prager constitutional model was used in order to simulate the non-linear behaviour of the granular and cohesive soil of the foundation. For these reasons, the Drucker-Prager constitutive model was used to simulate the nonlinear behaviour of the granular and cohesive soil materials. The simulation process proceeds step by step, verifying at each iteration the attainment of an equivalent stress value, equal to:

$$\sigma_t = 3\beta\sigma_m + \left[\frac{1}{2}\{s\}^T[M]\{s\}\right]^{\frac{1}{2}} \tag{1}$$

with:

$$\sigma_m = \tfrac{\sigma_1+\sigma_2+\sigma_3}{3},\ \{s\} = \{\sigma\} - \sigma_m[1\ 1\ 1\ 0\ 0\ 0]^T \text{ and } [M] = \begin{bmatrix} 1&0&0&0&0&0\\ 0&1&0&0&0&0\\ 0&0&1&0&0&0\\ 0&0&0&2&0&0\\ 0&0&0&0&2&0\\ 0&0&0&0&0&2 \end{bmatrix}.$$

Knowing the values of the angle of friction (ϕ) and of cohesion (c), it is possible to estimate the parameter β and the value of the ultimate tensile strength:

$$\beta = \frac{2\sin\varphi}{\sqrt{3}(3-\sin\varphi)} \tag{2}$$

$$\sigma_y = 3c\beta\text{cotg}\varphi \tag{3}$$

Figure 5 show the conical shape of the breaking surface defined in the Drucker-Prager model, which coincides with the hexagonal breaking surface of Mohr-Coulomb.

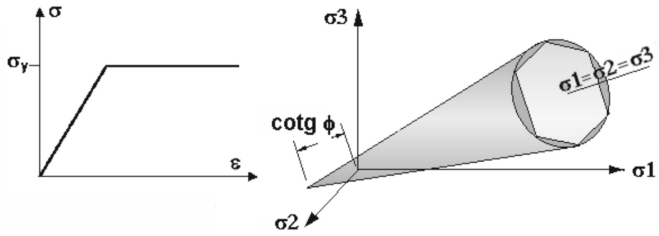

Fig. 5. Breaking surface of Drucker-Prager model

Once the plastic state is reached, the material flows, incapable of assuming ulterior stress states. Thus the stress is transferred to the adjacent zones that, depending on both the stress level and mechanical characteristics, can get plasticized. Therefore, it forms a plasticized volume that grows until reaching equilibrium that, in case of excessive stress levels, could not be achieved. On Table 1 are reported the values used for the FE simulation.

Table 1. Material parameters used for finite element model

Layer	Modulus Elasticity MPa	Coefficient of Poisson	Angle friction °	Cohesion MPa	Bulk weight KN/m^3	Drucker-Pragerσy MPa
HMA	3000	0.35	45	1.2	20	3.600
Foundation	300	0.4	35	0.04	19	0.1714
Subgrade	40	0.42	30	0.02	18	0.1039

The rectangular shapes of the asphalt pavement patching and pavement without UCP were simulated using FE analysis, implemented with ANSYS/Mechanical APDL 18.1 software, to evaluate the effect of the load position with respect to the UCP. Figure 6 shows details of the FE mesh and model dimensions. Contact materials have been introduced on the cutting interface to simulate the loss of mechanical characteristics of the materials introduced during roughening: 50% for the HMA and 30% for the granular foundation material. A 15% reduction in characteristics was considered for the subbase.

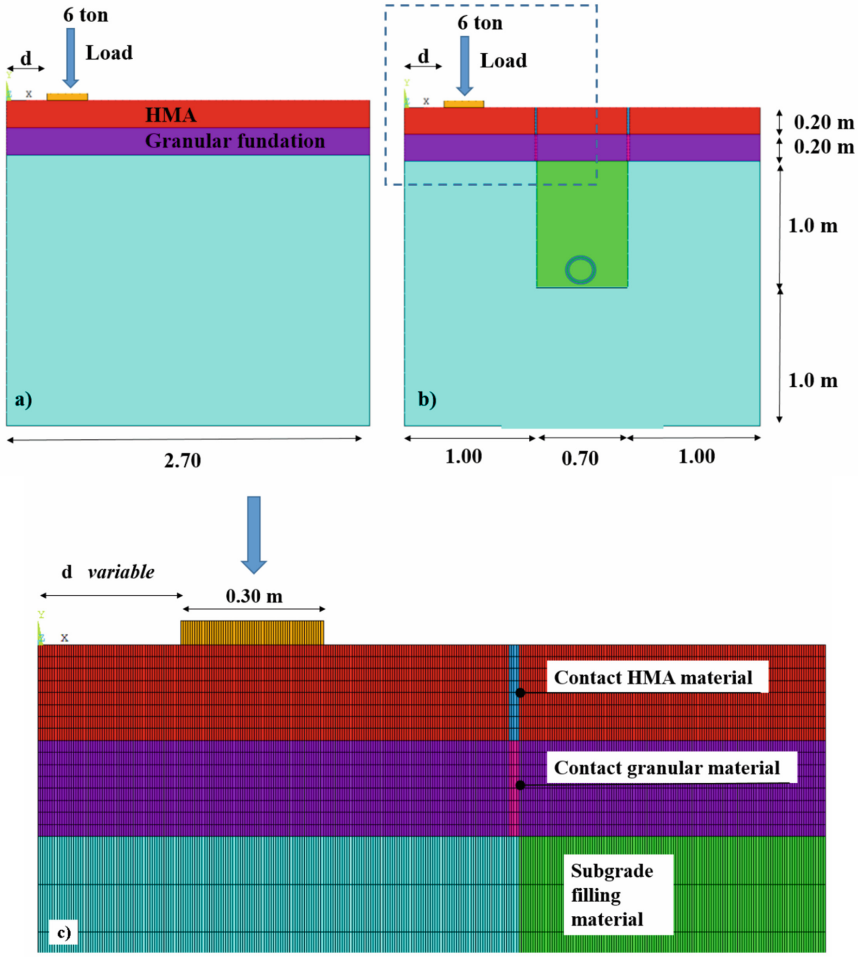

Fig. 6. Details of the FE mesh and model dimension: a) Original pavement without UCP; b) Pavement with UCP; c) contact materials are introduced in the cutting interfaces

4 Results

FWD deflection tests.

The results of the FWD test analyses are shown in Fig. 7. The two alignments tested with and without UCP were compared along the lane progression in terms of maximum deflections and deflection basin regularity. A greater variability is evident in the tests involving pavement with UCP compared to those where it is absent.

The average value of maximum deflection is 507 μstrain in the pavement without UCP, while in the one with UCP, the value increases to 633 μstrain, with a 24.9% increase. The mean BLI, correlated with the stiffness of the HMA, increases from 149 μstrain to 172 μstrain, with a 16% increase in deformability. Similarly, the deformability of the granular foundation and subbase increases. Mean MLI increases from 125 μstrain

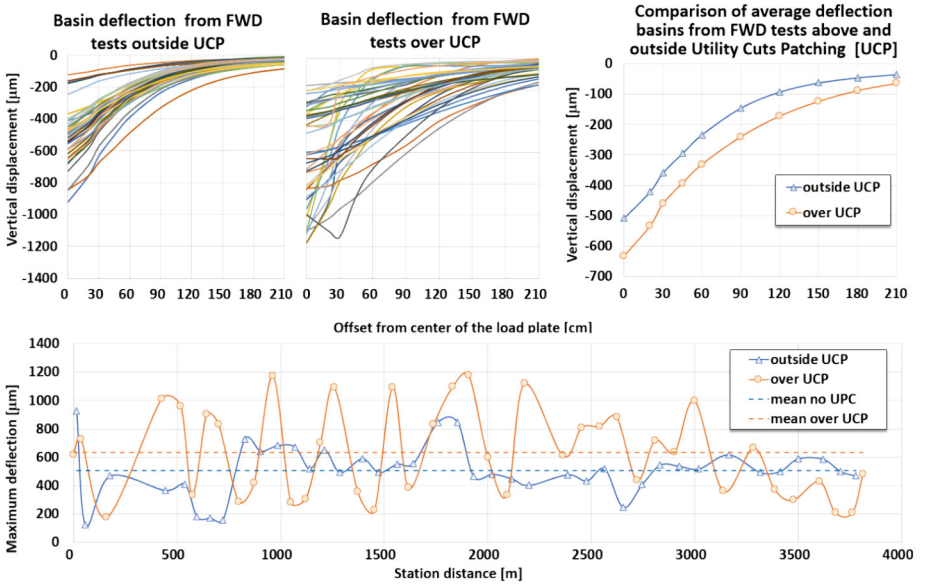

Fig. 7. FWD test results. **On the top**: The set of all deflection basins of the pavement with and without UCP, and the comparison of the mean deflection basins. **On the bottom**: the maximum deflections along the FWD tests alignments

to 129 µstrain, and mean LLI from 89 µstrain to 91 µstrain, with increases of 4% and 2% in deformability, respectively.

The increased variability in the response of the pavement with UCP is also evident in the results of the BLI, MLI, and LLI indices (Fig. 8). The coefficient of variation increases from 40% to 116%, from 40% to 73%, and from 37 to 58%, respectively. The high variability affected the backcalculation of the pavement with UCP, which resulted unreliable. The values of the moduli obtained for the pavement without UCP were 6227 MPa for HMA (T_{ref} 14 °C), 798 MPa for the foundation, and 148 MPa for the subbase.

FEM simulations

The simulation of the pavement without UCP was validated by introducing the values of the average modulus of the materials obtained from backcalculation of FWD deflection tests in situ, reproducing the deflection basin most similar to the average one found in the tests. Subsequently, the FE model was modified to introduce a rectangular cut filled with the same layers and thicknesses of the materials. The interface between the materials present on the edge of the excavation and those of the new filling materials was modelled considering the inability to fully restore the monolithic nature of the structure during filling.

To account for the reduced capacity of the filling materials and those at the interface of the cut, the modulus values were appropriately reduced, based on the fraction obtained in the deflection basin indexes.

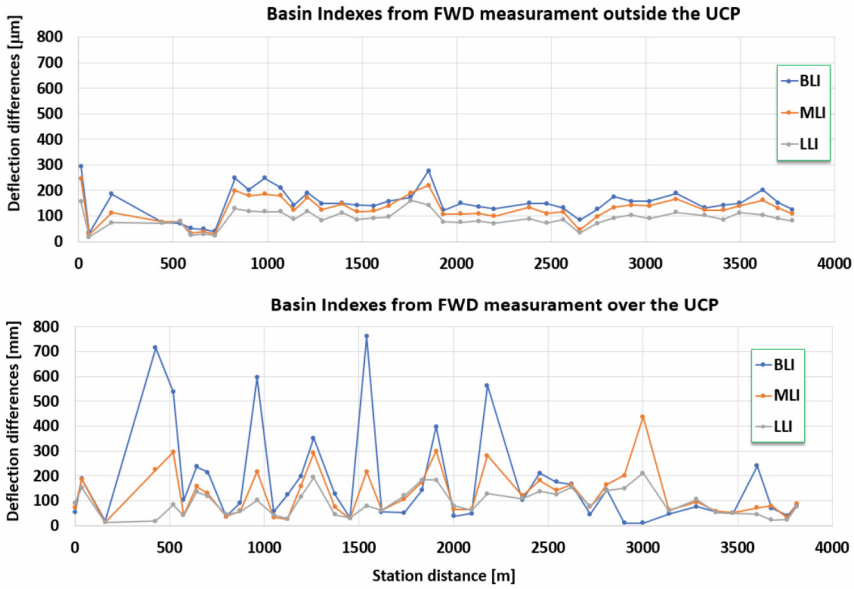

Fig. 8. BLI, MLI and LLI deflection index along the FWD tests alignments

Figure 9 illustrates the distribution of stress and deformation components in the modified model assuming a load positioned above the left joint of the UCP.

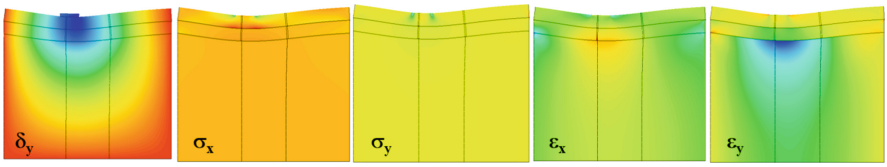

Fig. 9. The distribution of tensile and deformation components δ_y, σ_x, σ_y, δ_x, δ_y

The aim of the FE simulation was to assess the effect of the load position relative to the UCP. For this reason, the load, represented by a circular plate of 0.30 m loaded with 6 tons, was positioned at varying distances from the UCP, deriving the profile below the load axis of displacement components, horizontal stress, and horizontal and vertical deformations (Fig. 9).

The maximum deflection values occur when the load is positioned at the center of the UCP, at 0.49 mm. Values very close to this are also observed for load positions outside the UCP, within a wide range around the UCP. The maximum values of horizontal tensile stress of approximately 0.14 MPa occur in the granular foundation when the load is positioned outside the UCP. Horizontal deformations generally result in tension at the base of the HMA with maximum values when the load is placed at the side of the UCP (157 µstrain). Lower values are obtained when the load is positioned at the center of the

UCP. Finally, vertical deformations reach maximum values (350 μstrain) when the load is positioned above the road cut.

5 Conclusion

UCP is a critical aspect affecting pavement structure, with implications for integrity and performance, especially in terms of traffic safety and efficiency. Lack of quality control in UCP execution often results in rapid pavement degradation, increasing maintenance costs and posing safety risks.

The paper emphasize the need for management systems to address UCP-related issues, by employing FWD deflection tests and Finite Element simulation.

A systematic literature review identifies key factors influencing UCP, its impact on pavement performance, assessment methods, mitigation strategies, and future research directions. Results indicate increased pavement deformability and variability due to UCP, affecting pavement performance and reliability.

FEM simulations illustrate the effect of load position relative to UCP on pavement stress, deformation, and deflection. Maximum horizontal tensile stress occurs in the granular foundation when the load is positioned outside the UCP, while horizontal deformations result in tension at the base of the HMA, with variations depending on load position.

The main specific results of the study are:

- the FWD tests show greater variability in pavement performance with UCP compared to those without it;
- the maximum deflection in pavement without UCP averaged at 507 μstrain, while with UCP, it increased to 633 μstrain, marking a 24.9% increase;
- BLI, MLI, and LLI, correlated to the deformability of HMA, foundation, and subgrade, respectively increased with UCP by 18.3%, 3.5%, and 2.4%;
- the higher variability in results with UCP affects the reliability of backcalculation;
- In the finite element simulation under a load of 6.0 tons, the highest horizontal tensile stress of approximately 0.14 MPa is observed in the granular foundation when the load is positioned outside the UCP. Additionally, the maximum deflection reaches 0.49 mm.
- The vertical deflection peaks at 350 μstrain when the load is directly above the road cut, while horizontal deformations induce tension at the base of the HMA, with maximum values occurring when the load is positioned at the side of the UCP.

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Towards the Development of Injury Matrix: Preliminary Analysis Through Multi-body Codes for Vulnerable Users

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Abstract. In an era where cities worldwide advocate for walking and cycling as sustainable modes of transportation, concerns over the safety of pedestrians, cyclists, and e-scooter riders have intensified. This paper delves into the pressing issue of pedestrian accidents, which continue to pose significant challenges despite legislative and technological advancements. Drawing from a study conducted in literature, data analysis reveals a heightened risk of collisions between pedestrians and cyclists. Such collisions often result in severe injuries or fatalities for pedestrians, underscoring the urgent need for further research and interventions to mitigate these risks. Parameters such as peak head velocity, Head Injury Criterion (HIC) values, and vehicle stiffness play pivotal roles in evaluating the severity of injuries sustained in such collisions. As cities strive to promote active transportation, addressing the safety concerns arising from pedestrian-cyclist-scooter drivers' interactions remains paramount for enhancing road safety and fostering sustainable urban mobility.

The aim of this research is to investigate the injuries suffered by vulnerable road users due to accidents and to provide prediction models that can be used in the new design criteria of transport infrastructures.

Keywords: Sustainable mobility · Vulnerable users · Pedestrian · Collision

1 Introduction

Cities around the world are increasingly trying to promote walking and cycling as healthy and sustainable modes of travel [1, 2]. While such activities are suitable for exercise and reducing greenhouse gas emissions, their growing role leads to concerns for the safety of pedestrians, cyclists, and e-scooter riders.

These users, either because are not protected by external structures (bodywork) or because are mainly made up of children and the elderly, are more exposed to the risks

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deriving from road traffic and these risks can lead, in most cases, to serious injuries or fatalities as a result of road accidents [3, 4].

Despite new legislative efforts and technical improvements, research still needs to address the problem of pedestrian accidents, an issue that still has a heavy negative impact [5].

A study of literature [6] led to the analysis of some data derived from a survey carried out on the population of some Finnish cities. The data collected were used to assess close accidents and/or collisions between pedestrians and cyclists, to assess the frequency of such accidents and to assess the sense of safety of the population. Cycling on pedestrian paths has been found to increase the likelihood of a collision between pedestrians and cyclists. In fact, many studies confirm that sharing space between pedestrians and cyclists can be particularly dangerous [7]. Collisions between these two road users can cause serious injury to the pedestrian, especially due to the secondary impact between the skull of the user concerned and the road surface. In severe cases, this type of impact can even lead to death. Parameters of peak head velocity, HIC values [8–11], and likelihood of severe head trauma can be evaluated. These values are all a function of the speed at which the scooter rider is going and the angle of impact of the accident. As far as the impact with vehicles is concerned, the characteristics of the vehicle itself also become important. Some parts of cars are stiffer than others according to some EuroNCAP [12] motor vehicle safety standards and this aspect of stiffness plays a key parameter in scooter-to-vehicle impacts.

When examining road infrastructure, it is necessary to apply the principles of road safety from a multidisciplinary perspective, thus taking into account all possible road users. In urban areas a very important aspect is to make roads safe, especially for vulnerable users (pedestrians, cyclists and scooter drivers) to encourage sustainable mobility. Very often these users share the space with motorized vehicular traffic or even with each other and this can cause different accidents between the various types of users. Talking about vulnerability and therefore risk is equivalent to talking about an event that intervenes in the Vehicle – Driver – Environment system. Once the risk factors have been identified, it is necessary to assess the number, severity and recurrence of accidental events, as well as the severity of the physical consequences due to the impacts. To do this, it is necessary to have detailed data on the location and dynamics of accidents and the harmful and fatal consequences that are encountered by users. Many times, this data is difficult to find. Therefore, it is necessary to carry out a vulnerability study that sees the definition of the results of an impact and the examination of the phase following it.

The research aims to analyze the dynamics of a vulnerable user's collision, for this purpose, numerical simulations were conducted, through the use of Virtual Crash software, taking into account a pedestrian model with a multi-body system structure, and the vehicle represented as a rigid body. A general presentation of the methodology used for crash simulation is presented. An insight on Multi-Body concepts is reported as it constitutes the mathematical structure for the numerical simulations and a calibration of the methodology is showed. Later on, an extensive sensitivity analysis is showed and obtained results are analysed and commented providing the basis for the development of a vulnerability prediction model.

2 Method

Most accident reconstructions are based on mathematical models, which can provide quantitative results and are able to cover multiple scenarios in a more cost-effectively.

There are several types of pedestrian kinematic estimation:

- Projectile models: in which a pedestrian is assumed to be a point mass;
- Empirical models: described by single-argument regression equations that are based on the statistical approximation of the results of fictitious experiments or analysis of real accidents;
- Two- and three-segment 2D analytical models: the pedestrian body is composed of rigid segments connected with a hinge joint;
- Numerical models;

Empirical and projectile models are the easiest to use, as they are described by single-variable equations that are easily solved. The equations describe the relationship between the speed of impact and the distance of the pedestrian's throw.

Two- and three-segment models are limited to 2D cases and have found limited application in traffic accident analysis.

Numerical modeling, on the other hand, has found ample space in the reconstruction of road accidents and can be used to study impacts under various conditions.

2.1 Multi-body Models

The most common approach to pedestrian modeling is multi-body. The basic principle is to model mechanical systems as kinematic chains consisting of rigid and non-deformable bodies, connected to each other by kinematic torques (kinematic constraints or joints).

The history of multi-body models began in the 1960s when the first numerical simulations of vehicle occupants were created. Currently, the most widely used multi-body bodies are MADYMOs. They are special multi-body simulators mainly used in the automotive industry. There are two types of MADYMO solvers available in commercial distribution. The first is the ellipsoidal model and the second is the faceted model of multi-body rigid bodies. Faceted models are represented by a rigid mesh of faceted surfaces covering rigid bodies with contact forces calculated using the standard multi-body body. Faceted models do not come with controllers and are not scalable, unlike MADYMO multi-body bodies which can be scaled and allow the body to be shaped following human muscles.

Many traffic accident reconstruction and commercial vehicle dynamics programs are equipped with multi-body models of the human body such as: HVE, PC-Crash, Virtual Crash and Cybim V-Sim. The mentioned solvers use a contact algorithm similar to MADYMO, i.e. an algorithm based on the calculation of penetration depth. Multi-body forensic models are simpler than MADYMO models, the main advantage being that they can be scaled to any height and mass. The user can integrate the data collected at the scene during an investigation into the software, create a digital environment of the accident site and simulate the dynamics of vehicle movement using mathematical models of the vehicle's subsystems.

2.2 Virtual Crash

Virtual Crash software [13] has been used as a tool to simulate collisions between e-scooter and pedestrians in different scenarios. Virtual Crash is a well-known impulse moment-based crash reconstruction software that has been widely used in car accident research and by law enforcement agencies in Europe and America. The software is based on Kudlich–Slibar rigid body impulse models [14] and uses mixed Euler and Runge-Kutta numerical integration methods [15]. It is possible to import different models such as CAD of vehicles, pedestrians, terrain and obstacles to be able to reconstruct the working environment in the best way.

The software uses 13 ellipsoidal objects connected by joints to create a ragdoll model of cyclists and pedestrians in which shape, size and weight are adjustable. It is possible to change mechanical properties such as joint stiffness, damping, and postures to create a realistic human model. The models have been adapted to replicate the postures of e-scooter riders and pedestrians.

This software allows to develop a sensitivity analysis with a low computational burden, for this reason it was used for the present research.

2.3 Calibration of the Model Through Literature Data

As a first step, it was decided to replicate studies in the literature in order to calibrate the model and proceed with new simulations.

To reconstruct the vulnerable user's collision phenomena, numerical analyses have been carried out using a pedestrian model based on the multi-body system, while the vehicle has been modelled as a rigid body. The simulations' plan to be undertaken is conveniently reported in Fig. 1. Before commencing the simulations data related to the vehicle characteristics (such as type, speed, trajectory, weight) and to the pedestrian features (such as age, height, mass, speed and initial position about the vehicle) should be primarily evaluated and implemented in the models.

	E-scooter	Pedestrian	Bike	Car
E-scooter		X		X
Pedestrian			X	
Bike				
Car				

Fig. 1. Matrix of simulations carried out.

As far as the pedestrian is concerned, the profiles with the various characteristics are reported in Table 1.

Impact conditions may play a remarkable role in the outcome of a collision. Therefore, according to aforementioned technical literature [16] different impact conditions (namely, angles of impact) were evaluated:

– 0° = frontal impact;

– 0° off-center = off-center frontal impact;
– 90° = side impact;
– 180° = rear impact;
– 180° off-center = off-center rear impact.

Table 1. Anthropometric data for the dummies models used as pedestrian [16].

Profile	Weights (kg)	Height (m)	Body Width (m)	COG Height (m)
Child	34.7	1.367	0.365	0.862
Adult	69.2	1.73	0.460	1.094
Elder	63.2	1.647	0.440	1.035

2.4 Calibration Scenario: E-scooter – SUV

In this analysis, the scenario in which an E-scooter crashes into a car was evaluated. In the analysis, the points of impact against the car, the speed of the scooter, and the posture of the scooter driver were varied. The study by Ptak et al. [17] was followed since the aim of the work is to compare the results obtained by a refined calculation software used by the previously mentioned author and software that uses multi-body models such as VirtualCrash.

In the study, an aluminium scooter model was used, a typical scooter of sharing companies, with a mass of 14 kg.

The rider was modelled as an adult with a height of 174 cm and a mass of 75.7 kg.

The vehicle used for the impact assessment (see Fig. 2.) was defined as an SUV (Sport Utility Vehicle) with an overall mass of 1266 kg.



Fig. 2. Type of vehicle used (SUV).

The first scenario described is that of a side impact between the vehicle and the electric scooter. In this impact, an electric scooter hitting the front of the vehicle laterally on the bonnet was simulated.

In the second and third scenarios, the side impact in the pillar of the vehicle have been evaluated. This configuration was chosen because the side pillar of the vehicle is the most rigid part of it. This scenario has been divided into two positions acquired by the manikin, the first in which the manikin has a fully upright position, and in the second the manikin assumes a slightly bent position.

In the fourth and final scenario, a frontal impact was assessed.

In the first three scenarios, the speed of the electric scooter is assumed to be 25 km/h, while in the last scenario, the speed is reduced to 21.6 km/h. These specific speed values have been established in such way since it is assumed that in side impacts the scooter driver does not notice the arrival of the vehicle, while in frontal impact the speed decreases assuming braking i.e. evasive manoeuvres to avoid the impact with the vehicle by the rider.

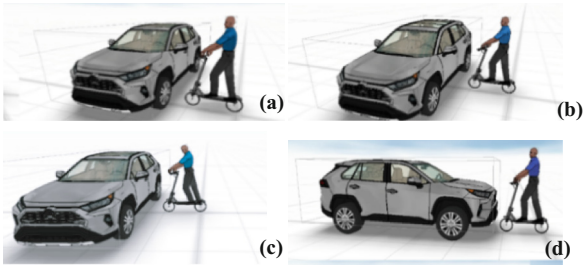

Fig. 3. E-scooter - SUV bonnet Impact a), E-scooter -SUV Side Impact in standing b), E-scooter - SUV Side Impact in folded c) and E-scooter - SUV Frontal Impact d).

In the side impact on the bonnet scenario (see Fig. 3a), the first rider-vehicle contact takes place in the centre of gravity of the dummy. The point of contact between the scooter and the vehicle acts as a pivot point.

In the side impact scenario on the mast in an upright position, (see Fig. 3b), the main contact is between the dummy's legs and the vehicle. The head-neck system is the part that impacts the vehicle with the highest energy, but since the scooter-rider system has a greater height than the vehicle, the rider's head hits the roof of the vehicle and not the pillar.

In the side impact on the pillar in a slightly bent position scenario (see Fig. 3c), contrary to what has been highlighted above, the main impact occurs between the head and the pillar of the vehicle, while the rest of the body has the same behaviour as in the analysis mentioned above.

In frontal scenario (see Fig. 3d), the user maintains kinetic energy and is projected forward. The point of contact between the scooter and the vehicle acts as the dummy's temporary axis of rotation. The dummy rotates around this axis until it reaches the centre of the bonnet where it impacts with its head. However, it can be seen that the main impact is with the rider's torso; then, thanks to this main contact, the head hits the bonnet at a later time.

From the following figures, it is possible to evaluate the head acceleration data and it can be seen that the impact with the pillar in the bent position is the most dangerous compared to bonnet impact (see Fig. 4), side impact in standing (see Fig. 5) and frontal impact (see Fig. 6) because the acceleration of the head reaches values of 900 m/s^2 (see Fig. 7). In this case the handlebars of the scooter act as a pivot point for the rider and provide the reason for increased acceleration by the head when impacting the vehicle.

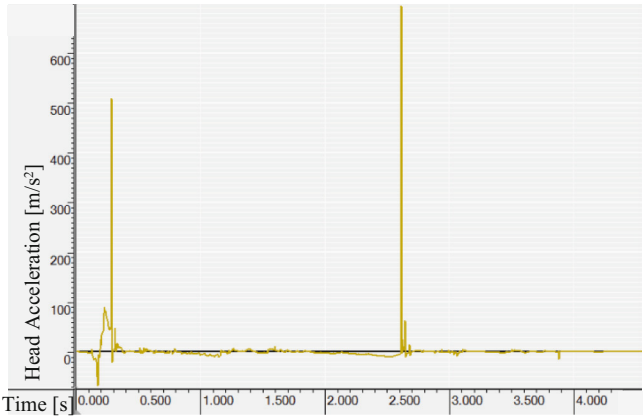

Fig. 4. Head acceleration of e-scooter rider in e-scooter - SUV bonnet impact.

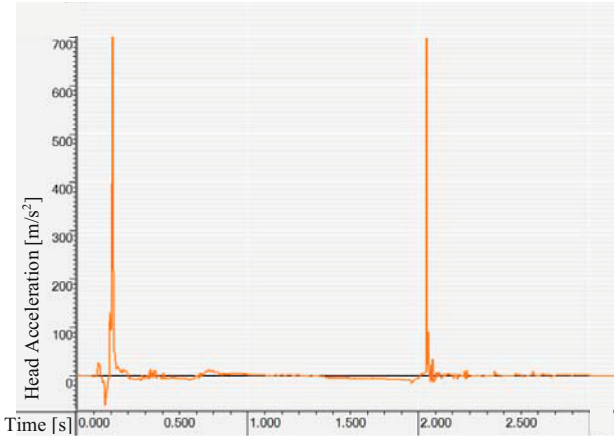

Fig. 5. Head acceleration of e-scooter rider in e-scooter - SUV side impact in standing.

A comparison has been carried out between e the data obtained from the Virtual Crash simulation and the results obtained by Ptak et al. [17] with Madymo in terms of maximum accelerations.

It has to be reminded that the VirtualCrash software uses a multi-body approach whereas the model used by Ptak et al. [17] employs a combined multi-body and finite element numerical model that it is able to take into account for a more realistic deformation in contact area. A question therefore arises whether this different modelling approach may affect the reliability of the results obtained by Virtual Crash.

As can see from the value of Pearson (P) (see Fig. 8) evaluated on the simulations carried out, the calibration is somehow satisfying, so the results obtained with the Virtual Crash software appear to be very similar to those obtained with a more refined numerical

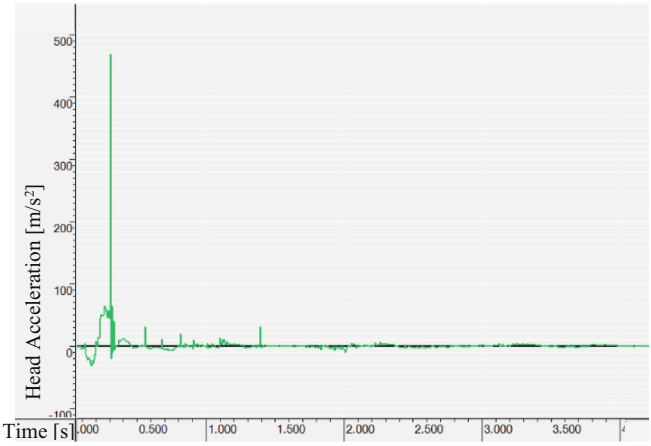

Fig. 6. Head acceleration of e-scooter rider in e-scooter - SUV frontal impact.

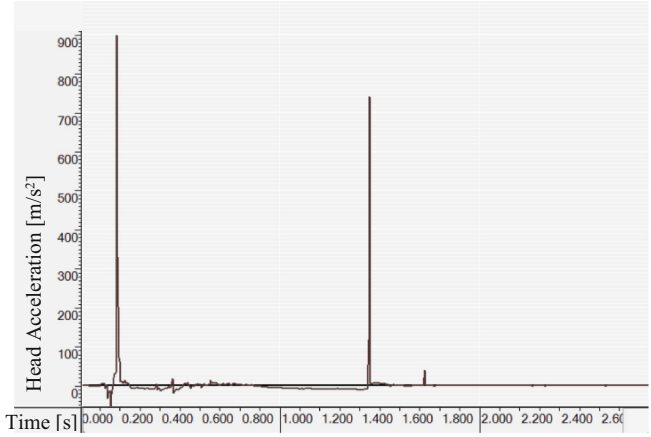

Fig. 7. Head acceleration of e-scooter rider in e-scooter – SUV side impact in folded.

approach (Madymo). As a matter of fact, as regards frontal impact, b-pillar (squat) and b-pillar (upright) impact scenarios (depicted by black circles), the results are comparable. The collision scenario that leads a dramatic decrease of Pearson statistics (down to 0.464) and appears somehow erratic compared with the aforementioned results is that pertaining the impact against the bonnet (see the red circle in Fig. 8). This is probably due to a problem with the car model that is modelled as a rigid body in Virtual Crash unlike what happens in Madymo where deformation of the car bodywork is taken into account. In frontal impact, when the rider hits the bonnet, this latter should deform and plasticize thus allow energy to be dissipated, whereas in the rigid a significant increase in the acceleration suffered by the e-scooter's rider can be registered. On the other hand, this problem does not occur for the other impact scenarios as they occur at points of the car that are already much less deformable by themselves.

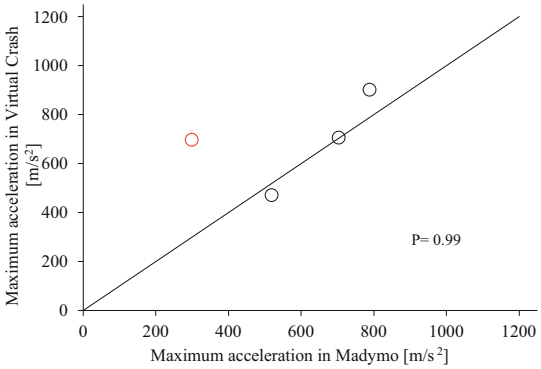

Fig. 8. Calibration between Maximum acceleration in Virtual Crash and Madymo the Pearson coefficient value, P, for the comparison between maximum acceleration values provided by both simulation software (black dots) is also conveniently reported.

3 Simulation of E-scooter – Pedestrian Accident

Soft mobility is implying an increasing interaction with various traffic components, including pedestrians and scooter riders. Therefore, it was decided to investigate the dynamics of collisions between these two vulnerable road users. In the technical literature the most relevant parameter used to determine the injury suffered by the pedestrian is the HIC (Head Impact Criterion, or Criterion of Traumatic Brain Injury) [8–11].

This criterion for assessing head injuries, which are the most serious compared to other parts of the body, following an accident between a pedestrian and a vehicle is based on the evaluation of the actual deceleration of the braincase following an impact, by means of the following relationship:

$$HIC = \max\left[(t_2 - t_1) \cdot \left(\frac{\int_{t1}^{t2} a(t)dt}{t_2 - t_1}\right)^{2.5}\right] \tag{1}$$

where:

- a represents the acceleration over the time interval;
- t_2 e t_1 represent the time interval that maximizes the average deceleration.

The equation proposed above can be simplified as a mass-spring model [16]:

$$HIC = K * V^{2.5} \tag{2}$$

Where:

- K is a constant of proportionality equal to 33.93;
- V is the maximum velocity of impact (m/s);

HIC values (dimensionless) can be converted to assess the likelihood of serious injury using the AIS scale. This probability can be assessed through the following relationship for AIS4:

$$Probability\ of\ \ injur = \frac{1}{\left[1 + exp\left(\left(\frac{4{,}9+200}{HIC}\right) - 0,\ 00351 \cdot HIC\right)\right]} \tag{3}$$

This relationship uses the maximum head-to-ground impact velocity from crash test simulations to estimate HIC values. The HIC values are then used to estimate the likelihood of severe TBI (Traumatic Brain Injuries) based on the AIS abbreviated injury scale (see Fig. 9). This establishes a relationship between the vehicle's collision speed and the likelihood of serious head injuries.

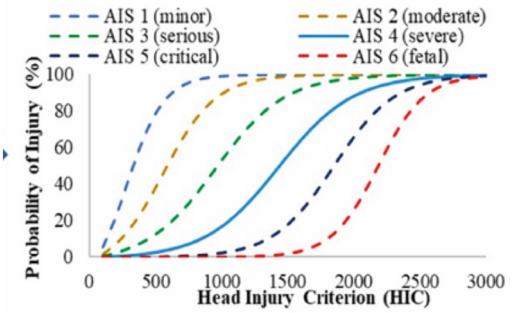

Fig. 9. Scale of AIS proposed in Prasad and Mertz and reported in Paudel et al. [16].

By varying the speed of the scooter, the pedestrian anthropometric properties, the scooter models and collision conditions an overall amount of 180 simulations were carried out.

As far as pedestrian anthropometric properties are concerned, reference is made to Table 1. The rider, on the other hand, was modelled as an adult with a height of 175 cm and a weight of 75 kg.

The angles of impact were: 0°,90°,180°,0° off,180°off.

As far as scooter models are concerned, the different technical characteristics of the scooters on the market and the scooters supplied by sharing companies have been analyzed and viewed. As far as scooters on the market are concerned, an initial classification is made based on weight and material.

They can be classified into:

1. Carbon fiber (12 kg)
2. Aluminum (15 kg)
3. Steel (20 kg)

In addition, they can also be classified according to height (measured from the ground to the handlebars). The latter can vary from 108 cm to 120 cm. Finally, they can also be classified according to the width of the handlebar, which can vary from 45 cm to 50 cm.

From the technical data sheets of the scooters, it has been found that the maximum speed reached varies from 25 km/h to 30 km/h. On the basis of these speeds and also due to the fact that scooter accidents are increasingly widespread on European area, the new Highway Code D.L. 2021 [18] has established new speeds limits on roads and in pedestrian areas. The maximum speed allowed in urban areas is 20 km/h, while in pedestrian areas this limit drops to 6 km/h.

During the simulation, no brake was applied by the rider, as it was decided to analyze the worst-case scenario that could occur, i.e. the one in which none performs evasive

and/or protective maneuvers. From the simulations, it is possible to extrapolate the launch distance and the peak velocity of the head before impact on the ground. Throw distance is defined as the distance traveled by the pedestrian's head from initial collision to the impact with the ground. Similarly, the impact velocity of the head represents the maximum speed reached by braincase.

The results obtained from these simulations were compared with those proposed by the scientific literature [16]. As can be seen from Fig. 10, the model results are again in agreement with data derived by similar studies.

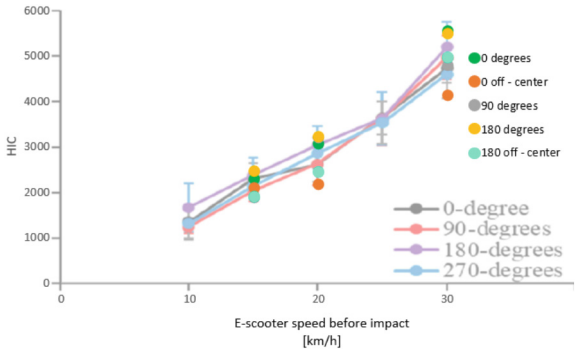

Fig. 10. E-scooter - Pedestrian Model Calibration [16].

4 Analysis and Discussion of Results

In order to better understand the physics underlying the event it could be beneficial to examine the various phases of impact between e-scooter and pedestrian.

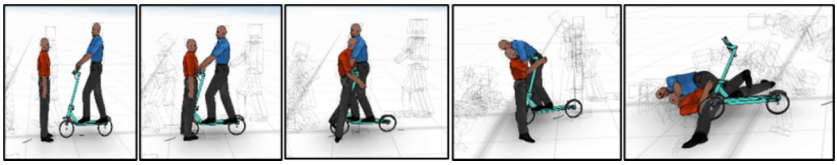

Fig. 11. Phases of E-scooter- Pedestrian impact.

As it can be observed from Fig. 11, the first impact on the pedestrian is close to the waist and comes from the handlebars of the electric scooter. Later on, the bodies of the rider and the pedestrian collide. Since the impact of both the handlebars and the collision between the driver's body and the pedestrian is above the center of mass, the pedestrian falls to the ground.

For a defined type of pedestrian profile and of e-scooter relationships between HIC and the velocity according to different impact angles can be obtained.

By way of example, the specific case involving an adult pedestrian and a 12 kg scooter is depicted in the following figure (see Fig. 12).

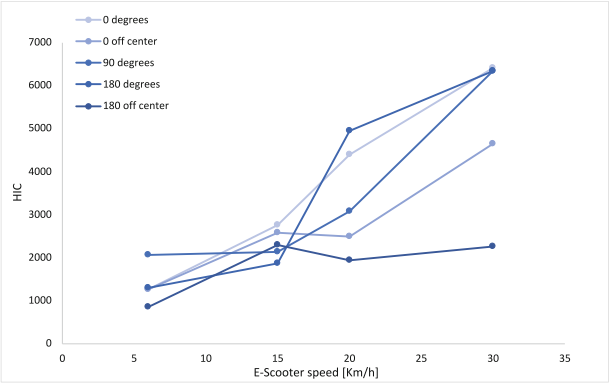

Fig. 12. HIC-speed relationship in adult for center and off -center degrees of impact with weight of E-scooter 12 kg.

As can be seen from Fig. 12, although a monotonic increasing trend can be observed HIC-velocity relationships of the centered and off-center impact angles are very different from each other's.

Following these encouraging results, by combining all impact angle values, e-scooter speed values, e-scooter types and adult pedestrian properties a general relationship HIC versus speed has been sought, that is conveniently reported in the following figure (see Fig. 13).

As can be seen from Fig. 13 and Table 2, regression statistics of the obtained mathematical model are somehow poor exhibiting an high dispersion.

Table 2. Main statistics of interest and prediction accuracy of the model.

Mod	Param.	Value	Stand. error	t-ratio	Prob(t)	Adj-R^2
$Y = a*x^b$	a	215.0203	101.4050	2.1204	0.0380	0.5618
	b	0.9542	0.1488	6.4111	0.0000	

Higher differences between results provided in centered and off-center impact scenario are probably due to an energy dissipation in the roto-translational motion that occurs in the case of impacts with off-center angles. Basing on these outcomes, a new mathematical model employing Impact Kinetic Energy as the independent variable has been proposed.

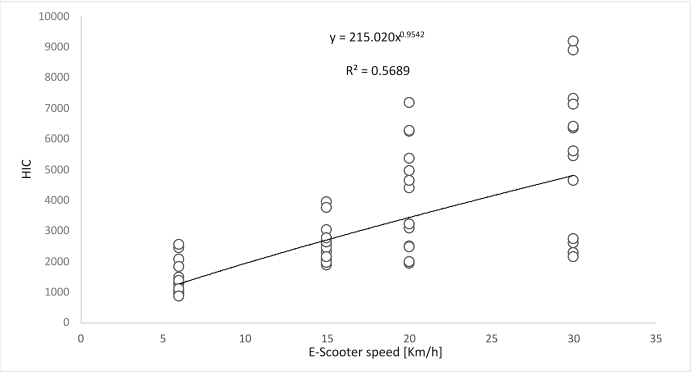

Fig. 13. Model of regression between HIC and Speed E-Scooter.

The kinetic energy for centered impact angles was then evaluated as expressed in Eq. 4.

$$E_{c,center} = \frac{1}{2}mV^2 \tag{4}$$

where:

– m is the mass of the E-scooter and the rider that impact on pedestrian;
– V is the speed of e-scooter

For off-center impact angles, kinetic energy was evaluated as expressed in Eq. 5.

$$E_{c,off-center} = \frac{1}{2}mV^2 * S_c \tag{5}$$

where:

– m is the mass of the E-scooter and the rider that impact on pedestrian;
– V is the speed of E-scooter;
– S_c is the dimensionless overlapped contact surface between the two colliding bodies that in this case is 0.347 depending on the selected off-center value.

The new regression model is conveniently reported below with relevant statistics (see Fig. 14 and Table 3).

Table 3. Main statistics of interest and prediction accuracy of the model

Mod	Param.	Value	Stand. error	t-ratio	Prob(t)	Adj-R^2
$Y = a*x^b$	a	84.8162	26.9497	3.1472	0.0025	0.8172
	b	0.5479	4.25E-02	12.8826	0.0000	

As it can be observed, by making use of kinetic energy as an independent variable, it is possible to obtain a better description of accident outcomes in term of HIC values.

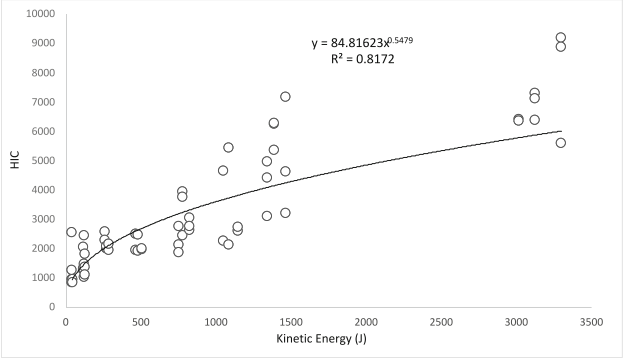

Fig. 14. Model of regression between HIC and Kinetic Energy.

4.1 Impact of Rider

Since the e-scooter rider can be also considered a road vulnerable user, it seems important to analyze the injuries suffered by the rider as a result of the impact with the pedestrian by comparing these latter with those suffered by the pedestrians themselves.

Speed Effect

Speed is again the crucial factor in a collision as the momentum and kinetic energy of the rider-scooter system is transferred to the pedestrian. The following Fig. 15 show the overall effect of the speed of the electric scooter on the rider's HIC in the case of E-scooter's mass of 12 kg.

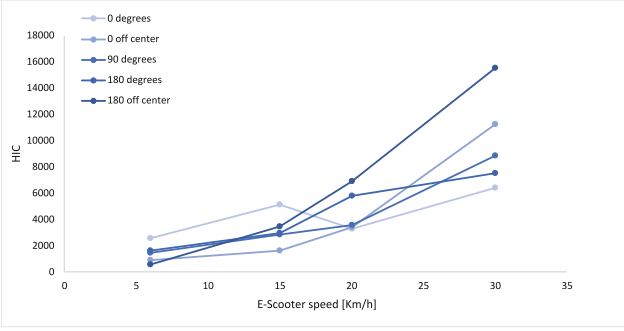

Fig. 15. HIC-Speed relationship.

The results showed an increase in the average rider's head peak speed as the speed of the scooter increased and therefore an increase in HIC and consequently an increase in the probability of severe head trauma.

For the 0-degree impact angle, a different trend occurs from the others, i.e. for a higher speed of the scooter (20 km/h) a lower HIC value is recorded than that obtained at a lower speed (15 km/h).

Analyzing the video of the two simulations, it is clear that for a higher speed of the scooter the rider tends to cushion the impact on the pedestrian and then only subsequently impact the ground, on the contrary for a lower speed this mechanism does not occur and the rider hits the ground cushioning the blow only with his shoulder.

Rider's Fall Mechanism

From the analysis of the videos of the simulations carried out, it was possible to analyze the mechanism of the rider's fall. This mechanism can be divided into three sections as shown in the following figure (Fig. 16 and Fig. 17).

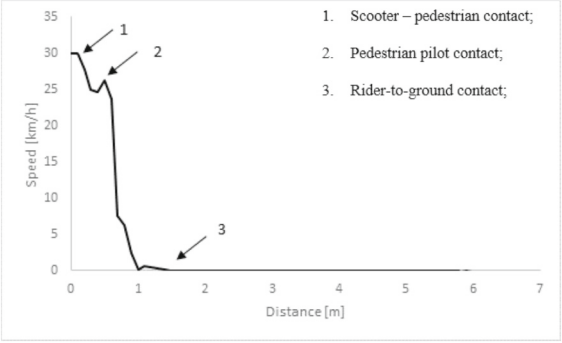

Fig. 16. Mechanism of the rider's fall.



Fig. 17. Mechanism of the rider's fall in Virtual Crash animation.

Comparison of Pedestrian - Rider Effects

It is worth to compare the HIC values of the pedestrian with those pertaining the e-scooter rider following the impacts on the ground.

The figure below (Fig. 18) shows the dispersion of the data provided by the simulations compared with the equality line.

As can be seen from Fig. 18, the relationship between pedestrian and rider in terms of HIC is highly dependent on the angles of impact.

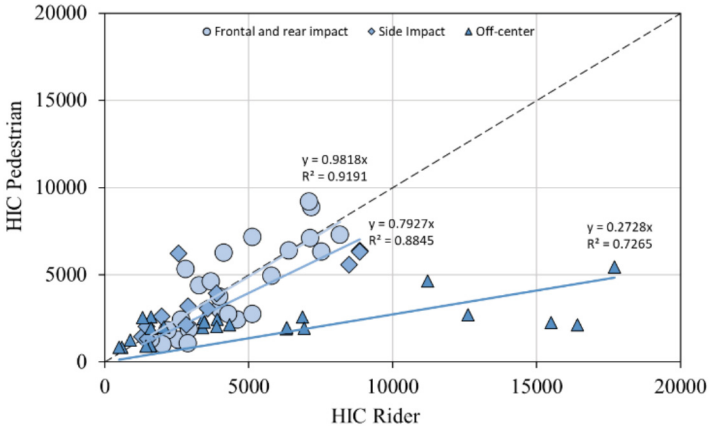

Fig. 18. Comparison of HIC values for pedestrian and rider.

For frontal and backward angles of impact, these values align on the equality line, whereas, as far as lateral angles of impact are concerned, the difference in HIC values between the two bodies are dramatically differing.

Specifically, the rider, in such an impact, undergoes to a higher head velocity than the pedestrian. From the analysis of the simulation videos, it was clear that the latter directly impacts the ground without cushioning the blow, unlike the pedestrian who, thanks to a first impact with the shoulder and arm, cushions this blow.

For off-center angles of impact, the rider suffers from a much higher speed than that pertaining the pedestrian because he only hits the latter for a small area and then hits the ground directly without being appreciably slowed down.

One aspect that should be evaluated, however, is the impact of helmet use on rider's HIC. Recent studies [19–21] try to simulate this situation and to evaluate the difference in impact with and without helmets. What is clear is that with the use of helmets acceleration is significantly reduced. As regards the HIC, it is almost comparable for low impact speed values, whereas it is significantly reduced (with the presence of the helmet), for high impact speed values.

What has been noted, however, is that this reduction does not apply to angular velocity, where the values with and without the presence of the helmet are comparable, and for low angular velocity values the case of a rider without a helmet produces a smaller impact.

5 Conclusion

The assessment of the vulnerability of vulnerable road users was carried out through analyses with multi-body codes that made it possible to define what happened to the braincase following the impact on the ground.

Electric scooters are growing more and more and are spreading faster and faster among the population due to their various advantages, such as maneuverability and low

weight, which makes them more and more transportable, not to mention the ease of recharging, and lower operating costs.

Allowing electric scooters to share pedestrian paths with pedestrians must be carefully considered as this has been seen to result in an exponential increase in scooter-to-pedestrian and scooter-to-vehicle impacts.

As evidenced in the analyses carried out, it has been shown that, most of the time, the higher the speed of electric scooters at the time of impact, the more dangerous the consequences, are because both momentum and kinetic energy increase. When a scooter collides with a pedestrian, much of the momentum is transferred to the pedestrian, leading to a longer launch distance and a higher head-to-ground impact speed, resulting in a more serious potential head injury. Similarly, the results also showed that the outcome of accidents between scooters and pedestrians depends on the direction of impact.

Regarding the post-collision fall mechanism, simulations have shown that the direction of impact and the age profile have a significant influence. For direct impacts (0°, 180°, 90°), pedestrians tend to fall forward in the direction of travel of the rider, while off-center impacts cause pedestrians to rotate as they fall on the rider's side.

What happens to the rider's head for the impact, was also analyzed. It turns out that the HIC suffered by the rider is by no means negligible and highly depends on the angles of impact. To reduce the peak speed of the head in contact with the ground, the use of a helmet is therefore strongly recommended.

The impacts analyzed seem to be able to capture the complexity of these proposed accident scenarios and provide a reliable estimate of the possible outcomes.

By extending the field of simulation scenarios to be investigated, it is believed that it will be possible to achieve a better understanding of the problem and provide prediction functions for pedestrian vulnerability. In future simulations, it will be essential to focus on the use of helmets and how they may or may not reduce HIC values.

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Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

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A Literature Review on Bus Comfort On-Board

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Abstract. According to the UN's 2030 Agenda, cities and human settlements aim to become inclusive, safe, resilient, and sustainable. In this context, cities are pivotal for social and economic development, serving as gathering places where everyone should enjoy a high standard of living and accessibility. Public transportation, particularly bus comfort on board, significantly influences the quality of urban transportation services. Measuring this comfort is essential for transportation providers to track, assess, and implement targeted improvements. Comfort is a complex concept influenced by factors like temperature, noise, vibration, acceleration, passenger load, and cleanliness.

The literature offers various approaches to measuring bus comfort, prompting this paper's review of existing research to establish a structured research base for future studies. Despite a wealth of literature on onboard bus comfort levels (OBCL), no methods yet establish graduated, dynamic comfort scales incorporating diverse passenger characteristics and real-time acceleration data. This gap prevents a comprehensive, real-time OBCL assessment that accurately reflects passenger experiences. Furthermore, extensive data collection is necessary to calibrate models and consolidate comfort scales effectively.

The insights from these studies help identify specific areas where comfort levels are inadequate, enabling transportation agencies to focus on targeted interventions for enhancing the passenger experience. While considerable progress has been made in understanding and measuring bus comfort, there remains a need for more sophisticated methodologies to develop comprehensive and dynamic comfort assessment tools aligned with the diverse needs of passengers and the dynamic nature of urban transportation systems.

Keywords: Comfort · Bus · Review · Approaches

1 Introduction

Public transportation (PT) plays a key role in creating sustainable and smart cities [1]. Indeed, PT helps reduce the carbon footprint by decreasing the number of private vehicles on the road, thereby lowering emissions of greenhouse gases and pollutants. This

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contributes to better air quality and helps combat climate change. Moreover, accessible and affordable public transportation ensures equitable access to essential services, education, employment opportunities, and recreational activities for all residents, regardless of their socioeconomic status or mobility needs. It fosters social inclusion and reduces transportation-related barriers to economic and social participation. Finally, a robust public transportation network stimulates economic growth by connecting people to job centers, educational institutions, healthcare facilities, and commercial areas. It attracts businesses, supports local economies, and enhances property values, driving overall prosperity in urban areas.

To achieve these goals, municipalities and public transportation agencies must provide reliable, accessible, clean, healthy, and comfortable transportation networks to encourage citizens to switch from driving private automobiles to public transit. In particular, on-board bus comfort (OBCL) appears to be a critical factor in achieving these improvements, and, moreover, offers a strategic advantage for public transportation companies (PTCs) [2–4]: improving OBCL conditions, driver performance may be raised, safety can be increased, and passenger discomfort can be decreased.

Today, public transportation systems can leverage technology and real-time data, such as location, digital payment options, and multimodal platforms, to streamline operations, improve efficiency and the overall passenger experience, as well as make public transportation more convenient, reliable, and user-friendly.

The OBCL of buses has received more attention by scholars in the past ten years, with an emphasis on measurement techniques and associated features. Research on passenger comfort primarily investigates technical factors such as space on board [5, 6], vibrations [7–14], noise [15, 16] and temperature [17–19]. Additionally, attention has been given to factors like driver behavior, which presents an intriguing aspect [20–25]. Therefore, exploring the relationship between driving style and passenger comfort is deemed beneficial. A smooth driving style ensures safety by reducing the risk of accidents among users, and discomfort. It, therefore, has a direct impact on customer satisfaction, encouraging positive feedback and repeat trips. Conversely, aggressive driving behavior may contribute to passenger discomfort, influencing their perception of the service quality.

Furthermore, adopting a smooth driving style is in line with environmental sustainability objectives, as it decreases emissions and enhances operational efficiency while reducing costs. Good driving practices enhance the public perception of public transportation services.

Again, a smoother driving technique leads to decreased fuel consumption and maintenance expenses. As a result, this relationship makes it easier to identify areas that need improvement and enhances the overall travel experience. Furthermore, customers worldwide usually provide feedback on their driving habits to PTCs, which inspires them to improve their driving practices in order to meet passengers' onboard comfort levels.

Previous studies examined the effects of movement variations (such as accelerations) on passenger comfort, using both subjective and objective approaches [26]. Subjective measures are labor-intensive because they involve surveys and interviews, whereas systems like [7], which focus on objective data, may prioritize the perspective of PTCs.

Consequently, an emerging approach [21, 22, 27] proposes measuring subjective and objective characteristics at the same time.

However, there is a need for real-time comfort scales that integrate these diverse measures to give drivers a tool to control their driving style [28, 29].

This paper aims to review the various studies conducted on OBCL to provide a thorough knowledge of both the characteristics impacting on users 'comfort and wide range of methods and relevant theories used to assess it, by considering research from several nations.

The rest of the paper is organized as follows. Section 2 describes and analyzes the models and methods used to calculate OBCL in bus services. Section 3 shows and discusses the results. Finally, Sect. 4 concludes the study and recommends new avenues of research.

2 Methodology

Articles from 1980 to 2024, indexed by Web of Science, Scopus, Google Scholar, IEEE, Semantic Scholar, Cambridge Core, and JSTOR, were used to evaluate the literature on passenger comfort on bus. This study's search strategy yielded a total of 55,000 articles. The studies were screened based on title and abstract, and after removing duplicates, manuscripts concerning medicine, occupational medicine, ergonomic, biology, etc., 70 eligible articles were included in this study. The selected studies dealt with the measurement of passenger comfort on buses by considering various attributes and subjective, objective, and mixed methodologies.

Initially, the research focused on identifying factors that influence the quality of public transportation. It turned out that service quality can be influenced by a variety of factors such as speed, travel time, convenience, reliability, cost, accessibility, maneuverability, safety, and comfort [30, 31].

OBCL is a critical factor, and several studies have attempted to delineate its characteristics. For example, Nguyen et al. [32] comfort (or being comfortable) can be identified as a sense of physical or psychological ease and ride comfort is defined as "*the overall comfort and well-being of the vehicle's occupants during vehicle travel*", in which noise, vibration, or both are the main source of [33, 34]. Hoberock [26] emphasizes that comfort in transit systems relies on passengers' experiences of motion in various directions and is also influenced by environmental factors. Faris et al. [35] define ride comfort as the vehicle's response to different road conditions. Recently, Roncoli et al.[5] associated passenger comfort with crowding in the post-COVID-19 era. Thus, comfort can be perceived as a multifaceted concept and several attributes can be used to evaluate the OBCL.

Furthermore, literature suggests that OBCL assessment is commonly conducted through three distinct approaches: subjective, objective, and combined.

Considering these observations, the decision was made in this study to rearrange the manuscripts according to two distinct classifications.

The first one categorizes the studies based on the attributes analyzed to assess comfort, while the second is based on methodologies (see Fig. 1).

In the following paragraphs, the classification is provided, and the contents and the results of the reviewed manuscripts are summarized.

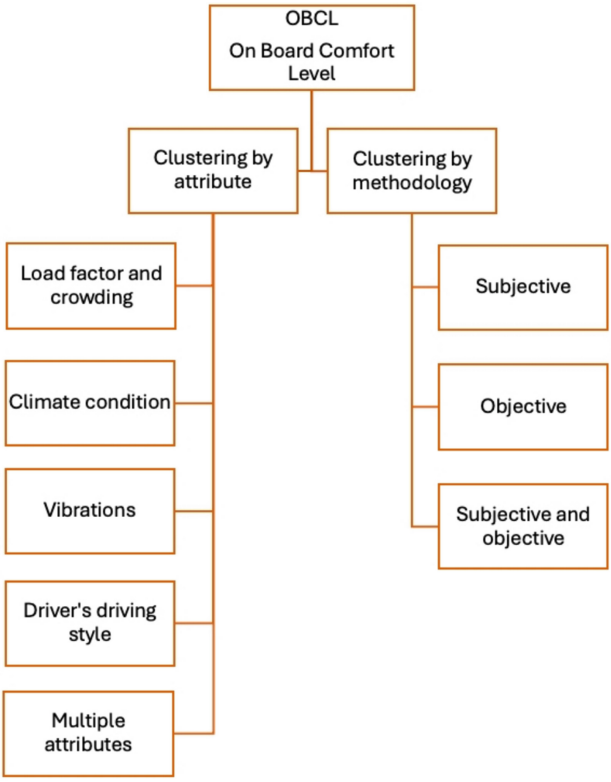

Fig. 1. Classifications for studies on on-board bus comfort level (OBCL).

2.1 Clustering Comfort on Board by Attributes

Hence, the initial phase of this study involved clustering the various studies based on the attributes used to evaluate comfort. Five groups were identified and reported in Table 1.

The initial group primarily comprises factors related to personal space that is available on board, including seating and personal space, passenger facilities usability, passenger loads, and load factor. The aspects related to climate conditions inside the bus, including temperature and cleanliness, are encompassed in the second category. The third cluster includes studies on vibrations experienced by passengers and generally on physical and cinematic elements related to road conditions and traffic. The fourth category involves elements of the driver's driving behavior, covering longitudinal acceleration resulting from acceleration and braking maneuvers, lateral accelerations influenced by road curves, and vertical accelerations stemming from pavement irregularities. Lastly, the fifth group comprises several characteristics that address various comfort aspects simultaneously as cleanliness, seat quality, staff behavior, level of crowding, security, temperature, sound pressure, acceleration change rate, speed; vibrations and noise effects on discomfort during travel while performing sedentary activities (reading a newspaper); space on-board, cleanliness, driving style; passenger facilities, seating

Table 1. Studies clustered by comfort attributes.

Comfort attributes	Authors, year, source
Load factor, crowding	Kittelson & Associates Inc. *et al.*, 2003, 2013 [31–36]
	Kumar *et al.*, 2004, [37]
	Vovsha *et al.*, 2014, [38]
	Shen *et al.*, 2016, [3]
	Więcek et al., 2019 [39]
	Zhou et al., 2021 [40]
	Roncoli et al., 2023 [5]
	Darsena et al., 2023 [6]
Climate condition	Pala, 2020 [17]
	Yunus et al., 2023 [18]
	Cigarini et al., 2022 [19]
	Volodkin et al., 2022 [41]
Vibrations	ISO 2631, 1997, [9]
	Coni, 1994 [42]
	Coni, 1995 [43]
	Strandemar, 2005 [44]
	Lin *et al.*, 2010, [10]
	Lin and Chen, 2011, [11]
	Heißing, and Ersoy, 2011 [33]
	Sekulic and Mladenović, 2016, [14]
	Zhao *et al.*, 2016, [8]
	Sekulic *et al.*, 2013, 2016, 2018 [7, 12, 13]
Driver's driving style	Hoberock, 1977, [26]
	Af Wahlberg, 2006, [20]
	EN 12299, 2009, [45]
	Castellanos and Fruett, 2014, [27]
	Maternini and Cadei, 2014, [46]
	Eboli *et al.*, 2016, [21]
	Meiping and Wen, 2017, [23]
	Barabino *et al.*, 2018, [22]
	Barabino *et al.*, 2019 [47]
	Barabino *et al.*, 2019 [48]

(*continued*)

Table 1. (*continued*)

Comfort attributes	Authors, year, source
	Chin, *et al.*, 2019 [49]
	Nguyen *et al.*,2019 [50]
	Wang *et al.,* 2020 [51]
	Karapetkov *et al.*, 2021 [25]
	Coni, *et al.,* 2020 [52]
	Fazio, *et al.,* 2020 [53]
	Nguyen, *et al.*, 2021 [32]
	Zeng, *et al.,* 2023[54]
Multiple attributes	Oborne and Clarke, 1973, [15] EN 13816, 2002, [30]
	AFNOR, 2005 [55, 56]
	Silva, 2002 [34]
	Eboli and Mazzulla, 2009 [4] Barabino and Di Francesco, 2016 [24] Barabino *et al.*, 2012 [57]
	Prashanth *et al.*, 2013 [58]
	Islam, 2014 [59]
	Zhang *et al.*, 2014, [16]
	Anik *et al.*,2020 [60]
	Deb *et al.,* 2022 [61]
	Zahra *et al.,* 2023 [62]
	Maltinti et al. 2020 [63]

and personal space, ride comfort, ambient conditions; noise, vibrations, temperature, and posture, vehicle condition & hygiene.

2.2 Clustering Comfort on Board by Methodologies

Studies can also be categorized based on the methodology used to evaluate OBCL. Typically, OBCL assessment employs three main approaches: subjective, objective, and combined methods. Following this classification, Table 2 reports studies collected in this work.

Subjective Approach. The subjective approach captures passengers' viewpoints on various attributes through customer satisfaction surveys [64]. These surveys are conducted via questionnaire distribution [66] or through face-to-face interviews with passengers on board [32, 61].

Table 2. Studies clustered by methodologies.

Approach	Authors, year, source
Subjective	de Oña and de Oña, 2014 [64]
	Oboknb and Clarke, 1973 [65]
	Deb *et al.,* 2022 [61]
	Nguyen, *et al.*, 2021 [32]
	Islam, 2014 [59
	Zhang *et al.*, 2014, [16]
	Zahra *et al.,* 2023 [62]
	Silva, 2002 [34]
	Volodkin et al., 20 [41]
	Preston and Colman, 2000 [66]
	SAE, 2014 [67]
	Maltinti et al. 2020 [63]
Objective	ISO 2631, 1997, [9]
	Sekulic *et al.,* 2013 [7]
	Sekulic *et al.*, 2016 [12]
	Sekulic *et al.*, 2018 [13]
	Sekulic and Mladenović, 2016, [14]
	Lin *et al.*, 2010, [10]
Subjective and objective	Lin and Chen, 2011, [11]
	Wang *et al.,* 2020 [51]
	Zhao *et al.*, 2016, [8]
	Meiping and Wen, 2017, [23]
	Hoberock, 1977, [26]
	Maternini and Cadei, 2014, [46]
	Af Wahlberg, 2006, [20]
	Castellanos and Fruett, 2014, [27]
	Eboli *et al.*, 2016, [21]
	Barabino *et al.*, 2018, [22]
	Coni, *et al.,* 2020 [52]
	Karapetkov *et al.*, 2021 [25]
	Barabino *et al.*, 2019 [47]
	Nguyen *et al.,*2019 [50]

(*continued*)

Table 2. (*continued*)

Approach	Authors, year, source
	Anik *et al.*,2020 [60]
	Zeng, *et al.,* 2023[54]
	Chin, *et al.*, 2019 [49]

In such surveys, passengers evaluate their perception on a wide range of attributes (e.g., cleanliness, ride comfort, temperature) using either a qualitative or quantitative scale. In this way, it is possible to capture the passengers' perspective on desires and perceptions on public transport system. The authors differ in the way they approached data analysis, in the number and type of characteristics they chose for their investigations, and, of course, in the results of their findings.

The analysis of the subjective studies revealed that the main factor influencing customer satisfaction with bus services is safety, followed by comfort. Other significant indicators of public transportation quality encompass reliability, punctuality, seating availability, speed, cleanliness, accessibility of equipment and facilities at stations and on vehicles, as well as air conditioning. A study conducted by [63] focuses on the ratings provided by vulnerable users of public transport services and concludes that these users place significant importance on the courtesy of employees and the frequency of service.

Subjective studies can be further categorized by considering the rating scales employed.

Several studies, including [16, 32, 59, 62], and [34], used a four or five-point scale, with 1 denoting very poor or very unsatisfied and 4 or 5 denoting very good or very satisfied. This scale, known as the Likert scale, is a widely used psychometric tool in questionnaires, appreciated for its precision in estimating opinions, perceptions, and behaviors.

Other research utilized scales ranging from 1 to 9 or 10 points respectively [41, 62]. Specifically, Deb et al. [61] concurred with Preston and Colman [66] in advocating for scales with higher reliability, suggesting that 7, 8, or 9-point scales are more dependable compared to those with only 3 to 5 points. Indeed, scales with more response levels offer greater flexibility and may better capture respondents' attitudes while also exhibiting higher internal consistency. This approach, employing a scale from 1 to 10 in line with AE J1060 [67], is, in particular, adopted in studies conducted in Italy since akin to the scholastic rating system familiar to all citizens of the nation. Indeed, [47, 48], and [52] assume these scales for subjective ratings.

Objective Approach. Objective measures can be used to assess comfort. They undoubtedly provide an unbiased evaluation of OBCL. Technical tools such as accelerometers, which offer unconditioned data, offer a means to monitor various comfort attributes. It has been noted that much of the research has focused primarily on vibrational comfort. This is explained by the fact that both drivers and passengers experience road surface vibrations during travel, which can impair driving ability and cause discomfort not only to drivers but also among passengers. The international standard ISO 2631 [9] is the

reference of numerous studies to establish a connection between objective measurements and subjective comfort experiences. This standard utilizes the Root Mean Square Weighted Accelerations (RMSWA) across the x, y, and z axes from passenger seats to quantify whole-body vibrations, assessing their impact on health, comfort, perception, and the likelihood of experiencing "seasickness".

Three main groups can be used to categorize studies directed towards objectively evaluating bus comfort depending on passenger involvement and adherence to [9]. Establishing threshold values that can elucidate the degree of comfort or discomfort experienced by passengers while traveling is their primary aim.

The first categories include studies that assess OBCL without direct passenger involvement.

Specifically, [7, 12], and [14] recorded acceleration signal recording using a tri-axial seat pad accelerometer and investigated the effects of vibrations on onboard bus comfort. [7] measured the vertical oscillation of the driver, passengers seated in the center of the bus, and the rear overhang, concluding that the least comfortable seats are those in the back overhang of a bus moving at 100 km/h. These findings were supported by other studies, including [12] and [14]. In [13], researchers evaluated the impact of vibrations on exposure time, noting that passengers in the front and rear overhang of the bus may experience vibrations for only a brief period.

Wang et al. [51] used a three-dimensional human-bus-road coupled vibration system to study the dynamic response and human comfort on buses. They introduced the annoyance rate index to quantify and evaluate the level of discomfort or annoyance experienced by passengers more accurately. They also carried out parametric analyses to explore the effects of road surface roughness, bus weight, bus speed, and seating location on human comfort, identifying road surface roughness as the most significant factor. Fazio et al. [53] conducted a comparison of onboard comfort levels between metro and buses. Utilizing kinematic data gathered from sensors and following [9], they assessed acceleration values and concluded that metro services provide superior comfort levels.

Studies in the second category utilized a passive approach to assess onboard comfort levels, which introduced a novel mode of passenger crowdsourcing. In these investigations, willing users collected acceleration data in all directions. For instance, in studies [10, 11], researchers developed systems that utilized passengers' mobile phones to gather data on their movements and measure vibrations associated with longitudinal, transverse, and vertical accelerations. These data were then transmitted to the systems via GPRS networks and analyzed according to established protocols [9]. The findings indicated significant variations in comfort levels along a trajectory, with smaller buses generally being reported as the least comfortable vehicles. [8] and [23] proposed analogous systems albeit utilizing WiFi as communication networks. The outcomes demonstrate that the experimental system's bus vibration comfort corresponds with the passengers' subjective perceptions, so validating the viability of this assessment technique.

In the third category are gathered studies that deviated from the international standard [9] or did not involve passengers in their assessments. For example, [26] indicated that steady accelerations between 0.11 g and 0.15 g are within the "acceptable" range while trigger values above 0.30 g are unlikely to be acceptable. Additionally, [46] introduced an objective scale for evaluating onboard comfort levels. This scale integrated dynamic

effects on standing bus passengers, a comfort index, and several route characteristics as the presence of roundabouts.

Mixed Approach. The emerging approach to assessing OBCL involves evaluating comfort aspects through both subjective and objective means. Studies can be categorized into three groups depending on models adopted to evaluate OBCL.

The first group, called descriptive models, comprises studies that utilize descriptive statistics to quantitatively evaluate OBCL. Using basic statistical methods such as correlation analysis and percentage values, these models seek to establish a connection between the subjective perception of comfort and objective parameters. This approach assists in defining comfort thresholds that correspond with passenger preferences. In Wahlberg's study [20] it was discovered that passengers perceived their bus journeys as less comfortable, noisier, and riskier after taking part in a driver training program focused on fuel efficiency.

In [27] the authors developed a system consisting of hardware, firmware and software for to identify inadequate driving styles and road surface problems. By two algorithms they detected acceleration and jerk magnitudes out of the comfort range. The results revealed that 0.7 g, 0.8 g, and 1.4 g for lateral, longitudinal, and vertical events, respectively, represent the maximum accelerations above which users experience discomfort. Eboli et al. [21] focuses on analyzing the comfort levels on board a bus service, particularly related to route roughness and driving behavior such as slowing down, braking, steering, and accelerations. They established thresholds for determining good or poor comfort levels and by analyzing frequency distributions, they developed a straightforward and simple method for evaluating comfort levels. Similarly, Barabino et al. [22] identified a comfort domain based on horizontal accelerations to facilitate the recognition of instances where passengers experience comfort or discomfort related to the bus drivers' driving style. In [52], how passenger assessments on three-axis acceleration components in relation to road factors varied by age and time is examined. The study found modest correlations, indicating that passengers did not differentiate among the three accelerations.

The second classification comprises research that evaluates OBCL through various formulations of inferential models. These models illustrate how different variables affect the perception of OBCL and consider users' subjective perception as the dependent variable and the attributes observed during bus trips as independent variables. These models have the capability to assess the impact of individual factors on OBCL and adhere to a generalized linear assumption.

In [16], a model was created to gauge OBCL by incorporating physical factors such as noise, vibration, thermal comfort, and acceleration, as well as personal characteristics like age, gender, and health. Karapetkov et al. [25] segmented passengers by age and gathered assessments on turns to construct an OBCL forecasting model for each age category, achieving prediction accuracy levels of up to 98%. Additionally, they introduced a straightforward dashboard to prevent driver distraction during driving. Barabino et al. [47] presented a progressive scale for real-time OBCL assessment combining objective acceleration data with subjective assessments of driving style. The spatial linkage of OBCL allows bus drivers to monitor the ongoing quality of the bus journey. Nguyen et al. [50] utilized a smartphone application to measure accelerations to examine annoyance

experienced on buses, pinpointing most discomforting factors like lateral acceleration and duration of turns, and standing being.

Lastly, a framework study [60] proposes structural equation model to observe the effect of observable and non-observable variables on public bus comfort in Dhaka. The authors identified 'jerking', 'sound pressure level', 'fan/AC quality', 'inside temperature', 'security', 'cleanliness' as the most significant observed variables. To determine how commuters' perceptions of comfort vary depending on trip features, socioeconomic factors, and demographic attributes, an ordinal logistic regression model was developed. The findings of this study showed that 'gender', 'car ownership' and 'income' of passengers have significant relationship with comfort.

The final classification comprises studies that utilized machine learning models (MLMs) to assess OBCL. MLMs represent functional relationships between inputs and outputs of a system, with parameters lacking physical interpretation. Employing MLMs provides a chance to catch the intricate, frequently nonlinear interactions between comfort and its influencing factors.

Classification and regression tree method was used in [49] to correlate kinematic motion characteristics with ride comfort. The authors found that passenger discomfort was primarily linked to sharp turns in conjunction with changes in elevation or sudden turns.

An artificial neural network algorithm was created by Nguyen et al. [32] and showed good performance and output-to-input correlation. Instead of weighted acceleration magnitude, they utilized vibration dose value and maximum transient vibration value, emphasizing the impact of horizontal-direction acceleration and speed.

Zeng et al. [54] determined the factors affecting ride comfort via a questionnaire, focusing on velocity, longitudinal acceleration, and yaw rate. They utilized long short-term memory models to forecast these factors and evaluate driver behavior. Their findings led to the development of an application program offering real-time driving recommendations based on speed, acceleration, and yaw rate.

3 Results and Discussion

The reviewed literature showed a wide array of characteristics, systems, models, and methodologies for evaluating OBCL all of which are highly interesting. These investigations have highlighted the multidimensional nature of comfort and showcased various approaches to its assessment, owing to the complexity of the concept. However, despite the extensive research in this area, several gaps remain.

Subjective analyses of OBCL in public transportation are crucial as they offer user perceptions essential for transportation agencies to enhance services. Understanding passenger expectations through subjective feedback enables agencies to make improvements that align with passenger preferences, consequently attracting more users to the service. However, users' socio-economic background, the diversity in tastes and attitudes towards public transportation, personal comfort thresholds and, nevertheless, mood, past experiences, and external conditions can influence subjective ratings [64]. So, it might be restrictive to focus only on passenger views, particularly when dealing with non-representative samples and outside factors like fare hikes.

Objective measurements guarantee accurate and quantifiable data enabling consistent and repeatable assessments of comfort in a variety of settings and conditions ensuring reliability in the evaluation process [44]. They allow direct comparisons between different modes of transportation, routes, or vehicles, so that transportation planners and operators can make well-informed decisions. Data acquisition can occur under static conditions in the laboratory or directly on the vehicles as they operate in service. The latter option provides a more accurate representation of the dynamic nature of real-world bus networks. Moreover, findings from analogous studies conducted on rail vehicles cannot be transferred to buses due to the vastly different driving phenomenon: consider, for instance, traffic interruptions or changes in road conditions [46].

Objective measures alone, while easy to acquire and evaluate, may not be sufficient to measure comfort because they lack the human element of subjective experience. Noise levels, vibrations, and accelerations provide quantifiable data but do not capture the nuances of individual passenger's feelings and preferences. Table 3 summarizes advantages and disadvantages of subjective and objective analyses.

Table 3. Summary of advantages and disadvantages of subjective and objective analyses.

Analysis	Advantages	Disadvantages
Subjective	They offer user perceptions	Users' background and their diversity in tastes and attitudes towards public transportation can influence subjective ratings
Objective	They guarantee accurate and quantifiable data They allow direct comparisons between different modes of transportation, routes, or vehicles	They do not capture the nuances of individual passenger's feelings and preferences

Therefore, combining subjective assessments with objective data is essential for a comprehensive understanding of OBCL in public transportation. This hybrid approach takes into account both quantifiable indicators and subjective sensations to provide an exhaustive understanding of comfort levels.

Indeed, this bibliographic research indicates a notable shift towards this direction in recent studies.

At this juncture, further and broader opportunities of investigation can be identified.

Expanding the sample size in terms of monitored bus routes, the number and characteristics of surveyed passengers, and measured accelerations is necessary. Indeed, some authors study one or two route, others interview only students [21, 32, 50], others measure only longitudinal and transversal acceleration [47]. Moreover, there is a lack of algorithms designed to handle large volumes and data complexity [20–22, 27, 32, 50, 60]. Working with limited data can introduce a significant level of empiricism and

unpredictability, as it involves overly localized analysis and narrow conclusions. Consequently, the results may lack generalizability. In contrast, using a huge amount of data for the measurement helps build comfort scales that are more consolidated.

Moreover, it is crucial to consider the vertical component of acceleration, as it has a significant impact on OBLC. Long-term exposure to high levels of vertical acceleration can cause discomfort and, in some cases, trauma, which can engender in physical problems and cause pain by affecting the general well-being of travelers both during and after travel. Vertical motion greatly influences stability especially for standing passengers also playing a crucial role in safety.

Finally, the evaluation of driving style should differ based on the age of the passengers.

Indeed, younger passengers may tolerate more dynamic driving styles since their physical performance allows them to react immediately to any abrupt changes in direction or acceleration and braking. Whereas older passengers, who may have health issues as mobility limitations (joint pain or balance problems), often prefer smoother, gentler driving for increased comfort and safety. Therefore, if the driving style could adapt to the different needs of passengers, the well-being of all passengers would be ensured.

Based on the above observations, the following flow chart (see Fig. 2) suggests a methodology for applying the mixed methodology that can help transit operators in design more reliable surveys and experimental investigations on OBCL.

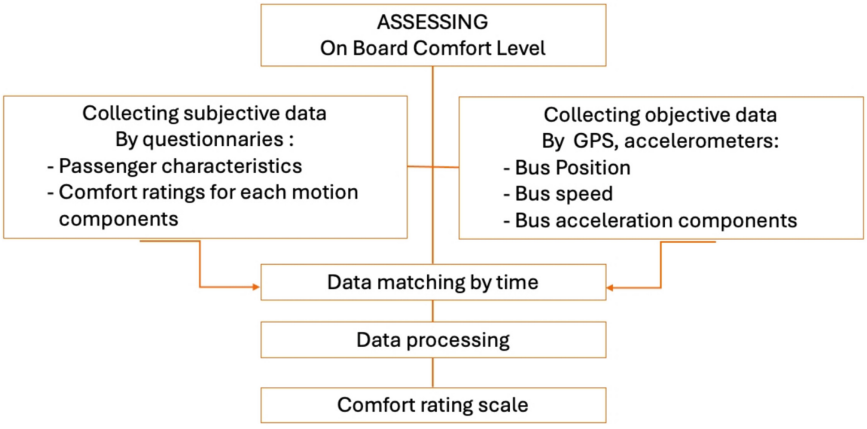

Fig. 2. Flow chart suggesting a methodology for applying the mixed methodology.

4 Conclusion

This paper aims to report a review of the research conducted on bus comfort on-board to date and to provide an ordered research base for those who wish to try their hand at these studies.

After an initial filter through all the searches across different databases, which totaled approximately 55,000 papers, 70 searches relating to the engineering aspects of comfort were identified.

These were categorized according to the attributes considered by the authors for analyzing comfort. Subsequently, the studies were clustered based on the methodologies used to analyze comfort.

For the first classification, five groups were identified: load factor and crowding; climate condition; vibrations; driver's driving style and multiple attributes.

Whereas, for the second classification, three methodologies were identified: subjective, objective, and mixed. The contents and results of the revised manuscripts were summarized.

Although there is a particularly large body of literature available on OBCL, there are still no methods for establishing graduated and dynamic comfort scales that incorporate different passenger characteristics (such as age and seating position) along with real-time acceleration data. This limitation, to date, has prevented the creation of a comprehensive, real-time assessment of OBLC that accurately reflects passenger experience. Moreover, there is a need to collect a huge amount of data for the measurement to calibrate models and to build comfort scales more consolidated.

The findings from these studies facilitate the pinpointing of precise areas where comfort levels are insufficient. This enables transportation agencies to concentrate on specific areas requiring improvement and to enact targeted interventions aimed at enhancing the passenger experience.

In addition, in competitive transportation markets, these comfort analyses can serve as a valuable benchmarking tool, allowing companies to differentiate themselves based on superior comfort offerings.

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International Ports in Medium-Sized Cities in Greece – Coexistence Problems and Planning Challenges in the Era of Smartness and Sustainability

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Abstract. In the current era of blue growth and smart green development, port cities are undoubtedly in international competition as key drivers of the global maritime transport and trade system. In this evolving context, port and spatial policies are challenged to reconcile global trends with the specificities of each port city in order to ensure sustainable urban development. For small and medium-sized cities in particular, the operation of a port of international importance is a complex, contradictory and challenging planning issue. On the one hand, medium-sized cities face multiple pressures from port operations due to their limited size; on the other, they cannot always support the global role of their ports, mainly due to lack of infrastructure. Under these circumstances, it is crucial to reconsider the difficulties/risks facing this specific category of cities to address critical resilience issues. Taking as case study cities with international ports in the Greek periphery, the article presents a methodology for the correlated study of their dynamics, based on spatial and development criteria examined at three basic spatio-functional units, i.e. the city, the port and the waterfront. At the same time, through a consideration of the development policies and planning practices of ports and their cities, the article seeks to highlight challenges and dilemmas at the level of spatial perspectives, reintroducing issues of urban resilience and sustainability.

Keywords: City-Port Relations · Green and Resilient Port Cities · Regional and Urban Development · Sustainable Planning · Risk Assessment and Management · Waterfront Regeneration · Competitiveness · Spatial Cohesion

1 Research Framework

The dangers of climate change for cities are widely recognised. As a result, the growing political interest in combining *economic growth* with *green development* is at the top of the global urban agenda. Specifically, the EU aims to achieve climate neutrality by 2050 as part of its Growth Strategy for a sustainable future [1, 2]. In this context of adapting to climate change and smart development, the issues of maritime spatial planning and

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integrated coastal zone management remain open. In this sense, and with the EU's Green Deal calling for a green transition, port cities are facing a new set of developmental and planning challenges and opportunities [3]. This is because ports are key drivers of local-regional-national and international development through their role in multi-modal transport and logistics, energy, industry, leisure and tourism. In this respect, the growing emphasis on resilient/sustainable port development models creates new conditions for port cities to address key strategic planning issues.

At the same time, current transport system conditions and the emergence of new intermodal hubs, together with port industry restructuring, are dramatically affecting port-city interactions, challenging the traditional mutually beneficial relationship between these two systems. Historically, ports and cities have been characterised by a high degree of interdependence and proximity. However, the emergence of a new economy based on trade and new transport technologies in the 19th century created the need to develop a new type of port, one that would no longer function as an international trading centre but as a transshipment point in the global transport chain [4]. As a result, many ports and their host cities have grown apart, especially since the end of the 19th century. Over time, port operations have moved away from city centres due to other changes in shipping, such as larger ships and/or rapid urban industrialisation in most developed countries. Consequently, some ports have moved to new purpose-built sites outside urban areas. However, most ports remain in or near cities. This confirms that the world's major ports are still urban, as argued by Hall and Jacobs [5]. Despite the debate about the separation of cities from their ports and the resulting weakening of direct links, port cities tend to retain specific economic, social and cultural identities [6]. Ducruet and Lee define port cities as the result of the integration of port and city, sharing both common and specific characteristics [7]. Based on the above, port cities are undoubtedly a category of place that requires simultaneous and dynamic monitoring of the port and the city, and the relationship between these two systems [8, 9].

In this sense, the article argues that in a port city, urban and port functions are interdependent and interact at different spatial levels and in different ways in time. This requires both a broader view of port cities as an organic part of the wider national and international transport and urban systems, and a consideration of how the main spatial levels of a port city (i.e. port, city and waterfront) interact in the urban environment. In the context of the above basic assumptions, the article aims to formulate a multifactorial methodology for optimal understanding of port-city relations and their impact on port city sustainability in a highly competitive international environment. Taking five Greek regional cities with an international port as a research area for the proposed methodology, the focus at this stage is on the simultaneous monitoring of these cities using criteria/indicators of regional scope. The aim is to critically identify coexistence problems and key planning issues to be further addressed at city level in the next phase, using quantitative/qualitative indicators. In this context, the article is intended to serve as a basis for recognition at the regional level. It also provides an opportunity to consider how the next stages of research should be organised. This reflection is already underway in the five participating port cities (Alexandroupolis, Kavala, Igoumenitsa, Volos, and Patras - from north to south) (Session 3).

In approaching the object of research, the article is divided into seven sessions. The first introduces the problem to be addressed. The second is an attempt to set the stage for developing the framework of the proposed methodology for assessing the dynamics of port cities. In particular, a brief review of key milestones in the current literature emphasises the need to simultaneously monitor how both systems operate /interact. The third is a description of the proposed methodology. The fourth presents the case of medium-sized mainland Greek cities with international ports. The fifth examines the importance of the five port cities studied as hubs in the European and Greek transport network, while the sixth assesses their dynamics as part of the Hellenic urban network focusing on three spatial levels, i.e. the port, the city, and the waterfront. Finally, the seventh presents the results of the comparative study of the Greek port cities studied and identifies critical issues for further research.

2 Assessing Port City Relationships – The Need for a Dynamic Multifactorial Approach

In an era of network organisation, technological revolution and the threat of climate and energy crises, the functions and scope of ports are constantly changing. This fact is shaping a new reality, which implies the need to rethink development policies and urban and regional planning practices in an era of smart, green and blue sustainability, due to the complex port-city relationships and their multiple impacts on the resilience of natural, cultural and man-made ecosystems.

In this dynamic context, the current literature has formulated numerous approaches to assess and measure port city dynamics. At this stage, the aim is not to present these approaches in detail, but to highlight the dominant trend that emerges from them, namely the need for a holistic perspective in order to have a better understanding of port city relations and their impact on urban-regional development. This is the objective of the proposed methodology (Session 3). Therefore, an attempt is made to briefly present the current debate by reviewing the approaches that could be considered as milestones in the construction of the proposed methodology (principles, spatial reference units, main thematic areas of criteria/indicators), since they clearly support the need to study the port and the city simultaneously. Specifically:

The Context of the Discussion: a Brief Literature Review. Although the assessment of the port-city relationship and its impact on local development involves both qualitative and quantitative aspects, several researchers mainly use quantitative indicators [9]. However, it is interesting to note that these indicators are increasingly used to create composite indicators, i.e. the two systems (port and city) are not assessed independently, but are inextricably linked. For example, many studies focus on the dynamic relationship between port operations and urban development. In this respect, Ducruet and Lee's approach to port-city relations is based on the study of the population and container throughput of port cities in combination with other critical indicators such as transport activity, port infrastructure, sea and land networks and urbanised area [7, 10]. The correlated port-city view using quantitative indicators is reinforced by Guo et al.'s approach, piloted in China's maritime cities, which attempts to construct a more

multi-factorial assessment of the port-city relationship using environmental and socio-economic indicators [11]. Equally interesting are the approaches to assessing the port-city relationship, focusing on evaluating the competitiveness of both systems, i.e. the port and the city. This is a key parameter for sustainable development [12]. For example, Xiao and Lam propose a systems-based sustainability framework for Singapore's port cities. They consider the port one system and the city another. From the perspective of these two different but interrelated systems, they propose thirteen economic, social and environmental indicators [13]. Equally interesting is the approach of Oraga et al., who introduce the criticality of port governance as a crucial aspect of ensuring port city sustainability/competitiveness at local-supralocal level [14]. Taking Western Indian Ocean region as a study area, they propose an indicator framework to assess port city relations and dynamics, focusing on the simultaneous study of port city development (*socio-economic aspect*), marine/urban ecosystem sustainability (*environmental aspect*) and existing regulatory framework (*political aspect*). In a similar context, Merk and Dang propose a set of port city indicators to provide an overview of the effectiveness of port city development. These indicators mainly combine policy objectives in several areas: natural - cultural environment, transport, research - innovation, communication networks and spatial cohesion [15].

Existing Knowledge as a Driver to Develop a Multifactorial Methodology. The proposed methodology is based on the need to consider the simultaneous monitoring of the port and the city, and is enriched by the criticality of considering the waterfront, an area that is contested by the two systems. In order to ensure optimal assessment of competitiveness and sustainability of port cities, existing knowledge is used to organise the main themes of criteria/indicators that allow multifactorial monitoring of port city relations and their impact on local and regional development. The aim is to create a pool of criteria/indicators that can be updated and enriched, with the possibility to use them on a case-by-case basis.

In conclusion, the literature review highlights the challenges associated with establishing a suitable set of indicators for measuring port city performance. Moreover, the richness/complexity of the issues related to port cities is reflected in the large number of indicators identified. The majority of studies in the review propose an indicator-based approach. This involves measuring key relationships for a number of indicators related to the port and the city. This is a key priority that has led to formulating the proposed methodology and identifying the evaluation criteria. Both focus on the spatial expression of the relationship between these two often contradictory but mutually reinforcing systems.

3 Methodology and Main Stages of Research

In the context of the international debate on the evaluation of the city-port relations, the article formulates a multi-factorial methodology, based on spatial criteria, to study the different aspects of this interaction and its contribution to local - regional development. Given the size and scope of ports and related supralocal activities developed in the wider urban environment of their cities, it is argued that the port-city relations should be studied at all scales (i.e. local, regional, national and international), using a dynamic and critical

approach. It is also emphasized that the dynamics of port cities need to be considered in a broader perspective, as this specific category of space functions not only as a node in the (supra)national transport network, but also as part of the (supra)national urban network. It is therefore emphasised that the assessment of the port-city relationship must be considered in three spatial units simultaneously, i.e. ***the port***, ***the city*** and ***the waterfront***. Attention is given to the waterfront for two reasons. First, it is an area of increased vulnerability, simultaneously claimed by the port and the city to satisfy their particular development needs. Second, it is under increasing pressure from urbanisation, tourism and the development of human activities on land and at sea, with multiple impacts on natural, cultural and man-made ecosystems.

Based on the above assumptions, the article attempts a comparative study within a dynamic multi-level and multi-factorial approach, incorporating spatial criteria in six thematic areas, namely ***centrality*** *(*geographical location/geopolitical gravity*)*, ***demographic*** **and** ***socio-economic characteristics*** (population, production sectors, entrepreneurship, economic indicators, etc.), ***accessibility and connectivity*** (transportation network), ***natural - cultural heritage***, ***built environment*** (density, urban quality, functions/land uses, public space, etc.) and ***supra-local infrastructure*** (production, technical and social).

The choice of the above six themes is not arbitrary. On the one hand, they highlight the multiple aspects of the port city relations and its role in their development. On the other hand, they allow the development of indicators (quantitative/qualitative) that can be used in a next step to assess and measure the resilience and competitiveness of port cities. At this stage, attention will be given to the following indicators per spatial level: a) port: ***port functions/services***, ***turnover/profit***, ***traffic value***, and ***port governance***, b) city: ***population*** (size, % change), ***unemployment rate***, ***gross domestic product*** (**GDP**), ***administrative role*** [seat of regional unit (NUTS 3) or region (NUTS 2)], ***city scope*** (centrality in the national urban network as defined by the government or scientific approaches), c) waterfront: ***accessibility/connectivity***, ***natural-cultural ecosystems***, ***built density, land /sea uses***, and ***public space***. The contribution of above criteria to assessing waterfront quality, spatial continuity and organic integration into the urban environment is considered significant. In the current phase, the approach to the criteria is attempted in the broader context of an initial survey and mapping of the dominant land uses. The aim is to have a better understanding of the relationships so that a more detailed study can be attempted in the next phase. In all five cases, research is already underway in this direction.

The above criteria/ indicators are complemented by crucial issues such as ***port-city-waterfront governance***, ***ownership status***, ***port and spatial policies and planning approaches***, ***stakeholders and participatory planning***. At this stage, addressing these issues is indicative and supportive. The aim is to differentiate the dynamics of the five cases studied and to identify the common problems they face. At a later stage, an attempt will be made to conduct a detailed study combining quantitative and qualitative indicators at the level of specific port cities to draw conclusions for each case. To approximate the quantitative indicators, official databases were used [16] (Fig. 1).

The proposed methodology was tested in five medium-sized cities with international ports in mainland Greece. The choice was not made at random. In four of them, ports are

located within the urban fabric and close to the city centre. This spatial correlation creates a number of interdependencies, but also various conflicts/tensions. The main impact is on urban and coastal environmental quality, but also on the degree of open access to the waterfront. Of particular interest is the case of Kavala, where the port is adjacent to the city centre. This increases interdependencies, impacts or conflicts. Despite the fact that two of the five cities are considerably larger and more dynamic (Patras, Volos), they face problems similar to those of the three smaller and less developed cities (Alexandroupolis, Kavala, Igoumenitsa). The correlative monitoring of the five port cities confirms this.

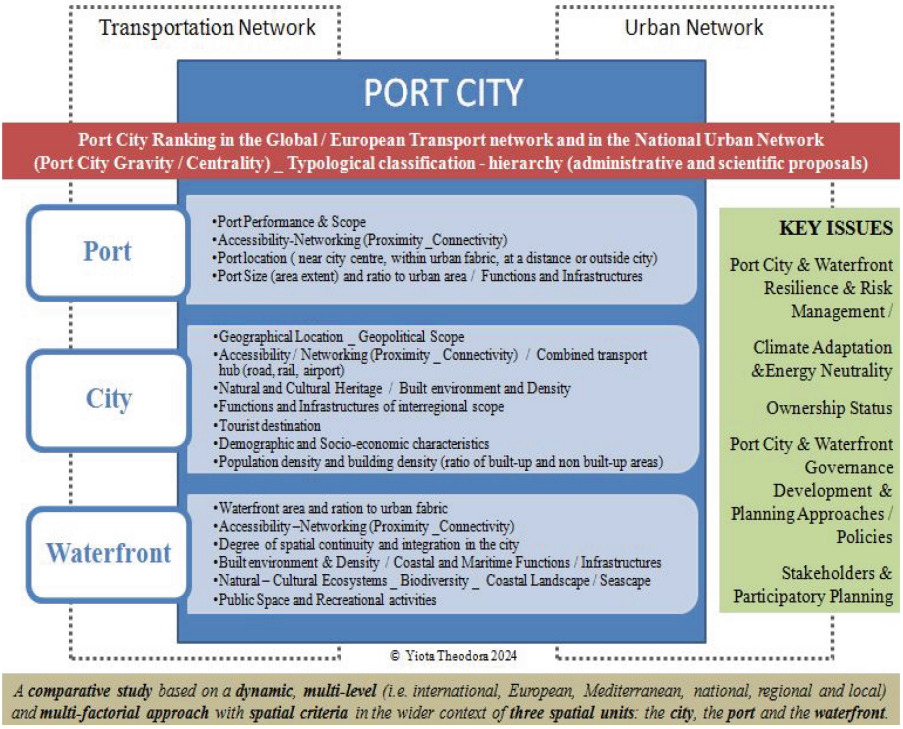

Fig. 1. Main Research Themes by Spatial Reference Level [own elaboration]

In conclusion, the proposed methodology aims to contribute to the scientific literature by proposing a framework for understanding and quantifying the dynamics of a port city from the perspective of port-city integration. It is worth noting that although the proposed methodology and criteria have been applied to medium-sized regional cities with an international port, they can be applied to any port city, regardless of size, location or scope. Its practical value lies in the ability to approach the following planning issues: a) identifying port-city linkages, b) evaluating policies and planning approaches, and c) highlighting opportunities and risks at the spatial organisation perspective level, reintroducing urban resilience/sustainability issues. This is undoubtedly a methodology that can provide the basis for moving from a correlated view of port cities to the next phase,

which will emphasise the spatial dimension, using indicators to assess the evolution of city-port relations over time and by city [17, 18].

4 International Ports in Medium-Sized Cities on the Greek Mainland

Port cities continue to be a key parameter in the transport and spatial planning of local and regional development. Therefore, in countries with an important maritime history and activity, port city planning should be a priority and part of their strategic development. Greece is such a case because of its geostrategic importance (south-eastern gateway to Europe and part of the trans-European network), its strong coastal/island character and diversity of port systems, and its global dynamism. The country has an extensive network of ports. Each plays a different role in the national /international transport network and is expected to develop differently. According to the Greek National Ports Policy (2007), ports are divided into four groups: ***Ports of International Interest***, ***Ports of National Importance***, ***Ports of Major Interest*** and ***Ports of Local Importance*** [19] (Fig. 2).

Specifically, the group of *Ports of International Interest* includes sixteen ports. Ten are located on the mainland and the rest are on islands. In particular, *international ports* are located in ***metropolitan areas*** [Athens Metropolitan Region (Piraeus, Elefsina, Lavrion and Rafina) and Thessaloniki Metropolitan Region (Thessaloniki)], ***medium-sized cities*** (Alexandroupolis, Kavala, Igoumenitsa, Volos and Patras - from north to south), and **insular regions** [Mytilene (capital of Lesvos, North Aegean Region), Corfu (Ionian Island Region), Rhodes (Dodecanese Complex, South Aegean) and Crete (Heraklion, Souda in Chania) - from north to south), as well as on **small islands** that are international tourist destinations (Mykonos). Although all sixteen port cities belong to the same group, they differ in terms of their geographical location (i.e. centrality in the global transport system and in the national urban network), the specialisation and reach of their ports, the characteristics/peculiarities of their cities (i.e. accessibility, city size, density, land use/infrastructure, local identity), but also the quality of their waterfronts and the extent of their integration into the urban fabric.

Particular attention is being paid to small/medium sized mainland cities with international ports, as the naval functions now operate in a completely new, globalised and highly competitive environment. This group includes the five port cities studied, from north to south, **Alexandroupolis** (capital of the regional unit of Alexandroupolis) and **Kavala** (capital of the regional unit of Kavala), both in the region of Eastern Macedonia & Thrace; **Igoumenitsa** (capital of the regional unit of Thesprotia) in Epirus Region, and the larger and more developed port cities of **Volos** (capital of the regional unit of Magnesia) and **Patras** (capital of the regional unit of Achaia) in the regions of Thessaly and Western Greece, respectively. The five port cities are expected to play a key role in the national-regional development of Greece as hubs of global transport networks and, in particular, as strong intermodal hubs. This is due to the location of the cities on the Trans-European Roads: Egnatia Odos, Ionian Odos, Olympia Odos, P.A.TH.E (Patras-Athens-Thessaloniki-Evzonoi) and the presence of a railway and an airport. Igoumenitsa is an exception. It has no rail or air connections (Fig. 2).

There are many reasons for focusing on the Greek periphery. First, despite the fact that European and national spatial policies support ensuring polycentric spatial development as a condition for territorial/socio-economic cohesion in the context of globalisation/networking, Greece is still dominated by the Athens-Thessaloniki dipole, which exacerbates regional inequalities [20, 21]. In this regard, the two metropolises are still the main beneficiaries of investment, while many small/medium-sized regional cities are left behind and have significant infrastructure deficiencies. The question is whether and how these regional cities can support international port activities [17, 18]. Second, new port reform initiatives are emerging around the world. They aim to attract private investment in regional ports, either through the sale of controlling stakes or through the granting of concessions for port operations. Discussing this issue is challenging and raises many questions. This is especially true in Greece, where the diversity of regional port cities, due to the different dynamics of the cities and the size/scope of their international ports, poses crucial planning dilemmas to ensure sustainability. These dilemmas must be addressed to ensure local development. The different characteristics of medium-sized regional cities with international ports have led to the formulation of the proposed multi-criteria methodology to assess the peculiarities of these cities, applied simultaneously to the three key spatial units that define the port-city relationship (i.e. port, city and waterfront). Third, the operation of an international port in a medium-sized city raises many planning issues related to the coexistence of the port and the city at all different spatial scales (local, regional, national) in an era of climate-energy crises.

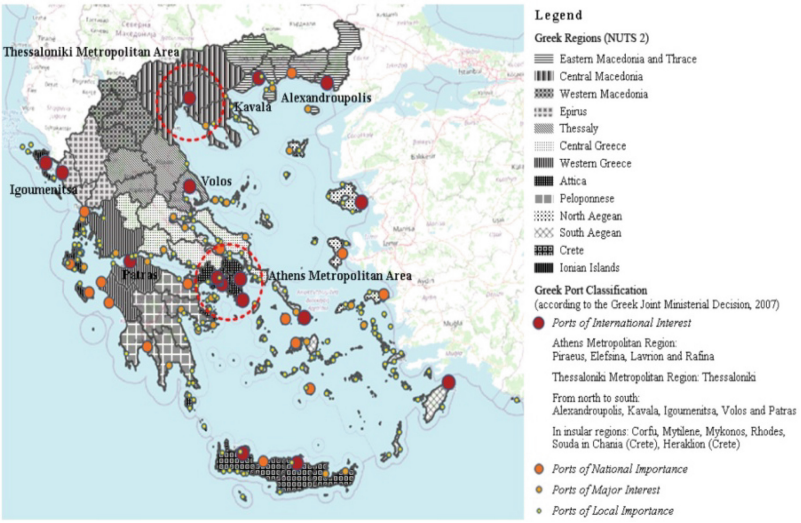

Fig. 2. Official Greek Port Classification [19] [own elaboration]

Last but not least, the selection of international ports in continental Greece makes it possible to study them combined with other transport systems (road, rail and airport). This is a crucial parameter for spatial planning - development in an intensively globalised economic environment, in which ports do not function in an autonomous way, but rather

as hubs of global supply chains [22]. More than ever, supply chains have an impact on port performance. They have become a relevant area to analyse for competitiveness and resilience. The interdependence of the supply chain and the ports has given rise to a new reality. This has many implications for the relationship between the port and the city. The creation of more efficient links between ports and their hinterland is one of the fundamental needs of this new reality. This requires integrated planning considering both port and city [17, 18].

5 Greek Regional Port Cities of International Scope as Hubs of the Global Transport Network. Accessibility, Proximity and Networking

As the quality of the inland transport infrastructure is becoming one of the most critical factors in the competitiveness of ports, the approach to the land transport networks is a key component in the dynamics of port cities. The new Trans-European Transport Network (TEN-T) guidelines also recognize the need to connect the port to the mainland. The importance of Greece in the global and trans-European transport network is crucial due to the geo-strategic and geo-political position of the country. Greece functions as a regional entity in the southeastern Mediterranean, far from the EU's powerful centre. Greece is also the main gateway to the EU from the east [23].

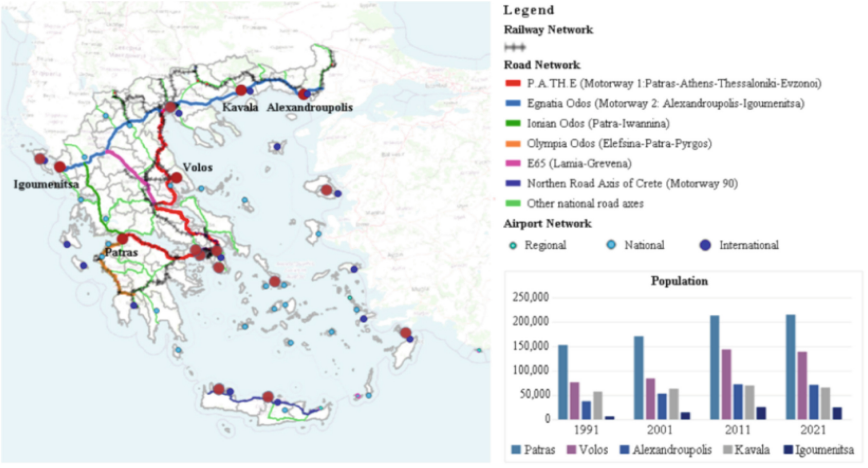

Fig. 3. International Ports in Medium-sized Greek Cities as part of the National Transportation Network (road, rail, and airport) [16] [own elaboration]

The main challenges for the competitiveness of the Greek transport network include overcoming the constraints imposed by the country's geomorphology (i.e. mountainous areas, insularity) on the development of road and rail networks, and exploiting the rich network of mainland and island ports. Regarding the port network, the ranking of the 25 Greek ports (Regulation (EU) 1315/2013) in the TEN-T recognizes their contribution

to the European economy. To be more precise, these ports are part of the south-eastern Mediterranean corridor and most of them are located on islands. Among the regional ports of international scope studied, Patras and Igoumenitsa are part of the national network, while Volos and Kavala are also included in the extended network. Note that the TEN-T network does not include the port of Alexandroupolis. This is despite its strategic location (Fig. 3).

At the national level, hinterland accessibility was also identified as one of the most critical factors for port city competitiveness. Land access to seaports is closely linked to the existence and quality of road, rail and air networks, both spatially and functionally [24]. In this sense, the accessibility of Greece is considered by taking into account the geographical proximity of the port cities studied to the main national motorways and railways. Road transport has historically captured the largest share of the freight market, both within the port area and in the hinterland. The European Union is making a major effort to promote alternatives to road-based transport. Despite the strategic importance of port-rail links for port development in economic and competitive terms, most regional ports in Greece have no direct rail links, such as the port of Alexandroupolis. This prevents them from becoming global intermodal hubs.

Finally, the use of substitute/complementary modes in maritime and air transport is of growing interest in transport planning [25]. Providing fast and efficient connections between ports and airports is becoming increasingly important. As two nodes, ports and airports are always connected by road and their proximity is an approximation of their distance. For Kavala, Volos and Patras, the distance is between 32 and 39 km. The closest airport to the port of Igoumenitsa is in Ioannina. Administratively, in all the port cities studied, except Igoumenitsa, the ports and their nearest airports are in the same regional unit.

6 Greek Regional Port Cities of International Scope as Part of the National Urban Network – Features, Peculiarities and Dynamics

After examining the importance of the five regional port cities in the global transport system, this session moves on to understand cities' dynamics by identifying their role/centrality in the national urban system (Session 3). The aim is to identify the regional cities that appear to have difficulties in supporting the operation of international ports and ensuring a balanced relationship between port and city, and to highlight the degree of difference in the dynamics of the five cases studied.

6.1 The Port – Approaching Its Performance and Scope

In order to assess the dynamics of the five ports, particular attention is paid to the analysis of data related to spatial criteria, such as: ***port functions and services***, ***turnover /profit***, ***traffic*** (vessels, passengers, vehicles and containers) and ***port governance***. These are criteria that can have a key role in the typological classification of the port cities studied, in order to better understand their dynamics at the local and supra-local level on the basis of different dimensions of their port specialisation/scope [26]. Specifically:

Port functions/services (2009–2020) An analysis of the functions carried out in the five ports studied shows that most of them cannot be considered as specialised. Kavala is an exception, as the new port of Nea Karvali, 8km from the city, specialises in commercial transport, while the main port, close to the city centre, has developed tourism, coastal and fishing activities. The other four ports have a wide range of cargo and passenger handling services. Specifically, the main activities of the Port Authority of Alexandroupolis are the conventional general cargo and bulk cargo, the storage and the coastal passenger transport. The Igoumenitsa Port Authority, on the other hand, mainly handles passengers and vehicles. Concerning container traffic, only the Port of Volos had such services until 2017, while the Port of Patras has been providing container handling services since 2018 [16].

Turnover/profit (2009–2020) To approximate the dynamics of the five ports, turnover/profit rates were selected from the annual accounts published by each port authority. In particular, the ports of Patras, Igoumenitsa and Volos are different from those of Alexandroupolis and Kavala. Alexandroupolis has the lowest rates, capped at €800,000 per year. Kavala port reported a steady increase from just fewer than €1 million in 2015 to around €2 million in 2019. Volos recorded the largest variations. In 2016, Volos port recorded a significant increase in turnover/profit ratio of almost €1 million, the highest ratio of the year. The port of Patras recorded the highest turnover/profit ratio in 2015 (€5,753,311). In 2019, it reached 6,375,385 €. Furthermore, the port of Igoumenitsa had the highest turnover in 2018 (€5,843,169) and Patras was in second place (5,687,350 €). Igoumenitsa and Patras have had similar turnover rates since 2017 [16].

Traffic volume (2009–2020) The analysis is based on the data collected by the Hellenic Association of Ports (ELIME). It is worth noting that the way Greek ports are organised and operate has changed in recent years. This is mainly due to the COVID-19 pandemic. Overall, the pandemic period is characterised by a significant reduction in coastal passenger traffic and very limited cruise activity. The performance of Greek ports in the freight sector is unstable. In particular, similar trends in port ranking can be seen in the analysis of coastal shipping and passenger transport. In both categories, the port of Igoumenitsa ranks first, followed by Kavala, with Alexandroupolis firmly in fifth place. In the coastal passenger category, the ports of Patras and Volos ranked third and fourth respectively. Generally speaking, vehicles handled followed a similar trend to passengers. Igoumenitsa is almost every year the number one port in terms of truck traffic. The same indicator is low and stable in Alexandroupolis. In addition, the port of Volos is a leader in the cruise ship sector. It was only in 2017 that more cruise passengers arrived at the port of Igoumenitsa (9,088) than at the port of Volos (7,618), although the number of cruise ships arriving at the port of Volos was slightly higher. On the contrary, Alexandroupolis port was almost every year the port with the fewest cruise ships and passengers. Notably, none of the four ports offered cruises in 2009. The COVID-19 outbreak and subsequent travel restrictions and border closures resulted in lower cruise ship and passenger arrivals in 2020 in all ports studied [16].

Port governance (1999–2024) In recent decades, it has undergone profound changes. Port reform initiatives have been launched in two major ports: Piraeus (2016) and Thessaloniki (2018), which were transformed into public port companies in 1999 (L.

2688/1999). Two years later, ten ports of national importance (Alexandroupolis, Corfu, Elefsina, Heraklion, Igoumenitsa, Kavala, Lavrion, Patras, Rafina and Volos -in alphabetic order) were turned into autonomous port administrations (L. 2932/2001). Since 2016, Greek ports have been structured as comprehensive port authorities. They are controlled by the State [27]. Undoubtedly, the privatization of the ports of Piraeus and Thessaloniki has decisively influenced the Greek port system's governance model and development prospects. In recent years, the privatization of the international ports of Alexandroupolis, Kavala and Igoumenitsa has been at the centre of the debate; but only Igoumenitsa was privatized [16].

6.2 The City – Identifying Characteristics and Developmental Prospects

For a better understanding of the importance of port cities within the global transport system and the Greek urban system, it is necessary to assess not only the dynamics of their ports, but also the dynamics of their urban environment (i.e. accessibility, functions of supra-local scope) within their wider spatio-functional area at the regional level. Thus, particular attention is paid to the demographic, socio-economic and spatial characteristics of the port cities, including ***population***, ***unemployment*** and ***GDP rates***, ***administrative gravity*** [position in national administration: region (NUTS 2); regional unit (NUTS 3)], and ***city scope*** [importance/gravity of port cities in the Greek urban network] (Session 3). The following results can be derived from the comparative study:

Population (1991, 2001, 2011, 2021) At the national level, Patras is the third largest city in Greece, after Athens and Thessaloniki. Patras and Volos followed by Alexandroupolis, Kavala and Igoumenitsa, with significant population differences. Between 1991 and 2021, Patras and Volos are always in first place, while the other three smaller and less developed cities change places. Specifically, in 1991 and 2001, Kavala and Alexandroupolis ranked third and fourth respectively among the five port cities studied. But Alexandroupolis climbed from fourth to third in 2011 and stays there in 2021. Igoumenitsa remains the least populated city in the study period. By 2021, Patras will have eight times the population as Igoumenitsa. It is also interesting to consider the ratio of the population of the port cities studied to the other cities- seats of regional units in their region. In the total population of Western Greece Region, Patras makes a significant contribution. In the region of Thessaly, Volos is the second largest city after Larissa, and together they form a strong urban dipole with national reach. Alexandroupolis and Kavala are the most populated cities in their region (Eastern Macedonia and Thrace), while Igoumenitsa is the least populated city in its region (Epirus). Finally, the population change in the five port cities increases until 2011. However, the population of Alexandroupolis, Kavala, Igoumenitsa and Volos will be in decline between 2011 and 2021. Only Patras will see a slight increase [16] (Fig. 3).

Unemployment rate (1991, 2001, 2011, 2021) Overall, Alexandroupolis had the lowest unemployment rate in all the years examined. Conversely, Patras had the highest unemployment rate in 2001 and 2011. On the other hand, although Igoumenitsa started with the highest unemployment rate, it fell from first to second place in 2001, when it was overtaken by Patras. In 2011, it ranked fourth. Finally, the unemployment rates of Kavala and Volos were very similar over the period under study. Comparing the five port cities' unemployment rates with the regions to which they belong, Patras, Volos, Kavala

and Igoumenitsa have higher rates over the period studied. The Alexandroupolis case in 1991 is similar. Finally, in terms of percentage change, the unemployment rate in all port cities was dramatically on the rise over the period. Only Alexandroupolis recorded a slight decrease in 2001 [16].

Gross domestic product rate (1991, 2001, 2011, 2021) The richest regional unit is Achaia (Patras), followed by Magnesia (Volos). GDP levels are similar in the Evros (Alexandroupolis) and Kavala (Kavala) regional units. Kavala ranks third, followed by Evros. However, the order is reversed in 2011, 2012, 2016, 2020 and 2021. It's notable that Thesprotia (Igoumenitsa) was always last. In terms of their GDP contribution to the total GDP of their regions, Evros and Kavala are the richest regional units (NUTS3) in Eastern Macedonia and Thrace (NUTS2). Magnesia follows Larissa in the case of Thessaly. Finally, Thesprotia still contributes the least to Epirus' total GDP, while Achaia contributes the most to Western Greece's total [16].

Administrative role Of the five port cities studied, only Patras is a regional capital (NUTS 2). The others are seats of regional units (NUTS 3). Greece's current administrative division was formed based on the *Kallikrates Programme* (L. 3852/2010).

City scope Both politically and scientifically, assessing the gravity/ importance of Greek cities in the national urban network has proven to be challenging. In the first, the population and the administrative role of the city are taken into account [28], while in the second, the supra-local infrastructure, which affects the centrality/gravity of the city, comes to the fore [21]. At the political level, the milestones in the assessment of urban dynamics and the classification of Greek cities over the last fifty years have been the following three proposals. The first was the proposal of the "*rival cities*" in 1979 [metropolitan regions of Athens and Thessaloniki; urban centres/dipoles of national reach: Kavala, Kozani- Prolemaida, Ioannina, Larissa-Volos, Patras-Aigio, Heraklion (Crete)]. The second was the "*open cities*" proposal of 1984, which divided Greek cities into five levels according to population size, namely *metropolitan centers* (1st level: Athens, Thessaloniki), *major national poles* (2nd level: *regional headquarters-serve about 500,000 inhabitants*), *secondary national poles*(3nd level: *prefecture headquarters*- serve about 100,000 inhabitants), *national poles* (4th level: *municipal headquarters* - serve about 50,000 inhabitants), and *other settlements* (5th level: *towns /villages*). Finally, the third proposal, supported by the *General Framework for Spatial Planning and Sustainable Development* (GFSPSD) (2008), adopts the five levels proposed by the "*open cities*" proposal of 1984 for classifying Greek cities. The current proposal has been criticised for using methods and criteria that do not correspond to contemporary conditions of network organisation (L. 2742/1999). According to this proposal, Patras, Volos and Alexandroupolis are considered as *major national poles* according to the GFSPSD, Kavala is a secondary national pole and Igoumenitsa a limited national pole due to its small population, although its international port is a national western gateway [28].

On the other hand, at a scientific level, the assessment of urban dynamics generally confirms that urban gravity depends more on the type, quality and intensity of concentration of supra-local infrastructures than on the size of the population. In other words, it is the lack of infrastructure that prevents the cities that have an international port from being competitive. This hypothesis is confirmed by the study of Theodora and Loukakis,

which shows that the centrality of cities depends not only on their population, but also on their geographical location, accessibility and the presence of supra-local infrastructure in the fields of administration, production and services (industrial and technological parks, SMEs), transport, education/innovation (universities, research centres, etc.), health, culture, tourism and leisure. According to this study, when population is disregarded and infrastructure of supralocal scope is weighted, the five port cities, with the exception of Igoumenitsa, belong to the group of cities of major importance. However, in terms of population, Patras and Volos still stand out (*interregional/national*), Kavala (*regional*) and Alexandroupolis (*inter-prefectural*) are downgraded, while Igoumenitsa is consistently limited *prefectural* [21].

6.3 The Port City Waterfront – Assessing Spatial Continuity and Urban Integration

Port city relations can be competitive, complementary or even indifferent. The waterfront is where this unique relationship becomes really visible. It is a special category of space where competition, public access and environmental concerns are making the issues of planning and management more relevant to urban policy. These problems seem more acute in small/medium sized cities where the waterfront is an important part of urban fabric and local identity. In this respect, a key challenge for coastal and urban sustainability in port cities is to ensure free access to the water through planning approaches that guarantee the waterfront's spatial continuity and integration into the city and daily life of residents and visitors [17, 18, 30].

Based on the above, at this stage the study of the urban waterfronts of the five port cities was based on the identification/mapping of the dominant land uses along the coastline and in the wider city. Figure 4 shows these main spatio-functional units as defined by the digital map of the Greek Ministry of Environment and Energy and the official master plans of each of the five port cities and their waterfronts (i.e. city centre, urban public space, waterfront public space, port uses, industrial uses). Using this data, the article takes a first step towards identifying key similarities and differences between cases [16]. The next step, which is currently underway, is to focus on the city scale, aiming to identify coexistence problems and prioritize interventions (Fig. 4).

Preliminary results show that the current condition of waterfronts varies. This diversity of port city waterfronts is mainly determined by ***geomorphological/spatial factors*** (coastline, landscape/sea features, location of the port in relation to the city centre and its interaction with other urban/maritime land uses, etc.) and ***developmental factors*** (the relative importance of the port to the city and the development prospects of the city). This spatial study shows that, particularly along the waterfront, the proportion of port uses and green/public space varies, but in most cases port infrastructure is dominant. Igoumenitsa is an example of that, because although the urban fabric extends along the sea, the relationship between the city and the sea is insufficient/problematic, since the port occupies most of the waterfront [17, 30]. The study also shows differences in port locations compared to city centres. Interesting cases are Alexandroupolis and Kavala, where the city centre is largely adjacent to the port. Another key parameter in the changing nature of waterfronts is the shipping industry. The port-city interface is greatly influenced by the spatial dimension of port infrastructure. In this context, ports

are recognised as engines of economic development. However, they can also have a negative impact on the attractiveness of the cities they serve. In order to address the diverse local impacts of port activities, urban studies are required for each city. This is beyond the scope of this study. However, given its importance for the sustainability of port-city relations, it is worth mentioning. But what's really important, and what emerges from the comparison of the five port cities, is that while they are different, they all share a vision of making the most of their main asset - their relationship with water. In order to achieve such a goal, a multi-level and multi-factorial study of the waterfront, which is inextricably linked to the city, is required. There is therefore a need to develop a methodology that can address quantitative and qualitative indicators simultaneously. These indicators, based on the broader context of the main criteria already presented in the proposed methodology (i.e. *accessibility/connectivity*, *natural-cultural ecosystems*, *built density and land /sea uses*, and *public space*), will emerge in the next phase of the study (Session 3).

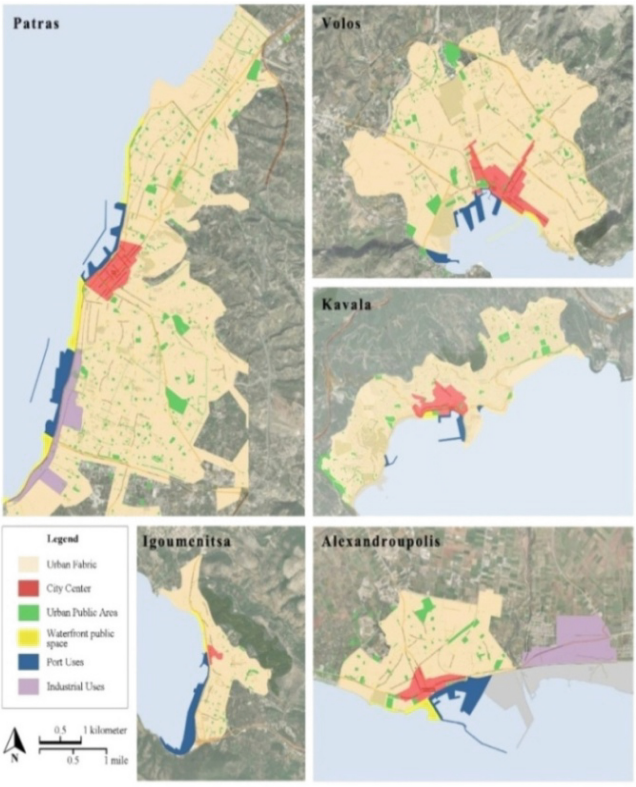

Fig. 4. Main Spatio-Functional Units in the five Port Cities [16] [own elaboration]

In conclusion, we can classify the five port cities typologically into three groups, based on the correlation analysis of gravity/centrality in terms of international/national transport networks. In the ***first group*** are Patras and Volos, the largest and most dynamic

port cities. In the ***second group*** are Alexandroupolis and Kavala. These ports are less dynamic but have significant development potential. Finally, Igoumenitsa is placed in the ***third group*** because of a number of infrastructure weaknesses of global importance. These weaknesses prevent Igoumenitsa, in spite of its geo-political importance, from playing a key role in the international transport network and in the national urban network. The city has only a small business park, no logistics and freight centres, and no rail or airport connections that would allow it to become a hub for intermodal transport. Igoumenitsa also suffers from limited economic activity and lacking social infrastructure (education, research-innovation, health, etc.). On the other hand, Igoumenitsa has great development potential due to its international port and centrality in the national road network [at the junction of the Egnatia and Ionian Odos] and the Trans-European Transport Network (Northwest Gateway). At the same time, the geomorphology of the city, urban development and the demands of the port put increasing pressure on the natural, cultural and man-made environment. It is the coexistence of these characteristics that makes Igoumenitsa an interesting pilot case.

7 Insights from the Comparative Monitoring of Greek Regional Port Cities of International Scope and Open Issues

Over the past 20 years, and especially during the multifaceted crisis, transport infrastructure has been central to Greece's development as a competitive option. The close link between transport infrastructure and development is reflected in Greek transport policy. Thus, the implementation of the *National Transport Plan for Greece (NTPG)* is expected to improve the overall efficiency of the transport sector and enhance the sector's capacity in order to support economic growth, environmentally sustainable practices, road safety, accessibility and regional/international connectivity [31].

Although the NTPG recognizes the need to improve the connectivity and accessibility of the outermost regions, most of the investment proposals are still concentrated in the two metropolitan areas of Athens and Thessaloniki. In particular, Epirus, the poorest region in Greece, still has very few investment plans, even after the completion of the Egnatia and Ionia Odos (Reference Scenario 2027). However, significant measures have been proposed for the development of the port cities studied. These measures are to be implemented by 2037. The relevant long-term plans include interventions in the rail network by creating new connections at Alexandroupolis, Kavala and Volos, and the development of new freight sacks at Larisa -Volos, Igoumenitsa and Patras (Reference Scenario 2037) [31].

On this basis, and although investigations are still underway, the comparative analysis of the five port cities has shown significant differences between ports, cities and waterfronts. Thus, ports differ in size and function. Cities have different strengths and weaknesses, and waterfronts have different characteristics/dynamics that affect port-city relations. In particular, Igoumenitsa seems to be the most vulnerable city, despite its international port. On the other hand, Alexandroupolis' port performance is very low. However, the host city appears to be more dynamic mainly due to the supralocal concentration of infrastructure in the education, health, energy and army sectors. At regional level, the two border regions of Eastern Macedonia and Thrace, and especially Epirus,

appear to be the most vulnerable as regards population and GDP distribution, while there are significant differences in the performance of their ports. However, the involvement of the private sector in the management of the port of Igoumenitsa is the most notable difference. While this process has had a positive impact on the competitiveness of ports, new socio-economic, spatial and environmental challenges for port city planning are emerging. Especially in cases like Igoumenitsa, where the city seems unable to support international port operations [17].

The multifactorial and multi-level research shows that the dynamics of the port cities studied are very different. This is due to the deformation of their characteristics/peculiarities. Therefore, as the majority of national investments seem to favour the more competitive metropolitan areas, dynamic monitoring at the port city level in the wider national and international context is crucial. In addition, the dominance of port functions on the waterfronts of port cities creates a wide range of constraints and difficulties for sustainable urban development. In an era of climate and energy neutrality, these need to be addressed.

The port city relationship is undoubtedly being redefined by the new requirements for sustainability and resilience. Today, ports and cities should work closely together for effective green port and spatial policies which help port cities grow and increase their resilience. The interdependence of port and city in implementing policy comes at a time when the privatisation of the regional ports of Alexandroupolis, Kavala and Igoumenitsa is dominating the national debate. This raises further questions and dilemmas at the level of urban-regional planning and local development in relation to the resilience of the port city. In this dynamic context of discussion and review of the sustainability and competitiveness of ports, the importance of a multifaceted approach to the port-city relationship is more than crucial [17, 18].

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Machine Learning Tools for Predicting the Outcome of Pedestrian Crashes: Preliminary Findings in the Metropolitan City of Rome

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Abstract. Creating cities and roads at a human scale is the main challenge of a not-distant future. The spread of new modes of transport reduces the distances from this future at a high speed and changes in vulnerable user urban mobility pose new questions in terms of sustainability a safety issues. Actions to promote these two vital conditions constitute the main prerequisites to be ensured by experts in the context of policies, economics, planning, and design.

Road accidents are among the top ten causes of death worldwide, ranking seventh overall. On the other hand, they occupy the first place as regards deaths between the ages of 15 and 29. More than 1.2 million people in a single year die and most of them suffer from non-fatal injuries that may often impair quality of life.

Although the damages to the human body are unfortunately well known, thanks also to the current scientific literature, accidents may cause a large economic cost, and knowing and understanding this macroeconomic burden could give a strong direction in an effective policy-making decision process.

In this paper, following a general review of pedestrian accidents that occurred in the city of Rome, several machine learning models are proposed to predict the outcome of an accident involving a pedestrian.

Keywords: Sustainable Mobility · Road Safety · Pedestrian accidents · pedestrian safety · Random Forest · SVM · Machine Learning

1 Introduction

Road accidents unfortunately represent one of the leading causes of premature death and permanent disability in many parts of the world [1]. This is particularly true for pedestrians, cyclists, and motorcyclists, who constitute the most vulnerable road users

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[2, 3]. Their vulnerability stems mainly from the lack of external protections, exposing them to significantly higher risks than other road users when interacting with the urban environment [3–5].

Pedestrians are exposed to risk by various factors including speeding vehicles, jaywalking, distractions, psychophysical impairments (such as alcohol, drugs, and disease), and poor infrastructure conditions [6]. These factors contribute to road accidents involving pedestrians, which often result in fatalities [2, 7–11]. Reducing risk factors and promoting responsible behaviors is a challenge for every national government, as fewer deaths and injuries on the roads would lead to fewer economic and logistical damages [12, 13]. According to some authors, it has been demonstrated that the promotion of pedestrian and cycling mobility requires changes to road infrastructure [14–25] aimed at increasing safety and encouraging this type of mobility [26–28].

Sustainability is not only about the environment but also about maintaining the balance between society and economy. To achieve this balance, it is essential to reduce the number of victims of road accidents [29]. In the pursuit of sustainable development and improvement of road safety, various initiatives have been adopted both nationally and internationally. The 2030 Sustainable Development Goals, established by the United Nations in 2015 [29], serve as a guiding framework for global efforts towards sustainable development. Complementing these objectives, Directive 2019/1936 in Europe highlights the importance of road safety rules and standards to mitigate risks on the roads [30]. Furthermore, the Next Generation EU initiative aims to address the socio-economic challenges posed by the COVID-19 pandemic and promote a sustainable recovery across Europe [31]. In Italy, the National Recovery and Resilience Plan (PNRR) is the plan for accessing the funds requested by the European Commission from each of the Member States to obtain the funds from the Next Generation EU plan [31, 32]. The PNRR adopts a proactive approach by allocating significant investments towards the strengthening and innovation of infrastructure to be implemented by 2026, following the ecological transition, for €61.5 billion. Italy has also established and updated the "National Plan for Road Safety 2030" to reduce road victims by 50% by 2030 with a series of investments and reforms [33]. These coordinated efforts underline the commitment to sustainable development while ensuring safer and more resilient transport systems.

Despite this great movement by international and European policies, as can be seen from the Global Status Report on Road Safety 2018 [1], the number of deaths and injuries worldwide has certainly increased, undermining the objectives of the Sustainable Development Goals (SDGs). As noted by WHO, it is possible to see a double trend that refers to countries with a high average income and those with a medium-income: in the former, mainly European Countries, it is associated with a decrease in the number of accidents [34], while in the latter (especially in African and South-East Asian countries in strong development) there is a general and dizzying increase in accidents leading to injury and death [2].

In a study on 166 countries, Chen et al. [35] evaluate the economic burden of all types of road accidents using a macro-economic model that explains the effects of fatal and non-fatal injuries on labor supply, differences in the education and expertise in involved people and fewer investments due to the diversion of treatment costs. The evidence suggests that road accidents cost the world economy US $1.8 trillion in 2015–2030,

which equates to an annual tax of 0.12% on global GDP: low-medium income countries have the greatest health burden but a lower economic burden than high-income countries.

Economic considerations, however, find time and place in the analysis of sustainability assessment. In the study of Karkalakos & Tselekounis [36], the authors study the impact of road safety (expressed as a number of deaths per million inhabitants) on sustainability performance in the Organisation for Economic Co-operation and Development area (OECD). The two authors suggest that about 61.88% of the variation in the sustainability score can be explained by a variation in the number of serious road accidents.

Several works have analyzed the occurrence patterns and risk factors of traffic accidents involving vulnerable road users in different contexts and some of the most important variables that influence vulnerable users' accidents are:

- The modal share of different road users, such as pedestrians, cyclists, and motorcyclists. Cities with higher rates of walking and cycling are safer for vulnerable road users than cities with higher rates of car occupancy [37], and a smaller amount of fatal and serious injuries [37, 38].
- The road infrastructure characteristics, such as segment length, driver sight clearance, land use, crash time, crash season, number of median openings, curves, and pedestrian crossings. These factors affect the visibility, maneuverability, and collision severity of vulnerable road users [39].
- The intelligent transport systems (ITS) that provide information and guidance to vulnerable road users through various devices and applications. ITS can improve the awareness, decision-making, and behavior of vulnerable road users in different scenarios [40].

However, it is important to emphasize that road safety responsibility is shared among all road users, including pedestrians [41]. Pedestrians must adhere to traffic rules and adopt cautious behaviors during urban movements to reduce the risk of accidents and protect their safety, according to the Italian Highway Code [41].

In this study conducted in the urban area of Rome, the understanding of pedestrian-involved accidents was deepened using data provided by ISTAT [42], referring to accidents involving at least one fatality or injury. Initially, an empirical approach to the data was adopted, employing descriptive analyses and categorizing accidents involving pedestrians based on their dynamics. Subsequently, the characteristics and information describing them are analyzed (road type, environmental conditions, circumstances, time, etc.).

Finally, machine-learning models [43–45] are used to predict the outcomes of such incidents, allowing designers to more accurately assess the risk of serious injury or death for pedestrians involved.

2 Crash Data

2.1 Descriptive Statistical Analysis

To analyze the accidents within the urban area of Rome, the database drawn up by ISTAT (Italian Institute of Statistics) [42] was used, which records accidents in which at least a road user involved is injured or dead, with a maximum observation time interval of

thirty days, further classifying deaths as having died within twenty-four hours or thirty days [46].

The event is recorded as a sample with various information and characteristics (independent variables or features). The 121 features are divided into information on the road users involved (sex and age, for instance), on the vehicles (type of vehicle, registration, etc.), dynamics, and environmental conditions. The analysis refers to the period from 2014 to 2020 for a total of 84,243 accidents that occurred in the city of Rome. Accidents with at least one pedestrian involved were extracted from this database, thus analyzing a total of 12,359 accidents.

As it is possible to see in Fig. 1 (and with particular detail in Table 1), the main circumstances that lead to a crash occur when the driver's car proceeds regularly, maneuvering or proceeding at high speed. A great part of accidents is also caused by non-direct accidents. Although there are other circumstances, for the descriptive statistical analysis, only the first six circumstances are described to give a preliminary overview.

Figure 1 and Table 1 are linked: the former shows a mean value of the frequency in the years analyzed, and in the latter, a focus on a single year.

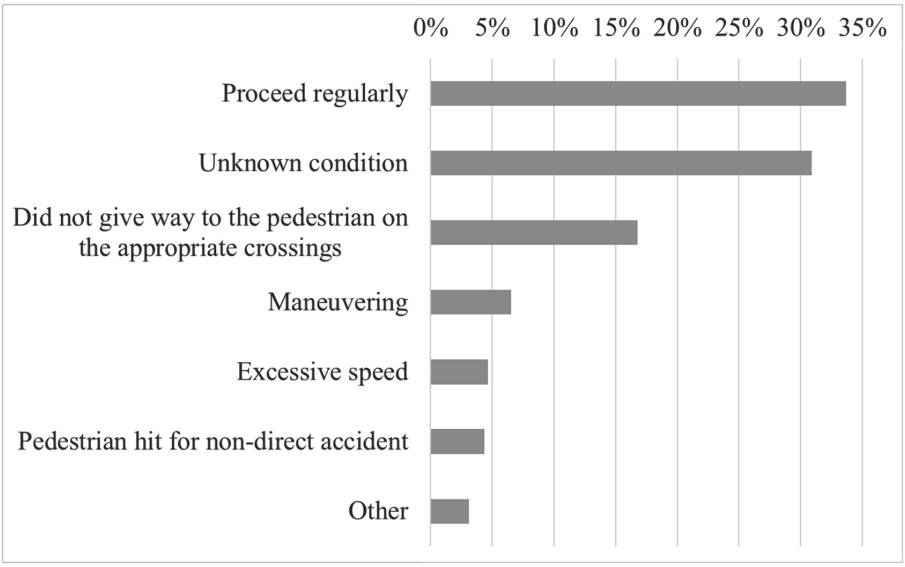

Fig. 1. Main circumstances that lead to a pedestrian accident.

The analysis also shows that the probability of being involved in a pedestrian accident, according to the circumstance analyzed, decreased in the period 2014–2020 and that shows a higher interest in last year's pedestrian safety than in the previous years, due to the awareness of road users and cities managers on the topic (see Fig. 2).

Although the number of accidents is decreasing, the problem of injured and dead road users needs to be analyzed in detail. As it is possible to see in Table 2 and Fig. 3 (in which the same results are proposed, in more detail in the table, and with a graphical output in the figure), according to each circumstance, the vast majority of crashes occur

on working days and this may be due to critical traffic conditions on city roads, while on the weekend, there is a large decreased of the number that involve a pedestrian. The hourly pattern in Fig. 4 shows that the number of accidents increases between 10 a.m. and 2 p.m. and between 6 p.m. and 10 p.m.

Half of all accidents happen on two-way carriageways for all circumstances identified: the second place is it possible to find two carriageways and this shows that the number of conflicts between motorized and pedestrian flows likely induce an accident (see Fig. 5 and Table 3, that show the same numbers differently). There is also a high probability of being involved in a pedestrian accident in a straight road and intersection for all circumstance (see Fig. 6). In Table 4, the majority of pedestrian crashes happen when vertical and horizontal road signs are present.

In Table 5 and Table 6, it is possible to see the probability that a pedestrian accident can happen according to weather and road surface conditions. There is a high probability that an accident will occur in sunny weather and on dry road surfaces: this is mainly because accident data are very unbalanced data, so there are more injured users than dead road users, so the frequency an accidents happening in normal conditions is high.

Table 1. Probabilities of accidents under specific circumstances: historical series [%].

Circumstances	2014	2015	2016	2017	2018	2019	2020
Proceed regularly	8.94	19.55	27.72	34.81	40.50	45.00	45.29
Unknown Condition	45.00	42.00	36.65	30.98	29.08	24.89	23.37
Did not give way to the pedestrians on the crossings	6.22	5.93	4.63	4.53	3.51	3.71	4.19
Maneuvering	0.53	0.16	0.22	0.16	0.17	0.05	0.16
Excessive speed	0.43	0.59	0.32	0.38	0.28	0.38	0.32
Pedestrian hit for non-direct accident	0.16	0.05	0.11	0.54	0.00	0.11	0.24
Maneuvered without complying with traffic signals	9.52	7.05	6.62	6.03	5.79	5.00	5.32
Running off-road and hitting the pedestrian	0.85	0.86	0.91	0.86	0.22	0.11	0.73
Hitting the pawn with the load	0.48	0.59	0.65	0.05	0.39	0.11	0.32
Proceed the wrong way	1.44	0.81	0.27	0.22	0.28	0.54	0.40
Backing without precaution from a driveway	20.32	16.86	16.47	16.97	14.43	15.43	16.76
Proceed without respecting the speed limits	0.16	0.27	0.22	0.32	0.33	0.05	0.08
Overtaking a vehicle stopped to allow crossing	0.85	0.54	0.59	0.48	0.28	0.38	0.32
Overtaking a vehicle on the move	0.00	0.16	0.00	0.00	0.00	0.00	0.00
Irregularly passed a tram at the stop	5.11	5.12	4.63	3.66	4.74	4.25	2.50

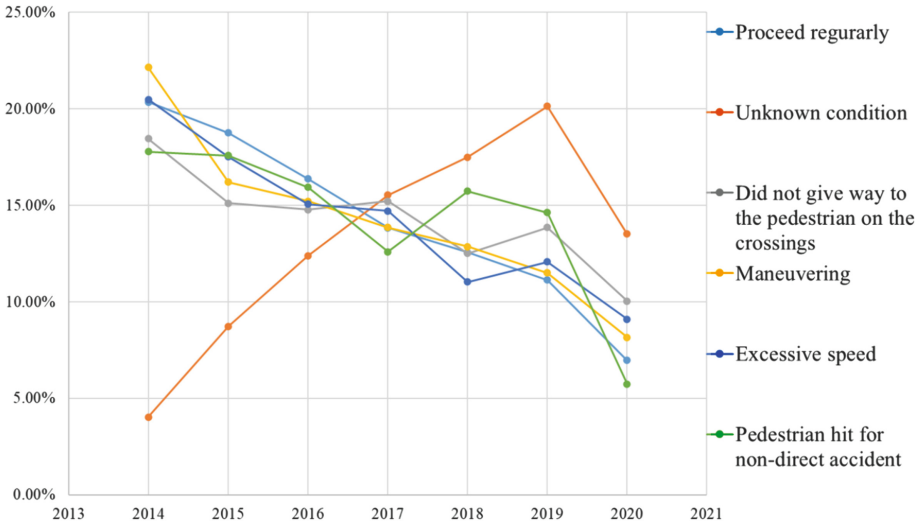

Fig. 2. Reduction of pedestrian accidents in the years 2014–2020.

Table 2. Number of accidents according to the circumstances and according to the day of the week (2014–2020).

Circumstances	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Proceed regularly	342	386	369	325	362	195	134
Unknown Condition	67	680	734	697	647	461	268
Did not give way to the pedestrians on the crossings	614	661	597	606	617	445	278
Maneuvering	134	155	140	119	120	89	51
Excessive speed	95	93	98	79	100	62	44
Pedestrian hit for non-direct accident	86	86	82	83	96	51	56

Evidence of that is shown in Table 7. The results show that the percentage of injured pedestrians is higher compared to the other types of outcomes.

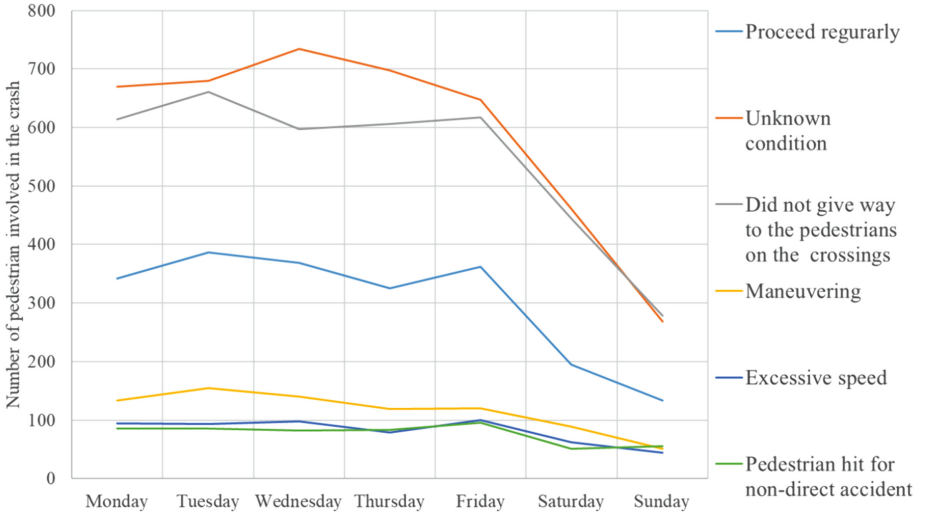

Fig. 3. Weekly pattern of pedestrian accidents in the years 2014–2020, according to the day of the week and the circumstances.

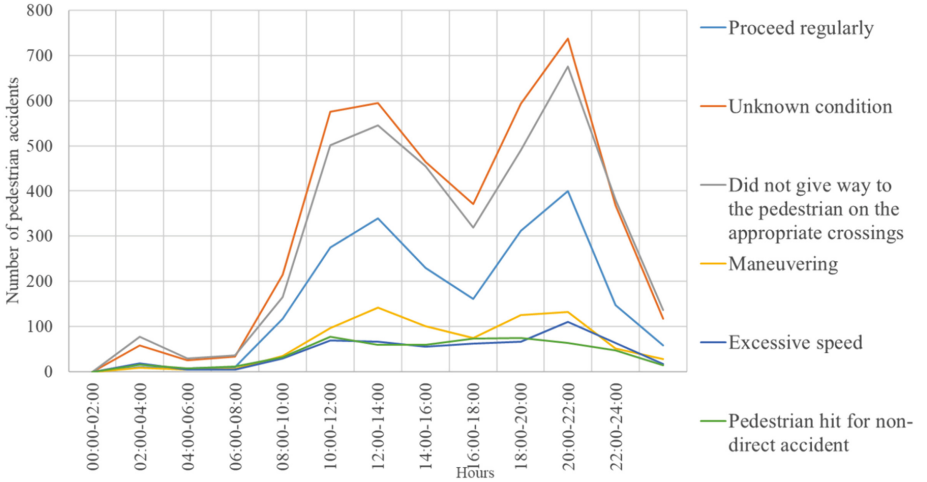

Fig. 4. Number of accidents according to the circumstances and the hour of the day (2014–2020): graphical output.

Table 3. Probability of accident [%] according to the circumstances and the road types (2014–2020).

Circumstances	One-way street	Two-way carriageway	Two carriageways	More than two carriageways
Proceed regularly	20.92	52.27	21.69	5.12
Unknown Condition	22.97	51.05	19.03	6.95
Did not give way to the pedestrians on the crossings	23.31	51.36	17.42	7.91
Maneuvering	26.98	51.11	16.96	1.05
Excessive speed	22.42	51.14	21.54	4.90
Pedestrian hit for non-direct accident	17.41	52.96	25.19	4.44

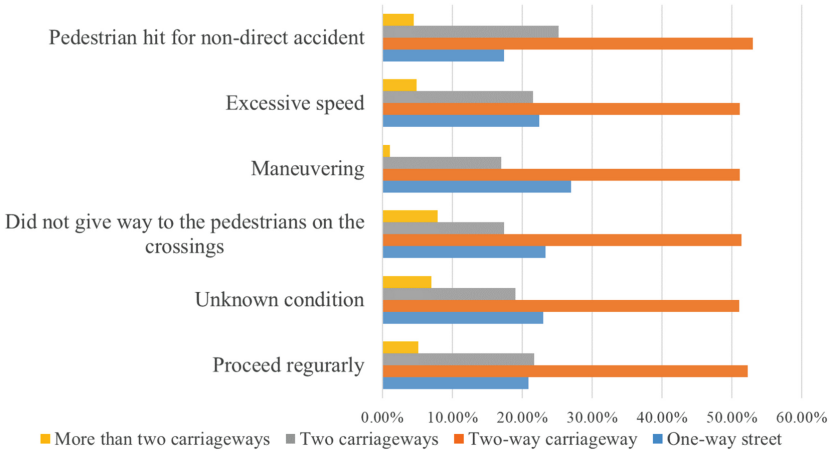

Fig. 5. Distribution of pedestrian accidents [%] according to the circumstances and the road types (2014–2020)

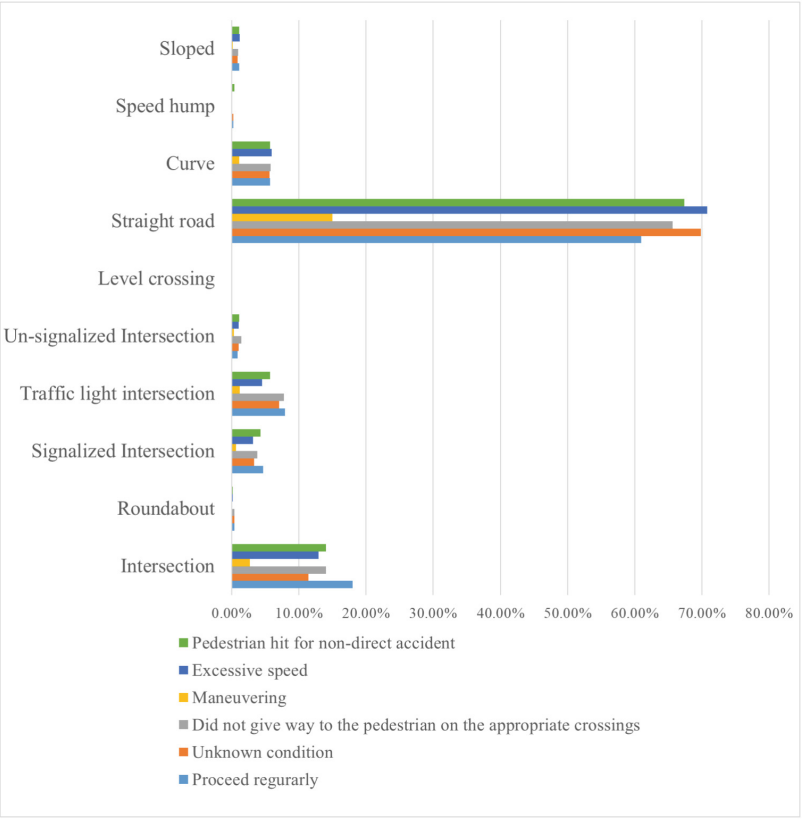

Fig. 6. Distribution of pedestrian accidents [%] according to road characteristics (2014–2020).

Table 4. Probability of pedestrian accident [%] according to road signs (2014–2020).

Circumstances	Missing	Vertical	Horizontal	Vertical and Horizontal	Other
Proceed regularly	3.09	2.17	16.09	78.26	0.39
Unknown Condition	8.47	4.50	16.60	70.12	0.31
Did not give way to the pedestrians on the crossings	8.51	3.93	14.51	72.81	0.24
Maneuvering	15.35	6.56	17.45	60.40	0.05
Excessive speed	8.58	4.38	14.01	72.68	0.35
Pedestrian hit for non-direct accident	4.63	4.26	16.48	73.89	0.74

Table 5. Probability of accident [%] according to the weather conditions (2014–2020).

Circumstances	Sunny	Fog	Rain	Hail	Snow	Other
Proceed regularly	87.10	0.34	11.11	0.00	0.05	1.40
Unknown Condition	87.76	0.34	10.37	0.00	0.05	1.49
Did not give way to the pedestrians on the crossings	88.48	0.50	9.17	0.00	0.00	1.86
Maneuvering	90.72	0.50	7.55	0.00	0.00	1.24
Excessive speed	86.16	0.35	12.26	0.18	0.00	0.74
Pedestrian hit for non-direct accident	90.93	0.56	7.22	0.19	0.19	0.93

Table 6. Probability of accident [%] according to the road surface conditions (2014–2020).

Circumstances	Dry	Wet	Slippery	Frozen	Snow-covered
Proceed regularly	81.93	17.97	0.10	0.00	0.00
Unknown Condition	82.68	17.30	0.00	0.00	0.02
Did not give way to the pedestrians on the crossings	82.79	17.10	0.08	0.03	0.00
Maneuvering	84.78	15.10	0.12	0.00	0.00
Excessive speed	80.21	19.61	0.18	0.00	0.00
Pedestrian hit for non-direct accident	83.70	15.56	0.19	0.37	0.19

Table 7. Probability of accident [%] according to the outcome of the crash (2014–2020).

Circumstances	Dead driver	Injured driver	Dead pedestrian	Injured pedestrian	Dead pedestrian in 24 h	Dead pedestrians in 30 days
Proceed regularly	0.04	5.48	2.04	90.37	1.24	0.84
Unknown Condition	0.06	8.32	2.64	86.28	1.91	0.79
Did not give way to the pedestrians on the crossings	0.02	7.00	1.42	90.11	1.11	0.34
Maneuvering	0.11	4.43	1.33	92.80	1.11	0.22
Excessive speed	0.11	4.43	1.33	92.80	1.11	0.22
Pedestrian hit for non-direct accident	0.11	4.43	1.33	92.80	1.11	0.22

3 Method

3.1 Machine Learning Process

Machine Learning (ML) is a sector of artificial intelligence (AI) that allows machines and computers to develop and improve models (or even algorithms). These models are instructed through input data to perform specific tasks and make predictions without being explicitly programmed, so the machine is predisposed to learn something independently. Machine Learning means the ability to perform with some precision and accuracy new tasks, or different circumstances not previously addressed, based on the experience gained from a set of training data [47].

Two main types of approaches to Machine Learning exist [48]:

- Supervised Learning: examples are provided to the model in the form of possible inputs and their desired outputs and the goal is to extract a general rule that associates the input to the correct output.
- Unsupervised Learning: the model aims to find a structure in the input provided, without the input being labeled in any way.

Machine Learning process can be summarized in the following points:

- Data collection: collection of data needed to train the model. Data can come from various sources and must be relevant and representative of the problem.
- Data Preparation: clean, pre-process, and transform data so that it is suitable for model training.
- Model selection: choose the model type best suited to the problem and the available data. The most famous models are, for instance:

  1. Linear Discriminant Analysis (LDA) [49];
  2. Quadratic Discriminant Analysis (QDA) [50];
  3. K-Nearest Neighbour (KNN) [51];
  4. Decision Tree (DT) [52];
  5. Random Forest (RF) [53];
  6. Support Vector Machines (SVM) [54].

- Model training: using training data to teach the model to make predictions or perform the desired task.
- Model evaluation: model performance evaluation using separate data (test and validation datasets) to assess its generalization capability and accuracy on new data.

4 Results

Before moving on to the discussion of the results, it is necessary to introduce the metrics to evaluate the model's assumptions and then make comparisons: all will start from the introduction of the concept of the confusion matrix (see Fig. 7) to clarify in detail terms such as specificity, recall, F1-score, etc.

A confusion matrix is a table that summarizes the performance of a classification model on a set of test data. It shows the number of true positives (TP), true negatives (TN), false positives (FP), and false negatives (FN) for each class. The output of the

	Real Values	
Predicted Values	True Positive (TP)	False Positive (FP)
	False Negative (FN)	True Negative (TN)

Fig. 7. An Example of Confusion Matrix.

model is the Confusion Matrix: the four elements that compose it are the relationship between the model's predicted and the actual values:

- True Positive (TP): are the cases where the model has correctly predicted a positive class;
- True False (TF): are the cases in which the model has correctly predicted a negative class;
- False Positive (FP): these are the cases where the model predicted a positive class that was negative (Type I error);
- False Negative (FN): these are the cases where the model predicted a negative class that was positive (Type II error).

A confusion matrix can help in evaluating the accuracy, precision, recall, and F1-score of models, as well as identify the classes that are most often confused by the model itself. Some common performance metrics for classification problems are:

- Accuracy: the proportion of correct predictions among all predictions. It is calculated as:

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \tag{1}$$

- Precision: the proportion of correct positive predictions among all positive predictions. It is calculated as:

$$Precision = \frac{TP}{TP + FP} \tag{2}$$

- Recall: the proportion of correct positive predictions among all actual positive predictions. It is calculated as:

$$Recall = \frac{TP}{TP + FN} \tag{3}$$

- Specificity: the specificity of a confusion matrix quantifies the true negative rate or the number of observations the model defined as negative that were truly negative:

$$Specificity = \frac{TN}{TP + FN} \tag{4}$$

- F1-score: the harmonic means of precision and recall. It is calculated as:

$$F1 - score = \frac{2 * Precision * Recll}{Precision + Recall} \tag{5}$$

There are also two other important metrics. The F2 and F3 scores are variations of the F1 score, which is a measure of a model's accuracy on a dataset. The F1 score is the harmonic mean of the model's precision and recall, and it ranges from 0 to 1. A perfect model has an F1 score of 1.

The F2 and F3 scores are adjusted F-scores that give more importance to recall than precision. Recall is the fraction of correct positive predictions among all actual positive instances. The F2 score considers recall to be twice as important as precision, while the F3 score considers recall to be three times as important as precision. The formulas for the F2 and F3 scores are:

$$F2 - score = \frac{5 * Precision * Recll}{4 * Precision + Recall} \tag{6}$$

$$F3 - score = \frac{10 * Precision * Recll}{9 * Precision + Recall} \tag{7}$$

In Table 8 below the main metrics analyzed for each model used to predict the outcome of a pedestrian accident.

Table 8. Main performance metrics used to assess the prediction accuracy of the model for the classification task.

Performance metrics	LDA	QDA	KNN	DT	RF	SVM-L	SVM-R	SVM-P
Accuracy	0.6787	0.7377	0.8824	0.9306	0.9378	0.4763	0.7818	0.6302
Recall	0.6901	0.7068	0.8939	0.9478	0.9542	0.9330	0.9845	0.9903
Specificity	0.6680	0.7815	0.3625	0.1605	0.1875	0.0325	0.0379	0.0414
Precision	0.6588	0.8205	0.9845	0.9806	0.9817	0.4685	0.7897	0.6281
F1-score	0.6741	0.7594	0.9370	0.9639	0.9678	0.6367	0.8764	0.7687
F2-score	0.6836	0.7270	0.9107	0.9542	0.9596	0.8114	0.9382	0.8879
F3-score	0.6869	0.7167	0.9022	0.9510	0.9569	0.8930	0.9608	0.9363

According to the F1-score, which is a harmonic mean value of precision and recall, the best model seems to be the Random Forest (RF) model. Another important metric to observe is the F3-score which ranges from 0 to 1, where 1 is the best possible score and 0 is the worst. The F3 score is useful for evaluating machine learning models that deal with unbalanced data or rare events, where recall is more important than precision. For example, in medical diagnosis, it might be preferable to have a high recall to avoid missing any potential cases of a disease, even if that means some false alarms. And that is the case of pedestrian road accidents, where the dataset is very unbalanced and the number of fatal injured pedestrians is very low compared to the only injured ones. The

best model according to the F3-score is the Support Vector Machine with a radial kernel model (SVM-R).

5 Conclusions

Although the number of road accidents involving pedestrians in Europe is decreasing, globally, especially in emerging or developing countries, there is a trend opposite to that in Europe. This may be due to increased interest on the part of governments to reduce the number of accidents by promoting projects, information campaigns, and establishing funds for road safety. Furthermore, the objective of reducing the number of accidents fits perfectly into the sustainable development objectives of Agenda 30, to make European and world cities safer, and reduce the number of pollutants released into the atmosphere.

Taking a look at the current scientific technical literature, there is a need to understand what are the main factors and the main characteristics that lead to the cause of an accident and what actions need to be undertaken to reduce the severity and degree of injury of a vulnerable road user. Being the problem of not-so-simple resolution, models based on artificial intelligence and supervised learning could be useful. For this purpose, a first step in this paper was made to predict the outcome of an accident. Taking as reference the ISTAT data of the metropolitan city of Rome, first a descriptive analysis was conducted, and then several models were trained and then tested. The performance of the model was evaluated on the test set and not on the training set. Furthermore, since the death of a pedestrian is very rare in comparison to the number of accidents leading to injury, the resulting dataset is very unbalanced.

In this regard, oversampling techniques have been applied to the training set to balance the minority class. Without this, the model would only have predicted injured pedestrians and dead pedestrians. Applying models based on their degree of complexity, without any prejudice to one or the other, the most performing model in terms of F1-score was the Random Forest, while according to the F3-score, which gives more importance to recall than precision, was found to Support Vector Machine with a radial kernel the most relevant model to the data collected. Evaluating also the F3-score metric is necessary when the dataset is very unbalanced towards a certain class. In this case, it is reiterated, that the outcome of the death of the pedestrian belonged to the minority class, so models that predict many more false positives than models that predict few events in the minority class are preferred. The novelty of this research consists of applying several Machine Learning models and making an exhaustive comparison among them, for a single Italian city.

Further analysis is necessary and other metrics of evaluation of the performance of the model could be used. The main limitation of these models is that they work as black boxes and therefore there is a lack in the interpretability side compared to simple models like Logistic Regression that have their own more explicit mathematical structure, so within this research, it is also difficult to understand which variables are strongly related to pedestrian crashes. Obviously, as future developments, it is necessary to apply techniques, tools, and methods that allow not only to predict the outcome of an accident but also to understand what variables are the most influencing the outcome of an accident.

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Sustainability and Cost Efficiency in Asphalt Production: A Comparison of Mixing Technologies and the Case Study in Sardinia (Italy)

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Abstract. The paper performs a comparative assessment of the industrial costs associated with the production of Warm Mix Asphalt (WMA), Warm Mix Asphalt enriched with Recycled Asphalt Pavement (RAP) material, and Hot Mix Asphalt (HMA). The objective is to identify the most cost-effective and environmentally sustainable solutions for road infrastructure. The operational and investment costs associated with each asphalt mixing technology were examined, paying particular attention to environmental aspects and the need to reduce costs through efficiency and innovations in production processes. The case study of Sardinia, an island in the middle of the Mediterranean Sea, provides a unique perspective for analyzing the influence of local variables such as material availability and climatic conditions on production decisions. This choice allowed the effectiveness of asphalt mixing technologies to be evaluated under well-defined boundary conditions, highlighting how WMA and WMA with RAP material can offer significant advantages in terms of lower emissions and reduced costs, especially when recycled material is widely available. The results underscore the importance of adopting innovative and environmentally friendly production practices, demonstrating how improvements in emissions can contribute significantly to lowering costs in the road construction sector. This study aims to provide crucial insights for decision makers, promoting the adoption of more sustainable and cost-effective asphalt production methodologies, with a specific focus on island contexts such as Sardinia.

Keywords: Pavements · Green Roads · Asphalt · HMA · WMA · RAP

1 Introduction

Road networks are the arteries of global economies, enabling the flow of goods and people, highlighting the importance of efficient and sustainable transportation infrastructure. Countries like Italy, the United Kingdom, as well as many European Union nations and the United States, depend heavily on road transport for most passenger and freight movements, underscoring the sector's central role in domestic and international

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trade [1]. The Italian transportation landscape, despite a significant decline in passenger miles traveled in 2020, continues to demonstrate an unwavering reliance on road transport [2, 3]. This resilience, even in the face of global challenges, underscores the need for sustainable infrastructure development, particularly in the face of environmental concerns. The construction and maintenance of road infrastructure, particularly through the use of asphalt, have significant environmental impacts, including greenhouse gas emissions and the consumption of large amounts of energy to produce the necessary materials.

In response to these challenges, the construction industry is exploring more sustainable practices, focusing on innovative asphalt technologies that promise to mitigate the environmental drawbacks traditionally associated with the industry, particularly that of road superstructure. Warm Mix Asphalt (WMA) has emerged as a major alternative to conventional Hot Mix Asphalt (HMA), offering the potential for lower energy consumption and reduced emissions. In addition, the integration of recycled asphalt pavement (RAP) into WMA and HMA formulations presents an attractive opportunity to further improve the sustainability of road construction by recycling existing materials and reducing the demand for virgin resources like land consumption.

This paper delves into a comparative analysis of HMA and WMA technologies, examining their industrial costs at elemental resources with and without the addition of RAP. The study is contextualized within the unique environmental and logistical framework of Sardinia, Italy, and provides a focused examination of how these asphalt technologies can be optimized to improve cost-effectiveness and environmental sustainability. By assessing the differences and potential benefits of these asphalt production methods, the research aims to shed light on the economic feasibility of more sustainable practices for future road construction and maintenance efforts. The goal is not only to assess the immediate impact of these technologies on cost and environmental sustainability, but also to envision the future of infrastructure development. The study focuses on the cost and production of individual types of asphalt mix, not going into the merits of the mechanical strength specifications of the materials, reserving the task of evaluating other key emission and cost items such as maintenance and paving operations for future study.

2 HMA, WMA, RAP – Definitions

In the context of asphalt production technologies, two categories can be distinguished: HMA and WMA [4]. The technologies may have different characteristics in terms of mix composition, thus different chemical and physical properties and processing temperatures, offering specific advantages and disadvantages that affect application effectiveness, sustainability and overall performance.

- Hot Mix Asphalt (HMA):

HMA represents the most traditional and widespread solution, characterized by the use of mineral aggregates and bituminous binders, occasionally enriched with additives aimed at improving performance. Aggregates, which constitute the predominant value of the total weight of HMA, are generally composed of crushed rock, gravel, sand, and

mineral powders. The bituminous binder, acting as a binder, gives the mixture considerable strength and durability. The production process of HMA requires the application of high temperatures, ranging from 150 to 180 °C for the aggregates and 160 to 175 °C for the bitumen, thus ensuring the production of a high-performance material that is ideal for withstanding heavy traffic and climatic adversity [5, 6].

The main advantages of HMA include high strength and durability, making it the preferred choice for road infrastructure under significant stress. The rapid installation process and ability to produce large volumes contribute to reduced construction time and costs. However, the production and laying of HMA involves high energy consumption and increased greenhouse gas emissions due to the high temperatures required. These aspects represent major disadvantages, to which are added safety risks for operators.

- Warm Mix Asphalt (WMA):

Warm Mix Asphalt is characterized by a similar composition to HMA, but is distinguished by the use of specific additives or modifications to the production process that allow it to be processed at lower temperatures, varying between 100 and 140 °C. These additives, capable of reducing the viscosity of the bitumen, facilitate the workability of the material, allowing significant energy savings and lower emission of harmful substances. WMA technology consists of several solutions, specific additives with organic or chemical components, each of which aims to decrease the temperature required for asphalt production and laying [6, 7].

The advantages of WMA lie in reduced energy consumption and emissions, improved workability, and the ability to extend the working season due to reduced production temperatures. These features not only promote less environmental impact but also greater safety for operators. Nonetheless, the relative newness of WMA results in a paucity of data on long-term durability and overall performance, as well as potential increases in cost and production time due to the use of additives. In addition, consideration must be given to the production chain of the latter, which are often produced by chemical processing and thus impact emissions.

Nevertheless, the study by Chehovits and Galehouse [8] shows that HMA production requires 275 MJ/t of energy, while WMA consumes 234 MJ/t, or 15 percent less. This comparison highlights the superior energy efficiency of WMA compared to HMA, offering an important perspective on the sustainability of different asphalt technologies.

- Recycled Asphalt Pavement (RAP):

A key aspect in the landscape of asphalt technologies is Recycled Asphalt Pavement (RAP), which consists of the recovery of milled material from pre-existing pavements. RAP can be incorporated into both HMA and WMA mixtures, helping to reduce the need for new aggregates and bituminous binders and promoting greater environmental sustainability. The added value of RAP in road construction is greatly recognized for its contribution to sustainability and cost reduction. The milling process that originates RAP results in milled material that can be used as a new resource, which can be granulometrically corrected and enriched with additives to meet the needs of new applications. As Oliveira et al. [9] point out, pavement quality is a key aspect of ensuring infrastructure functionality. If the implementation of RAP in maintenance operations lightens the environmental impact by avoiding the use of landfills, it allows the creation of renewed

asphalt mixtures, on the other hand, the integration of RAP presents challenges. Uncertainty about the percentages of use to be incorporated, reported by Bonfim [10], affects the workability and stiffness of the mixtures, with possible repercussions on fatigue and crack formation [11, 12]. This problem is due to the difficulty of regeneration and reactivation of oxidized bitumen, which results in higher stiffening than in virgin mixtures, from which arises a high susceptibility to fatigue cracking.

In accordance with L.F. Walubita, et al. [13] the design of flexible pavements is strongly influenced by fatigue durability, as the main cause of cracking in hot asphalt mixes, especially due to environmental conditions, significant traffic loads, but also due to own mineralogical composition of the aggregate, type of binder and precisely RAP incorporation [12, 14, 15].

Therefore, accurate evaluation of recycled material properties is essential to ensure pavement durability. Despite these obstacles, the increasing research and adoption in asphalt mixtures reflects a positive trend toward more efficient and responsible construction practices, promoting material reuse and recycling in the construction industry [14]. In conclusion, the choice between HMA and WMA, including considering the incorporation of recycled materials such as RAP, depends on a careful evaluation of project-specific requirements, including sustainability, safety, durability, and cost considerations. While HMA continues to be a solid option for demanding applications, WMA and the use of RAP are emerging as promising solutions to reduce environmental impact and improve working conditions while maintaining high standards of performance.

3 Trends in Asphalt Production in Europe – 2022

"Asphalt in Figures 2022" [5] is a detailed report presented by the European Asphalt Pavement Association (EAPA). The association represents manufacturers of asphalt mixtures and companies involved in asphalt road construction and maintenance in Europe. This report provides a comprehensive overview of key statistics and trends in the European asphalt industry for the year 2022, covering various aspects such as total production, reuse and recycling rates, applications in different road layers, and the introduction of technological innovations (Fig. 1).

Data compared to 2021 show a slightly decreasing trend in terms of annual production, but still close to the average of the last decade (Table 1).

The data show that Italy has seen the largest increase in production over the past three years, from 30 to 37.6 million tons produced by 2022, just behind Germany with 39.0 million tons and ahead of France with 30.7 million tons. These numbers reflect significant variations in asphalt production among different European countries, underscoring differences in the size of the road construction industry, infrastructure policies, and asphalt reuse and recycling practices.

Table 2 [5] presents the percentage distribution of hot and warm asphalt use in surface course (surface course), binder course (binder course), and base course (base course) applications for various countries in 2022. Data provide an important overview of how asphalt is used in road construction at the European level, reflecting the different construction needs and practices in different countries.

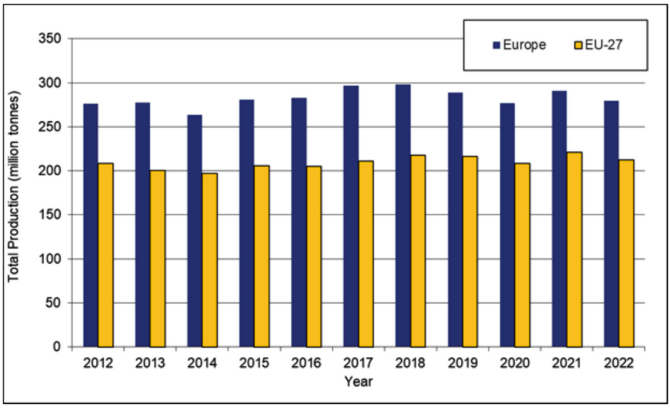

Fig. 1. Total production of HMA and WMA from 2011 to 2022 (Million tons) [5]

Table 1. Production of HMA and WMA from 2020 to 2022 (in million tonnes) [5]

Country	2022	2021	2020
Austria	6,5	7,3	7,4
Belgium	4,9*	4,627	4,34
Croatia	2,75	2,71	2,33
Czech Republic	6,8	7,2	6,7
Denmark	3,47	3,55	3,94
France	30,723	34,72	31,85
Germany	39	38	38
Great Britain	24,2	25,7	23
Hungary	4,47	4,919	4,847
Italy	37,6	37,6	30,1*
Netherlands	6,2	7,2	7,1
Norway	6,35	6,86	6,863
Poland	19,0*	19,0*	19,0*
Portugal	3,1	4	3,4
Slovakia	2,464699	2,371218	2,16435
Slovenia	2,06	2,1	1,88
Spain	17,1	18,9	17,1
Sweden	8,2*	8,2*	8,2*
Turkey	30,14	30,3	31,7

Table 2. Surface, binder and base courses - Application in surface-, binder- and base courses of total annual Hot and Warm Mix Asphalt production 2022 (%) [5]

Country	Surface course	Binder course	Base course
Austria	60	10	30
Belgium	53	0	47
Croatia	61	5	34
Czech Republic	55	22	23
Denmark	46	6	48
Estonia	63	5	32
Hungary	61	31	8
Norway	80	10	10
Portugal	68	18	14
Romania	28	25	47
Slovakia	70	19	11
Slovenia	55	6	39
Spain	75	19	6
Turkey	36	39	25

In Europe, the approach to asphalt use varies widely among countries depending on the road layers they intend to reinforce. In general, the percentage distribution of asphalt use in different road layers reflects each country's intervention priorities in terms of pavement rehabilitation, durability and performance, or in relation to new construction. Factors such as weather conditions, volume and type of traffic, as well as road maintenance strategies, can influence these choices. Regarding RAP utilization data, the report shows the following Table 3:

Also from the report reviewed in Italy, in 2022, 9.2 million tons of RAP were available for reuse by the asphalt industry. However, the table does not provide additional data on the specific percentages of how this recovered asphalt was actually used, so information on reuse and recycling in Italy for that year is lacking. In addition, the data are estimates of historical values with projections for that year.

Figure 2 [5] shows the percentage of recycled asphalt available in some European countries that has been reused to produce new asphalt mixtures, including HMA, WMA and cold mix asphalt (CMA). Recycled asphalt used as an unbound layer in civil engineering projects is also shown, in addition to its use in other unspecified applications or its landfilling. For the determination of these values, only the complete data provided by the countries (total quantities and percentages of use) were considered. The European countries considered in the study were Austria, Belgium, Croatia, Czech Republic, Denmark, France, Germany, Great Britain, Hungary, Norway, Romania, Slovenia, Spain and Turkey. In these countries, a total of 36.1 million tons of recycled asphalt was available, of which 76% was reused, 22% recycled into unbound road layers, and only 2%

Table 3. Re-use and Recycling of Reclaimed Asphalt in 2022 - [5]

Country	Total amount of site-won asphalt generated in 2022 in tonnes	Amount of reclaimed asphalt available to be used by the asphalt industry in 2022 in tonnes	% of available reclaimed asphalt used in						
			Hot and Warm Mix Asphalt Production	Half Warm Mix Asphalt Production	On-Site Cold Recycling **	Plant Cold Recycling **	Unbound Road Layers	Other Civil Engineering Applications	Put to Landfill /Other Applications/ Unknown
Austria	1.900.000	800.000	85	0	5	0	10	0	0
Belgium	1.684.000	1.025.000	100	0	0	0	0	0	0
Croatia	270.000	240.000	42	0	2	19	no data	no data	no data
Czech Republic	2.800.000	2.500.000	30	0	15	0	15	10	30
Denmark	1.306.000*	1.106.000	no data	no data	no data	no data	4	no data	no data
France	no data	7.340.000	45	no data	no data	no data	no data	no data	no data
Germany	14.800.000	12.876.000	87	0	0	0	13	0	0
Great Britain	5.814.442	no data	no data	no data	no data	no data	no data	no data	no data
Hungary	150.000	180.000	10	0	10	74	3	3	0
Ireland	500*	500*	45*	no data	no data	no data	no data	no data	no data
Italy	11.000.000*	9.200.000*	no data	no data	no data	no data	no data	no data	no data
Norway	>1.600.000	1.600.000	no data	no data	no data	no data	no data	no data	no data
Romania	34.000*	34.000*	0	0	95	0	5	0	0
Slovenia	305.000	51.000	58	0	9	0	14	9	10
Spain	1.900.000	2.000.000	66	~0	7	~0	24	0	3
Turkey	1.920.400	1.728.360	12	0	0	7	81	0	0

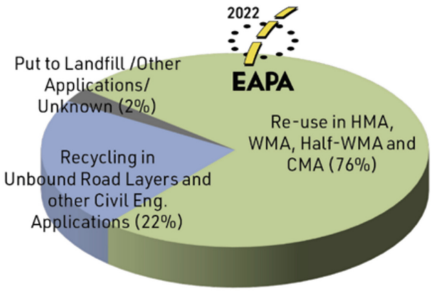

Fig. 2. Application of reclaimed asphalt in fourteen European countries providing data [5]

went to unknown applications or landfill. In conclusion, the report shows how the use of reclaimed asphalt, highlighted by data from various European countries, is significantly increasing toward reuse and recycling, with 76% of reclaimed asphalt reused in the production of new mixes and only 2% going to landfill or unknown uses. This orientation not only meets an environmental need, but also aligns with the goal of reducing industrial costs through efficient and innovative production processes.

4 Cost Analysis to 2024 to Produce HMA, WMA with and Without the Use of RAP - Case Study in Sardinia

The analysis of asphalt production costs is a crucial aspect in the evaluation of sustainable construction practices and material selection in the infrastructure sector. Focusing on Sardinia, an island that offers a unique and well-delineated geographic context, this

study aims to assess the economic impact resulting from the use of different types of asphalt, with material market prices updated to early 2024.

Sardinia's island status allows for the isolation of variables such as raw material availability and climatic conditions, providing an ideal scenario for analyzing the effectiveness of asphalt mixing technologies. In this well-defined context, the environmental benefits and economic advantages of using varying percentages of RAP material in specific mix designs for binder-type asphalt mixes can be observed. The use of WMA and HMA with RAP not only promotes the reduction of emissions and the use of resources already available in the area but can also result in a decrease in operating costs, which is particularly relevant in isolated settings where the burdens pertaining to transportation and logistics tend to be greater.

The objective is therefore twofold: on the one hand, to confirm the production efficiency and environmental sustainability of recycling and reuse techniques in the asphalt production process; on the other hand, to provide a replicable model, with the aim of promoting the adoption of innovative methodologies that can result in significant economic savings, in full compliance with environmental regulations.

The focus is therefore on mix design for an asphalt wearing course, exploring four distinct configurations: HMA with exclusively virgin material; HMA with 25% RAP; WMA with completely virgin material; and WMA with 25% RAP. This analysis will be conducted using a rigorous methodological approach, considering the elemental resource costs, as well as the benefits from the reduction in energy costs offered using WMA, and the land savings from the reduced supply of virgin material from quarries through the use of RAP.

As part of this assessment, the financial and environmental impacts of adopting variable percentages of RAP will be highlighted, providing a detailed comparison of different mixing techniques. Particular attention will be paid to the relationship between cost reductions from the use of recycled material taking into account that the mixtures considered, can be produced in most conventional asphalt plants.

4.1 The Production Facility

The plant under study in this study is configured as a batch-type asphalt production system, specifically a mixing tower, widely recognized for the high quality of the final product. The choice of a batch plant ensures greater quality control of the material produced, although it involves higher initial and operating costs than continuous plants.

Production begins with the selection and withdrawal of lithic aggregates from on-site deposits, followed by the drying and heating, hot reclassification, and weighing stages. These preparatory operations are crucial to ensure that the mix meets the required technical specifications. Next, bitumen, filler and any additives are fed and dosed into the production process, finally converging at the mixing stage, where all elements are amalgamated in the mixer. From here, the finished product is transferred to storage silos awaiting transport to the site of use by truck.

The detailed production cycle follows a well-defined path, from the collection of aggregates, which are characterized by various moisture levels and at room temperature, to their processing.

The drying and heating phase takes place in a rotating cylinder, where a burner generates the necessary heat. The aggregates advance in countercurrent to the hot gases, optimizing the heat exchange process. An innovative burner-dryer system ensures the high efficiency of the process, minimizing emissions and improving combustion efficiency.

The mixing tower, the centerpiece of the plant, handles the handling of hot and dried aggregates until they are mixed with bitumen and additives. This area of the plant is distinguished by its discontinuous functionality, allowing accurate weighing and batching of the components, which are essential to ensure the final quality of the asphalt mix.

The burner integrated in the plant under review, presents advanced technical characteristics, configuring itself as a closed and pressurized modulating type system, with automatic electrogas ignition. Its maximum capacity is 19,600,000 kcal/h (22.7 MW), with an LPG gas flow rate of 890 Nm3/h. The supply pressure is maintained at optimum levels, with 0.6 bar at the gas ramp inlet and 0.5 bar at the burner inlet, thus ensuring a constant and adequate flow for the effective operation of the plant.

A distinctive feature of this plant is the use of liquid LPG as fuel, which is regasified through specific regasifiers. These not only power the burner but also provide the energy needed to maintain the optimal temperature in the bitumen tanks, which are heated through an electrical system. This configuration not only highlights the efficiency and technological innovation of the plant but also emphasizes an approach aimed at optimizing energy consumption and reducing environmental impact. The use of LPG, in fact, allows cleaner combustion than other fossil fuels, with lower emissions of pollutants. The impact of aggregate moisture on energy consumption within the asphalt production process is a significant variable. In this regard, a strategic measure was adopted to optimize the energy efficiency of the plant by covering the aggregate piles with special canopies. This solution makes it possible to protect the materials from the weather, particularly rainfall, while ensuring that a low moisture level is maintained in the aggregates.

The presence of sheds that isolate the aggregate piles has a twofold advantage: on the one hand, it reduces the amount of energy required to dry the aggregates, contributing to a significant decrease in energy consumption; on the other hand, it ensures greater stability and predictability in the production process, facilitating the control of production variables and ensuring a final product of consistent quality. Then, being a support point for a photovoltaic plant, they allow to close the circle and the supply chain, providing sufficient energy input to make the production plant autonomous.

In summary, the plant analyzed represents an advanced example of asphalt production technology, where attention to operational details and the choice of cutting-edge technological solutions contribute to obtaining a high-quality product, in full compliance with the criteria of energy efficiency and environmental sustainability.

4.2 Mix Design

The development of innovative mix designs for asphalt production is a key aspect in the development of more sustainable and efficient paving techniques. The Table 4 illustrates a series of experimental mix designs, tested in the plant under consideration, that aim to optimize material use, recycling, and environmental impact reduction in the context of

road pavement wearing course production. These mix designs include both standard formulations HMA and WMA without the use of recycled material, and advanced versions that incorporate RAP to promote recycling in the road construction industry.

Table 4. Mix design considered for analysis

Type	Mix Design	RAP	Sand 0–4	Sand 4–8	Filler	Bitumen 50/70 [% on dosage]	Additive [% on bitumen]	Additive type
HMA	Asphalt wearing course 0/8	0,00%	50,00%	50,00%	2,00%	6,50%	0,00%	
WMA	Asphalt wearing course 0/8	0,00%	40,00%	60,00%	3,00%	6,00%	1,20%	Additive for WMA
HMA - RAP	Asphalt wearing course 0/8	25,00%	30,00%	45,00%	1,00%	4,90%	0,98%	Additive for HMA with RAP
WMA - RAP	Asphalt wearing course 0/8	25,00%	30,00%	45,00%	1,00%	4,90%	0,98%	Additive for WMA with RAP

For each mix design, these percentages of aggregates, RAP, filler, bitumen and additives are calculated relative to a predetermined total mass of 1 ton of aggregate material, allowing for effective standardization in formulations. The calculation of RAP and aggregate percentages relates directly to the total ton of aggregate material, allowing precise allocation of resources within the mix. For example, a 25% presence of RAP indicates the inclusion of 250 kg of recycled material for every ton of aggregate. Similarly, the amount of filler is defined as a fixed percentage of the total mass, providing a constant measure of this critical component for the volumetric stability of the asphalt mix. Conversely, the percentage of bitumen is expressed as a function of aggregate weight (aggregates + RAP), emphasizing the importance of adequate saturation of the mix to ensure optimal adhesion and mechanical properties. Finally, the additive is calculated as a percentage of the bitumen used, emphasizing its role in modifying specific chemical and physical properties of the mix, such as workability at low temperatures or regenerative capacity against aged bitumen from RAP.

The development of innovative mix designs for asphalt production is a key aspect in the development of more sustainable and efficient paving techniques. The Table illustrates a series of experimental mix designs, tested in the plant under consideration, that

aim to optimize material use, recycling and environmental impact reduction in the context of road pavement wearing course production. For the various mixtures, the use of various specific additives designed to optimize the properties required in the cases evaluated was considered.

Additive for WMA - NO RAP

This additive aims to reduce the temperatures required for asphalt mix production, paving and compaction, offering significant benefits in terms of energy savings and reduced air emissions. At the same time, it contributes to improved adhesion between aggregates and bitumen, thereby increasing the quality and durability of the final material.

The recommended dosage of the additive varies between 0.2% and 0.5% by weight of bitumen, depending on the specific operating conditions and the type of mix to be produced. Determining the optimum percentage of additive, however, requires laboratory testing to tailor use to the particular characteristics of production. Composed of a mixture of amine derivatives and specific additives, this additive is in liquid form with a yellow-brown color. Its physical properties include a density at 25 °C ranging from 0.95 to 1.05 g/cm^3 and a viscosity at 25 °C ranging from 150 to 250 cP. Safety of use is ensured by a flash point above 105 °C and a pour point below -5 °C.

The use of this additive in the WMA production process involves specific procedures both in the laboratory and in the plant, with the recommendation that the mixing temperature be maintained between 130 and 140 °C and that samples be conditioned to the suitable compaction temperature for about 2 h before compaction. The mixture should be spread and rolled at the optimum compaction temperature, usually between 100 and 120 °C, depending on the type of bitumen used and weather conditions.

Additive for HMA/RAP

The additive is particularly effective in handling mixtures with recycled material and makes it possible to optimize the mixing process, ensuring optimal integration of aggregates and recycled bitumen.

The recommended dosage varies from 0.2% to 0.4% on RAP weight, depending on specific production requirements, such as operating conditions and the type of mix to be made. Its formula, based on a mixture of amine derivatives and mineral oils, ensures effective dispersion within the bituminous mixture, promoting adhesion between the aggregates and the binder and improving the strength and durability of the finished product.

During application, both in the laboratory and in the plant, it is crucial to keep mixing temperatures controlled (150–160 °C) to ensure activation of the additive and its complete integration into the mix. Reclaimed asphalt mix should be dry and used at room temperature or preheated to 80 °C, to facilitate mixing and optimize the effect of the additive.

Additive for WMA/RAP

The additive is distinguished by its ability to significantly lower the temperatures required for production, paving and compaction of asphalt mixes, thus contributing to significant energy savings and reduced emissions to the atmosphere.

The recommended dosage ranges between 0.08% and 0.13% on RAP weight, although under certain operating conditions an increase up to 0.4% can be considered to handle special challenges such as high RAP rates or long transport times. Determining the optimal additive percentage requires specific laboratory and plant tests to adjust for production variables.

The additive has a composition based on amine derivatives and mineral oils, characterized by a yellow-brown liquid appearance, specific density and viscosity, and flash and creep points that attest to its safety and ease of handling. Regarding practical use, during mixing steps, it is recommended to maintain temperatures between 130 and 160 °C, ensuring that the RAP is dry to optimize the effectiveness of the additive. The introduction of this additive into WMA production processes with high RAP percentages stands as a significant advancement in the field of sustainable asphalting, offering a practical solution to improve the quality and environmental sustainability of road pavements.

4.3 Quantities and Costs

As part of optimized asphalt mix production research, the determination of the proportions between the different components of the mix design is based on a rigorous quantitative approach, which is critical to ensuring the desired performance of the final material. For each mix design, the percentages of aggregates, RAP, filler, bitumen and additives are calculated relative to a predetermined total mass of 1 ton of aggregate material, allowing for effective standardization in formulations. The calculation of RAP and aggregate percentages relates directly to the total ton of aggregate material, allowing precise allocation of resources within the mix. For example, a 25% presence of RAP indicates the inclusion of 250 kg of recycled material for every ton of aggregate. Similarly, the amount of filler is defined as a fixed percentage of the total mass, providing a constant measure of this critical component for the volumetric stability of the asphalt mix. Conversely, the percentage of bitumen is expressed as a function of aggregate weight (aggregates + RAP), emphasizing the importance of adequate saturation of the mix to ensure optimal adhesion and mechanical properties (Tables 5 and 6).

The costs highlighted in the table reflect the average costs incurred for the purchase of materials used in asphalt mixes, calculated by a company in Oristano, Sardinia, Italy. These prices, which include not only aggregates and bitumen but also specialized additives, are inclusive of transportation costs, which are essential in an insular geographic context where logistics greatly affect final costs. Bitumen, being a material strongly influenced by market fluctuations, is accounted for as an average value to facilitate financial planning in response to global price dynamics and the complexities of import operations (Table 7).

Incorporating RAP into HMA and WMA mixtures results in a reduction in overall cost per ton, which underscores the economic value of reusing materials in the road construction industry. Differences in sand costs between HMA and WMA mixtures could reflect variations in particle size properties or quality of materials used, suggesting optimization of compositions according to production thermal characteristics.

Although the addition of additives results in a marginal increase in total cost in WMA variants, this is balanced by the decrease in bitumen cost. This highlights the potential

Table 5. Amount of mixture

Type	HMA	WMA	HMA - RAP	WMA - RAP
Mix Design	Asphalt wearing course 0/8	Asphalt wearing course 0/8	Asphalt wearing course 0/8	Asphalt wearing course 0/8
RAP [kg]	0	0	250	250
Sand 0–4 [kg]	500	400	300	300
Sand 4–8 [kg]	500	600	450	450
Filler [kg]	20	30	10	10
Bitumen 50/70 [kg]	65	60	49	49
Additive [kg]	0	0,72	0,4802	0,4802
Additive type		Additive for WMA	Additive for HMA with RAP	Additive for WMA with RAP
Tot [kg]	1085	1090,72	1059,48	1059,48

Table 6. Unit costs elementary resources

Elemental materials	UM	€/UM
RAP	ton	6,50 €
Sand 0–4	ton	15,00 €
Sand 0–8	ton	12,00 €
Filler	ton	53,00 €
Bitumen 50/70	ton	640,00 €
Additive for WMA	ton	4.170,00 €
Additive for HMA with RAP	ton	4.570,00 €
Additive for WMA with RAP	ton	4.820,00 €
LPG - Gas	KG	0,45 €

of additives to increase process efficiency and contribute to wider energy savings and emission reductions.

The cost per kg of material remains essentially unchanged between HMAs and WMAs, implying that the reduction in production temperatures for WMAs does not substantially affect material costs. The cost per ton data reveal marginal savings among the different mix designs, highlighting how operational decisions can be driven by environmental and process performance factors as well as economic considerations.

Taken together, this information underscores the importance of an integrated approach that considers environmental sustainability, technical performance, and economic factors in the decision-making process for mix design selection in infrastructure projects,

Table 7. Cost Comparison and Environmental Impact of Asphalt Mix Designs with and without RAP

Type	HMA	WMA	HMA - RAP	WMA - RAP
Mix Design	Asphalt wearing course 0/8	Asphalt wearing course 0/8	Asphalt wearing course 0/8	Asphalt wearing course 0/8
RAP [€]	– €	– €	1,63 €	1,63 €
Sand 0–4 [€]	7,50 €	6,00 €	4,50 €	4,50 €
Sand 4–8 [€]	6,00 €	7,20 €	5,40 €	5,40 €
Filler [€]	1,06 €	1,59 €	0,53 €	0,53 €
Bitumen 50/70 [€]	41,60 €	38,40 €	31,36 €	31,36 €
Additive [€]	– €	3,00 €	2,19 €	2,31 €
Additive type		**Additive for WMA**	**Additive for HMA with RAP**	**Additive for WMA with RAP**
Tot [kg]	1085,00	1090,72	1059,48	1059,48
Tot [€]	56,16 €	56,19 €	45,61 €	45,73 €
[€]/kg	0,052 €	0,052 €	0,043 €	0,043 €
€/ton	51,76 €	51,52 €	43,05 €	43,16 €

especially in a framework of long-term financial sustainability for companies in the sector. As part of experiments conducted to evaluate the winter performance of asphalt mix designs, an average aggregate moisture content of 6% was found during the cold season. On a sample of 1,000 tons of material produced for the four mix designs previously discussed, it was observed that energy consumption varies with mix type and outdoor thermal conditions, specifically in an ambient temperature range of 10° to 15° Celsius.

For mix design HMAs, the average gas consumption stands at 3.7 Nm^3/ton, while for WMAs there is a significant reduction in consumption to 3.1 Nm^3/ton. This decrease reflects the inherent energy efficiency of WMA production processes, which operate at lower temperatures than conventional HMAs, confirming the hypothesis that WMA technologies can result in tangible energy savings.

The gas consumption figure is critical in calculating the economic and environmental impact of asphalt production. Lower consumption, such as that found for WMAs, implies less use of fossil resources and thus a reduced operating cost, and is also associated with lower emissions of greenhouse gases and air pollutants.

From the data evaluated from the examined plant and considering a purchase cost of bulk LPG used to fuel the burner of €0.45/kg, the following values were estimated (Table 8):

This table provides a detailed comparison of the costs associated with the production of different types of mix designs of asphalt wearing course mixes. The data refer to the

Table 8. Cost and Efficiency Analysis of 0/8 Asphalt Wearing Course Mixes

Type	HMA	WMA	HMA - RAP	WMA - RAP
Mix Design	Asphalt wearing course 0/8	Asphalt wearing course 0/8	Asphalt wearing course 0/8	Asphalt wearing course 0/8
Tot [€]	56,16 €	56,19 €	45,61 €	45,73 €
€/kg	0,052 €	0,052 €	0,043 €	0,043 €
€/ton	51,76 €	51,52 €	43,05 €	43,16 €
GPL	3,70 €	3,10 €	3,70 €	3,10 €
GPL [€]	4,33 €	3,63 €	4,33 €	3,63 €
Tot [€]	**60,49 €**	**59,82 €**	**49,94 €**	**49,36 €**

standard Hot Mix Asphalt (HMA) and Warm Mix Asphalt (WMA) mixes, as well as their variants incorporating Reclaimed Asphalt Pavement (RAP).

A total cost analysis reveals that the price difference between HMA and WMA mixes is minimal, suggesting that despite the energy savings offered by WMAs due to lower processing temperatures, the introduction of specific additives for these mixes increases their cost. Indeed, while LPG (used as an indicator of energy consumption) for WMA is lower than for HMA, the additional cost of additives brings total costs to comparable levels between the two types of mixes.

However, the most significant distinction emerges when considering RAP-containing variants. Both types of mix designs with RAP (both HMA and WMA) show a significant cost reduction compared to mixes without RAP, with a decrease of about €10 per ton. This saving highlights the economic benefit of using recycled material, which reduces the need for new aggregates and bitumen-resources that are typically more expensive.

In summary, the analysis indicates that the use of RAP in asphalt mixes can be an important cost reduction strategy for the road construction industry. While the adoption of WMA technologies is often justified by environmental sustainability considerations, the real cost savings, according to the data reported, are achieved through the incorporation of recycled materials, emphasizing the relevance of recycling in the financial optimization of asphalt production.

5 Conclusions

Examination of the costs associated with asphalt mix production highlights crucial considerations for the road construction industry, especially from the perspective of economic and environmental sustainability. The minimal variation in total costs between HMA and WMA, despite the lower energy consumption of the latter, highlights how the adoption of specific additives can significantly influence the production cost structure. This observation underscores the importance of balancing sustainability goals with the economic management of the production process.

On the other hand, the presence of RAP in asphalt mixtures marks a net cost saving, reducing the need for new materials and enhancing the recovery of existing resources.

The analysis confirms that incorporating RAP is a practical strategy for lowering costs, with the additional potential to minimize the carbon footprint of road operations.

The conclusions emerging from the study confirm that the asphalt industry is at a crossroads, where technological innovation and material reuse can not only coexist but, in fact, can enhance each other. Adoption of WMA production practices and efficient use of RAP appear to be viable paths toward greater environmental sustainability and economic savings. This is of particular relevance in geographically isolated settings such as Sardinia, where logistics and material import costs can place a significant burden on firms' cost structures.

Finally, the implications of these findings extend far beyond the local context of the island, offering insights for the global debate on the future of road infrastructure and the adoption of more sustainable construction methods. The challenge for decision makers, designers, and road builders will be to integrate this knowledge into construction and maintenance strategies that not only improve the quality and durability of infrastructure but also its compatibility with the environment and the circular economy.

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From Structural to Transformative-Change of City Environment: Challenges and Solutions and Perspectives (TRACE 2024)

Sustainable Finance Disclosure Regulations as a Tool for Change of City Environment

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Abstract. The sustainability paradigm, already central at the international level with the 2030 Agenda and at the EU level with the new policies of the European Union, has acquired increasing importance in the business choices of companies, which also consider the social and environmental dimensions in the definition of corporate strategies. By investigating the dimensions constituting ESG factors (Environment, Social, Governance) and considering the national and international regulatory framework on sustainability-related issues, the main benefits deriving from the integration of the three ESG components into business logic are highlighted. To understand how the factors of the acronym have guided the socio-economic activities of companies, it is necessary to frame the innovations introduced by the legislation in the field of CSR (Corporate Social Responsibility), which lead to new challenges and objectives in terms of sustainability reporting. Outlining the state of the art of international and national legislation in this regard, allows us to define the degree of diffusion and progress of non-financial disclosure in the context of corporate strategies as well as the main related reporting standards. This work aims to analyze, from a theoretical-conceptual point of view, ESG criteria, underlining their interconnection with the new nonfinancial disclosure system, considering the expansion of the set of information to be reported established by the Corporate Sustainability Reporting Directive with the introduction of new ad hoc sustainability reporting standards such as the ESRS (European Sustainability Reporting Standards).

Keyword: Non-financial disclosure · ESG · sustainability standards · city environment

1 Introduction

In recent years, sustainability has become increasingly important both at an international level, due to the global dimension of some phenomena, and at a regional and local level, due to the urgency of identifying managerial models capable of reconciling economic development and protection of natural heritage. Environment in different socio-cultural and institutional contexts. In this regard, business organizations can proactively contribute to sustainable development through management oriented towards economic growth and strengthening competitiveness, environmental protection, and the

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exercise of social responsibility. This is even more true if we consider the diffusion of ESG criteria, the implementation of which requires the involvement of the organization as a whole [1]. The numerous initiatives promoted at the European and international levels, such as the European Green Deal [2], the Paris Agreement [3] on the climate, and the Sustainable Development Goals of the 2030 Agenda [4], require organizations to identify in detail virtuous practices that become an integral part of their business [5]. To communicate to stakeholders the commitment of organizations towards ESG dimensions, the new sustainability standards that incorporate environmental and social as well as economic information are useful [6]. Therefore, asset managers who know how to correctly analyze non-financial information and develop greater know-how in the management and analysis of ESG factors will be able to obtain a series of benefits also from an economic-financial point of view [7]. The work therefore aims to define, through a theoretical-conceptual approach, the state of diffusion of ESG criteria, framing the evolutionary dynamics of the European regulation of sustainability, as well as on the topic of non-financial reporting. Conduct a critical analysis of the characteristics of the very recent European Directive on Corporate Sustainability Reporting and the ESRS sustainability standards introduced by it, is useful to guide organizations in non-financial reporting. The work is divided into two sections. The first section on ESG Criteria investigates in particular the existing literature, the meaning of the components of the acronym, and their impact on non-financial reporting. The second section, however, frames national and international legislation on sustainability, paying attention to the CSRD directive and the new ESRS sustainability standards.

2 Methods and Materials

2.1 An Overview of ESG

The term ESG has relatively recent roots, dating back to the 1970s, characterized by different approaches to the role that the company assumes within society. In particular, the scholar Friedman introduces a radical theory [8], according to which a company must be profit-oriented and shareholder-satisfied, regardless of responsibility towards the public, in the exercise of business activity [9]. In fact, in the work called "The Social Responsibility of Business is to Increase its Profit", he advances the thesis that social responsibilities are not the responsibility of companies, but of individuals [10]. The underlying logic is based on the belief that, if the company were to focus on social issues, it would lead to lower returns for shareholders, leading to considerable outlays. At the antipodes of Friedman's vision, awareness is developed on social issues such as the protection of minorities, workers' rights, and environmental protection. The first big step towards a greater focus on Corporate Social Responsibility and the sustainability paradigm came with the publication of the Brundtland Report in 1987[11] which contains the first definition, still shared today, of sustainable development and the main suggestions for implementing a radical change in lifestyles [12]. Another step in the evolution of Corporate Social Responsibility (CSR) towards the consideration of ESG criteria in business logic was made possible through the contribution of the scholar Elkington, who in 1999 published the volume "Cannibal with Forks: the Triple Bottom Line of 21st Century Business", which underlines [13] the importance of considering

not only economic-financial but also environmental sustainability [14]. 2005 is to be considered the year in which the diffusion of the ESG structure began, within the International Finance Corporation, aimed at promoting economic development and improving people's lives [15]. On this occasion, the report "Who Cares Win" was produced, to integrate environmental, social, and governance issues into assets and management services, securities brokerage, and associated research functions [16]. The dissemination of the contents of this Report has helped to improve the integration of criteria into investment decisions [17], aiming to define the roles of each counterparty to enhance and consolidate the issues under consideration [18]. Another significant step in the evolution of ESG can be found in the Freshfield Report [19], which highlights the importance of including ESG factors in the process of choosing institutional investments. This document can be considered the basis for the dissemination of the Principles for Responsible Investments (PRI), to improve sustainable and responsible investment among institutions [20]. Finally, the Sustainable Development Goals of the 2030 Agenda themselves have contributed to the definition of ESG criteria. In line with the decisive role played by the European Union in defining the 2030 Agenda for Sustainable Development, it has also undertaken to guide its implementation phase, through the integration of the Sustainable Development Goals (SDGs) into European policies [21]. In the same year, the European Commission, by signing the Paris Agreement, agreed with the Paris Climate Conference, 195 participating countries adopted the first universal and legally binding agreements on the global climate, to avoid dangerous climate change by limiting global warming [22]. The increase in demand for ESG investments has required the implementation of uniform criteria to ensure transparency regarding the disclosure to end investors on the development of environmental and/or social characteristics, in decision-making and advisory activities [23]. The impact of the advent of ESG criteria can be considered disruptive, they make it possible to bring the analysis of environmental, social, and governance aspects back to objective and shared measurement criteria [24]. National legislators have started to introduce non-financial reporting obligations for companies [25]. The theme of sustainability, therefore, despite having landed relatively recently, has become inestimably valuable, in response to a universal need for change.

2.2 The Main Characteristics of Environmental, Social, and Governance Factors

The adoption of ESG criteria in business logic is a useful tool for quantifying the environmental, social, and governance impact of companies, which are increasingly oriented towards sustainability initiatives [26]. The acronym ESG refers to the three components that the company, in its operation as an economic player, cannot fail to consider. These are aimed at quantifying the impact it has on the environment, and social and internal administration [27]. The environmental factor refers to the set of objectives and actions aimed at protecting the environment, concerning carbon dioxide emissions released into the atmosphere, the amount of waste produced, and more generally, how a company behaves as a steward concerning the natural environment [28]. The environmental criterion is closely linked to the direct and indirect impacts that the company causes on the environment (air and water pollution, deforestation, etc.) and the consequences that climate change may have on the life of the company itself (floods, hurricanes, desertification, etc.). The integration of the "E" factor, within business strategies, fosters a

significant contribution to the development of a sustainable environment and, at the same time, prevents external diseconomies [29]. Therefore, if correctly integrated into one's vision, attention to the environment can be a competitive lever with considerable results, preserving the company from strong negative repercussions [30]. The Social factor is linked to the impact that the company has on its stakeholders, all corporate decisions and initiatives that have a social impact, on customers, suppliers, collaborators, local community. Considering this factor means sharing universal values such as ethics, respect for human rights, inclusion, equality, and gender equality. Issues such as diversity, working conditions, including child labor and slavery, and the funding of projects to subsidize poor and disadvantaged communities globally [31]. Social aspects are certainly the most easily observed even by members outside the organization, their respect facilitates the development of a positive image of the company by improving its reputation for stakeholders and society [32] The Governance factor refers to how the company is directed, controlled, and administered. This component includes, for example, the quality and diversity of supervisory bodies, the fair remuneration of managers, the rights of shareholders, and transparency within the organization, as well as the fight against all forms of corruption. Governance makes it possible to define whether the sustainable actions and initiatives adopted by the company are also accompanied by organizational forms in the workplace that are equally close to ESG principles [33]. It is essential to emphasize that the S and G factors are strongly connected. In addition, a greater ethical awareness of one's work takes on fundamental importance within the company's core business, becoming a real intangible resource that does not oppose economic interest to that of the community but, on the contrary, allows for collaboration [34]. The integration of the three factors into business logic makes it possible to effectively measure, and based on common and shared parameters, the environmental, social, and governance performance of a company [35]. This has a positive impact on the opinion of stakeholders, also having a significant impact on consumers' purchasing choices [36]. Choices and investments designed for the environment and society have become the focal point of companies' activities, supporting, and completing the sole profitable purpose [37]. Therefore, it the important to integrate the economic and financial elements contained in the financial statements with environmental, social, and governance information, which can be an expression of the economic sustainability of a company [38]. Reporting on these aspects makes it possible to quantify the ability of companies to pursue environmental and social standards, which are more necessary than ever for the sustainable and ethical development of the entire community.

2.3 The Impact of ESG on Reporting

The interest in issues related to sustainability at the national and international level has considerably concerned the spread of the concept of Corporate Social Responsibility on a large scale, radically changing the path traced by organizations, towards a more sustainable and conscious one [39]. Above all, they have understood the need to implement a process of change, which has been underway for some time for many realities, by setting new information objectives and developing voluntary communication practices, in which to place new sets of information [40]. Companies have adopted, in response to new information and regulatory requirements, new non-financial reporting models [41].

The phenomenon of non-financial reporting, as it includes different aspects compared to traditional ones of a purely economic nature, has progressively seen companies introduce information content relating to the social and environmental impacts generated by their activities. The increase in disclosure levels by companies is substantiated by a progressive evolution of information in qualitative and quantitative terms, becoming increasingly detailed and extensive [42]. The creation of these documents, initially the result of initiatives developed independently, was carried out by many companies with the declared intention of making available information and data relating to the actions undertaken and the repercussions due to them in the perspective that the process of value creation brings social, environmental, and economic benefits and that these elements must be considered interdependent [43]. The forms of non-financial disclosure, therefore, take on a precise connotation in the field of reporting, as a useful tool to give expression and measure the company's process of accountability towards Stakeholders, from which the enhancement of its relational qualities derives. Considering this, the purpose of the voluntary reporting system is not to represent the social and environmental impacts of organizations but rather to represent the continuous and intense communication process between the company and its stakeholders [44]. In this context, the progressive development by the company of reputational capital passes through the effective communication of the positive effects related to the implementation of sustainability strategies. These benefits, in turn, are linked to the company's ability to integrate information regarding the social and environmental effects of its activities into its decision-making processes, which are mainly economic [45]. The widening of disclosure levels is not only a concrete factor in overcoming traditional corporate reporting models but above all an opportunity to detect the interdependence between economic and financial performance and socio-environmental and governance issues, capable of also decisively influencing the current and future value creation process. The most "innovative" companies, i.e., more able to combine and integrate innovation in the business model with the ESG perspective, will be able to achieve a virtuous path of development, achieving greater financial performance more easily [46]. The assessment of ESG practices allows for better identification of the risks and opportunities that companies face, thus favoring advanced technologies, risk management processes, and the conditions in which business results are formed, triggering virtuous processes for the entire organization [47].

3 Data Analysis: Impacts and Innovations

3.1 National and International Regulation

The growing awareness of issues related to sustainability has made it necessary to create and implement an organic regulatory framework, capable of clearly regulating the fields of action of ESG criteria. The latter, generally related to ethical and socially responsible investing [48], provide incentives for the corporate sector to engage in social and environmental, as well as economic, issues. Since 2001, the European Union, with the publication of the "European Union Strategy for Sustainable Development" [49], has actively put in place a series of regulations that could provide precise regulation on the subject, taking on a leading role in the transition to a more conscious economy. The intervention produced the European Green Deal [50], a system of investments aimed at tackling the

threats of climate change and environmental degradation, pursuing objectives such as eliminating net greenhouse gas emissions by 2050, decoupling economic growth from resource use, and leaving no person or place behind. These are long-term goals, based on the assumption that business performance will depend on balancing financial, social, and environmental considerations in business strategy. To prevent greenwashing, the European Union, with the adoption of Directive 2014/95/EU "NonFinancial Reporting Directive" (NFRD) [51], has detailed the rules on non-financial disclosure, obliging major European companies to disclose information about environmental issues, those relating to relations with employees, respect for human rights, the management of corruption and diversity, the influence that ESG factors also exert on performance reporting. With the publication of Directive 2014/95, sustainability reporting became mandatory by law, although limited to certain types of companies based on requirements, especially size [52]. The objective of the Directive, in line with the Commission's recommendations, was to improve the uniformity and comparability of non-financial information reported in the Union, through the preparation of a non-financial statement containing social and environmental information relating to personnel, respect for human rights and the fight against bribery and corruption. Thus, providing useful information about the information content that non-financial statements (NFS) should have had [53]. This Directive was also implemented into Italian law with Legislative Decree No. 254 of 30 December 2016 [54], representing an important step forward in the regulation of non-financial reporting in Italy. The Decree required companies that meet certain criteria to draw up and publish, starting from 2018, a non-financial communication on environmental, social, personnel management, human rights, and anti-corruption matters. The measure provided for the obligation to submit an individual non-financial declaration for relevant public-interest companies, i.e. Italian companies issuing transferable securities listed on Italian or European Union regulated markets such as banks, insurance companies, and reinsurance companies, as well as companies issuing financial instruments, which, although not listed on regulated markets, Entities[1] that have had an average number of employees over 500 during the financial year and, at the balance sheet date have exceeded or balance sheet total of €20,000,000 or total net revenues from sales and services of €40,000,000 [55]. In addition, all other companies not subject to the obligation can also submit a nonfinancial declaration voluntarily in the areas indicated in Article 3, providing, in a context of proportionality, for SMEs, simplified forms [56]. The Decree defines the minimum areas on which it is required to report on its activities and performance[2], leaving the freedom to individual companies or groups of companies to choose the reporting standard to refer to, to identify the key performance indicated by the most suitable to describe the activities concerning the issues considered. Individual organizations are left free to choose the reporting standard among those issued by authoritative supranational, international, or national bodies, of a public or private nature that are nevertheless suitable for fulfilling the reporting obligations provided for by the decree itself [57]. In 2018, the Commission intervened again on the issue of the integration of non-financial aspects among those

[1] For the complete identification of the subjects required to make the declaration, the Legislative Decree refers to paragraph 1 of Article 16 of Legislative Decree 39/2010, a decree implementing the EU directive on the statutory audit of annual and consolidated accounts.

[2] The minimum specific contents are described in the first two paragraphs of art. 3 of DL 254/16.

to be reported, with specific reference to the disclosure of climate impacts, within the Sustainable Finance Action Plan, accepting the suggestions of the task force on financial disclosure relating to climate aspects. The Action Plan for Sustainable Finance outlines the strategy and measures to be taken to create a financial system capable of promoting truly sustainable development, from an economic, social, and environmental point of view, contributing to the implementation of the Paris Agreement on climate change and the United Nations 2030 Agenda for Sustainable Development [58]. Another important step, that accompanies the regulatory framework launched by the European Union, is Regulation 2020/852, or Taxonomy Regulation, to classify economic activities that can be defined as environmentally sustainable. The primary objectives that the EU pursues through this instrument are to create security for investors, eliminate greenwashing, and mitigate market fragmentation. Another no less important purpose is to help companies become more climate-friendly and direct investments towards sustainable projects and activities, thus more likely to achieve global climate and energy goals [59].

3.2 The Corporate Sustainability Reporting Directive (CSRD)

The diffusion of CSR within companies is undergoing important evolutions and changes, not only in the managerial field but above all in the cultural field. By promoting the integration of sustainability within economic realities, progressively all company functions are involved in a process of profound transformation and search for opportunities for improvement, also through the identification of specific sustainability referents in the various structures and the organization of inter-functional task forces with a view to mutual collaboration [60]. Alongside regulatory obligations, there is the increasingly widespread practice of voluntarily drawing up a sustainability or social report, to represent the integration of CSR into the company's business in an in-depth and structured way [61]. With the introduction of the new Corporate Sustainability Reporting Directive (CSRD), the reporting of Corporate Social Responsibility is no longer a strictly voluntary decision but an information obligation for an increasingly large group of companies, leaving the degree of integration of non-financial factors into their business to the discretion of individual companies. On 21 April 2021, the European Commission adopted EU Directive no. 2464/2022 on Corporate Sustainability Reporting, published on 14 December 2022 and entered into force on 5 January 2023, aimed at revising the previous Directive 2014/95/EU. The proposal in question is part of an ambitious European project, aimed at promoting the pursuit of sustainability objectives in finance and, more generally, in the exercise of business activities, in line with the growth strategy promoted by the Green Deal at the European level and with the 2030 Agenda for sustainable growth set by the United Nations [62]. The European regulation is mainly based on transparency obligations to incentivize responsible conduct and virtuous behavior to trigger sustainable development processes [63]. As part of the objectives of the Directive, the intent to improve the quality, comparability, and manageability, especially digital, of information for the benefit of investors and their investment choices emerges [64]. The reporting of non-financial aspects was born voluntarily, but with the new CSRD, it becomes a legal obligation in Italy for a greater number of subjects the new subjective requirements outlined significantly expand the number of companies affected by the reporting obligation [65]. The new rules introduced by the CSRD update what was previously

established by the NFRD. Under the latter, large companies were required to disclose information on environmental and social issues, the treatment of employees, respect for human rights, the fight against corruption and fraud, as well as diversity on boards of directors in terms of age, gender, educational and professional background. These reporting rules applied to large public-interest companies with more than 500 employees, involving approximately 11,700 large companies and groups that included listed companies, banks, insurance companies, and other companies designated by national authorities as public interest entities [66]. With the introduction of the CSRD, which must be transposed into national legislation by 6 July 2024, and the adoption of ESRS, the number of companies subject to reporting requirements has been further expanded, according to a defined time roadmap. The first companies will have to apply the new rules for the first time regarding the 2024 financial year, for reports published in 2025. The deadlines identified by the CSRD and the types of companies involved are listed below [67]. From 1 January 2025 (regarding the 2024 financial year), large companies already subject to the NFRD (Public Interest Entities) will have to comply with the new reporting obligations if they exceed certain size criteria [68].[3] From 1 January 2026 (about the 2025 financial year), large unlisted companies will have to comply if they exceed specific size criteria[4]. From 1 January 2027 (regarding the 2026 financial year), listed small and medium-sized enterprises (SMEs) will have to comply if they meet certain size criteria[5]. The Corporate Sustainability Reporting Directive and the Non-Financial Reporting Directive, fall within the scope of European regulations governing sustainability reporting but differ significantly in their objectives and scopes of application as explained in Table 1.

In summary, while both directives aim to promote sustainability reporting by companies, the CSRD is designed to be more detailed and inclusive than the NFRD, to ensure greater consistency and reliability of sustainability information provided by companies [69]. Among the unpublished information provided by the CSRD, in addition to that already provided for by the previous legislation on the subject, for example, a description of the business model and strategy about the sustainability objectives, the sustainability targets, and objectives set by the company and the progress made towards achieving them, administrative, operational and control governance related to ESG issues, corporate policies and practices about sustainability factors, the main positive and negative impacts of the company related to the value chain [70]. Based on what has been presented so far, it emerges that the CSRD achieves an expansion of the informative scope of non-financial reporting, both in terms of content and in terms of the reliability and comparability of information, also providing for an expansion of the companies required to prepare the sustainability report [71]. Concerning sustainability reporting requirements, the new discipline therefore provides for extending the scope of reporting requirements to additional companies, including all large companies and listed companies, even if they are medium

[3] Average number of 500 employees; and at least one of the following limits: Total assets on the balance sheet > € 20 mln; Net revenues > € 40 mln.

[4] Average number of 250 employees. Total assets on the balance sheet > € 20 mln; Net revenues > € 40 mln.

[5] Average number of employees between 10 and 250. Total assets on the balance sheet: € 350,000-20 mln; Net revenues: € 700,000-40 mln.

Table 1. CSRD and NFRD: similarities and differences.

	Similarities
Sustainability Reporting	Both directives focus on the need for companies to report sustainability-related information, including environmental, social, and governance aspects
Objective of transparency	Both the CSRD and the NFRD aim to improve the transparency of information provided by companies regarding their sustainability impact
Involvement of large companies	Both directives apply primarily to large companies, with specific criteria for determining which companies are subject to reporting requirements
	Differences
Scope of application	The main difference between the two Directives is in their scope. The NFRD only applies to public-interest companies with more than 500 employees, while the CSRD extends to a larger number of companies, including large unlisted companies
Content and details of the information	The CSRD aims to define more detailed common standards for sustainability reporting than the NFRD, which has only provided general guidelines. The CSRD is designed to ensure greater consistency and comparability of sustainability information
Audit Requirements	The CSRD introduces an obligation to subject sustainability information to an external review or audit, while the NFRD does not explicitly require such a requirement

Source: Own processing data on CSRD,2022, and NFRD, 2014

and small (excluding microenterprises, even if listed) in a context of proportionality and specify in more detail the information that companies should report and require them to report in line with the mandatory EU sustainability reporting standards that will be drafted [72]. It is also guaranteed that all information is published as an integral part of the Annual Report of companies and that it is published in a digital format that can be processed and identified automatically and make any relevant information easily accessible. In addition, new information requirements on strategy, objectives, the role of the Board of Directors and management, main negative impacts related to the company and its value chain, and how to identify such information are introduced, compared to the existing legislation. The adoption of forms of non-financial reporting brings with it a wide range of appreciable advantages and benefits. It guarantees greater transparency towards stakeholders regarding social activities and environmental initiatives and investors are increasingly attentive to issues related to ESG opportunities, facilitating access to substantial amounts of capital. Furthermore, virtuous practices generate an increase in staff motivation as well as a better reputation, contributing to the management of corporate

responsibility from a strategic perspective through non-financial reporting. This triggers an orientation towards continuous improvement, considering that the drafting of a sustainability report leads the company to continuously set qualitative and quantitative performance objectives that allow it to improve over time [73]. The main objective of the CSRD is to provide corporate stakeholders with more comprehensive, detailed, and standardized access to sustainability information [74]. This involves ensuring that undertakings disclose non-financial information in a relevant, comparable, reliable, and easily accessible manner to stakeholders, thus reducing the additional costs of preparing such information [75]. This approach is expected to benefit the financial market by improving the completeness, transparency, and comparability of data, allowing investors to better assess the risks related to the sustainability and impact of investments [76]. In addition, the Directive should facilitate investors' access to comparable non-financial information provided by investee companies across the EU, thus contributing to the completion of the Capital Markets Union. In general, these new provisions are expected to strengthen the social relationship between society and businesses, making the latter more aware of and responsible for their socio-economic and environmental impact.

3.3 The Introduction of New Sustainability Standards: The ESRS

The new CSRD includes the obligation to report according to EU sustainability standards. In this regard, the European Commission has entrusted the European Financial Reporting Advisory Group (EFRAG) with the development of these standards, with the request that they be consistent with the ambition of the European Green Deal and with the existing legal framework in Europe. The need to establish a robust and accessible framework for non-financial reporting to ensure data reliability, and avoid *greenwashing* and double accounting [77]. The oversight of the reporting rules is entrusted to the various authorities including ESMA. The guidelines for non-financial disclosure establish a set of information to be disclosed, in detail they report on [78]. The information that companies are required to keep about environmental factors like climate change, such as greenhouse gas emissions, adaptation to climate change, the use of resources and the circular economy, pollution, biodiversity, and ecosystems. The information that companies keep regarding social factors and human rights such as equal treatment, including gender equality, equal pay, training, skills development, and inclusion of persons with disabilities, collective bargaining, workers' rights to information, consultation and participation, work-life balance, health and safety; respect for human rights. The information that undertakings are required to disclose about governance factors like the role of the company's administrative, management, and control bodies about sustainability issues and their competencies and capabilities; the main features of the company's internal control and risk management systems, regarding sustainability reporting; business ethics, including anti-corruption and animal welfare. The new European Sustainability Reporting Standards (ESRS) were adopted on 31 July 2023 and intended to become the guidelines for all companies that must draw up sustainability reports according to the CSRD. ESRS are divided into two categories [79], general ESRS and sectoral ESRS, which will be published in June 2024, together with standards for SMEs. The General ESRS is divided as follows in Table 2.

Table 2. ESRS structure.

Cross-cutting standards	Environmental Thematic Standards	Social Thematic Standards	Thematic Governance Standards
ESRS 1 General principles *ESRS 2* General Information Requirements	*ESRS E1* Climate Change *ESRS E2* Pollution *ESRS E3* Water and Marine Resources *ESRS E4* Biodiversity and Ecosystems *ESRS E5*	*ESRS S1* In-house workforce *ESRS S2* Workersin the value chain *ESRS S3* Communities Concerned *ESRS S4* Consumers and End Users	*ESRS G1* Business Conduct
	Resource Use and Circular Economy		

Source: Own processing data on ESRS, 2023

ESRS are used for sustainability reporting, starting from the financial year 2024, with the first sustainability statement published in 2025, by companies already subject to the NFRD. Starting from the 2025 financial year, other large companies (with 250 employees and/or €40 million in turnover and/or €20 million in total assets) will have to be aligned, with the publication of the first sustainability statement in 2026 [80]. Listed SMEs, on the other hand, are required to adopt ESRS from the 2026 financial year, with the first sustainability statement published in 2027. However, listed SMEs may decide to extend their reporting requirements for a further two years. In addition, simplified and proportionate reporting is provided for SMEs. The main innovations of the new ESRS standards are the complete integration of ESG aspects into the business model and the assessment of companies' risks and opportunities. This follows the introduction of new and fundamental concepts indicated below [81].

Double materiality. Organizations must consider both the impacts of their activities on the environment and society (impact materiality) and the impacts of these issues on their economic and financial performance (financial materiality).

Value chain. Companies must identify and report on material impacts, risks, and opportunities (IROs) related to direct and indirect business relationships in the upstream and/or downstream value chain.

Due diligence. Attestation of compliance with sustainability reporting by an independent auditor becomes mandatory before filing with the competent authority.

The aim of using ESRS is to gradually align all large EU companies with the disclosure of the impact of their activities and any sustainability risks to which they are exposed. This would strengthen the Union's social market economy and lay the groundwork for sustainability reporting standards globally [82]. In execution of the obligation to provide the information necessary for the preparation of the sustainability statement, which is included in the management report, EFRAG has developed the ESRS I and

ESRS 2 reporting standards. The ESRS 1 standard, divided into 10 chapters[6], identifies and classifies the "general requirements" for adequate sustainability reporting [83]. The ESRS 2 standard, identifies the mandatory general ESG information that is not subject to the materiality assessment. It is structured on 4 pillars and aligned with international regulatory frameworks, they are Governance, Strategy, Impact, Risk and Opportunity Management (IRO), and Results and objectives [84]. Through the adoption of the CSRD and ESRS, European companies will be required to integrate sustainability into their decision-making processes and communicate their environmental, social, and governmental impacts [85]. This will foster greater confidence among investors, consumers, and other stakeholders, and help drive the transition to a more sustainable and responsible economy [86]. However, organizations need to recognize the opportunity that sustainability represents for innovation and long-term value creation, and for there to be adequate support from regulators, businesses, and other stakeholders, so that the CSRD and ESRS can have a meaningful impact [87]. ESRS are therefore fundamental tools to promote corporate sustainability and guide companies towards greater social and environmental responsibility, thus contributing to building a more sustainable future for all [88].

4 Conclusion

In recent years, the attention linked to the environmental and social component, considering its influence on the economic system, has assumed considerable importance. This increased sensitivity and the urgent need for action are demonstrated by the numerous initiatives implemented by the international community, which in recent years has made a growing commitment to tackle climate change. From these national and international experiences that call the economy to a growing and more conscious social responsibility of their work, the analysis of non-financial factors has entered forcefully into the evaluation of the performance of companies. The need not only of investors and stakeholders but above all Civil Society to have adequate elements for assessing companies' exposure to sustainability opportunities, has long highlighted the need for the reporting prepared by companies not only to be limited to financial information but also to non-financial information. This is evident in the new CSRD, the most recent EU legislation on ESG reporting, and due diligence for the disclosure of non-financial information relating to the individual and consolidated financial statements of companies established in the context of the European Union. For this Directive, the Commission has carried out coordinated work with the main organizations developing reporting standards at the international level to conduct a harmonization process by establishing ESRS as sustainability reporting standards. For the benefit of all stakeholders, a defined transparent and accountable public disclosure and reporting framework has been established to identify and quantify ESG risks and opportunities and to integrate these risks and opportunities

[6] Categories of standards and information in the ESRS; qualitative characteristics of the information; double materiality; due diligence; value chain; time horizon; preparation and presentation of sustainability information; structure of sustainability reporting; links to other sections of the business report; transitional provisions.

into their strategies. The establishment of a more unitary and coherent reporting framework has also brought benefits to all companies, ensuring that they operate in a system of common sustainability standards with obvious advantages in terms of comparability but also in terms of reducing implementation costs. Fair and correct reporting of ESG impacts on corporate activities through forms of non-financial disclosure is a way to achieve greenwashing and inefficient financial capital allocations to companies that are not sufficiently green. Making the transition to a fairer and more circular economy a reality, starting with reporting, is certainly an ambitious goal. The adoption of an adequate performance metric of ESG dimensions with the use of the new ESRS, and the attention to sustainable development issues, as a reversal of the degrowth process, can represent concrete actions to mitigate the impacts of human activities on the climate and the environment. In the light of what has been briefly illustrated so far, the breadth, articulation, and complexity of the information required by the European legislator is evident. To comply with the CSRD, a rapid and profound organizational and cultural evolution of companies is necessary. Now, enterprises must widely and quickly adopt risk-oriented management processes and tools. This approach, consequent to the regulations issued in the field of sustainability, will consequently and by osmosis, transversally and widely, involve all business processes. This induced and widespread cultural evolution will be able to strengthen the governance and management processes of companies, even more so in smaller ones. The challenge will be to measure the progressivity and proportionality with which SMEs will have to evolve to comply. Excessive regulation and compliance costs could boomerang if they undermine the dynamism and agility of smaller companies. The orientation of the European legislator towards the progressive and staggered implementation of the rules appears to be consistent but, in the absence of adequate effective and substantial controls and sanctions, if the cost of non-compliance with the standard is not adequate and significant, the effectiveness and effectiveness of the regulatory framework could prove to be weak and greatly decreased. Regarding the correct implementation of the sustainability framework, the company's top management and governance play a fundamental role, which must have adequate skills, and strategic clarity and make effective and measurable commitments. There is still a long way to go for the adoption of models that can be defined as sustainable, but the direction traced seems to be oriented towards increasingly stringent rules, aimed at increasing companies' awareness of their negative externalities, to introduce virtuosity in business processes in a long-term perspective. The future goal is not only related to harmonizing reporting processes and ensuring a reporting system that provides clear, transparent, reliable, and verifiable information but above all to recognize the value of sustainability reporting as financial, marking awareness of the relevance of environmental, social, and governance issues.

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Sustainable Initiatives of Industrial Archaeology Conservation and Reuse: The Case-Study of the St Paul's Storage in Rome

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Abstract. The aim of this work is the economic-financial evaluation of a restoration and functionalization project on the former "St Paul's storage", an example of industrial archaeology in Rome. The term "industrial archaeology" denotes an interdisciplinary approach to studying past industrial sites, specifically in relation to their impact on the territory or with a view to their possible preservation. Industrial sites often consist of buildings lacking particular aesthetic qualities, designed solely to meet production needs. Consequently, they are rarely undergoing historical-artistic protection constraints by local Superintendencies, and their existence is jeopardized by urban regeneration processes. The "voids" left by the decommissioning of factories are frequently situated in strategic locations within cities. These areas become attractive for economic stakeholders involved in transformations, including administrations and businesses. However, repurposing the buildings, once designated for production, presents challenging issues, ranging from land pollution to high management costs, due to their considerable size. The ensuing study aims to demonstrate the economic sustainability of these actions on industrial archaeology, aligning with the needs and requests of the population and in perspective to become potential strategy-nodes of the sustainable development.

Keywords: Industrial archaeology · Sustainable practices · Co-participatory process

1 Case Study Description

St Paul's store dates back to 1928, when it was built under the name *Littorio* Depot to house the first electric tram vehicles to reach the Basilica of San Paolo. The substantial restrictions on trams in Rome resulted in a steady fall in the garage's tram utilization. As a result, starting in the 1970s, it was mostly used for buses until its closure in 2000. Since then, as with other structures of its type, several suggestions for reuse have been proposed, but none have been materialized, and the warehouse remained abandoned. Similar case studies include the renovation of *Testaccio*, a former nineteenth-century abattoir in Rome

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that was decommissioned in 1975 and repurposed in 2000 while preserving its original features for use as a Department of Architecture campus and a branch of the Museum of Contemporary Art MACRO. The *Guido Reni* District features 23 separate, adaptable rooms in a post-industrial design, all of which were created from an old barrack by the *Cassa Depositi e Prestiti* Group. The major renovation of the former ATAC *Vittoria* terminal produced the *Prati* Bus District. The city of *Prato*'s former *Campolmi* shearing factory, which was once an industrial complex for the manufacturing of textiles, has been transformed into the Textile Museum and municipal library while maintaining its historical layers and original structure.

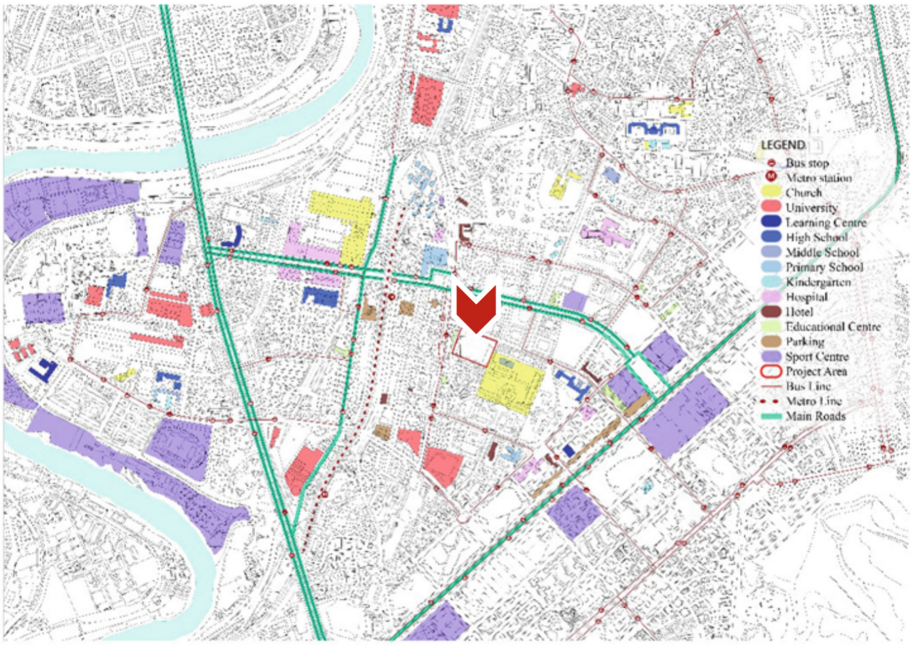

Fig. 1. Main services and connections in the neighborhood near the depot.

The project is located in Municipio VIII of the municipality of Rome. The population amounts to 128,914, with a density of 2501 – 7000 inhabitants per square kilometres, mainly composed of families with children. Namely, the case study is placed in Rome, in the *Ostiense* district between *Alessandro Severo* and *Settimio Severo* St., and, as seen in Fig. 1, it is encircled by several facilities and services.

Before the twenties, the *Gazometro* was near the southern border of Rome, but the area developed significantly over the years into a district and now it is mostly built-up. Beyond the *Gazometro*, the *Garbatella* was constructed and, going further South, the St. Paul's Church was an important point of attraction. The opening of many new tram lines has resulted in the requirement for a public transportation depot in this area.

Since it was built at a higher level in the fifties, the large depot is now underground instead of being on top of *Alessandro Severo* Str. The structure is made of reinforced concrete and has four large arched roofs that are supported on pillars (Fig. 2).

The degradation analysis is presented n Fig. 3. It is a graphical and technical elaboration describing the pathologies and failures of an existing building. The purpose is to analyze the "defects" that the studied building exhibits in order to identify the most appropriate "treatment" to address the issues it manifests. The degradation analysis is a process regulated by the "UNI 11182 Cultural Heritage" standard and is the foundation of every recovery or restoration project in Italy.



Fig. 2. Tram depot entrance

The sports and wellness centre, complete with a gym, sauna, and swimming pool, as well as leisure and eating sections and student cultural spaces, are all part of the depot's revitalization project. The upper floors house classrooms and labs for the architecture faculty of Sapienza University in Rome, while the lower levels house administrative spaces and services.

In order to prove the case study's economic-financial viability, the following methodological approach was taken:

i. *Socio-urban context analysis* (Sect. 2). In order to support the initial project intents and compare the demands of the people with the services already provided, a SWOT analysis (2.1) and an online survey (2.2) were created.
ii. *Cost-revenue analysis* (Sect. 3). The characteristics of the San Paolo Deposit Requalification Project are estimated in terms of construction and management costs, as well as primary and secondary revenue sources. These are based on the interests expressed

by the community, as well as the meanings of demand and supply in the reference market.

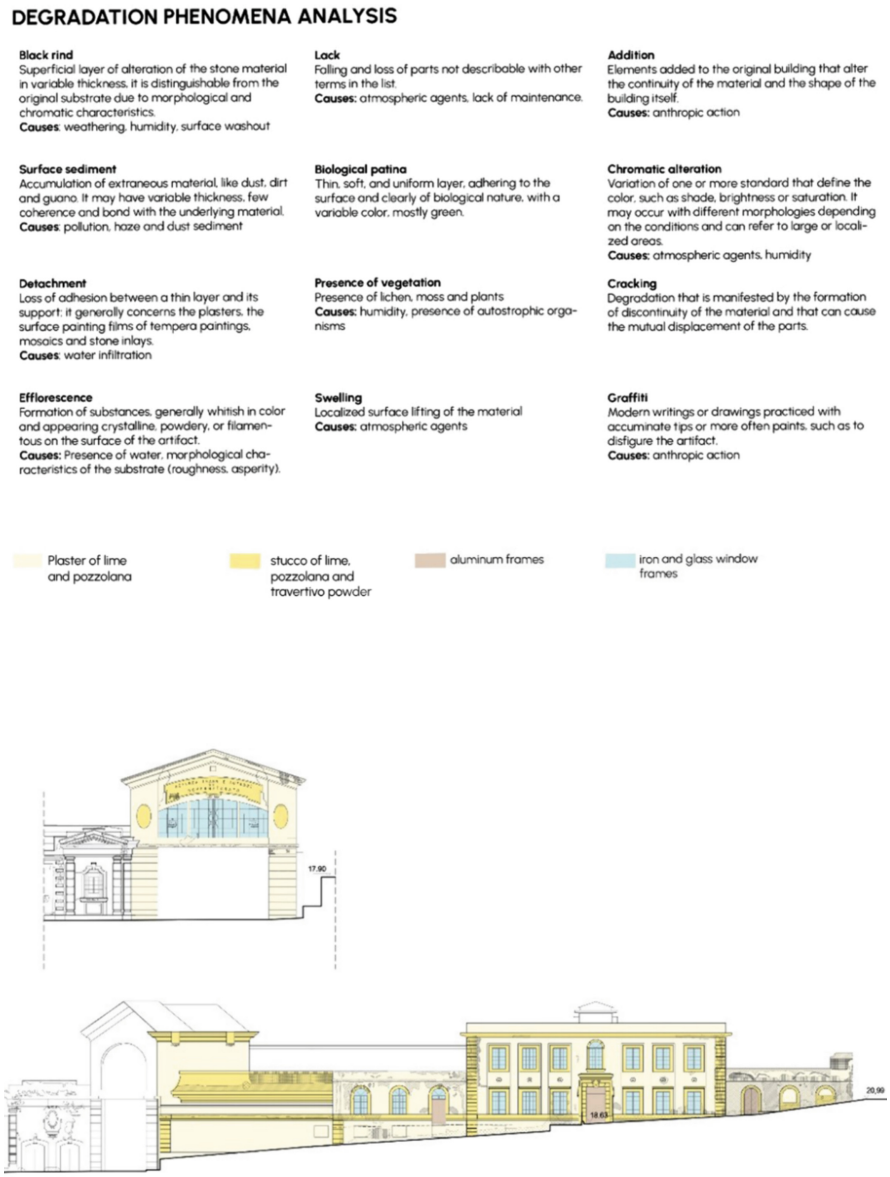

Fig. 3. Degradation phenomena analysis

2 Socio-Urban Context Analysis

The economic-financial feasibility analysis of the St. Paul deposit recovery project is developed by first analysing the urban context of reference and then comparing its potential to the analysed recovery intervention. This involves creating a SWOT matrix (2.1) to express the project's significant and less characteristics, considering potential risks and opportunities for growth in the context that might result from a recovery project, such as that under analysis. Second, to ensure the coherence of the project's intentions, a survey is designed (2.2) to capture the population's demands and quantify the willingness to pay for investing in the realization of particular functions of interest. The two sub-sections are explored below.

2.1 SWOT Analysis

The SWOT matrix is a strategic planning tool used to assess the strengths, weaknesses, opportunities, and threats of a project. The analysis can focus on the internal environment (strengths and weaknesses) or the external environment (threats and opportunities). The SWOT analysis identifies possibilities and risks within the environment in which the intervention of our investigation is placed. In addition, the project's strengths and weaknesses have been discussed [1–4].

The analysis was undertaken initially from a broad viewpoint, analyzing the entire neighborhood, and then more precisely, focusing on the project area. Among the building's qualities, it is crucial to highlight the importance of collective memory in the neighborhood since the former St. Paul depot acts as a reference point for the locals.

SWOT	S	W	O	T
Analysis	Strenghts	Weaknesses	Opportunities	Threats
Garbatella district	- **Key position**: easy to access to main public transport (subway, bus, ...); - **High presence of public green area**; - **High presence of schools and academies**: it allows education from the youngest to university student; - **Numerous attractions** like: "San Paolo fuori le mura", lot of sports centres; - **Commercial road**: excellent distribution of all kinds of shops.	- **Lack of parking**; - **Public green area abandoned and too much degradated.**	- **High presence of attractions for student**; - **High presence of public transport** which encourage the arrival of many people; - **Possible connection between green areas and attractions**; - **High presence of hospitals and clinics**.	- **Intervention limits** given by the PRG (public service at urban level) and by the **architectural constraint** of cultural interest.
St Paul's Storage	- **Collective memory** of the building: currently use as a market for the sale of local products (San Paolo District); - **Architectural value of the building.**	- The building is surrounded by **one-way streets**: difficult to vehicular access; - **Poor visibility**: the building is undergrounded compared to street level; - **Poor maintenance of the sidewalk** and limited usable pedestrian space. - **Large abandoned public green area.**	- **Volumetric and structural power** of the building; - Maintenance of a **collective memory** (historical recognisability).	- Very **degraded** building; - **Roof always in contact with the sun** (completely absent on the facades); - **Natural light is almost absent** (it is present only in some points thanks to the presence of skylights; - **Large nearby green area neglected**.

Fig. 4. SWOT analysis

As a result, the identity of the building has been viewed as an important aspect in architectural decisions. Figure 4 summarizes the SWOT analysis results.

2.2 Survey of the Local Needs

A survey was performed to assess the project proposal by potential users of the spaces, namely that are destined to the exhibition [5–7].

The questionnaire received 31 replies, with around 55% coming from those aged 19 to 25. The survey intended to better understand the neighbourhood's lacking services in order to suggest a concept that would meet the requirements of both residents and visitors.

77.4% of respondents said they are students. Income is distributed pretty evenly: 32.3% report earning less than €15,000 per year, 32.3% between €15,000 and €28,000 per year, and 35.5% between €28,000 and €50,000 per year. According to the survey, 87.1% do not live in the reference neighborhood, yet more than 32% have heard of it, and 35% know and visit the region.

According to the survey (Fig. 5), the places designated for cultural activities, green spaces, and leisure were the ones that voting users valued the most. This finding is consistent with the social and urban study that was done earlier since there are green spaces, but they are generally neglected or in bad shape, and there are no cultural or recreational sites.

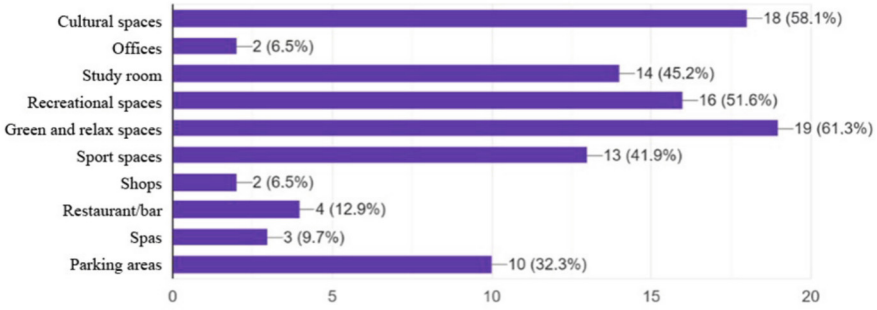

Fig. 5. Bar chart for the question: "What services do you think are missing in the neighbourhood?"

Based on the aforementioned results, an initial market investigation on the "willingness to pay" for the proposed service was conducted. The data obtained (Fig. 6) indicates that 45% of the public would be willing to pay between 5 and 10 euros per entry.

The third and final part of the survey (Fig. 7) is dedicated to understand the macro-themes that can be present in the project and concern common interest issues. The macro-themes derive from the extrinsic characteristics of the analysed territory. The overall survey results point to: crime reduction (14 responses), increase in the young population (18 responses), greater attractiveness of the area (19 responses), and improvement of public green spaces (18 responses).

In conclusion, it can be stated that the proposed project meets the needs of the users. Despite the higher percentage of residents being over 50, the survey responses

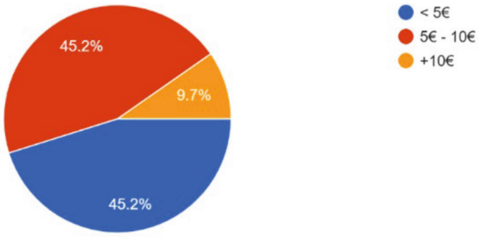

Fig. 6. Pie chart for the question: "How much would you be willing to pay for admission to access the services proposed in the previous question?"

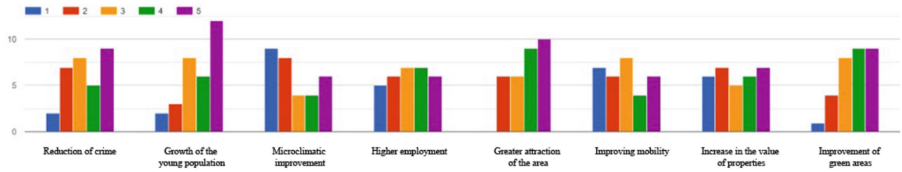

Fig. 7. Histograms for the question: "What effects on the neighbourhood do you expect from the redevelopment of the depot?"

demonstrate that the area is widely frequented by young people due to the presence of schools and universities. Therefore, the project has been calibrated based on the high number of students, which is its primary target audience.

3 Economic and Financial Feasibility of the Intervention

Financial evaluations have been conducted using the Discounted Cash Flow Analysis (DCFA) to give a comprehensive picture of the medium- to long-term implications of the development project. The goal of this approach technique is to evaluate each intervention's sustainability. In order to use DCFA, it is necessary to make some assumptions about the duration of the study and the discount rates that will be used in the assessment, as well as to identify income and cost components that help determine the operation's viability. The study time is set at twenty years, in accordance with the custom of the average investor, who tends to sell the asset that is being evaluated after a fair amount of profitable operations.

3.1 Direct and Indirect Revenue Appraisal

To determine the market value of the project offices, we conducted a direct market assessment, comparing similar properties to ours and utilizing floor space as a technical distinguishing factor [8]. After entering surface area data, we calculated the unit price (per square meter) for each comparison. We next proceed to create the pricing scale, which is just an ascending arrangement of unit prices based on the previously described market survey. Our unit pricing (20.88 €/sqm), calculated as the average of the reported data, falls within the analysis-range.

Otherwise, the search for the unit pricing of exhibition spaces necessitated more particular study since, in the spatial research horizon, there were few equivalent or consistent case studies with the leasing technique we hypothesized - namely, a fixed fee upon "entry" rather than monthly leasing of the building.

In addition, several indirect sources of revenue were evaluated, based on the questionnaire answers. These included the arranging of workshops, conferences, and study rooms.

3.2 Intervention and Management Costs

The theoretical idea of production cost—the total of all the expenses an entrepreneur must incur for a production cycle to continue—is applied to the building costs. To ensure a more comprehensive assessment, the building costs are determined using a metric calculation that is generated using software, employing the unit price of the Lazio Region's price list as a point of reference for the works' costs estimation.

It is projected that the cost of uncommon maintenance will account for 15–20% of the building cost, while the cost of routine maintenance would account for 5–10% (Fig. 8). The total annual cost is obtained from the sum of construction costs (for the first three years), fixed costs, management costs and costs for routine maintenance and extraordinary maintenance (Fig. 9). Both fixed and operating costs were estimated based on the assumption of use and capacity of the structure: the estimated costs were 35% in

Electricity	n.	Total Power	Time	Energy	Rate	Total annual
		(kW)	(h)	(kWh)	(€/kWh)	€
Lighting	70	28	4,863	136,164.00	0.16	21,786.24
Video surveillance system	20	0.01	8,760	87.60	0.16	14.02
Elevator	2	5	8,760	43,800.00	0.16	7,008.00
Cutting machines	1	0.08	4,863	389.04	0.16	62.25
3D printers	1	0.12	4,863	583.56	0.16	93.37
Plotter	2	0.60	4,863	2,917.80	0.16	466.85
Air conditioning	10	-	-	33,852.00	0.16	54,163.20
TOT.						83,593.92 €

Management costs	€
Cost for staff	
Screener (x2)	29,900.00
Bookkeeper	18,000.00
Costi operativi	€
Maintenance and cleaning charges	30,000.00
Electricity	75,550.00
General costs	€
Management	4,800.00
TOT.	158,250.00

Maintenance (from the fifth year)	
Ordinary	5-10%
Extraordinary	15-20%

Fig. 8. Management and fixed costs

COSTS					
	Construction	Fixed costs	Management	Maintenance	Total
1° year	66,500.00 €	- €	- €	- €	66,500.00 €
2° year	23,614.85 €	- €	- €	- €	23,614.85 €
3° year	53,342.00 €	- €	- €	- €	53,342.00 €
4° year	-	27,866.67 €	52,750.00 €	- €	80,616.67 €
5° year	-	27,866.67 €	52,750.00 €	- €	80,616.67 €
6° year	-	41,800.00 €	79,125.00 €	- €	120,925.00 €
7° year	-	41,800.00 €	79,125.00 €	- €	120,925.00 €
8° year	-	58,520.00 €	110,775.00 €	- €	169,295.00 €
9° year	-	58,520.00 €	110,775.00 €	- €	169,295.00 €
10° year	-	83,600.00 €	158,250.00 €	- €	241,850.00 €
11° year	-	83,600.00 €	158,250.00 €	- €	241,850.00 €
12° year	-	83,600.00 €	158,250.00 €	- €	241,850.00 €
13° year	-	83,600.00 €	158,250.00 €	- €	241,850.00 €
14° year	-	83,600.00 €	158,250.00 €	- €	241,850.00 €
15° year	-	83,600.00 €	158,250.00 €	- €	241,850.00 €
16° year	-	83,600.00 €	158,250.00 €	- €	241,850.00 €
17° year	-	83,600.00 €	158,250.00 €	- €	241,850.00 €
18° year	-	83,600.00 €	158,250.00 €	- €	241,850.00 €
19° year	-	83,600.00 €	158,250.00 €	- €	241,850.00 €
20° year	-	83,600.00 €	158,250.00 €	- €	241,850.00 €
21° year	-	83,600.00 €	158,250.00 €	- €	241,850.00 €
22° year	-	83,600.00 €	158,250.00 €	- €	241,850.00 €
23° year	-	83,600.00 €	158,250.00 €	- €	241,850.00 €
24° year	-	83,600.00 €	158,250.00 €	- €	241,850.00 €
25° year	-	83,600.00 €	158,250.00 €	- €	241,850.00 €

Fig. 9. Total annual costs

the fourth year, 50% in the sixth year, 70% in the eighth year, and 100% from the tenth year onwards.

3.3 Discounted Cash Flow Analysis

The analysis of the financial feasibility of the intervention includes an analysis of costs and revenues for the construction and management phases over 25 years.

To conduct a cost-profit analysis, it is necessary to calculate the cost of construction, the total operating expenses (including management and maintenance), and tariff returns depending on potential users. The Discounted Cash Flow Analysis is used to calculate the net present value of return flows minus costs, discounted at a conventional rate of 3 per cent, and the IRR or discount rate, which, applied to the return flow minus costs, resets the net present value [7, 10–14].

The subdivision of the construction costs was assumed over three years according to the construction phases, organizing the interventions in chronological order.

The estimate of revenue is made assuming for the first three years, that is, for the construction phase, no income. Starting from the fourth year, considering a use and a capacity of 35%, a daily income was assumed based on the market analysis carried out before. The revenue comes from the rental of the conference room and offices, from the entrance fee to the study rooms and laboratories, estimated by the survey. The procedure was repeated for the following years, assuming a use and a capacity of 50% from the sixth year, 70% from the eighth year and 100% from the tenth year onwards.

By analyzing the costs and revenues mentioned above, we can determine the cash flows obtained from the project (Fig. 10), which allows us to calculate the net present value of the project and the internal rate of return.

The IRR is equal to18% and the NPV is equal to 4,030,460.90 Euro.

CASHFLOW				
Time	Costs	Earnings	Total	Cashflow
1° year	66,500.00 €	- €	- 66,500.00 €	- 66,500.00 €
2° year	23,614.85 €	- €	- 23,614.85 €	- 90,114.85 €
3° year	53,342.00 €	- €	- 53,342.00 €	- 143,456.85 €
4° year	80,616.67 €	93,500.00 €	12,883.33 €	- 130,573.52 €
5° year	87,786.07 €	93,500.00 €	5,713.93 €	- 124,859.59 €
6° year	120,925.00 €	143,510.00 €	22,585.00 €	- 102,274.59 €
7° year	120,925.00 €	143,510.00 €	22,585.00 €	- 79,689.59 €
8° year	169,295.00 €	211,820.00 €	42,525.00 €	- 37,164.59 €
9° year	169,295.00 €	211,820.00 €	42,525.00 €	5,360.41 €
10° year	256,188.80 €	307,340.00 €	51,151.20 €	56,511.61 €
11° year	241,850.00 €	307,340.00 €	65,490.00 €	122,001.61 €
12° year	241,850.00 €	307,340.00 €	65,490.00 €	187,491.61 €
13° year	241,850.00 €	307,340.00 €	65,490.00 €	252,981.61 €
14° year	241,850.00 €	307,340.00 €	65,490.00 €	318,471.61 €
15° year	263,358.20 €	307,340.00 €	43,981.80 €	362,453.41 €
16° year	241,850.00 €	307,340.00 €	65,490.00 €	427,943.41 €
17° year	241,850.00 €	307,340.00 €	65,490.00 €	493,433.41 €
18° year	241,850.00 €	307,340.00 €	65,490.00 €	558,923.41 €
19° year	241,850.00 €	307,340.00 €	65,490.00 €	624,413.41 €
20° year	249,019.40 €	307,340.00 €	58,320.60 €	682,734.01 €
21° year	241,850.00 €	307,340.00 €	65,490.00 €	748,224.01 €
22° year	241,850.00 €	307,340.00 €	65,490.00 €	813,714.01 €
23° year	241,850.00 €	307,340.00 €	65,490.00 €	879,204.01 €
24° year	241,850.00 €	307,340.00 €	65,490.00 €	944,694.01 €
25° year	270,527.60 €	307,340.00 €	36,812.40 €	981,506.41 €

Fig. 10. Development of the Cash flows

4 Conclusions

The research focuses on an industrial structure of historical and architectural importance that should be preserved via recovery, even if it is economically costly. The goal of this study is to give an objective assessment of the viability of the interventions under consideration, that is, their potential to favorably integrate into the reference environment and attract a large number of users, particularly students and young people. That purpose is intended to offer economic and social benefits to a hypothetical private investor. Furthermore, using the net present value (NPV) and internal rate of return (IRR) as financial sustainability criteria, it may be concluded that the project is economically viable. Apart from conducting an analytical analysis, it is imperative to emphasize the utilization of surveys as a fundamental instrument for involving citizens in project decision-making. This is done with the aim of achieving both financial and social benefits from the work. This is applicable to both urban industrial archaeology conservation and reuse projects.

Note: The current study has been developed within the current research P.R.I.N. Project 2022: "INSPIRE—Improving Nature-Smart Policies through Innovative Resilient Evaluations", Grant number: 2022J7RWNF.

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Financialization of the Real Estate Market in Spain

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Abstract. The process of financialization of the economy greatly affects the real estate sector, a sector that represents two-thirds of the planet's total capital and which is highly attractive to investors at the same time as low risk. The transfer of real estate assets to companies that base their business on leasing models is led by the tax figure of Real Estate Investment Trusts (REITs). This work analyzes its impact in Spain from its initial regulation in 2009, studying its financial results from the points of view of the volatility of the sector and the generation of results. It highlights, on the one hand, the importance of the revaluation of the assets themselves and their accounting in the results and, on the other, the increase in market volatility under a high level of liquidity and a modification of the leverage criteria. The results show how the objectives of public policies of increasing liquidity and energizing the market present another side of the coin, effects of attracting capital and generating uncertainty in the sector, results opposite to the objectives of facilitating access to the home.

Keywords: financialization · volatility · sustainable development · economic valuation

1 Introduction

The financialization process includes aspects such as the increase in the role of financial markets in the economy [1, 2], the generation of profits through financial channels [3], or the mastery of the financial logic of shareholder value [4, 5]. It is a concept usually worked together with those of Neoliberalism and Globalization [6], in which a combination can be seen that includes a tendency for markets to globalize by reducing the barriers and differences between them [7], favored by a 'neoliberal' logic of investment profitability [5] in markets of increasing dimensions and under the growth of finance as a means and end of said profitability. Three concepts that, although they are presented together under the criticism of the economic model, are also presented as a result of a market highly intervened by the public sector of different countries with the capacity to modify investment conditions with the objective of attracting capital to their economies. National, generating new balances of profitability and risk in a way in which fiscal policy decisions become a necessary ally of the model considered neoliberal.

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In the process of financialization, the role of the real estate sector stands out, a sector that at the international level represents two thirds of the total capital existing in the sum of the value of land plus the value of buildings. Thus, the process of financialization plays an important role in the real estate sector by making the most rigid assets of the economy liquid, associated with long periods of exchange, price uncertainty, high transaction costs and the participation of numerous intermediaries. Through the acquisition of properties in the hands of companies it is possible to distribute their ownership in small participations that have the opposite characteristics to the traditional real estate sector, thus becoming liquid assets in which investment is easier, exchange times can be reduced to a minimum, quoted prices are used that value the asset in real time, and transaction costs and intermediation are reduced to a minimum.

Traditional real estate models based mostly on build-to-sell or buy-to-sell [8] are facing a growth of rental-driven models, in the form of build to rent or buy to rent, in which corporate profit reduces its focus from speculative purposes to real market purposes under the lease of space. The increase of real estate assets directed towards leasing is embodied as a form of financialization 2.0 [9] in which the stability of rents under growth conditions is combined together with the expected effects of real estate appreciation. These models are based on the transfer of assets from natural persons to legal entities with the aim of increasing their profitability [10, 11] due to both the possibilities of transfer and the tax burdens associated with each type of legal entity. This is a progressive transfer of assets in which those that present a greater profitability differential are progressively incorporated [12]. This process of asset transmission is based both on a socialization of the investment through small participations, either in the form of business shares as well as intermediate proposals for the tokenization of assets and the participation of smart contracts with the capacity to automatically distribute the assets. Rents obtained from leases [13].

Along with these types of investment there are other figures in which the legal personality plays an important role. Another type of investment in the construction of buildings consists of the company making the expense to build (for example: the building of the headquarters, and then renting it to the company, to recover the investment as if it were a life annuity. It is similar to what is called reverse mortgages, whereby a highly valuable asset can be converted into a constant income over time. An example of this can be seen in the case of the Santander group's City, its banking headquarters near Madrid, came into operation in 2004. The investment was valued at $3 billion and was expected to produce income of $100 million each year. But the property has been greedy and has gone through different financial companies, which demonstrates the interest of real estate assets as a future income [14]. Another aspect to highlight is that due to the cyclical nature of the economy, and the interest in buildable tourist land, When, in Spain, the economy is in decline, European citizens compensate for the lack of demand from Spain with an added demand from non-Spanish citizens [15].

The financialization process of the real estate sector poses a significant effect on market volatility [16]. This situation presents higher volatility levels than the traditional real estate market, while lower than those that can be found in other sectors [17]. With respect to the sources of financing, the change in the level of market leverage stands out [18].

Real Estate Investment Trusts (REITs) emerged in 1961 in the United States as a business form dedicated to the leasing of real estate assets under specific criteria regarding the participation in the company, the investments to be made or the distribution of dividends. This type of company has grown significantly over the last three decades, both in terms of specific regulations in different countries around the world and in terms of the number of companies and the value of investments made. The first decade of the 20th century was the main period in the internationalization of this type of taxation with the creation of regulations in countries such as Japan, France, Germany, Italy, the United Kingdom, and Spain. In contrast to this generalized growth, the conditions in each country differ, which has led to very different levels of implementation. The United States maintains a significant level of investment in this type of company, which is more than 10 times the capitalization of Japan as the second country with the second largest application of the model. This regulatory process has had an international impact on the growth of the number of REITs to over 900 in 2023, distributed among number of REITs to exceed 900 in 2023, distributed among the Americas (36%), Europe (29%), Asia (27%), Oceania (4%) and Africa (3%). (29%), Asia (27%), Oceania (4%) and Africa (3%). The conditions described have led to the capitalization of REITs accounting for 1.35% of U.S. GDP in 2000, 2.59% in 2010 and 5.93% in 2010.

The investment in REITs is highly diversified at the sectoral level; in the case of the United States, the main sectors according to capitalization are residential, followed by retail, infrastructure, industrial and data centers, all of which individually account for between 15% and 10% of the total capitalization of REITs. Although all sectors are related in aspects such as land value or access to credit, they may also have differences and particular uses that are legally delimited. Of all of them, the most controversial among the different policies is the residential sector, which is also the most capitalized. REITs offer an equity investment model with a reduced level of risk compared to other sectors. They allow generating long-term returns with a high level of guarantee. On the other hand, they pose a high dependence on the markets, with a special emphasis on residential rentals given their conceptualization as a home for citizens. This implies accepting the possibility of substantial changes in the rents to be paid as well as non-renewal of the lease contract.

In the case of Spain, the real estate sector is the main source of savings for a large majority of society, which traditionally owns its own home. Only in the highest income and wealth percentiles are investments in financial assets to a greater extent than in real estate [19]. It is in this context that the regulation of REITs in Spain by Law 11/2009 with the objective of "searching for constant improvements in the well-being of citizens" to "provide liquidity to real estate investments", aspects for which a tax regime is developed with special tax conditions in Law 16/2012 that allow obtaining higher returns on real estate investment with respect to those generated through other corporate forms. Its regulation continues in 2018 and 2021 with modifications aimed mainly at income generated by non-residents and profits not distributed by REITs respectively.

This document analyzes the role of REITS in Spain, studies the generation of profits of this type of companies as well as the relationship between the rigidity of real estate prices that represent the largest proportion of their assets, and the volatility associated with business actions. The document begins with the present introduction and continues

in the second point with the methodology followed. The Sect. 3 collects the results obtained, the Sect. 4 shows the discussion of the results and finally the Sect. 5 is dedicated to the conclusions.

2 Methodology

This study is based on the compilation of financial data from the different REITs in Spain, locally called "Real Estate Investment Companies" and known locally as (SOCIMI). These are companies that, due to their tax status, are required to be listed on the stock market. At the Spanish level, these are listed on different markets such as the Ibex35, the Continuous Market, the Euronext Access or the BME Growth. The largest ones can be located in the Ibex 35 index (Merlín Capital SOCIMI (Merlín) and Inmobiliaria Colonial SOCIMI (Colonial)) that includes the highly negotiated companies at the national level, while the vast majority can be found in BME Growth associated with significantly lower negotiation conditions. For the compilation, the audited financial reports of the different companies in their stock indices have been accessed based on information from Spanish Stock Exchanges and Markets as well as the National Stock Market Commission. In Table 1 the main companies are highlighted together with their capitalization level and their share price at the end of the years 2019 to 2022, as well as the main sector in which their business is located (Fig. 1).

MAIN SOURCES	MAIN DOCUMENTS	MAIN DATA
IBEX35	FINANCIAL REPORTS	INCOME
CONTINOUS MARKET	STOCK EXCHANGES	REAL ESTATE INVESTMENTS VALUE
EURONEXT ACCESS	NATIONAL STOCK MARKET COMMISSION	ASSETS
BME GROWTH		STOCK PRICES

Fig. 1. Summary table of the sources of information used in the preparation of the study as well as the main documents extracted from these sources and the main data analyzed. Source: own elaboration.

In order to carry out the analysis, the balance sheets and income statements of these companies have been accessed, from which the most representative values have been taken. On the balance sheet side, the most representative values were those related to the value of real estate investments, their reported changes over the years, the total composition of their assets, the distribution of their liabilities and shareholders' equity. In the case of the income statement, the income generated, and the different profit levels of the companies have been used.

Table. 1. List of the main REITs in Spain ordered according to their capitalization in 2022. It includes their name, Tickr, capitalization according to closing balances between 2019–2022, 2019–2022 share price collected by Yahoo Finance and the company's main business sector. Source: Own elaboration based on data from the Spanish stock market as included in [20].

REIT	Tickr	Cap 2019	Cap 2020	Cap 2021	Cap 2022	Cot 2019	Cot 2020	Cot 2021	Cot 2022	Main Sector
MERLIN	MRL.MC	6.008	3.654	4.495	4,122	12,79	7,78	9,57	8,77	Offices
COLONIAL	COL.MC	5.772	4.077	4.452	3,243	11,36	8,02	8,25	6,01	Offices
GMP	YGMP	1.090	1.090	1.080	1,070	57,00	57,00	56,00	56,00	Several
VIVENIO	YVIV	503	706	837	947	1,15	1,14	1,35	1,35	Residential
ZAMBAL	YZBL	794	781	762	729	1,23	1,21	1,18	1,13	Offices
TESTA	YTST	846	839	833	714	6,40	6,35	6,30	5,40	Residential
CASTELLANA	YCPS	603	474	590	646	7,00	5,50	6,85	6,55	Commercial
SILICIUS	YSIL	–	–	613	436	–	–	17,00	14,10	Several
EMPERADOR	YEPSA	–	–	–	428	–	–	–	4,20	Offices
FIDERE	YFID	145	141	136	409	14,40	14,00	13,50	40,60	Residential
MILLENIUM	YMHRE	270	245	298	387	5,40	4,50	3,88	3,34	Hospitality
LAR ESPAÑA	LRE.MC	643	409	428	353	7,10	4,67	5,12	4,22	Commercial
ATOM	YATO	355	322	305	322	11	10	9	10	Hospitality
ALBIRANA	YAPS	324	324	270	270	33,60	33,60	28,00	28,00	Residential
TRIVIUM	YTRI	249	247	235	231	5,00	5,00	5,00	5,41	Commercial
ARIMA	ARM.MC	321	235	260	213	11,30	8,30	9,18	7,50	Offices
OLIMPO	YORE	194	200	208	206	0,99	1,02	1,06	1,05	Commercial
IBERVALLES	YIBV	–	–	–	148	–	–	–	5.55	Offices

Given the large number of REITs in the Spanish market, a selection has been made to show their results in the following pages according to those shown in Table 2. This selection has been based on the most representative companies in terms of their size, the markets in which they are listed and, finally, their involvement in the residential sector.

3 Results

The results show the continued growth of REITs in Spain from 2012 until 2020, when growth slows down due to the pandemic. The high share in the REITs portfolio of investments in sectors such as offices, shopping centers or logistics spaces shows a substantial change in returns from the pandemic onwards. Three years follow between 2021 and 2023 in which capitalization has remained relatively stable above 20 billion euros, with a growth in proposals aimed at the residential sector to the detriment of profitability and investment in other sectors, among which the office sector stands out.

In the first place, the high share of real estate investments in the balance sheet of the companies can be observed, as indicated by the regulation, this type of assets represents

Table. 2. List of the main REITs mentioned in the results, including their abbreviation and the market in which they are listed. Source: own elaboration.

Name		Stock Market
Merlin Properties SOCIMI, S.A	(Merlín)	IBEX35
Inmobiliaria Colonial SOCIMI, S.A	(Colonial)	IBEX35
Lar España Real Estate SOCIMI, S.A	(Lar)	M.CON
Árima Real Estate SOCIMI, S.A	(Arima)	M.CON
Gmp Property SOCIMI, S.A	(GMP)	BME.G
Vivenio Residencial SOCIMI, S.A	(Vivenio)	BME.G
Testa Home, S.L	(Fidere)	BME.G
Testa Home, S.L	(Testa)	BME.G
All Iron RE I SOCIMI, S.A	(All Iron)	BME.G

an amount of over 80%. Spanish REITs have been obtaining rental income in a range between 2% and 5% with respect to available real estate assets. The differences are mainly due to the profitability of the sectors in which they invest, being higher for offices or logistics centers than for real estate. There are also variations in terms of time. In addition to this type of income, there is the impact of the recording in the income statement of the professional estimate of the variation in the value of real estate investments, which is recorded as income or loss for the year, and which, in the case of REITs, has an effect similar to that obtained by the income from the leasing business.

Figure 2 shows the relationship between the income derived from leasing the real estate spaces owned by the respective REITS divided by the change in the fair value of the real estate assets. Both data reported according to the income statement of the companies analyzed. It can be seen that for all years except for 2020 (the year in which the Covid19 pandemic began), the variation in the value of assets computes an average of 0.78 of the income generated during the year, with 2016 representing the lowest average value with 0.59, and 2021 the highest with 1.13, representing the year in which the distorting effects of the pandemic are carried forward. In the case of 2020, the average figure of -2.48 implies a high correction in the value of assets combined with a reduction in income generated in the period. At an individual level, the behavior of Merlín stands out, whose assets grow on average by 0.92 between the years 2014 and 2019, which implies an impact on the profit of the period almost equivalent to that of the income generated by the leases. On the opposite side, the role of Colonial can be seen, with an average revaluation impact of 0.44 for the same period, an aspect that continues to mean that close to half of the operating profit recorded in the income statement is not due to the normal income of the business.

For the cases of Merlin, Colonial or GMP, in the five-year price growth period between 2015 and 2019 the growth in asset value remained higher than the revenues received during all years, except for 2019 for Merlin and 2017 for GMP. Similar situation to Lar between 2016 and 2017 or Arima between 2018 and 2021. In the case of the

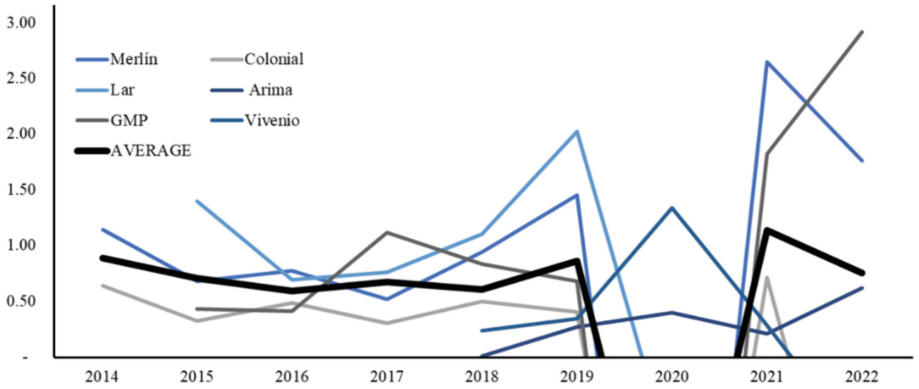

Fig. 2. Evolution of the ratio of income from leasing business divided by the change in value of real estate investments, according to the annual income statement. Source: own elaboration based on the annual results of selected companies.

residential sector, the role of companies such as Testa, Fidere and Vivenio stands out. The first two are owned by Blackstone through its own investment funds. For Testa, leasing revenues remained lower than those accounted for by the change in assets during the years 2017 to 2019, while for Vivenio a different behavior is observed in which leasing revenues prevail, with the exception of 2019 when the change in value of assets goes from having moved in the 0–2% environment to exceed 10% annual change. Lastly, Vivenio proposes a behavior similar to that shown for Merlin, Colonial or GMP, with sustained growth before the pandemic and a significant correction in 2020.

Table. 3. Evolution of the ratio of income from leasing business divided by the change in value of real estate investments, according to the annual income statement. Source: own elaboration based on the annual results of selected companies.

	2014	2015	2016	2017	2018	2019	2020	2021	2022
Merlín	1.14	0.68	0.77	0.52	0.94	1.45	−5.31	2.64	1.76
Colonial	0.64	0.32	0.48	0.30	0.50	0.41	−4.32	0.71	−2.46
Lar		1.40	0.69	0.76	1.10	2.03	−0.93		2.50
Arima					0.01	0.27	0.40	0.21	0.62
GMP		0.43	0.41	1.11	0.83	0.68	−6.06	1.82	2.91
Vivenio					0.23	0.34	1.34	0.28	−0.82
AVERAGE	0.89	0.71	0.59	0.67	0.60	0.86	−2.48	1.13	0.75

It can thus be observed that the recognition of income from change in the value of assets does not appear as an exceptional situation, but as a norm in the results of these companies, as can be seen in Table 3. The inclusion of the variation in the price of real estate assets in the balance sheet of companies has both advantages and disadvantages.

From the point of view of the true and fair view of the accounts, it can be understood as a necessary mechanism to have the truest possible representation of the value of these assets on the balance sheet. However, it becomes at the same time the use of an estimate that poses risks of the estimate itself, at the same time as the risks associated with a distribution of profits on which there has been no liquid income for the company and can generate greater cash flow problems as the revaluation of the assets increases and therefore the dividends that these companies are obliged to pay out are greater.

Figure 3 shows the price value of the selected REITs based on a unit value for July 2, 2021. The existence of different behaviors is observed, on the one hand REITs such as Merlín, Colonial, Lar or Arima, shows high volatility, with growth of more than 40% in one year as for the Lar group in 2023. On the contrary, in the case of colonial there is a decrease of 34% in four months between May 30 and 27 September 2022. All Iron and Testa show the opposite behavior, whose prices remains practically unchanged between October 2022 and March 2024. These results show low trading on the stock market. The results of Adriano, All Iron or Testa serve as an example of the performance of shares listed on BME Growth, a market in which trading volumes are low compared to the shares of larger companies.

The behavior of REIT investment contrasts with that of the real estate market. In contrast to the changes of more than 10% that are observed in the price of shares in a matter of weeks or months, the price of housing has shown lower but continuous growth rates over the last decade, with very limited corrections in value, both in terms of the number of events and their amplitude. Between 2015 and 2023 the maximum price growth at the Spanish level has occurred in the Community of Madrid with 63%, while the average growth among the 17 Spanish regions has been 47%.

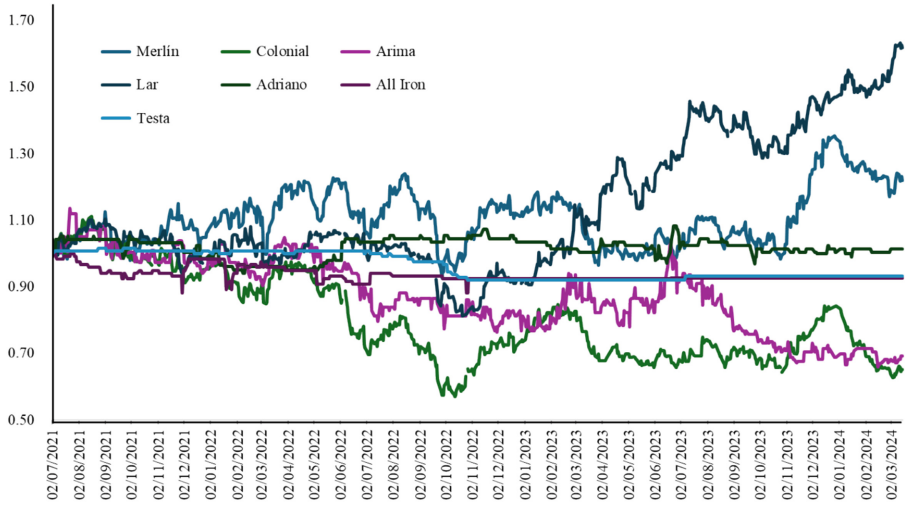

Fig. 3. Evolution of the prices of seven Spanish REITs from July 2, 2021, to March 15, 2024. Source: own elaboration based on Yahoo Finance data.

The analysis shows how REITs are an attractive investment option compared to other forms of investment due to their preferential tax treatment. By providing particular conditions, the market equilibrium is modified, altering the decision criteria in areas such as real estate development, housing supply, or the refurbishment of existing properties. The modification of tax conditions acts as a tool for market innovation from the tax point of view, generating higher returns without any improvement in the supply of the company's products and services.

4 Discussion

The results show the behavior of REITs as a modifying agent of the current market equilibrium, favoring the attraction of capital through an increase in liquidity, the possibility of periodically benefiting from the effects of asset revaluation or the ability to improve the operating conditions of real estate compared to other traditional forms of tenure.

Only four of the companies analyzed show continuous changes in the value of their share, an aspect that questions the expected effect of providing liquidity to the sector that is included in the preamble of the Law of initial regulation of REITs in Spain. On the contrary, most of these companies have a high stability in value as a result of their low trading in the stock markets. In this way, only companies listed on the IBEX35 or on the Spanish "continuous market" show continuous trading of their securities, while most of those listed on BME Growth show low or very low levels of trading at the same time as a large continuity in the value of its contribution.

The results also show the volatility in the value of the REITs analyzed. It is observed that there is a significant change in the valuation of companies whose assets are based on real estate for more than 80%. This situation faces the relative price stability of the real estate market, in which small percentage variations in prices can be considered highly significant. This condition implies applying to the real estate market the benefits and risks of business investment under forms of acquisition or purchase for lease, modifying under specific legal conditions behaviors such as capital attraction, financing sources or the profitability of the sector.

Reason helps update asset values based on market conditions, providing a more accurate picture of current conditions on a company's balance sheet. At the same time, there are other reasons to realize a capital gain by selling an asset, in which case it reflects a combination of facts rather than market expectations. The contradiction between these two concepts does not prevent us from considering that the non-consolidated financial profitability presented by the analyzed companies significantly affects market activity and the relationship between profitability and investment risk. The conversion of real estate assets into liquid assets in the stock market also affects market profitability, as their valuation becomes dependent on corporate standards. As a result, volatility has increased significantly due to increased dependence on changes in company reported results and macroeconomic factors. Interest rates have a direct impact on corporate behavior and greatly increase the speed with which they affect markets, displacing the delays caused by the extension of long-term credit and the formal buying and selling of assets. The public sector seems to be a key player in this process, as it is able to change the terms of real estate profitability according to the wishes of the owners. This ability leads to a

current equilibrium situation that is subject to uncertainty arising from the regulation of the asset stock or the possibility of changing its rate of active incorporation. Considering that four specific SOCIMI regulations were adopted in less than 15 years and the real estate market has specific regulations, it becomes difficult to predict the profitability of the industry.

In terms of financing sources, the change in the role of debt stands out. The companies in the sector have a debt level in Spain of less than 50%, with ratios that are between 35 and 50% for the majority of cases and years of the REITS analyzed. Element that poses different criteria compared to traditional real estate credit, in which acquisitions are mostly considered on a unitary basis and there is a tendency to accept a level of debt at the time of purchase of 80% of the value of the property. The transfer of numerous properties to companies thus causes a socialization of the risk between the properties invested from the point of view of the asset while leading to a modification of the sources of financing in terms of business leverage.

The consideration of legal workers is expected to increase in the current economy. There are two basic elements such as the choice of current liquidity conditions and fiscal policy. In terms of liquidity, it is worth noting the fact mentioned in this document that illiquid assets such as real estate can be converted into other liquid assets such as company shares or tokens. In that sense, the process of economic development in the real estate sector can increase liquidity in these properties, so it is expected that the market will contribute to the increase in liquidity with appropriate tax conditions. In the second case, the difference in tax policy is that the costs associated with these two properties are related to the cost of ownership of the property, but they are different between the different legal personality that creates differentiated returns based on asset ownership criteria.

In addition, the role of regulatory objectives can be viewed from the perspective of maximum use of material resources, followed by general conditions of use under current conditions in business-based development models, such as land leases, and vice versa, in the absence of others. Business, fashion, leasing rights for related economic activity. Another issue also has macroeconomic implications, as geographic development increases national GDP in the form of rents, while ownership of the aforementioned assets contributes less to the national accounts, mainly in the form of maintenance and supply. According to the above reasoning, increasing efficiency through the influence of legal entities should reduce prices according to the maximum use of premises, thereby improving people's welfare.

The current situation of real estate wealth shows a growing trend in the impact of the real estate sector on global wealth. In the 1950s, total wealth represented 2.5 times that of the real estate sector, an amount that has been reduced in the second decade of the 21st century to a value of 1.7 [21]. This variation may increase under market conditions that favor real estate investment over other options.

5 Conclusions

The process of financialization of the real estate market has a fundamental element in the transmission of assets from individuals to companies. Companies, more focused on the leasing of real estate that allows the generation of value for the shareholder, become

an investment tool that allows reducing the amount of investment in the real estate sector under the stability of the sales associated with the leases. This situation, which on the one hand poses benefits such as a considerable increase in liquidity, with reduced investment times, the ability to diversify investments, professionalization, or reduction of intermediaries, at the same time poses impacts with opposite effects, among which the increase in the volatility of the real estate market.

The regulation of REITs as real estate investment instruments that allow special tax conditions modifies the balance of the market by favoring leasing models over traditional ownership, while promoting the attraction of capital thanks to a combination of liquidity, stability and low taxation of a market that is traditionally associated with opposite conditions in terms of liquidity and public intervention. Under this criterion, the result of the specific regulation of the sector in Spain in the form of attracting capital for real estate investment can help to offer dynamism to the sector, but on the other side of the coin it facilitates the attraction of capital and the increase of the value of real estate, results that can be considered contrary to the generally announced housing protection policies that are included in the constitution. This shows the two sides of the coin described by Hazlitt [22], under his conceptual application, intervention in the real estate sector for the positive purposes of generating liquidity and dynamism has effects that are difficult to control in the market in the form of varying incentives for real estate investment, affecting the general structure of the market and its relative attractiveness with respect to other investment options. The main result is an increase in the availability of real estate for rent without necessarily leading to a reduction in prices or greater accessibility for the population.

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Renewalling Public Real Estate Asset in Sustainable Perspective: Guidelines from International Best Practices

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Abstract. Contemporary models of urban transformation emphasize regeneration as a strategic response to mitigate and reverse the negative impacts of urbanization. The acknowledgment of evaluation methodologies and frameworks for sustainable development in a global setting highlights the necessity to analyze the urban sustainability until the building-scale of analysis. Although sustain-ability is more measurable at broader dimensions, it is challenging to apply the same evaluation methodology to more constrained geographical areas with more detail. This complex framework makes measurement particularly difficult for those interested in studying urban sustainability from different perspectives. This paper aims to identify key indicators used to assess the sustainability at various urban scales, focusing on key categories such as economic-financial, environmental and socio-cultural analyses. Using a dual approach, a bottom-up perspective - which derives indicators from a real tangible case (the redevelopment of a public housing neighborhood in Le Lignon)- is integrated by a top-down one, which identifies commonly used indicators in key sustainability categories through a review of the literature. A comparative analysis of the results obtained from both approaches allows a set of key sustainability indicators to be formulated.

Keywords: sustainable development · system indicators · urban regeneration · assessment methodology

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1 Introduction

Conurbations play a central role in sustainable development, with their increasing urbanization leading to environmental, social and economic consequences. In particular, cities significantly affect the global environment through CO2 emissions, resource consumption, and other issues including pollution, waste production, and urban heat islands [1]. Rapid sprawl also intensifies economic and social inequalities, leading to limited access to resources for low-income residents and increased social exclusion. Cities may be catalysts for constructive development, despite the difficulties presented by the fast urbanization of the world [2].

In order to mitigate and reverse the detrimental effects of urbanization on the ecosystem, regeneration is emphasized in modern models of urban transformation. As a result, it plays a crucial part in modelling sustainable development strategies [3].

These issues are widely included in international policies and agendas [4–7], highlighting the critical importance of the sustainability analysis within regeneration strategies.

The complex nature of urban sustainability requires an assessment holistic approach, by taking into account the interconnectedness of the economic, social and environmental dimensions of urban development [8]. In this context, indicator-based assessment systems are widely used by scientific communities, governments and policy makers [9]. Indeed, indicators are increasingly recognized as indispensable tools for measuring the effectiveness of sustainable development policies, initiatives and actions due to their ability to articulate and simplify complex aspects of sustainability [10–12].

The wide variety of available indicators, quantitative or qualitative, addressing a range of issues at different spatial scales, presents a challenge in identifying those best suited to capture the complexity of the specific context, scale of analysis and objectives of urban sustainability assessment [13, 14].

Therefore, defining each urban regeneration intervention involves a complex decision-making process that must take into account a wide range of factors at various scales with interrelationships between the components, stakeholders, and procedures to be taken into consideration in a diachronic dimension of time that is iterative and interactive [15]. In order to achieve this, the identification of potential solutions depends on the application of evaluation frameworks that integrate participatory techniques, multi-criteria decision-making analyses, and strategic planning tools. The objectives, which serve as the foundation for evaluating alternative intervention scenarios, must also be defined and communicated to stakeholders in relation to indicators that have been carefully chosen to take into account the effects that, e.g., adopting Nature-Based Solutions (NBS) can have on the ecosystem [16]. Composite Indicators (CI) are often required to measure the level of urban environmental and economic sustain-ability in order to express both qualitatively and quantitatively the socio-economic and environmental impact (trade-off) that the single initiative generates in the settlement context taken into consideration in the transition between the ex-ante and ex-post phases of the urban transformation process [17].

One of the challenges associated with the appropriate selection of indicators to be used to evaluate urban development and regeneration policies is the interconnectedness of issues related to sustainability [18]. In fact, many sustainability issues related

to environmental, social, and economic aspects are interrelated and affect each other, which makes it difficult to isolate and measure individual indicators by complicating the selection of appropriate indicators and the context in which they are applied [19].

A key issue that can influence the selection of indicators for sustainability assessments of urban regeneration interventions is related to the scale of analysis [20]. There are tools and indicator frameworks at different geographic scales, operating at the building, neighborhood, city, region, up to the national and supranational scale, each providing results specific to the scale considered [21, 22]. The effectiveness of indicators is closely related to the context in which they are used. For example, at the level of individual buildings, the assessment focuses mainly on aspects related to individual structures [23]. Extending the analysis to the neighborhood level, a number of interrelated issues emerge regarding the organization of different elements, such as neighborhoods, commercial areas and green spaces [24, 25]. At the city or metropolitan level, indicators tend to address general issues that affect the entire urban area, taking into account, for example, city infrastructure, regional economic trends, and environmental issues that are broader than individual neighborhoods [12]. National or international urban sustainability indicators, on the other hand, take a broader perspective, addressing general issues and trends that extend beyond individual cities [2].

The data availability is another important challenge in defining urban sustainability indicators. In fact, assessment is highly dependent on the quantity and quality of available data, with availability varying at different spatial scales. For example, data tend to be more complete at larger spatial scales, while it is more difficult to collect data at smaller scales [26]. This problem can hinder the comprehensive assessment of sustainability at different spatial scales. The data availability may also vary between different urban areas, with some having well-documented information and others lacking detailed datasets. Such spatial disparities can lead to biased assessments, favoring areas with more available data and excluding many countries from assessment and comparison [6].

In addition, there may be biases due to temporal limitations: some datasets may have limitations in terms of temporal coverage, i.e. they only include data for a specific period or a few years, hindering the ability to analyze long-term trends and understand the sustainable performance of urban areas over longer periods [27].

While there is a greater degree of measurability of sustainability at larger scales, the resulting measures may provide too general insights that fail to capture the complexities of more localized scales [26]. Replicating the same approach used in large-scale sustainability assessments becomes complicated when applied to geographically limited scales, which are characterized by unique issues and needs that require addressing [27]. The great number of existing indicators, frequently applied across various scales, coupled with the challenges related to their adaptability according to the specific purpose of the assessment, make a complex framework that causes difficulty for those subjects interested in studying urban sustainability [18].

Consequently, the guiding research questions are:

Q1: What are the main indicators used for assessing the sustainability level at different urban scales?

Q2: Was the sustainability assessment carried out through the adoption of upscaling methods?

To address the research questions, this paper aims to provide a comprehensive overview of key sustainability indicators applied at different urban scales, with reference to the main categories of economic-financial, environmental and socio-cultural analysis. To this end, a dual approach is adopted, integrating *bottom-up* and *top-down* strategies.

The rehabilitation of a social housing community in Le Lignon (Vernier, Switzerland) serves as the basis for putting the bottom-up method into practice. An expert group consisting of planners, estimators, architects, and modern architecture historians chose this community as a model for best practices in residential development neighbourhoods constructed between the 1970s and the 1990s. This approach makes it possible to derive indicators from a real case that reveal the sustainability of the intervention by assessing the variations between the *ex-ante* and *ex-post* intervention status.

Conversely, the *top-down* strategy begins with a literature review to identify commonly used indicators in the main categories of sustainability. The most widely used important performance indicators for sustainable accounting are chosen by examining the current contributions to the literature on sustainability in relation to metrics related to sustainability aspects that may be applied to the design visions.

The simultaneous use of both methodologies – top-down and bottom-up – is meant to capture the characteristics of the given situation and permit a comparison study with frequently used indicators in existing literature.

Following it provided showing to the work-flow based on the aforementioned methodologies used along the route of case-specific formulation of sustainable indicators.

2 Materials and Method

2.1 Two-Way Researching Method: Bottom-Up & Top-Down

A methodology including the systematic and parallel application of two way researching method: bottom-up & top-down is presented in order to pursue the work's purpose. Generally these approaches differ in their analytical orientation.

i). The bottom-up analysis focuses on particular elements or situations to get a full grasp of a topic. The bottom-up approach examines the fundamental and qualitative parameters/factors of the study issue from a "micro" perspective to identify those that give a better description of the phenomenon, particularly from a future perspective. It permits the progressive identification and rearrangement of a system's components, allowing knowledge of each part's function as well as the right manner to utilize and integrate it into the larger system. In the present study, it is used to examine pilot cases that are thought to be representative of a wider global environment, as was expected by the argumentations in the next Subsect. 2.2.

ii). The top-down approach starts from a broad perspective of the object of analysis and gradually delves into specific details and aspects [28, 29] After defining an overall picture of the problem under inquiry and identifying its components from a "macro" viewpoint using the top-down method, an attempt is carried out to manage and comprehend how the many pieces are related to the whole.

In the present research the combined use of *i*) and *ii*) allows for the use of the indications generated by the two approaches in a non-unidirectional manner; however, by comparing and combining them, significant common components can be identified and integrated on the basis of the discovered functionalities, as well as possible innovative paths of experimentation. Using both *bottom-up* and *top-down* to define the overall reference set for selecting indicators to be used in specific urban sustainability assessments provides a more comprehensive and balanced assessment-view [30].

The synoptic framework underlying the proposed integrated analytic technique is shown in Fig. 1.

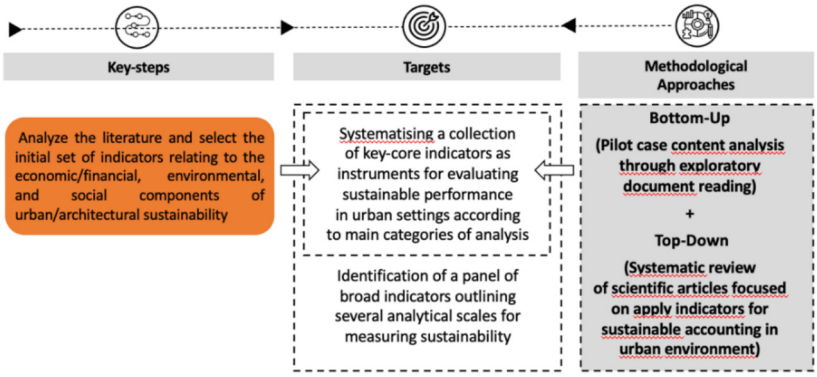

Fig. 1. Key-steps, Target and Methodological approach

The two approaches *i*) and *ii*) have been concurrently utilized in this study to establish a panel of general indicators that may be used at various analytical scales to assess the sustainability [31]. The articulation of the individual steps of two methodologies have been illustrated and shown in Fig. 2 at the conclusion of Subsect. 2.3.

2.2 *Le Lignon* Pilot Case

The modernist housing complex Le Lignon, located in the city of Vernier in the canton of Geneva, Switzerland, and designed by Georges Addor, Dominique Julliard, Louis Payot, and Jacques Bolliger, is used as a pilot case to demonstrate good practice redevelopment. Built between 1964 and 1971, with a reinforced concrete structure built using the "tunnel form" technology and 125,000 square metres of curtain wall panelling in wood, aluminium, and glass, this complex is one of the most monumental neighbourhoods in the world and the first in Switzerland. With 2,700 flats (used for a heterogeneous mix of housing forms, from subsidised rent to condominium ownership), plenty of green spaces, and public and private services, it was originally designed to quickly address the housing needs of about 10,000 people. It covers an area of 70 acres (28 ha), reflecting the architectural directions and logic of industrialised social housing typical of 1960s architecture. Its impressive architecture, which consists of two towers with 26 and 30 stories each, as well as a linear building with a Y-shaped design that extends 1,065 m,

ensures double orientation, maximum sunlight for each apartment, and the integration of green spaces and a variety of community amenities (like shops, schools, a medical centre, and a rooftop swimming pool).

A Conservation Plan de site, an urban-scale protection measure intended to preserve the architectural unity of the buildings, the planning design, and the landscape quality of exterior spaces, was adopted by the Canton of Geneva in 2009, formally establishing the complex's value as a cultural asset. Between 2008 and 2011, the Canton of Geneva faced issues related to energy consumption. To address these issues, an Applied Research Project led by Professor Franz Graf and Giulia Marino of the Laboratoire des Techniques et de la Sauvegarde de l'Architecture Moderne (TSAM) at the Ecole Polytechnique Fédérale de Lausanne, along with a working group comprised of representatives of building owners, identified and developed appropriate solutions that collectively and holistically address the goals of respecting original material identity (Heritage), reducing energy consumption (Energy), considering the investment potential of the individual owners of the properties (Economy). The multi-criteria approach used in project research has sparked significant interest in Europe and North America, as described in several scholarly publications [32, 33], as well as it has received several awards and recognitions, among which: "European Heritage Awards/Europa Nostra Awards" (2013) [34] and good practice of the CoE21 Strategy' from the European Cultural Heritage Strategy for the 21st Century, Council of Europe" (2018) [35].

The library of model solutions compatible with the adopted guiding criteria, which was created by the study, validated by the participating public administrations, and added to the Plan de Site, has developed into an operational and flexible guiding and control tool that combines comprehensive implementation prescriptions and the thermal performance of the component parts to be used for the various levels of intervention that will be implemented gradually in accordance with the needs, preferences, and financial means of the occupants. This is a true instruction manual for the preventive maintenance and upkeep of buildings and common spaces, on which are based the intervention solutions to be implemented in the complex's many restoration shops, which are currently undergoing a multi-phase makeover. Despite covering 28 hectares, only 8 percent of the district's total area is built up. This arrangement facilitates the development of large green spaces, preserving the forest heritage along the Rhone and the Nant des Grebattes. The result is a rich biodiversity that has a lasting and visible impact on the social life of the neighborhood. In recognition of its importance, Le Lignon was also included in the Federal Inventory of Swiss Settlements to be Protected in 2021, under the auspices of the Swiss Conference and the Federal Law on Nature and Landscape Protection.

According to what has been pointed out, the redevelopment of the Le Lignon social housing neighborhood was chosen as a best practice example by a panel of experts and used as a pilot case to develop the bottom up approach for identifying and measuring sustainability on a micro scale.

2.3 Implementing the Two-Way Research Methods

As stated, the analytical procedure for analysing source databases, extracting and interpreting data from them, and creating a panel of indicators for gauging urban sustainability is divided into two parallel processes: i) top-down and ii) bottom-up.

The steps taken to construct the bottom-up method were as follows:

- starting with a careful examination of the document specific to the pilot case, which contains comprehensive details about the pre- and post-redevelopment circumstances. Making use of this paper facilitates comprehension of both the location's distinctive features and the overall redevelopment activities. It makes it easier to identify the key variables that are necessary to define a set of sustainability indicators that span several dimensions. Therefore, it is feasible to explore the various facets of sustainability, including the technical, typological, social, and environmental facets that are documented in the analysis document; the variables are specified by their kind (categorical/ordinal, numeric/continuous), unit of measurement, and usable source for computation. Each variable is also assigned to the appropriate sustainability category (economic, financial, environmental, social, or cultural).

With the top-down approach a systematic review of national and international literature is proposed to identify the key indicators used to assess sustainability in urban environments, in order to compare them with those identified in the bottom-up process. The systematic literature review requires the delineation of the key issues to be studied in relation to urban sustainability [36–38]. This involves carefully defining the research questions in line with the objectives of the study.

In particular, the following was done:

- identifying the databases to be used in the literature search and, therefore, the selection of keywords that can identify research articles aligned with the objectives of the study, such as "urban sustainability assessment", "urban sustainability indicators" and "sustainability indicators". The establishment of exclusion criteria that are applied to the acquired articles ensures that only those directly relevant to the objectives of the study are retained. This selection process results in a set of scientific studies relevant to the work. Articles without a complete set of indicators and those that are not relevant to the top-down urban scaling approach are excluded;
- selecting articles gather a range of information data. Specifically, since the indicators are the main object of analysis, the proposed methodology involves collecting the following data: the year of publication of the article, the title of the article, the main objective, the categories of sustainability considered and variables/indicators used, and, for each indicator, the type of methodology (e.g., quantitative or qualitative), the mode of measurement, the unit of measurement, the spatial scale, and the sustainability services/disadvantages associated with each indicator.

Figure 2 illustrates the many phases and outputs of the top-down and bottom-up approaches used to provide answers to the evaluation questions posed in the introduction. The results obtained from the comparison and union of the outputs obtained from the combined use of the two methods are described in Sect. 3.

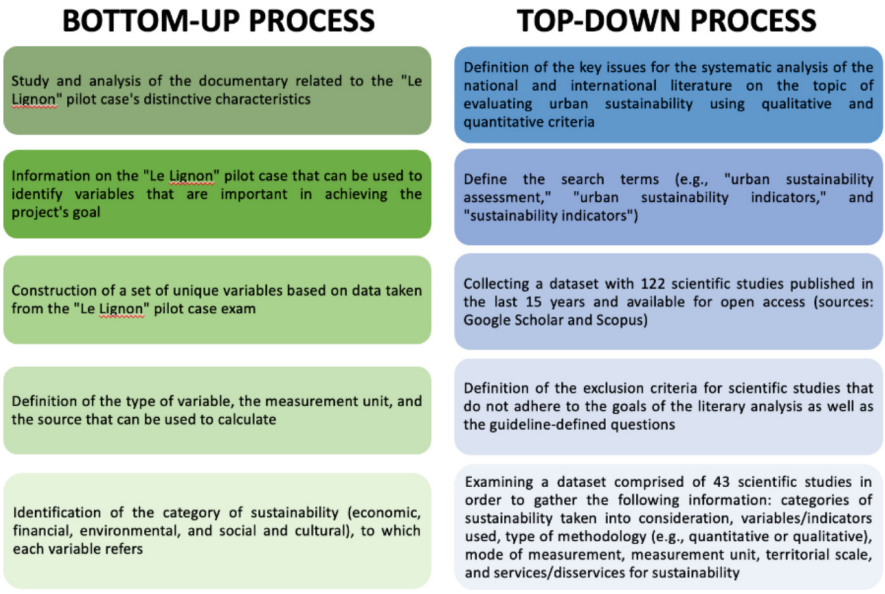

Fig. 2. Steps in both top-down and bottom-up processes

3 Results

The integration of the results obtained from the application of the two approaches mentioned above facilitated the formulation of a set of essential sustainability indicators. In fact, the *bottom-up* approach applied to the *Le Lignon* pilot case allows the identification of initial indicators that allow to capture the specificities that should be taken into account while redeveloping social housing areas constructed between the 1970s and the 1990s. The *top-down* approach, on the other hand, allows to identify, from the literature analysis, sustainability indicators of a more general nature. An initial comparison of the results obtained from the application of the two approaches allows them to be validated and allows the systematic organization of a collection of key indicators as tools for assessing the sustainable performance of urban areas at different scales and according to the main categories of analysis: environmental resilience, socio-cultural adequacy and economic and financial sustainability.

An extract of the total number of indicators identified is shown in the Fig. 3. For each of them, the unit of measurement is indicated, as well as the type of variable, specifying whether it is numeric/continuous, categorical/nominal, or whether it is a variable to be calculated. In addition, the sources of the indicators are made explicit, specifying whether they are official sources (e.g. statistical institute, territorial real estate market agency, etc.) or from a survey.

The environmental resilience category within the framework outlined includes key indicators for assessing the impact of urban development on the environment. Specifically, these indicators provide an assessment of the overall environmental quality of

N.	Variables	Is it indispensable data to acquire?	Unit of measure	Type of variable	SUSTAINABILITY CATEGORY: Enviromental	Economic-financial	Socio-cultural	Source	Source in Italy	Possible combination of variables
1	Number of dwellings for non self-sufficient people	x	n.	Numeric/continuos			x	from relief		Housig typology by users type
2	Cost of construction	x	€	Numeric/continuos				from relief		
3	Cost of renovation project	x	€	Numeric/continuos				from relief		
4	Minimum temperature (Year based)	x	°C	Numeric/continuos	x			from climatic analysis		
5	Maximum temperature (Year based)	x	°C	Numeric/continuos	x			from climatic analysis		
6	number of parking lot	x	n.	Numeric/continuos		x	x	from relief		in relation with 13
7	number of garage		n.	Numeric/continuos		x	x	from relief		in relation with 13
8	Building typology		type	Categorical/nominal		x	x			
9	number of commercial space typology	x	n.	Numeric/continuos		x		from relief		in relation with 13
10	Employment status of residents		n	Numeric/continuos		x	x	Statistics Institute	ISTAT	in relation with 13
11	is the project a masterpiece?	x	Yes or no	Categorical/ordinal		x	x			
12	Does the Upcycling involves the residents?	x	Yes or no	Categorical/ordinal		x	x			
13	Are the architects specialist in Upcycling?		Yes or no	Categorical/ordinal		x	x			
14	is the project fittable for The UpCycling?	x	Yes or no	Categorical/ordinal		x	x			
15	is the type of construction usual in the area?	x	Yes or no	Categorical/ordinal	x	x	x			
16	Are the clients Private or Public?	x	Yes or no	Categorical/ordinal		x				
17	Gross internal floor area	x	m^2	Numeric/continuos	x			from relief		
18	extension of the green area	x	m^2	Numeric/continuos	x			from relief		10/9
19	extension of the built area	x	m^2	Numeric/continuos	x			from relief		10/9
20	Density of the building/the area	x	ab/ha	to be calculated	x					13/11
21	Number of inhabitants		n.	Numeric/continuos	x	x	x	from relief		13 - 16 age pyramid
22	number of family members		m^2	Numeric/continuos			x	from relief		
23	sqm for inhabitant	x	m^2	to be calculated	x	x	x			
24	Age of inhabitant	x	n.	Numeric/continuos		x	x	Statistics Institute		
25	number of houses		n.	Numeric/continuos		x	x	from relief		in relation with 13
26	number of commercial space		n.	Numeric/continuos		x	x	from relief		in relation with 13
27	Construction technologies for natural risk minimazing	x	n.	Numeric/continuos	x	x		from relief		
28	Sources of renewable energy system	x	n.	Numeric/continuos	x	x		from relief		
29	minum sqm for residential	x	m^2	Numeric/continuos		x		from relief		in relation with 13
30	Systems of water recycle	x	n.	Numeric/continuos	x	x		from relief		
31	number of residential typology		n.	Numeric/continuos		x		from relief		in relation with 13
32	average sqm for residential		m^2	to be calculated		x				
33	maximum sqm for residential		m^2	Numeric/continuos		x		from relief		in relation with 13
34	average sqm for commercial		m^2	to be calculated		x				
35	minum sqm for commercial		m^2	Numeric/continuos		x		from relief		in relation with 13
36	maximum sqm for commercial		m^2	Numeric/continuos		x		from relief		in relation with 13
37	Average temperature (Year based)		°C	Numeric/continuos	x			from climatic analysis		
38	relative humidity	x	%	Numeric/continuos	x			from climatic analysis		
39	wind condition	x	m2/s	Numeric/continuos	x			from climatic analysis		
40	Rain precipitation (average)		mm	Numeric/continuos	x			from climatic analysis		
41	Minimum Rain precipitation		mm	Numeric/continuos	x			from climatic analysis		
42	Maximum Rain precipitation		mm	Numeric/continuos	x			from climatic analysis		
43	local radiation average value			Numeric/continuos	x			from climatic analysis		
44	exposure of the apartments	x		dummy variable	x			from relief		

Fig. 3. Extract of the total number of indicators identified (N/C: Numeric/continuous, C/O: Categorical/ordinal)

urban areas in terms of sustainability of resource use and ecosystem health. For example, temperature-related indicators have been included that provide insight into the state of the atmospheric environment. Land use indicators are also included in this category, that provide information on the spatial distribution of built and green areas in relation to the total area under analysis, facilitating the assessment of the environmental impact of different land uses. The environmental resilience category also includes indicators related to building technologies, which provide information on the impact that the built environment can have on the surrounding environment.

The socio-cultural suitability category involves a set of indicators designed to assess various dimensions of urban life related to social and cultural dynamics. These indicators shed light on social dynamics, cultural diversity, and the general well-being of individuals in the urban context. Within this category, indicators are represented by a number of critical aspects such as the quality and accessibility of educational institutions, the availability of health services, and safety conditions as measured by crime rates. In addition, measures such as the amount of green space in the city and the distance to public transportation and public services provide insight into the accessibility and impact of these spaces on the well-being and connectedness of urban residents. Indicators focused on the regeneration project are also involved in the category of the socio-cultural suitability, which provide information on residents' perceptions of the project.

The economic and financial sustainability category provides a comprehensive assessment of the district's resource management and overall economic vitality. This category includes employment considerations, with indicators analyzing unemployment rates, employment opportunities, and local job creation. Indicators of residential market and rental values are also in this category, as well as average costs associated with water supply and heating and cooling services. In relation to the regeneration project, this category involves indicators that measure the investment costs of interventions, while also providing information related to building maintenance, including the cost and frequency of such maintenance.

4 Conclusions

The growing importance of urban sustainability requires a careful assessment of urban regeneration initiatives in the broader context of sustainable development. Despite the availability of numerous indicator-based tools and frameworks designed to assess these interventions, the challenge lies in adapting these indicators to different scales of analysis in a context characterized by abundance and generality. To address this complexity, this research has proposed a methodology to bridge the measurability gap at different scales.

Beginning with an in-depth examination of the redevelopment intervention of the district of the *Le Lignon* as a best practice pilot study, the methodology adopts a dual approach. First, a *bottom-up* strategy is used to identify an initial set of elementary variables that involve the unique features of the case in analysis. Simultaneously, a *top-down* approach is used to identify key sustainability indicators derived from existing literature.

A comparative analysis of the results derived from these two approaches has generated a set of indicators, that provide a framework for measuring the urban sustainability of interventions, offering a perspective specifically adapted to the case under consideration. Regarding the analyzed case study, as the initiatives are carried out in a public housing complex, the characteristics and the needs are specific, affecting both the scale of the building and the broader urban context that must address the immediate requirements of the neighborhood.

It is crucial to point out that the proposed methodology, although it has been developed starting from the characteristics of the specific case study, is replicable for different urban regeneration interventions and located in other territorial contexts, due to its ability to systematically capture the specificities that distinguish urban regeneration initiatives in different market locations.

An initial comparison of the results obtained from the simultaneous application of the two approaches makes it possible to mutually validate the information first obtained from the in-depth study of the specific case with the more general information obtained from the literature review. In order to prove the general validity of the information that emerged from this comparison, future research activities will include a validation phase. This will involve administering questionnaires to professionals, including technicians and operators in the construction and real estate sectors, as well as environmental and social experts. This step aims to strengthen the reliability and applicability of the results.

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Ecosystem Services Accounting and AHP for Prioritizing Landscape Design Strategies in Urban Areas

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Abstract. The Ecosystem Services (ES) concept encourages research into a wide range of assessment techniques that may be used for planning and landscape design projects, particularly in urban settings. Starting with their categorization, a suitable evaluation technique might be linked to each of them to identify the highest inherent value that should be included in the decision-making processes.

After considering the operations of ES accounting and the various ES types (cultural, supporting, provisioning and regulating) that a single area is able to supply in the context of reference, an inter-sectorial assessment approach is required to prioritize the primary design line when evaluating the primary ES delivery in urban zone. The Analytic Hierarchy Process (AHP) is shown in this light as a useful tool for emphasizing the coherence of a mixed-set of ES supply and, concurrently, the relative relevance of each one compared to the ecological, socio-economic, and environmental aspects in urban region.

An integrated evaluation method based on ES accounting and AHP is put forth in order to assist with the individualization of urban planning and environmental design strategies case-specific. The paper concludes with an explanation of the findings from the Italian case study that the proposed method has evaluated.

Keywords: Analytic Hierarchy Process (AHP) · Ecosystem Services · Decision Making · Planning · Valuation

1 Introduction

Ecosystem services (ES) are gaining attention in different areas, including natural and social sciences [16]. They have the potential to enhance human well-being and economic prosperity [7, 11], regulate natural processes (e.g., water and air treatment, oxygen production, recreation areas), enhance the overall quality of urban society [3, 4, 6, 13, 21]. According to García and Estruch-Guitart (2022), these functions play a crucial role in the sustainability of Earth's different ecosystems.

The broad concepts of ES have been discussed for more than three decades [15], indicating long-held concerns that global changes will have a large and negative impact on terrestrial and aquatic populations. Much of the present emphasis on ecosystem services

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(ES) may be traced back to the Millennium Ecosystem Assessment (MEA), which was published a decade ago [23]. Beginning with the MEA Framework, several proposals for organizing the terminology and classification of ecosystem services have emerged, namely the Economics of Ecosystems and Biodiversity (TEEB 2010) and the Common International Classification of Ecosystem Services (CICES) [10, 13]. Additionally, Costanza et al. (1997) grouped ecosystem services into 17 major categories, focusing solely on renewable ecosystem services, while excluding non-renewable fuels, minerals and atmosphere [21]. Each form depends on geo-biophysical structures and processes, which vary in intensity, geographically, and temporally [2].

Anthropogenic impacts, particularly land-use and land-cover changes, as well as climatic variations, are among the major determinants influencing the qualities and quantities of ES supply. Land-use patterns and changes in land cover can be surveyed, spatially analyzed, and regionally assessed, providing direct insights into human activities and illustrating the relationships between ES supply and demand [2].

In recent years, the need for practical applications and tools related to the often conceptually employed ecosystem service (ES) ideas has become increasingly apparent [2]. Daily (1997) offers a comprehensive compendium detailing the description, measurement, and valuation of ecosystem services. Additionally, several assessment and valuation methods have been developed, by employing various biophysical and economic approaches [3–5, 13].

Recognizing and accurately quantifying ES are fundamental prerequisites for their valuation, irrespective of whether the valuation is conducted using biophysical, social, or economic strategies. Both in modern ES science and landscape design practices, the use and integration of these methodologies provide substantial hurdles [22].

Furthermore, it is imperative to acknowledge that valuing natural capital plays a central role in mainstreaming conservation efforts in modern societies [15]. Palomo et al. (2016) illustrate how the quantity and quality of delivered ES depend on different types of capital, resulting in various trade-offs that impact ES sustainability [11, 15].

Numerous methods and tools have been developed over the past decade for characterizing ecosystem functions and services in landscapes. Existing methods and data collection programs are poised to be integrated into the ES concept due to their thematic diversity (e.g., monitoring within the Long-Term Ecological Research (LTER) network) [2]. These methods encompass measurements, monitoring programs, mapping activities, expert interviews, statistical analyses, model applications, and transfer functions [6], as well as Analytical Hierarchy Process (AHP) [2, 5, 11]. Each is intended to solve a specific value concern, whether related to the environment or the socioeconomic structure of territory, especially in dense urban settings where the intricacy of linkages between various value-layers is heightened [11].

AHP is a technique developed to aid decision-makers in in systematically and structurally performing complex decisions [1]. This method combines both objective and subjective evaluations in an integrated structure, employing scales with a pairwise comparison matrix to help analysts organize the essential aspects of a problem hierarchically. Additionally, this method can measure the consistency of decision-makers' judgments regarding criteria and alternatives, facilitating the creation of pairwise comparisons between options to identify optimal solutions and alternatives [12].

The purpose of this contribution is to provide a decision-making framework based on the Analytic Hierarchy Process (AHP) for driving the individualization of landscape design strategies case-specifically [17, 18]. The way forward takes into account the measurement of ecosystem services, which vary by zone of the same urban context, and the mutual trade-off between the ecosystem services taking in analysis. The case study in Rome, Italy, involves the possibility of requalification of an area near the Sapienza University's Architecture Faculty located in Valle Giulia. This serves as a test case for the proposed assessment methodology based on AHP with ES accounting.

The overall work is organized as follows: Sect. 2 explains the materials and methods, including the methodological approach and the case study description (2.1); Sect. 3 provides results and comments above the procedure implementation; and Sect. 4 highlights the main conclusions of the work.

2 Material and Methods

2.1 Study Area

The *Valle Giulia* site, situated in proximity to historical, cultural, and educational hubs within the city of Rome, embodies a rich tapestry of environmental significance. It adjoins esteemed institutions such as the British Academy, National Gallery of Modern Art, Academy of Romania, Academy of Egypt, and shares borders with the stately *Villa Borghese*. This enclave encompasses open and verdant spaces intertwined with the architectural precincts of the *Sapienza* University, augmenting its allure with a botanical heritage, notably marked by the venerable oak trees dotting select locales. This arboreal presence serves as a poignant testament to the historical resonance embedded within the verdant realms of this territory (see Fig. 1).

In the quest for a spatial strategy that seamlessly integrates heritage preservation with contemporary needs, a thorough exploration of ecosystem services is imperative. Thus, an initial effort is made to outline and elaborate on the range of ecosystem services inherent to this area.

By employing the AHP method, this study systematically investigates the identification and assessment of ecosystem services within the study area. Through this detailed examination, it aims to provide insights that will guide prudent spatial planning efforts to optimize the utilization of these natural resources. This academic endeavor not only seeks to uncover the intricate ecological dynamics within the *Valle Giulia* site, but also aims to provide a blueprint for sustainable development, one that harmoniously blends the richness of its natural heritage with the demands of contemporary urban life.

2.2 Methodological Approach

The primary objective of conducting an ecosystem services assessment in this study has been to determine an appropriate methodology for planning activities within the designated study area. This involved categorizing the study area into three distinct zones, namely the semi-natural-urban zone, urban zone, and natural zone, based on their respective physical and biological attributes. Figure 1 depicts the indicated borders of these three distinct zones.

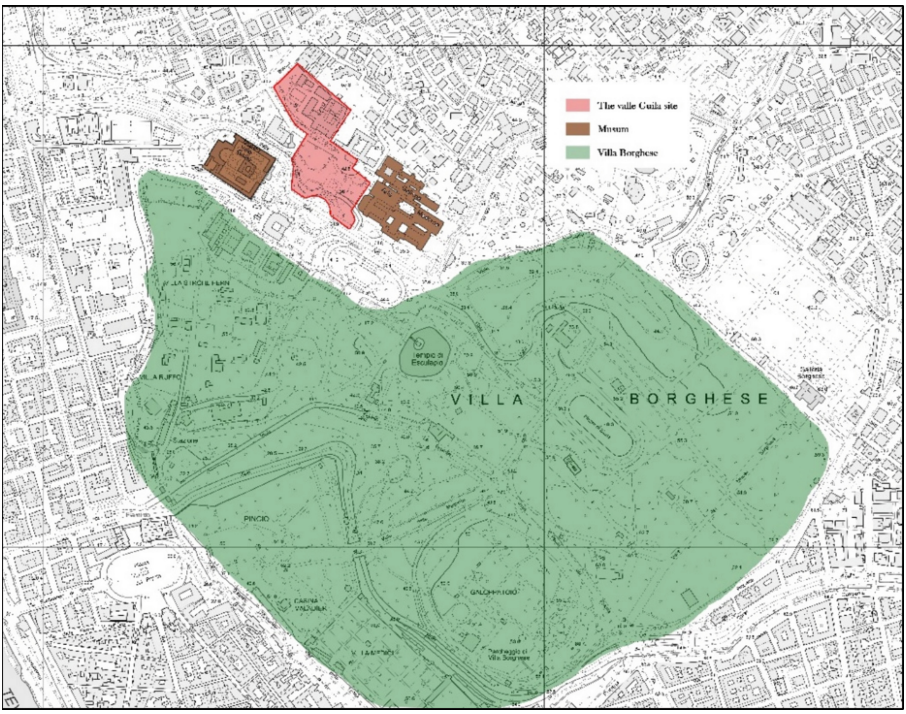

Fig. 1. The Valle Guilia site location and its surrounding users.

Following the zoning process, a comprehensive inventory of ecosystem services has been compiled. The main purpose of this inventory has been to identify the most significant ecosystem services associated with each zone. Subsequently, this information has been utilized to formulate a physical planning framework and land use strategies that take into account the ecosystem services, alongside other pertinent factors such as ecological and biological capacity. It is noteworthy that assessments of ecological and biological capacity have been carried out for each zone, although detailed discussion of these assessments is provided elsewhere in the article. This approach facilitates the development of sustainable planning and design strategies tailored to the unique environmental and ecological characteristics of each zone. By incorporating ecosystem services considerations into the planning process, the aim is to mitigate environmental degradation resulting from development activities.

In the subsequent phase of the study, the prioritization of the most significant ecosystem services for each zone has been developed by applying the AHP method. The outcomes of this assessment are intended to inform further stages of planning and design initiatives (Fig. 2).

2.3 Ecosystem Services in the Study Area

Ecosystem services are aspects of the ecosystems used directly or indirectly to induce human well-being, and some of them are easily observable, as they are involved in the

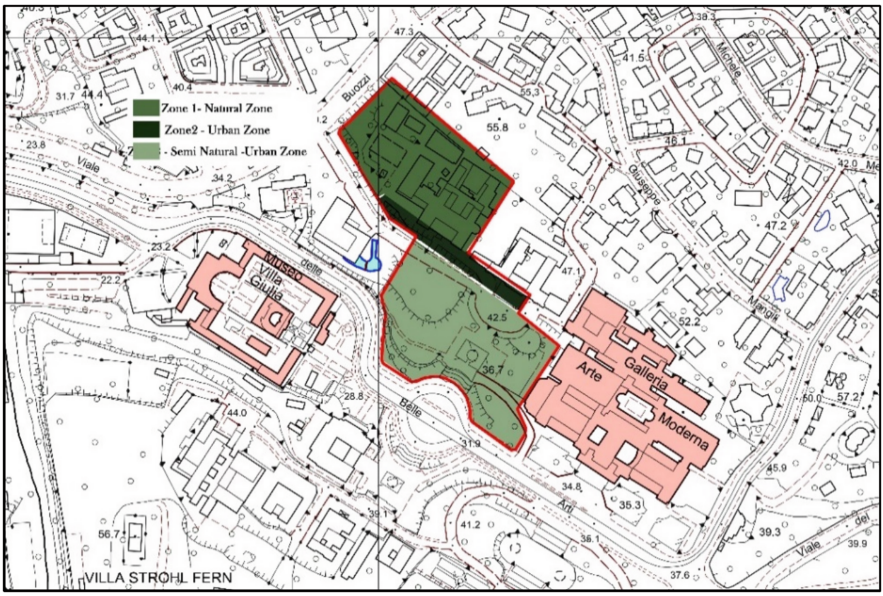

Fig. 2. The Valle Guilia site area and its Zones

economy (such as food supply or raw material). Nonetheless, society hardly perceives others despite contributing to these areas' social and economic value (including cultural services) [11]. This has caused inefficient use and progressive deterioration of natural resources [8]. According to the Millennium Ecosystem Assessment, the ecosystem services are classified in four main groups: supporting services (those that are necessary for the production of all other ecosystem services), provisioning services (products obtained by the ecosystems), regulation services (benefits obtained from the regulation of ecosystem processes) and cultural services (nonmaterial benefits people obtain from ecosystems) [3, 11]. Table 1 in the manuscript presents a comprehensive listing of the identified ecosystem services within the delineated study area.

2.4 Ecosystem Services Accounting and AHP

AHP is a well-known decision-making method that decomposes a complex problem into a multilevel hierarchical structure of objectives, criteria, and alternatives [19]. It is particularly effective in situations involving subjectivity and is well-suited for solving problems where decision criteria can be logically organized in schemes described by a directed graph [19]. AHP represents a structure with a unidirectional hierarchical relationship. AHP provides a decision tree structure with pairwise comparisons at each level of the tree. This method allows the calculation of the importance or weight of each group of ecosystem services as a percentage [11, 17, 18].

In the context of ecosystem services, AHP serves as a valuable tool for assessing and prioritizing various ecosystem services. By breaking down the decision-making process into manageable subproblems, AHP enables decision-makers to systematically

Table 1. Ecosystem services considered in the study

Cultural Services	Recreation and Tourism
	Education and Research
	Cultural Identity and heritage
	Mental welling
	Aesthetic Value
	Social relationship
Supporting services	Nutrient Recycling
	Biodiversity
	Heterogeneity
Provisioning Services	Biochemical and Medical
	Genetic Resources
Regulation Services	Climate Regulation
	Water Sanitary
	Nutrient Regulation
	Pollination
	Water Flow Regulation

evaluate and rank different services based on their significance. Moreover, its ability to handle subjective assessments and organize decision criteria into logical structures makes it particularly useful in this context. AHP's hierarchical structure and pairwise comparison approach facilitate a comprehensive analysis of ecosystem services, leading to informed and robust decisions [12].

In this stage, the data have been analyzed through the AHP method, which emphasizes weighting and prioritizing ecosystem services. The AHP method combines both objective and subjective evaluations in an integrated structure, based on scales with a pairwise comparison matrix. It assists analysts in organizing the essential aspects of a problem in a hierarchical format. Additionally, it measures the consistency of decision-makers' judgments regarding criteria and alternatives, enabling pairwise comparisons between options to choose optimal solutions and options [12].

The AHP framework for identifying and prioritizing the relative significance of ecosystem services consisted of three levels based on the construction of the evaluation hierarchy: 1) goal, 2) criteria and 3) alternatives.

2.5 Implementation Pathway

Expert Choice Software has been utilized in ecosystem services research as a valuable tool. This software is well-known for its robust decision-making capabilities, offering a structured framework to analyze and prioritize ecosystem services based on stakeholders' preferences and predefined criteria. Its application in this field has gained recognition

due to its systematic assessment and prioritization of ecosystem services, considering ecological, economic, and social factors.

The methodology involved in using Expert Choice Software for ecosystem services research encompasses several essential steps:

Criteria Definition. Initially, researchers identify and define relevant criteria for evaluating ecosystem services, including ecological importance, economic value, social benefits, and feasibility of management actions.

Alternative Assessment. Different alternatives or management strategies aimed at enhancing ecosystem services are evaluated, ranging from conservation measures to sustainable land management practices.

Pairwise Comparison. Expert Choice facilitates pairwise comparisons between criteria and alternatives to determine their relative importance or effectiveness. Stakeholders assign weights to each criterion and alternative based on their judgment or empirical evidence.

Analytical Hierarchy Process (AHP). The AHP methodology embedded within Expert Choice Software is utilized to analyze the complex interactions and trade-offs among criteria and alternatives. AHP helps synthesize stakeholders' preferences and develop a comprehensive decision model.

Sensitivity Analysis. Sensitivity analysis is conducted to assess the robustness of decision outcomes to changes in criteria weights or input data. This process identifies key drivers of decision uncertainty and refines the decision model accordingly.

The Expert Choice Software was utilized to calculate the geometric means of every expert's pairwise comparison and form matrix A = (aij) for a consensus on n criteria, where the element aiI (i,j = 1,2, …, n) in matrix A denotes the quotient of weights of the criteria (Eq. 1). Then, the analysis started to normalize and find the relative weights for each matrix. The relative weights were given by the right eigenvector (W) corresponding to the largest eigenvalue max (λmax), as follows: [12]

$$\mathrm{AW} = \lambda\mathrm{max}\ \mathrm{W}\,\mathbf{A} = \begin{vmatrix} a_{11} & a_{12} & a_{1n} \\ a_{21} & a_{22} & a_{2n} \\ a_{n1} & a_{n2} & a_{nn} \end{vmatrix} \tag{1}$$

When the local weights of the elements in each level were obtained, the overall weight of the quality attributes at the bottom level concerning the objective of the top level can be acquired by multiplying the local weights of related elements in each level.

In an entirely consistent pairwise comparison matrix (aij × ajk = aik), matrix A has rank 1 and λmax = n. In this case, the weights can be obtained by normalizing any of the rows or columns of A. When the comparison matrix is not fully consistent and the maximal eigenvalue is slightly greater than n, the consistency index (CI) is used for the coherence evaluation between the comparisons (Eq. 2).

$$\mathrm{C} = \frac{\lambda\mathrm{max} - \mathrm{n}}{\mathrm{n} - 1} \tag{2}$$

The consistency ratio (CR) is proposed to understand the consistency of the evaluation (Eq. 2), where RI is the average random consistency index.

$$CR = \frac{CI}{RI} \tag{3}$$

According to Saaty (1980), the CR < 0.1 is accepted, which can help decision-makers or evaluators confirm the consistency of the pairwise comparison matrix and the overall hierarchy [12].

3 Results and Discussion

The results have been initially examined within each group of ecosystem services, followed by an overall analysis and breakdown of ecosystem services within the study area.

Cultural Services. Within the realm of ecosystem services, the criteria weighting delineates the relative importance of each criterion when compared to others. In Zone 3, the prominence is evident, with Recreation and Tourism, Cultural Identity and Heritage, Mental Wellbeing, and Aesthetic Values garnering the highest weights, while Education and Research lag behind with the lowest weight. Shifting focus to Zone 2, the chart highlights Social Relationships as the dominant criterion, juxtaposed with Mental Wellbeing, which occupies the lower end of the spectrum. Conversely, in Zone 1, Educational and Research endeavors take precedence, contrasting starkly with the relatively diminished weight attributed to Recreation and Tourism.

Supporting Ecosystem Services. The criteria weighting of supporting ecosystem services reveals notable disparities across the study zones. In Zone 3, the highest weights are attributed to Biodiversity, whereas Nutrient Recycling obtains the lowest weight. Conversely, Zone 2 exhibits the highest weight for Heterogeneity and the lowest weight for Biodiversity. Interestingly, Zone 1 mirrors Zone 3 in terms of criteria importance, with Biodiversity holding the highest weight and Nutrient Recycling the lowest. Overall, the most critical criterion across all zones is Biodiversity, indicating its significance in supporting ecosystem functions. Additionally, Zone 3 stands out for its abundance of supporting services.

Provisioning Ecosystem Services. The assessment of provisioning ecosystem services showcases significant variations across the study zones. Within Zone 3, Genetic Resources emerge as the weightiest criterion, while Medicinal Resources lag behind with the lowest weight. Conversely, in Zone 2, Genetic Resources command the highest weight, compared with Medicinal Resources, which garner the lowest weight. Transitioning to Zone 1, Genetic Resources once again reign supreme in terms of criterion importance, boasting the highest weight, while Ornamental Resources trail with the lowest weight. Overall, Genetic Resources stand out as the paramount criterion across all zones.

Regulation Ecosystem Services. Significant variations emerge across the study zones. Zone 3 notably assigns the highest weighting to Pollination, while Nutrient Regulation receives the lowest weight. In contrast, Zone 2 allocates the highest weight to Pollination and the lowest to Nutrient regulation. Surprisingly, in Zone 1, water flow regulation takes precedence with the highest weight, while Nutrient regulation obtains the lowest. Overall, Pollination emerges as the most critical criterion across all zones, underscoring its pivotal role in regulating ecosystem services.

The outcomes derived from the evaluation of ecosystem services across various zones offer valuable insights that can profoundly impact planning and management strategies. By leveraging these findings, decision-makers can tailor resource allocation and development initiatives to maximize the benefits derived from different ecological zones.

For example, by going into depth the implications of prioritizing education-related ecosystem services in Zone 1, given its substantial weight in educational services, this zone presents a ripe opportunity to focus on environmental education programs. By implementing targeted initiatives such as school curricula centered on biodiversity conservation, soil conservation on slops, community workshops on sustainable practices, or nature-based learning experiences, stakeholders can foster a deeper understanding and appreciation for the local environment among residents and visitors alike.

Similarly, in Zone 3, where pollination services reign supreme, strategic interventions can be devised to bolster pollinator populations and enhance ecosystem resilience. This could involve initiatives such as establishing pollinator-friendly habitats, promoting organic farming practices that minimize pesticide use, or conducting public awareness campaigns to highlight the crucial role of pollinators in food production.

Moreover, for zones prioritizing medicinal services, there exists an opportunity to harness the therapeutic potential of native plant species. By creating medicinal plant gardens or supporting local herbalists in sustainable harvesting practices, communities can not only preserve traditional knowledge but also promote natural healthcare solutions that are culturally and ecologically aligned.

In essence, by integrating the valuation of ecosystem services into planning and decision-making processes, stakeholders can foster holistic approaches to land use management that prioritize environmental sustainability, community well-being, and economic prosperity. These efforts underscore the importance of recognizing and capitalizing on the multifaceted benefits that ecosystems provide, ultimately leading to more resilient and harmonious human-environment interactions.

4 Conclusions

Utilizing a structured decision-making approach in assessing ecosystem services proves indispensable for effective planning and informed choices. Ecosystem services, crucial for both human well-being and environmental sustainability, encompass a wide array of benefits, including clean water provision, pollination, and carbon sequestration. By employing a structured methodology such as the Analytic Hierarchy Process, several advantages emerge:

i. Decision-makers can systematically prioritize ecosystem services based on various factors such as ecological significance, economic value, and societal benefits. This systematic approach ensures optimal resource allocation and effective environmental asset management;
ii. AHP facilitates the evaluation of trade-offs between different ecosystem services, enabling decision-makers to navigate competing priorities and resource constraints effectively;
iii. AHP fosters stakeholder engagement in ecosystem services evaluation by providing a transparent and systematic process. This inclusive approach promotes collaboration and consensus-building among diverse stakeholders;
iv. Insights derived from AHP analysis inform policy and planning decisions related to ecosystem management, conservation, and sustainable development. Informed decisions, in turn, contribute to environmental resilience and human well-being.

In essence, structured decision-making methodologies like AHP play a pivotal role in valuing ecosystem services and integrating them into planning processes. By offering a rigorous and systematic approach, AHP empowers decision-makers to make choices that support sustainable development and environmental stewardship. The next stage of the research is to investigate the interlinkages between ecosystem services using a collaborative approach targeted at meeting ES supply and demand in connection to people's tangible needs.

Note. All the authors of the current study contributed equally to its creation, which was done as part of Sapienza University of Rome's continuing minor research project, "ECO-think: Integrating the ECOsystem services by nature in urban environment".

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Temporary Real Estate Management: Approaches and Methods for Time-Integrated Impact Assessments and Evaluations (TREAT 2024)



Roles and Responsibilities. Analysing Stakeholder Roles and Value Transactions in Temporary Use of Buildings

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Abstract. Temporary projects, reactivating vacant buildings, are a growing phenomenon, and their implementation is increasingly embraced by policymakers, building owners and the society at large. However, the current approach to temporary use appears to be fragmented, hindering their effectiveness and potential. Consequently, there is a pressing need to expand the understanding of temporary projects and their role in extending the service life of vacant buildings and their materials and supporting the shift towards circularity. To ensure this, stakeholders need to understand their own roles in a temporary project and recognise their responsibilities. This study focusses on analysing stakeholders involved in temporary projects, examining key players, roles and responsibilities. Five temporary projects in the Brussels Capital Region are analysed, identifying stakeholders, among which property owners, managers, residents, and intermediate actors, and their actions. Insights derived from interviews, discussions and literature identify necessary actions for each stakeholder. By uncovering connections in these responsibilities, or their absence, the study aims to inform stakeholders; guiding them towards better-informed decisions that support temporary initiatives.

Keywords: Temporary use · Stakeholder analysis · Vacancy

1 Introduction

1.1 The Duality of Vacancy

In the Brussels Capital Region, a staggering 6.5 million square meters of space languish in disuse [1]. While vacancy is not uncommon, its underlying causes are multifaceted, ranging from shifts in real estate demand to policy uncertainties [2–4]. Speculation also plays a role, with property owners holding onto buildings until market prices rise [4, 5]. Even planned transformation projects contribute to prolonged vacancy periods due to the lengthy process of securing permits and commencing construction [7, 8].

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Urban disinvestment and neglect exacerbate the problem, turning vacant spaces into social, security, and economic liabilities [2, 4]. The wasted energy, materials, and budget allocated to these buildings compound the issue, posing a persistent challenge to society and the built environment [7]. However, within this challenge lies an opportunity; the abundance of unused buildings, nearly equivalent to the size of the Municipality of Ixelles, presents fertile ground for experimentation and innovation [1, 8, 9].

1.2 Recognition of the Value of Temporary Use to Activate Vacant Buildings.

Existing literature underscores the manifold benefits of temporarily activating vacant buildings, providing a platform for social, environmental, and economic initiatives [9–14]. Temporary projects, with their predetermined end dates, offer a solution to activate unused spaces while awaiting transformation [9]. Originating from historical squatting movements, various forms of temporary projects have emerged, driven by bottom-up initiatives and neighbourhood organisations [9, 15, 16].

While temporary projects prevent the negative effects of vacancy, such as vandalism and decay, they also hold economic appeal, mitigating high maintenance costs associated with prolonged vacancy [4]. In Belgium, property owners can even avoid vacancy taxes through temporary use projects [8, 20]. Recognising the potential of temporary use, public and private actors are increasingly interested in reactivating unused spaces [19].

In Brussels, public entities like perspective.brussels and citydev.brussels collaborate to support temporary use initiatives, developing tools and guidelines to facilitate their implementation [21–23]. Recent endeavours include the launch of 'temporary.brussels,' an online matchmaking tool, and the co-signing of a charter aimed at aligning temporary use practices and streamlining project development stages [21–23]. Through concerted efforts, temporary projects offer a promising avenue to transform vacant spaces into vibrant hubs of activity, fostering sustainable urban renewal and community engagement.

Even though the added value of temporary use projects is getting recognised, and stakeholders' ambitions and supports are rising in temporary use, the organisation of projects remains primarily an organisational and legal challenge that requires capacity and commitment of many actors.

1.3 Aims and Methods

To tackle this and encourage stakeholders in temporary use, this paper sheds light on the involved stakeholders and their roles in the organisation of temporary projects and the activation of vacant buildings. To do this, the following research question is put forward:

Which stakeholders in the field of temporary use can be identified in the Brussels Capital Region, and what are their roles and responsibilities?

To formulate an answer, this study investigates the Brussels' most-known temporary use projects and their key stakeholders. Five temporary projects are chosen for this analysis: Allée du Kaai, Le TriPostal, See U, Circularium, and Studio Citygate. These five temporary projects were selected to represent the diverse nature of temporary use in vacant industrial buildings, and their involved actors.

Through personal endeavours, among which interviews, discussions, site visits, and seminars, detailed information was gathered about these Brussels' temporary projects

and the current practice of activating vacant buildings. For each temporary project, an in-depth case study analysis is conducted to explore stakeholders, their actions, and their relationship.

Following the method of Value Network Mapping, proposed by VITO Nexus, key stakeholders and actions were mapped and explored. Subsequently, these findings are discussed to shed light on the ecosystem of stakeholders in temporary use. Furthermore, the power dynamics and stakeholders' interests are discussed to understand their influence on the success of temporary use projects (Fig. 1).

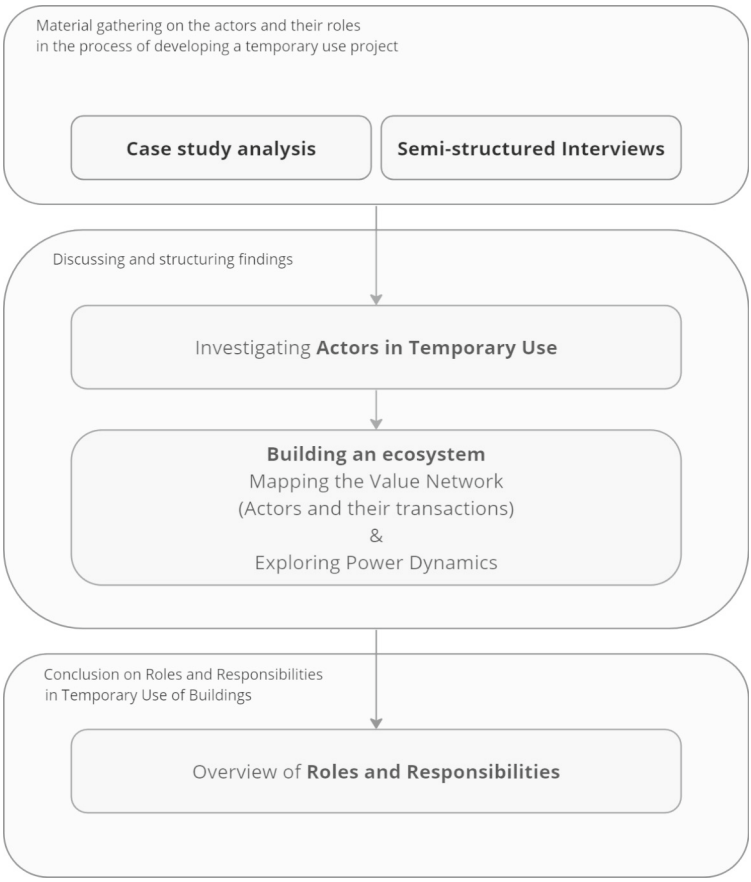

Fig. 1. Overview of the method applied in the research.

2 Brussels' Temporary Projects

Brussels has been establishing a leading role in the field of temporary projects. Lately, several temporary projects have gained national and international attention, resulting in internationally organised site visits and seminars to learn from the Brussels' practice

(e.g. seminar of Metropole Lille, visit of the European research project T-Factor, and conference of the STUN (Social Temporary Use Network)).

In the following section, five noteworthy temporary projects, and their contexts, are elaborated by focussing on the initiating and developing process. The information presented here was gathered through interviews and discussions with the temporary projects' managers and completed with additional literature. Figure 2 illustrates the locations in Brussels of the selected case studies.



Fig. 2. Map of Brussels, with the five analysed temporary use projects.

2.1 Allée du Kaai

Allée du Kaai, a temporary project by Toestand vzw in collaboration with Leefmilieu Brussel, ran from 2014 to 2022 in unused hangars and a vacant plot of land along the Canal, opposite Thurn&Taxis. Originally slated for transformation into a public park, the site awaited construction. To activate the space in the interim, Leefmilieu Brussel sought a temporary project manager, leading to a project call. Toestand was selected and tasked with testing various sport activities suitable for the future park. Additionally, they provided space for other Brussels-based social and cultural organisations such as Magazin 4, In Limbo, and various social organisations. Through their adaptable approach, Toestand facilitated the site's evolution, making Allée du Kaai the first large-scale socio-cultural temporary project in Brussels.

2.2 Le Tripostal

Le Tri Postal, a temporary project by Communa asbl, operated in an unused building owned by NMBS, the Belgian railway company, from 2020 to 2022. Located near Brussels-South station, the building will be renovated into an office tower. The neighbourhood committee, Saint-Gilles Midi/Zuid, petitioned to activate the site, prompting NMBS to allow a temporary project. A project call, led by Saint-Gilles municipality and NMBS, sought a manager. Communa asbl applied and was selected to manage and coordinate the project. Their responsibilities included space layout, repairs, creating workspaces, inviting external projects, and establishing an innovative public space for socio-cultural experimentation. This collaborative effort aimed to revitalise the area around Brussels-South station [21, 22].

2.3 See U

See U, a temporary project by Pali Pali and MSI (Maatschappij Stedelijke Inrichting), activated a former military site from 2019 to 2022 in preparation for the USquare renovation and transformation project involving MSI, VUB/ULB[1], BGHM[2], and others. MSI initiated the temporary project in 2018 through a public project call and expressions of interest for site management. Pali Pali, selected as the dynamic site manager, collaborated closely with MSI to define project objectives and themes. Their responsibilities included managing resident projects, facilitating interactions, site coordination, communication, and overall management. See U aimed to revitalise the site and foster dynamic community interactions in anticipation of future development [23].

2.4 Circularium

Circularium, a temporary project by Makettt and D'Ieteren, activates a former car dealership from 2020 to 2025, awaiting future site transformation plans. D'Ieteren collaborated with the city's planning department and architectural office 51N4E to organise co-creation sessions. These sessions established short-term actions and long-term objectives for building transformation. Makettt, appointed for the short-term initiative, aligns with core values of sustainability, circularity, and flexibility set during co-creation. They manage daily operations, undertake placemaking activities to define the site's identity, organise events to attract consumers, and foster community engagement. This collaborative approach allows for a strategic and sustainable temporary use of the site while awaiting future development plans [24].

2.5 Studio Citygate

Studio Citygate, a temporary project by Entrakt, activates a former pharmaceutical factory near Brussels South train station from 2018 to 2023. Initiated by citydev.brussels,

[1] Vrije Universiteit Brussel/Université Libre de Bruxelles; the two Brussels universities.

[2] Brusselse Gewestelijke Huisvestingsmaaktsschappij; Society for Housing of the Brussels Capital Region.

the regional development institute of Brussels Capital Region, the project aims to prevent criminal activity, vandalism, and squatting. Entrakt, selected through a public project call, transforms the site into Studio Citygate, aligning with future transformation project Citygate II. Entrakt manages repairs, adaptations, and coordinates resident projects. Residents are selected through an open project call procedure and occupy spaces under tendency-at-will contracts, allowing flexibility in duration. This collaborative effort ensures the site's temporary use while awaiting permanent transformation, contributing to urban revitalisation and community safety.

3 Actors in Temporary Use Projects

By looking into the project's design processes, differences in stakeholders' roles and actions could be grasped. In the following section, the identified stakeholders are presented: temporary projects' residents and managers, property owners, and multiple intermediate actors. For each stakeholder a general description of their role and responsibility is given. The description of some stakeholders also includes subdivisions to highlight respective findings with notable examples.

3.1 Temporary Users

Temporary project users can be categorised into two groups: residents and visitors. Residents are individuals or entities who organise their own projects or activities on-site. These include artists, start-ups, young entrepreneurs, local organisations, and various social and non-profit organisations, who benefit from an affordable rent made possible by temporary use. On the other hand, visitors are individuals who come to the site for specific events or activities.

Residents play a crucial role in temporary projects. However, it was noted that their selection often alights with the values and ambitions of the decision-making stakeholder, typically the temporary project manager. In many cases, residents are chosen through a project call process that seeks projects aligning with the project ambitions. Notable examples here of are Circularium and See U since the projects' objectives were clearly communicated before the selection procedure.

3.2 Temporary Project Managers

Temporary project managers emerged from the study as crucial decision-making stakeholders in defining a temporary project. They not only ensure the proper functioning of a temporary project, but they are also appointed by building owners to select,manage and coordinate the projects and activities of residents, in addition to their own activities. Table 1 presents the temporary project manager and their roles and highlights the difference between the two kinds of temporary project managers identified in the Brussels Capital Region: non-profit organisations and companies.

Table 1. Overview of the temporary project managers and their respective responsibilities, with a subdivision of two categories: non-profit organisations and companies.

Temporary project managers	
Can ensure functioning of overall temporary project Can select suitable residents through open project call Can facilitate, coordinate and manage residents' projects	
Non-profit organisations	**Companies**
Economically weak Supported through subsidies or funding 'Rent by free contribution' model	Economically stable (transitional real estate & vacancy management) Service fee from property owner Rent per square meters

3.2.1 Non-profit Organisations

Non-profit organisations, like Toestand vzw and Communa asbl, play a crucial role in repurposing vacant buildings in Brussels to create vital community spaces. Their focus on socially impactful projects aligns with local needs, fostering social gatherings, workshops, and collective building moments. By providing low-threshold access, they ensure inclusivity and welcome participation from the public. Moreover, they extend their impact by making their spaces available for other initiatives and organisations. Relying on subsidies and donations, they sustain their operations and use funds to enhance and maintain their sites for seamless functionality.

3.2.2 Companies

Companies, like Pali Pali, Makettt and Entrakt in Brussels, have emerged and support the commercialisation of the practice of temporary use. These companies are economically viable since they manage vacant buildings and coordinate temporary activities within them according to a certain economic business plan. Each company had their approach, reflecting a diverse range of strategies and objectives.

Pali Pali and Makettt emerge as transitional real estate entities, dedicated to facilitating the evolution of organisations and neighbourhoods. Working closely with both public and private stakeholders, these firms receive a specific service fee and predefined objectives from their clients. By curating a diverse array of socio-cultural, sporting, and economic activities [25], they aim at contributing to the revitalisation and transformation of urban spaces. Their emphasis on placemaking underscores their role in activating areas, laying the groundwork for future development initiatives.

On the other hand, Entrakt distinguishes itself as a real estate management company with a history rooted in vacancy management. Originally focused on mitigating risks such as vandalism and squatting, Entrakt has since pivoted towards breathing life into neglected spaces through engaging activities. In instances where Entrakt takes the helm, it assumes full responsibility for executing temporary projects, including essential repairs to ensure the functionality of the premises. To recoup investments, Entrakt adopts a flexible approach, leasing spaces to artists and start-ups under tendency-at-will

agreements. These agreements afford residents the freedom to operate without fixed time constraints, albeit with the understanding that they may be asked to vacate the premises as needed.

3.3 Property Owners

Property owners can grant permission to activate their building and organise activities within in. Property owners, however, can do more than that. They can actively shape the activation and use of vacant buildings and brownfield sites. The analysis revealed that property owners work closely with temporary project managers for the definition and creation of a temporary project. However, within this collaboration, property owners take on an initiating of an allowing role. Table 2 presents these roles of property owners, and it further highlights the differences between them.

Table 2. Overview of the property owners, subdivided into two categories (i.e. initiating and allowing) with their respective responsibilities.

Property owners	
Can grant permission to property Can support temporary activation	
Initiating owner	**Allowing owner**
Operational support Co-create ambitions and objectives aligning with public/private stakes Facilitate with building permits	Allows activities on its property, but is not involved in the project
Financial support Ensure basic utilities, repairs and maintenance Working costs	

3.3.1 Initiating Property Owners

Initiating property owners actively support temporary project managers, whether companies or non-profit organisations. Encouraging collaborations were notably observed in Circularium, See U, and Allée du Kaai. Two types of support were identified: financial and operational.

Financial support from property owners such as D'Ieteren (private company), MSI (public regional development agency), and Leefmilieu (governmental agency) was evident in all three cases. In projects managed by companies, like in Circularium and See U, service fees were established (e.g. from D'Ieteren to Makettt and from MSI to Pali Pali). In contrast, in projects managed by non-profit organisations, subsidies were provided (e.g., from Leefmilieu Brussel to Toestand).

Beyond covering working costs, this financial support also included maintenance expenses since initiators also took on the responsibility of maintaining the existing buildings or carrying out necessary repairs for basic functionality.

In cases where compensation via service fees was identified, residents of temporary projects rented spaces under tendency-at-will contracts. These contracts, between property owner and resident, lack fixed end dates and offer attractive rents defined by a fixed amount per square meter.

Operational support was also provided by property owners, who outlined various ambitions and objectives for the temporary projects. This included defining themes, types of activities, and selection criteria for residents. In projects like See U and Allée du Kaai, MSI and Leefmilieu Brussel were actively involved in co-creating and managing daily operations.

Furthermore, governmental agencies assisted temporary project managers in obtaining necessary permits, easing administrative burdens. This support provided organisations like Toestand with flexibility to experiment with activities without administrative hurdles [26].

Both financial and operational support from property owners aim to ensure that desired activities are effectively managed by project managers and that envisioned objectives are achieved. Additionally, property owners leverage the value of temporary projects in their communication strategies to market both the future projects.

3.3.2 Allowing Property Owners

Not all property owners actively participate in the development of temporary projects. Some assume an 'allowing' role, granting organisations permission to temporarily activate their sites in anticipation of future transformation projects. This passive stance was observed in Le Tripostal and Studio Citygate.

In Studio Citygate, the property owner Citydev, a public developer, enlisted Entrakt, a real estate management company specialising in preventing vandalism and squatting in unused buildings. Citydev permitted Entrakt to activate their property through various activities and rent out spaces to other initiatives, start-ups, and artists. Recognising the added value of this activation, Citydev marketed the temporary projects as a precursor to future transformations. It appears that their primary aim wasn't solely to prevent negative effects of vacancy or provide space for those in need but rather to attract a new population group. Consequently, this strategy may consciously or unconsciously exclude the existing population of the area, potentially leading to gentrification as both the temporary and future projects unfold.

In Le Tripostal, property owner NMBS, a private company, did not initiate the temporary project. Only after a neighbourhood petition advocating for the activation of the unused building did the owner allow a temporary project to proceed. Consequently, NMBS lacked any ambitions for the temporary project and remained uninvolved in its creation and development.

3.4 Intermediate Actors

This study revealed that in addition to three crucial stakeholders, i.e. users, managers and property owners of temporary use, various intermediate actors can also be involved in the organisation and creation of a temporary use project. Table 3 presents the identified actors that were involved in a certain moment of the temporary projects.

Table 3. Overview of multiple intermediate stakeholders and their responsibilities.

Intermediate actors Can guide, advice and support property owners and temporary project managers towards the temporary activation of unused spaces			
Neighbourhood committees	**Designers**	**Planning departments**	**Governmental agencies & Municipalities**
Can launch petitions for temporary activation	Can support and advice on short-and long-term design decisions	Can develop practical guidelines	Can recognise temporary use as a standard practice
Can represent the voice of the community		Can acts as mediators	Can provide subsidies and funding
		Can take hesitation away of property owners	Can develop a frame of rules and regulations
			Can take hesitation away of property owners
			Can facilitate the acquisition of building permits

3.4.1 Neighbourhood Committees

Neighbourhood committees can launch a petition advocating that unused properties of private or public actors should be made available for associative, cultural, and social purposes. By petitioning and collecting signatures, property owners can be persuaded to grant permission and allow activation of their property. Through a project call for a temporary occupation and a selection procedure, a suitable temporary manager can be chosen.

A notable example is the temporary project Le Tripostal, which was initiated after a petition of the neighbourhood committee Saint-Gilles/Midi. The petition was able to persuade the building owner to allow a temporary occupation to take place.

However, it was not enough to ensure that the temporary project can reach its full potential. NMBS gave permission for a temporary project of "a minimum of one and a half year" [22]. The owner did not prolong the temporary project when the initial end date was nearing, even if the permits of the transformation of their building were not received. As such, the vast building returned to its vacant and decaying state. This observation highlights that property owners need to be open to and interested in the opportunities of temporary projects. They might be unaware of these opportunities initially if they did not initiate the temporary project themselves. However, enough time needs to be allowed for temporary projects for them to show various potentials.

3.4.2 Designers

Designers, such as architectural and design offices, can support and advise property owners, as well as temporary project managers, in designing temporary projects, from both a material and a building perspective.

In the case of the development of Circularium, the co-creation sessions between the property owner, and the local planning department were moderated and advice by the architectural office 51N4E. As such, the office was employed by the property owner in advising them, and aligning their ambitions with the future urban planning ambitions of perspective.brussels.

3.4.3 Planning Departments

Planning departments can provide building owners with guiding material to develop ambitions on the short term that are in line with the long-term objective. Since urban planning and redevelopment are long and slow processes, with little direct impact, temporary activities can provide benefits on the short term. Moreover, temporary interventions can inspire a wider discussion about the re-planning process, as highlighted by Pfeifer (2013). In this regard, temporary activities can be analysed on ground, and then adapted to fit within the future project.

An example is the involvement of the local planning department perspective.brussels in the co-creation sessions with the client D'Ieteren. Perspective.brussels is currently working on a strategic transformation vision for the area. Given D'Ieteren's commitment to innovation and constructive practices, they have chosen to actively contribute to the district's transformation by utilising their building as a steppingstone for the transition. Rather than making premature decisions about the building's future, D'Ieteren has opted to await the outcome of the planning process, leveraging the intermediate period to their advantage. To determine the fate of their unused building, collaborative co-creation sessions have been organised. These sessions provided an opportunity for the stakeholders to establish both short-term actions and long-term objectives for the building's transformation [24].

3.4.4 Governmental Agencies and Municipalities

Temporary use should be recognised as a practice by the municipal administration and include a legal frame of building regulations [27]. In Brussels, actions towards a legal frame for temporary use have been taken by governmental agencies and municipalities, with the ambition to improve the access to temporary use and to support of initiatives in the organisation of temporary use projects. The introduction section of this paper highlights the Brussels' efforts for the organisation of temporary use, among which a 'practical guide' providing answers to legal and administrative aspects for the organisation of temporary activities and a matchmaking tool.

To fully encourage and support the organisation of temporary project, municipalities can act as mediators between the property owners and economically weak temporary project managers and residents. In addition to financially supporting such initiatives through subsidies or funding, they can also practically support initiatives and

organisations through coaching and mentoring. However, the latter is not yet common practice.

A notable example of the involvement of a governmental agency or municipality, that was not as a property owner, is the case of Le Tripostal. The municipality of Saint-Gilles supported and encouraged the temporary project. They supported the petition launched by the neighbourhood committee and persuaded the private company NMBS in allowing a temporary occupation, resulting in the "agreement" of the added value of a temporary occupation of the site. In addition to the first contacts with the property owner, the municipality also had a role in the selection procedure of a temporary manager. As such, they were part of the interdisciplinary jury when appointing an organisation to manage and develop a temporary project.

In addition to municipalities, governmental agencies, such as the one of the Brussels Capital Region, can be invited to be part of a jury in the selection procedure for the appointment of temporary managers. This is known to be the case in Le Tripostal and See U.

4 Building an Ecosystem

The activation of vacant spaces through temporary projects in the Brussels Capital Region involves various stakeholders. Figure 3 visualises the identified stakeholders and their actions.

4.1 Value Network Mapping

Temporary project managers (resp. Manager), property owners (resp. Owner), and users (resp. Residents) emerged as pivotal stakeholders in defining and creating temporary use projects. Consequently, they were given central importance during the ecosystem mapping process. Intermediate actors were categorised into two surrounding circles, with proximity to the centre indicating their current significance in project design and development or their substantial role in analysed Brussels' temporary use projects. Neighbourhood committees, governmental agencies, and municipalities were placed in the first surrounding circle, while designers and planning departments were included in the second circle.

In addition to stakeholders, varying transactions, grasped according to VITO's Value Network Mapping, are mapped and visualised. These transactions can be valuable material (orange), immaterial (blue) and financial (green) actions from one actor to another. The consistent transactions, identified in the analysed temporary projects, are visualised as a full line, while the inconsistent and case-dependent transactions are visualised by a dotted line.

4.1.1 Actors and Their Transactions

Figure 3 illustrates the ecosystem of actors involved in temporary use projects, depicting their roles and responsibilities and the transactions they engage in with other stakeholders. At the centre, the relationship between owner and manager, manager and residents, and residents and owner are depicted. Surrounding this are intermediate actors and their actions.

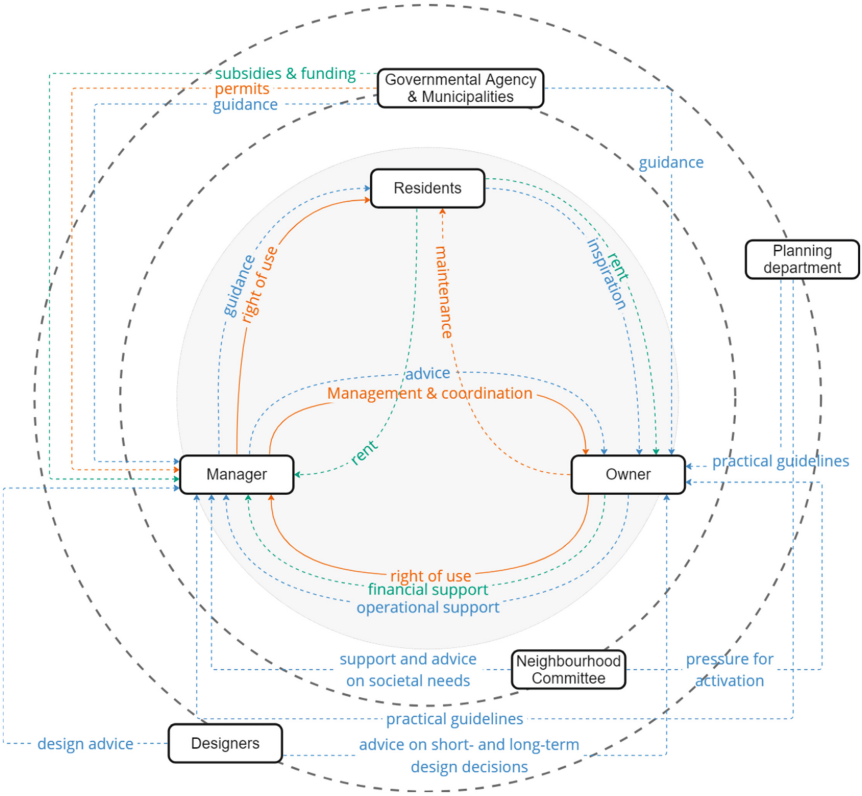

Fig. 3. Value Network Map: Stakeholders in temporary use and their value transactions, with in the inner circle the crucial actors of a temporary project, i.e. Resident, Manager and Owner, and surrounded by the intermediate actors, i.e. Neighbourhood committee, Designers, Planning Departments and Governmental agencies and Municipalities. Colour code: Green: financial transactions, Orange: Material transactions, and Blue: Immaterial transactions. (Color figure online)

In the relationship between owner and manager, the owner grants the right of use of their property to the manager in exchange for management and coordination of projects. Initiating owners can further provide operational and financial support to managers, which can lead to advice regarding the transformation potential of the site.

Between manager and residents, the manager grants the right of use to residents, potentially receiving rent in return. Additionally, managers can guide residents in their projects and activities.

Regarding the relationship between residents and owner, the owner may provide maintenance of the building in exchange for rent and inspiration from residents.

In the outer circles, intermediate actors are positioned in relationships with either the manager of the owner, with no direct transactions observed with residents.

Neighbourhood committees can offer support and advice to managers on the societal needs of the local community and pressure owners to open their property temporarily through petitions.

Governmental agencies and municipalities can subsidise or fund temporary projects, assist in acquiring permits, and provide guidance. They can also support property owners in allowing and initiating temporary projects, alleviating hesitations and uncertainties.

Planning departments can support owners and managers by offering practical guidelines for temporary use. This is exemplified by the ambition of the Brussels planning department perspective.brussels to develop a framework and instruments supporting actors involved in temporary use.

Designers can advise owners during co-creation processes on both short- and long-term design decisions and provide guidance to managers on design decisions for temporary use projects.

4.2 Power Dynamics

The collaboration among various stakeholders is crucial in temporary use projects. Moreover, the relationship between the degree of power and stakeholder interest can significantly influence project feasibility and success. Power dynamics among stakeholders play thus also a vital role in shaping project outcomes.

In temporary use, the degree of power often correlates with the level of stakeholder interest. Property owners typically hold significant power due to their control over the physical space and resources. Their level of interest in temporary project may vary depending on factors such as financial considerations, long-term development plans, and community relations.

Managers, on the other hand, wield power in terms of project coordination and implementation. Their interest in projects may be driven by factors such as community engagement objectives (e.g. non-profits), and financial incentives (companies).

Residents and other users hold power, particularly in projects where they are actively involved in organising activities and shaping the project's direction. However, in the analysed cases, residents were not very often involved in decision making processes.

Intermediate actors, such as neighbourhood committees, governmental agencies, municipalities, planners and designers can also exert power and influence project outcomes through advocacy, funding, regulatory support and design input.

The balance of power among stakeholders and their respective interests can determine the feasibility and success of temporary use projects. Projects where stakeholders collaborate effectively, with power shared and interests aligned, are more likely to achieve their goals and create positive impacts for communities (e.g. Allée du Kaai, See U, and Circularium). Conversely, projects marked by power struggles, conflicting interests, and unequal distribution of resources (e.g. financial resources) may face challenges and struggles to realise their potential. Therefore, understanding and navigating power dynamics, as well as roles and responsibilities of stakeholders, is essential when considering the feasibility and success of temporary use projects.

5 Conclusion

Temporary use projects involve a network of stakeholders, each playing unique roles that significantly influence project outcomes. Property owners serve as initiators, granting the right of use to managers, and providing support for project implementation. Temporary project managers and residents serve as activators, effectively reactivating sites and opening them up to the society. Governmental agencies, including municipalities, acts as mediators, offering support, funding, and guidance, while planning departments fulfil an informative role, providing guidelines for temporary use. Designers serve as advisors and supporters, contributing to design decisions.

Such a delineation of roles among stakeholders in temporary use is crucial for effective collaboration and project success. Establishing categories of stakeholders and their roles, and level of involvement, can serve as a foundation for developing comprehensive decision support systems tailored to the unique need of temporary use projects.

The stakeholder analysis, integrated with value network mapping and multi-actor decision support systems, can provide valuable insights into power dynamics, interests, and transactions among stakeholders. This holistic approach can enhance project planning, implementation, and evaluation, ultimately maximising the potential of temporary use to benefit communities and sustainable urban development (Table 4).

Table 4. Overview of stakeholders and their roles

Stakeholder	Role
Property owner	Initiator
Temporary Project Manager & Resident	Activator
Governmental agencies	Mediator
Planning Departments	Informational
Designers	Advisory and Support

Despite providing valuable insights, this study has limitation that warrant consideration. The focus on a specific set of five case studies in Brussels may limit generalisability. Future research could broaden the scope by including more diverse projects, and in different urban contexts. Moreover, exploring temporal dynamics and including a wider array of stakeholders, such as partners, sponsors, citizens, etc. in future research could enhance the understanding of temporary use initiatives and their success factors.

This research has also led to the realisation that certain elements, not explicitly addressed in the current study, warrant further investigation for a more comprehensive understanding of temporary use projects. Specifically, the positions of various stakeholders in terms of their stakes – whether public, private, or social – and the specific property owners' backgrounds, such as companies, developers, governmental agencies, or municipalities, merit deeper exploration. Recognising the influence of these factors on stakeholders' dynamics could offer valuable insight into the intricacies of temporary use initiatives and enhance the effectiveness of collaborative efforts among diverse

entities. Furter research should this delve into these dimensions to enrich our understanding of the multifaceted relationship shaping the success of temporary project sin urban environments.

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A Co-governance Process for the Adaptive Reuse of Cultural Heritage: The Experience of St. Michael Cloister in Anacapri

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Abstract. The paper presents an action research process focused on exploring the potential of a hybrid evaluation methodology for urban, social, and cultural regeneration projects involving cultural heritage. Implemented in Anacapri, Italy, the In.Kiostro decision-making process suggests a proposal for the adaptive reuse of the former of St Michael Cloister, an under-utilised cultural asset. The methodological approach, articulated in five phases, integrates the Quintuple Helix co-governance model and the Social Multi-Criteria Evaluation (SMCE) approach, developing an inclusive co-design platform. The co-governance model, rooted in the collaborative city concept, emphasises multi-level integration to engage a diverse group of stakeholders representing community interests and to recognise established values to enhance cultural heritage and promote a heritage community. The proposed methodology facilitates an interactive decision-making process through multi-criteria and multi-group analysis to identify preferred alternative scenarios and manage local conflicts, generating new complex values.

Keywords: Heritage community · Adaptive reuse · Integrated evaluation · Quintuple Helix · SOCRATES method

1 Introduction

In reflecting on the future of our cities and their transformative strategies, it is crucial to explore how to design them according to a methodological approach capable of capturing and interpreting the complex economic and non-economic values of the context in which we operate. This complexity can be explored by understanding and monitoring the social, environmental, and economic impacts [1] of project proposals by implementing

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appropriate decision-making strategies based on integrated evaluation. The development of collective choices is based on the knowledge of the multidimensional values that characterise a context, identifying possible project alternatives while considering both the potential impacts and the conflicts that need to be managed, integrating the Sustainable Development Goals (SDGs) [2] and adopting a place-based approach that focuses on active community involvement.

In general, Europe is moving towards models of inclusion and sustainability that emphasize citizen well-being [3, 4] and require community participation in decision-making processes. Such participation is now a consolidated, indispensable, and determining condition for the success of the design process. The community is central to its ability to inject into the decision-making process the specific knowledge and needs that are crucial for the formulation of project scenarios that are aligned with the real contexts in which they operate. Furthermore, when considering the future of the Italian urban landscape, it is essential to reflect on the existing cultural heritage and, in general, the propulsive role that culture can play in the transition to sustainable socio-economic models. Many international contributions are supporting this thesis [5, 6].

The reactivation of existing heritage through participatory design processes allows for the aggregation of new Heritage Communities [7] and facilitates the reappropriation and reassignment of values to the complex disused architectural palimpsest that permeates Italian urban landscapes. This reactivation can contribute to building a network of cultural outposts of resilience. Exploring the transformative opportunities that develop around existing heritage means looking at stakeholders, with particular attention to the third sector and, more generally, the cultural entrepreneurship sector [8], which has been a rapidly growing sector in Italy in recent years [9].

In this perspective, a specific interpretation of the social context is functional and allows us to imagine the intervention area as a productive environment in which five actor platforms collaborate in the formulation and co-definition of collective choices [10]. Through a specific interpretation of this model, it is possible to highlight the crucial role of the community and cultural promoters.

This paper explores the opportunities of integrating the Collaborative City model [10] and the Social Multi-Criteria Evaluation (SMCE) [11] approach through an adaptive, iterative, and dynamic decision-making process, developing a hybrid evaluation methodology capable of facilitating culture-led urban and social regeneration processes. The implementation of the methodology in the context of Anacapri, in Southern Italy, through the development of an adaptive reuse project for the former St. Michael's Cloister, allows us to highlight potential and critical issues and to improve the process through continuous updates and feedback.

The paper is structured as follows: Sect. 2 deepens the methodological approach (2.1) and the tools used to define a multi-value, incremental, and adaptive decision-making process (2.2); Sect. 3 describes the case study, focusing on the former St. Michael's Cloister and the results obtained; Sect. 4 presents the co-design phase in detail (4.1) and the decision-making strategy (4.2); finally, Sect. 5 describes the methodology outcomes (5.1) and the research perspectives (5.2).

2 Materials and Methods

2.1 Co-governance Models and Social Evaluation

Building and designing social, cultural, and urban innovation requires the integration of institutional, cognitive, and entrepreneurial resources [12], combining heterogeneous knowledge and multidisciplinary skills in the decision-making process. In this perspective, a relevant question concerns understanding which actor platforms should be integrated and how to develop a governance model capable of interpreting the complexity of the socio-urban context in which we operate in an inclusive way.

The Quintuple Helix innovation model [13], introduced for adding the perspective of the "natural environments of society", represents the suitable decision context able to overcome the limits of the previous helix. Indeed, the Triple Helix innovation model focuses on university-industry-government relations, emphasizing knowledge production and innovation; and the Quadruple Helix includes the Triple Helix by combining as a fourth helix the "media-based and culture-based public" and "civil society" [14], and encouraging the interaction between the knowledge society and the knowledge democracy. The Quintuple Helix stresses the necessary socio-ecological transition of society and economy, considering the natural environments of society and the economy as drivers for knowledge production and innovation, supporting the formation of a win-win strategy between ecology, knowledge, and innovation, and promoting synergies between economy, society, and democracy [14]. The Quintuple Helix approach is particularly relevant today, in a society that places the community at the centre as an essential resource for social innovation and the transition towards inclusive, innovative, and sustainable city models [4]. Indeed, the Quintuple Helix includes the socio-cultural and environmental dimensions of the decision-making problem in the formulation of collective choices, highlighting the close correlation between the dimensions and the territorial actors in the construction of collective choices [15].

The helix model's evolution allows to elaborate some considerations [16] about the possibility of imagining an alphabet of n-helices from which to draw, developing site-specific interpretative models on a *case-by-case* basis, which include the different dimensions based on the characteristics of the context. The risk of taking the model to the extreme is an impoverishment and a loss of meaning of the model itself. Nevertheless, a specific interpretation of the Quintuple Helix model, recently formulated, is very interesting, through which the city is read as a platform of urban co-governance in which the various actors collaborate for the co-formulation of decision-making scenarios and the co-management of the city [17].

The model of the *collaborative city* or "Co-city", explicitly designed to put the socio-cultural dimension at the centre, is based on the close relation between technological, institutional and economic innovation and social innovation, based on three principles: sharing, collaboration and poly-centrism [10]. A decisive role is assigned to *civil society,* which is divided into two distinct segments: *organized civil society* and the *unorganized public* [18].

Starting from the Co-City Model, which reinterprets the Quintuple Helix model, for the enhancement of cultural heritage [19], the opportunity to consider *civil society* divided into two segments was explored: the *socio-cultural ecosystem* and *active civil*

society. The first nucleus includes third-sector entities that operate specifically in the field of social and cultural innovation. The second nucleus is made up of stakeholders representing the community that is not necessarily present in an organized form, expressive of different knowledge of the territory. The two groups collaborate in the formulation of choices alongside *institutional*, *cognitive* and *entrepreneurial* resources and allow the activation of a collaborative governance model capable of integrating plural roles, interests and knowledge.

The proposed study is developed in line with the reflections of the action research [20] and presents the elaboration and implementation of a hybrid, replicable and scalable methodological approach, aimed at the enhancement of cultural heritage, interpreting the social context of reference as a co-governance platform, where five actors participate and collaborate in the co-formulation and co-evaluation of collective choices [16]. The methodology developed represents a specific interpretation and extension of the SMCE approach [11] to support the decision-making process aimed at the development of shared design choices, able to contribute to the construction of a new *heritage community* around a cultural asset that is abandoned and/or used inappropriately.

The Social Multi-Criteria Evaluation (SMCE) approach [21] allows for the structuring of a replicable methodology that facilitates the implementation of urban and social regeneration processes for the enhancement of cultural assets, contributing to the development of innovative sustainable models. Specifically, the approach makes it possible to structure an adaptive methodology which, by integrating multi-criteria and multi-group evaluations in an iterative logic, considers the qualitative and quantitative knowledge acquired and enhances the requests made by the community involved. In this way, it is possible to outline a compromise solution shared by stakeholders, able to reduce conflicts and to include different preferences.

The SMCE approach makes it possible to structure a project path between transparent and equitable, favouring the co-design of a preferable alternative, and allowing the activation of a process of collaboration and cooperation between stakeholders through multi-group evaluation. In addition, through multi-criteria evaluation, the SMCE makes it possible to assign decisive importance to specific dimensions that structure the decision-making problem, taking into account the characteristics of the context and how they may affect the decision-making process.

The integration of the Quintuple Helix model in the SMCE approach and the use of multiple tools for the analysis of stakeholders and the system of relationships that characterizes them makes it possible to improve the engagement of territorial actors, enabling the elaboration of projects that adhere to and respond to the needs of the community.

2.2 The Methodological Approach: Phases, Steps and Tools

The methodological process (Fig. 1) is articulated into five phases, which develop in an iterative, adaptive and dynamic way and which outline a co-governance model, supported by different steps and specific tools for each phase: 1) Co-exploration; 2) Identification; 3) Co-evaluation; 4) Selection; 5) Project and Testing.

As part of the elaboration of the *Co-exploration phase*, necessary for the construction of the basic knowledge of the territory, the integration between *hard* and *soft data* is

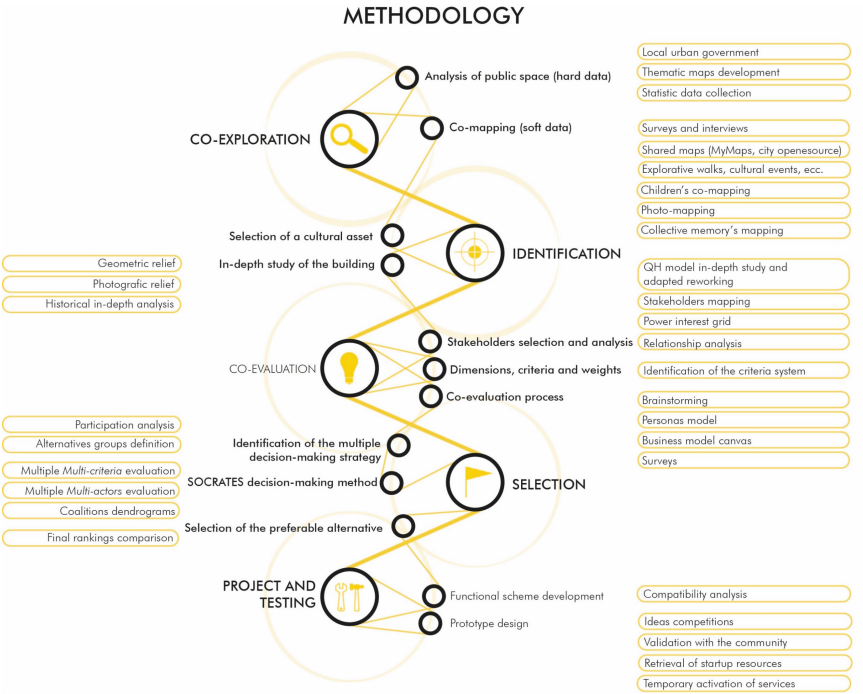

Fig. 1. The methodological process: phases, steps, tools

essential. The hard data can be systematized through the analysis of the context (quality, typology, prevailing users, etc.), elaborating multiple *thematic maps* capable of explaining the different territorial and urban, social, cultural and economic components. These data can be collected by exploring the main platforms for disseminating statistical information [22] as well as through the survey of the urban context, through the in-depth analysis of territorial governance tools. The urban planning study, however, must be integrated by qualitative investigations, crucial to developing the complex knowledge system. Soft data can be collected in many ways. The most popular and simple technique is the dissemination of *surveys and interviews* to the population as the first form of community involvement in the process. The data collected through the *survey* describe the *subjective-perceptual* aspects and the *intangible* value elements that are fundamental for understanding the complexity of an urban environment and its community. In addition, the different forms of *urban trekking* are an interesting way to co-explore the city [23, 24]. Another interesting contribution can be offered by the photography of the city, through the organization of photography workshops or contests. In this sense, the use of photography as a co-mapping tool is interesting because of the multiple opportunities given by digital collaborative mapping platforms [25]. In this context, other ways of co-investigating the urban space can make children and young people gaze at the centre [26, 27]. The urban space understanding also passes through the knowledge of its historical memory. Indeed, the collection and geolocation of the past's evidence - in their various forms (photographs, documents, works, etc.) – is a stimulating way to explore the city.

This makes it possible to develop a deep knowledge of the socio-urban environment, looking at the collective memory as an essential value in design processes. Community archives, in this sense, are an experimentation that must necessarily be considered [28]. Finally, the use of GIS facilitates the systematization of this knowledge, giving rise to a multi-layered and multi-meaning knowledge, that integrates qualitative-quantitative data and that allows to identification of the characterizing issues. For these different tools, it should be emphasized the different temporal dimension that characterizes their implementation. The construction of a truly in-depth and deep knowledge of a territory is subject to a slow evolution, with a co-design process of continuous integration over time.

The *Identification phase* is related to the selection of an architectural asset, which has emerged as significant for the community and takes into account the needs expressed by the community itself in the Co-exploration phase. Therefore, starting from the results of the first phase, it is possible to rationalize the choice, selecting a cultural asset where the desires and aspirations of the community converge, and in which the favourable conditions already exist to host a process of regeneration. This choice should make it possible to select those assets without planning, forgotten by territorial governance, to facilitate the grafting of new enhancement processes starting from the recognition of the architectural, urban and historical values and the role they have had over time for the community, improving the level of awareness. The conclusion of the second phase, integrated with the results of the first, allows a critical interpretation of the opportunities for regeneration and innovation of the cultural asset, analysed concerning the context and the system of relationships that have been generated over time.

In the *Co-evaluation phase*, some significant tools can be identified to develop the evaluation process as part of the co-design of reuse strategies [29]. Specifically, a participatory process should always start with *Stakeholder Mapping and Analysis* [30] to be involved, in line with the chosen co-governance model. The use of the *Power-Interest Grid* [31] also makes it possible to visualize the relationship between *power* and *interest* of the various stakeholders active in the area (Thamma Reddi, 2023) and identify different strategies for involving stakeholders in the *Co-design phase*. Another tool to support stakeholder analysis is *network analysis* [32] through which it is possible to read the relationships between the various actors involved. The types of relationships (virtuous or conflictual) are crucial for understanding the opportunities to activate alliances and the risk of generating conflicts. On a local scale, it can be useful to map both the institutional relationships between the various stakeholders involved, as well as the personal ones, since the latter generally tends to influence the former. If *brainstorming* [33] represents the key tool in collective participation operations, another useful tool for the co-identification of needs can be represented by the *personas model* tool [34], through which the typical users of the products, services or projects to be developed are imagined and defined, in a human-centred logic. Another relevant tool is represented by the *business model canvas* [35, 36], able to highlight the managerial, economic and sustainability aspects of the project idea, emphasizing the key resources, quantifying the costs and benefits, and identifying the possible users of the process who may be involved in the reuse project. Submitting the business model canvas to stakeholders means making them aware of the complexity of project management, inducing them to imagine concrete

and plausible, as well as innovative, solutions, and supporting building a collaborative decision context based on the willingness to work together for common shared goals.

With regards to the *Selection phase* an essential role is played by the *Multi-Criteria* and *Multi-Group Analysis* developed according to the *SMCE* approach, applied in many cases as a methodological tool useful for guiding decisions [37]. The literature on the SMCE approach shows that only a small number of cases concern urban regeneration issues. In addition, in most trials, the most widely used method is the Novel Approach to Imprecise Assessment and Decision Environments (NAIADE) [38]. A recent evolution of NAIADE is the SOCRATES method [39], which integrates mixed qualitative and quantitative information, allowing carrying out multi-criteria analysis, equity or multi-group analysis and sensitivity analysis (local and global) [40, 41]. As far as multi-criteria analysis is concerned, SOCRATES requires the definition of *dimensions* and *criteria.* The method also provides for the attribution of specific *weights*, proportional to the criteria that describe the impact on the specific dimensions. The possibility of introducing weights is also found in equity analysis, through which the preferences expressed by stakeholders concerning alternatives are collected and systematized. The SOCRATES method also allows a synthetic reading of the distances of the positions taken by the stakeholders during the evaluation phase, through the construction of the dendrogram of the coalitions, which supports the identification of the preferable choice expression of the consensus reached among the different stakeholders involved in the decision-making process.

The *Selection phase* consists of the identification of the decision-making strategy, supported by the SMCE approach and the SOCRATES method, through which multi-criteria and multi-group evaluations are conducted. The construction of the impact matrix and the equity matrix allows us to verify the preferability of the alternatives, taking into account both the ability of these to respond to the various dimensions of the problem and the level of satisfaction of the stakeholders.

Finally, through the *Project and testing phase*, the preferred functional address is validated in terms of the spatial and temporal compatibility of the selected functions. At this stage, the preferable functional articulation for the cultural asset can be transformed into a temporary set-up project, to be validated with the community. The temporary set-up project and its implementation can be preparatory to the experimentation and validation of the scenario identified through the reopening of the asset for an experimental period. Temporariness, in its many forms, is conceived as a tool for the reactivation of the cultural asset in the long term, through the concrete validation of the innovative uses, chosen by the stakeholders. The co-design and co-construction of the equipment suitable for carrying out the activities in the building can be an interesting way to start the aggregation of a new community for the building. This makes it possible to co-prepare the asset to welcome experimentation, involving the local community (activists, young people, associations, etc.) and the sectoral community (universities, architecture students, makers, collectives, etc.). This temporary experimentation of uses and scenarios aligns with the *living lab* approach [28], which is expected to be the direction of future action-research steps, in line with ongoing experiments in similar urban and architectural contexts [42].

3 The Case Study

The territory of Anacapri, on the island of Capri, was the context of experimentation. The Blue Island is characterized by its environmental peculiarities, which justify its strong tourist attraction. The latter, in the space of a century, has led to a substantial transformation of the local economic structure, which today is based almost exclusively on the tourism sector.

This transformation has generated a varied and complex set of imbalances, about the strong extrinsic pressure that affects the summer months, the on/off dichotomy that characterizes the cycle of the tourist season, incoming work tourism (which affects the employees of accommodation facilities) and outgoing (young people who leave the island for study or work), housing deprivation (caused by uncontrolled *overtourism*, the constraint regime and the application of short-sighted local policies). The strong attractiveness of the island has produced the gentrification of the inhabitants and the emptying of the historic centre of Capri, as well as a growing localized inflation highlighted by the dynamics of the real estate market. These issues have a profound social and environmental impact and fuel numerous conflicts in the local community worried about the risk that the island could become an artificial scenario [43]. Anacapri has been partially protected from these phenomena and, to this day, still retains a strong sense of community and a segment of entrepreneurship based on local craftsmanship and family business. Many elements contribute to defining Anacapri as a territory that favourably turns to sustainable transition through territorial regeneration; nevertheless, the absence of prudent political choices and the presence of strong extrinsic pressures are rapidly transforming this context as well, impoverishing it of its identity.

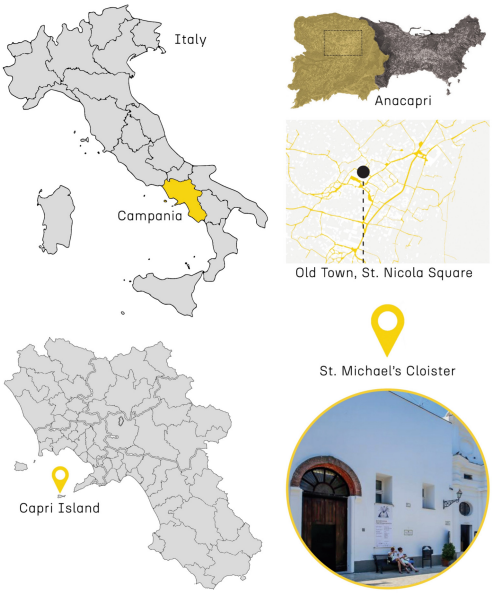

Fig. 2. St. Michael Cloister's territorial framework

In general, many policies have recently been developed to preserve the island, particularly from an environmental point of view. On the other hand, there are few programmatic initiatives relating to the cultural dimension. On the merits of the case study, the Co-exploration phase allowed the identification of an under-utilized cultural asset in which to implement the co-design process and activate an innovative co-governance model.

The former St. Michael Cloister (Fig. 2) is a cultural asset owned by the municipality which, during the co-mapping phase, has been reported by the community as one of the priority assets on which to intervene. This property enjoys particularly relevant spatial, urban and historical characteristics. Its adaptive reuse can contribute to the aggregation of a new heritage community, to the regeneration of the neighbourhood and to the creation of new forms of co-management and innovative social entrepreneurship culture-led, based on the enhancement of existing heritage.

4 The In.Kiostro Decision-Making Process

The results of the experimentation, the so-called In.Kiostro decision-making process, are described with specific attention to the alternative formulation and Co-evaluation phase (4.1) and the Selection phase (4.2), with the identification of the preferable alternative scenario.

4.1 Alternatives Formulation and Co-evaluation

The first part of the *Co-evaluation* phase has been dedicated to the elaboration of three design alternatives ($Ap_{1–3}$), bearers of as many general visions of enhancement with new possible scenarios for the adaptive reuse of the Cloister, synthesis of the thematic issues that emerged in the Co-exploration phase. The three alternatives thus formalized, therefore, represented three decision-making contexts that the community enriched with meaning and significance, identifying the actions that could make the scenarios operational. Based on the obvious spatial problems related to the aggregation of young people, the first scenario made it possible to imagine in the cloister a new point of reference for the youth community. A second scenario has been identified starting from the presence of an inter-generational community that the Cloister could network. In this sense, a community's point is the second proposal that has been made explicit. Finally, considering the tourist-cultural potential of the Monumental Church of St. Michael, the historical route that links it to the Cloister, and the tourist attractiveness of the site, for the third scenario a tourist-cultural function has been identified, which sees the Cloister as a point of cultural promotion and social innovation of a tourist nature.

The second group of *alternatives* ($Af_{1–10}$) was developed by disaggregating the functions, identified by stakeholders during the co-design phase, and identifying specific actions. The evaluation of the disaggregated functions made it possible to understand the preference expressed for the three scenarios, the significance and relevance of the specific actions of the alternative scenarios, and to verify the presence of redundant or peculiar actions in the three different project scenarios.

Afterwards, a system of criteria was structured to evaluate the projects developed in the Co-design phase. The system of criteria considers four significant dimensions for the context of Anacapri, to which a proportional weight differentiated according to the importance recognized by stakeholders has been assigned: Social dimension; Tourist-cultural dimension; Economic dimension; and Environmental dimension. At the same time, stakeholder mapping and analysis was drafted, including:

a. *the identification of the stakeholders* referred to each co-governance helix;
b. *the stakeholders analysis*, through the mapping of missions, areas of intervention and possible relations with the Cloister, and to understand the general characteristics of the group of stakeholders involved;
c. *the power-interest analysis*, developed through a *Power-Interest Grid* (*PIG)*;
d. *the network analysis*, through which the institutional and personal relationships between the stakeholders involved have been identified.

In this regard, the positioning of stakeholders on the PIG is particularly interesting. The analysis was very useful to visualize the ability of stakeholders to influence the implementation of the proposed project, as well as the interest that stakeholders have shown concerning the participatory process. Before proceeding with the division of stakeholders into working groups, a weight proportional to the role assumed by each was assigned, based on the surveys carried out in the first phase. The highest percentage weight was assigned to decision-makers and, considering the results of the PIG, the other weights were assigned reflecting the interactions between skills and influence level. The analysis and proportional weighting made it possible to divide the stakeholders into three working groups balanced in terms of age, level of education and skills, interest and decision-making power. The three groups were decisive for the design definition and significance of the three proposals. The members of each table collaborated in the formulation of one of the three proposals as part of a workshop organized through the focus group technique. The division of the participants into the three tables allowed the immediate dissipation of the existing conflicts between them and triggered an interesting and virtuous mechanism of competition between stakeholders who usually collaborate. The next step was the design, organization and implementation of the *In.Kiostro.Lab* co-design workshop, which was held in February 2023 at the Cloister of San Michele. To build a workshop that would facilitate interaction between stakeholders, some gamification techniques were applied to build an enabling context for the understanding and carrying out of the Missions by the participants. It is essential to underline that, to obtain quality data and conspicuous participation, it was necessary to apply a careful strategy of raising awareness among stakeholders through direct contact with the people involved. The workshop was articulated in a program of actions organized in such a way as to involve and guide the participants, building the conditions favourable to interaction and collaboration: a) Welcoming; b) Guided tour of the building; c) Presentation of the activities; d) Brainstorming; e) Team Work; f) Sharing and discussion. The workshop required the production of numerous graphic materials to support the interactions, as well as the creation of a temporary set-up project for the building. It is interesting to note how the decision-making process, already in its preliminary phase, has allowed the implementation of an innovative way of temporarily reusing the building (Fig. 3).



Fig. 3. The co-design workshop *In.Kiostro.Lab*

4.2 Selection of the Preferable Alternative

The elaboration of the main issues that emerged in the Co-evaluation phase made it possible to construct a multiple decision-making problem (Fig. 4). Indeed, together with the evaluation of the design alternatives ($Ap_{1–3}$), an assessment of the individual functional components ($Af_{1–10}$) was equipped. The need to integrate this second double evaluation can be understood if we consider the redundancy of some functions proposed by the stakeholders in the three projects elaborated. The implementation of the SMCE approach allowed for an effective integration of all the issues at stake and the use of the SOCRATES method facilitated the identification of the preferable scenario.

The *multi-criteria analysis*, carried out for both design and functional alternatives, highlighted the ability of the alternatives to meet the previously defined criteria through the assignment of a *qualitative* score on a scale of seven points, corresponding to seven linguistic judgments. As regards the assessment of $Ap_{1–3}$, the *impact matrix* was structured in three columns and twenty-five rows. In the case of the individual functional components valuation, the resulting matrix consists of ten columns and twenty-five rows ($C_{n(m)}$). As far as the *multi-criterion analysis* of $Ap_{1–3}$ is concerned, for example, in *the frequency matrix,* there is a clear preference for *In.kiostro.young* (Ap_3) *alternative, which* obtains preferability in 60% of cases. Compared to the *multi-criteria analysis* referred to the $Af_{1–10}$, the functional proposals *Neighbourhood Concierge, Info-point, Eventopia, and Bar Bistrot* are the winners.

The *multi-group analysis* - also carried out for both $Ap_{1–3}$ and $Af_{1–10}$ - highlighted the ability of the alternatives to satisfy the needs of the stakeholders involved. Data on participants' preferences were collected through a *post-workshop survey*, which was

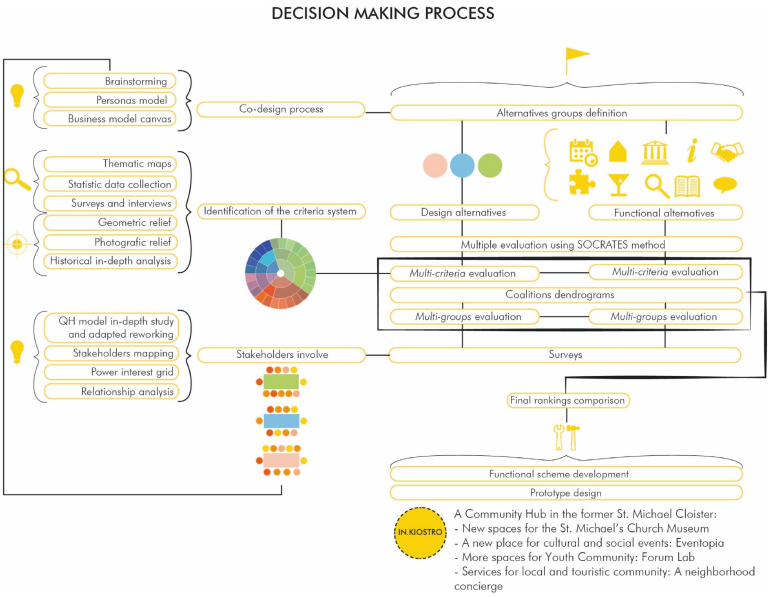

Fig. 4. The decision-making process developed for *In.Kiostro* evaluation

administered only after the revision and redefinition of the decision problem. In this case, the results are influenced by the assignment of differentiated *weights* to stakeholders *($G_{1–18}$)*. The multi-group matrix of *$Af_{1–10}$* was constructed by asking stakeholders to indicate their preference ranking to the ten alternatives (1st–10th), therefore using an ordinal scale (where the lower numerical value corresponds to the best position in the ranking, and therefore the best evaluation) while the one referring to *$Ap_{1–3}$* was built by asking stakeholders to assign a *linguistic rating* on a scale of seven points (good-bad) to each functional alternative. The result of the *coalition's dendrograms* (Fig. 5) also allows us to understand the proximity/distance assumed by the stakeholders during the evaluation process.

The carrying out of multiple evaluations has made it possible to highlight - as the number of alternatives increases - a greater difficulty for actors to create strong coalitions. Credibility values are significantly lowered. Finally, the deduced frequency of the preferability of the functional alternatives that emerged from the four evaluations made it possible to identify a preferable compromise solution, which collects and integrates the functions present in the preferable *Young project proposa*l and some functions considered preferable by stakeholders in the evaluation of $Af_{1–10}$.

4.3 Results

The partial results of the experiment carried out, related to the temporary use project for the cloister, open a critical analysis of the tools chosen and outline the direction of future research steps. The implementation of the methodological process has allowed the achievement of multiple objectives, the deepening of theoretical and operational

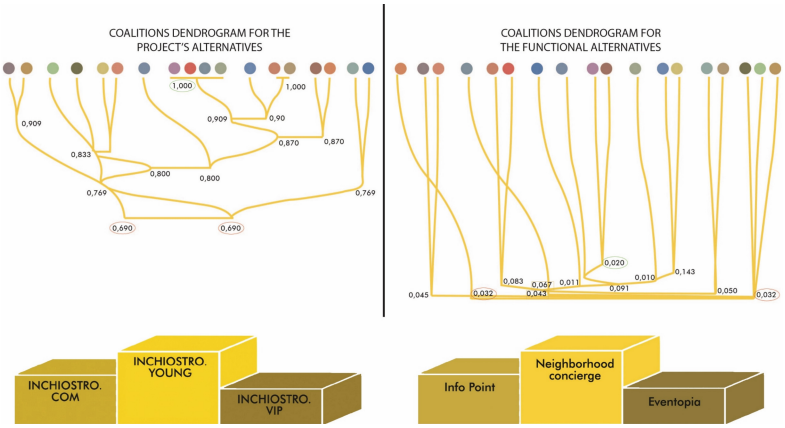

Fig. 5. Actor's dendrograms and final rankings.

considerations, as well as the activation of a concrete consultation with the decision-makers for the reopening of the Cloister. The implemented process makes it possible to formulate a compromise design solution between the design alternatives, considering four functional strategies: a) Connection to the Monumental Church of St. Michael the Archangel (museum); b) Opening of *Eventopia;* c) Activation of a *Neighborhood Concierge;* d) Extension of the *Forum Lab.* At the same time, a new scenario is outlined for the Cloister which sees it in a network with the neighbouring Monumental Church of St. Michael the Archangel, according to which the property could provide some services such as ticketing, the sales area, and refreshments. This would make it possible to restore the historical and functional continuity of two sister works of art. It would also make it possible to interpret the phenomenon of tourism as a driving force for regeneration, through the establishment of innovative management, considering culture and tourism as essential for regeneration and social integration. In addition, some of the spaces are imagined hosting numerous cultural promotion activities, through the *Eventopia* proposal: a space co-managed by local non-profits for shows, events, exhibitions, debates, workshops, etc. This makes it possible to inhabit the building all year round, giving it an aggregative and cultural resilience value. Furthermore, some rooms are directed to the service of the community through the opening of a *Neighborhood Concierge*, where some functions dedicated to citizens and tourists can be activated. Finally, the proposal extends the spaces of the *Forum Lab* and the services provided in them, with particular attention to the youth community. Regarding the temporary use of the Cloister, two aspects are underlined: the first refers to the implementation of the methodology and how this has allowed an innovative use of the Cloister already in the co-design phase; the second refers to the project outcomes and the proposal for experimental use of the cultural asset, through the co-construction of a temporary installation to test in a period of one year. The development of the co-design phase inside the Cloister required the creation of a temporary installation project, that allowed stakeholders to inhabit the property unexpectedly and innovatively, facilitating the success of the co-design. Temporariness, therefore, is confirmed to be a very important tool for the implementation of co-design

processes. Among the objectives achieved were the activation of ongoing consultation with decision-makers on the reopening of the site, and a growing awareness among some stakeholders of the opportunities that the Cloister could offer if reactivated. The process highlights the driving role that the Cloister could play, both from an urban point of view, in relation to St Nicholas Square and the many public buildings that overlook it, and from a social point of view, in promoting the integration of the communities that inhabit the neighbourhood.

5 Discussion and Conclusions

The use of the SMCE approach, integrated with the interpretation of the socio-urban environment as a Co-City Quintuple Helix, allows the formalisation of a hybrid and replicable methodology for a co-governance process. The Quintuple Helix makes it possible to involve in the decision-making process a truly representative group of stakeholders, making the outcomes more responsive to the real needs of the territory. The *In.Kiostro* action-research process underlines the role played by culture, in its spatial declination (existing cultural heritage) and social interpretation (cultural promoters). At the same time, the implementation of different tools, especially during the Co-exploration phase, makes it possible to collect the needs of the community by integrating them into the knowledge and analysis of the territory, spatializing formal/informal uses and the prevailing subjective and perceptive aspects. The construction of a deep knowledge of community needs emphasized the temporal variable role, supporting the development of practices and processes with different durations and adopting an iterative, adaptive, and dynamic approach, allowing incremental knowledge in the Co-evaluation phase of design choices. In addition, the brainstorming tool makes it possible to collect and visualise all the proposals, rank them and identify a few salient themes that form the core of the co-design phase. At the same time, the business model canvas stands out for its ability to engage stakeholders in a co-design process that considers economic aspects and facilitates the development of innovative and operational proposals. In addition, the personas model allows us to focus on the end users and their needs, and the power-interest grid supports the visualisation and classification of stakeholders according to the power and interest they potentially have in the design process and is a relevant tool for identifying the weight of stakeholders in the decision-making process.

Considering the Selection phase, in dealing with complex decision-making problems, the selection of appropriate evaluation methods is essential, and SOCRATES allows the inclusion of a multi-dimensional process into the assessment. This method, indeed, facilitates the systematizing of qualitative and quantitative information in an integrated way, interpreting its heterogeneity into a coherent system. Moreover, the use of open-source software makes it possible to carry out research characterized by continuous integrations, facilitating the updating of final rankings. In perspective, the SOCRATES method could be implemented in the co-evaluation of a preferable design alternative, testing the dynamism and adaptability of the method, which can potentially be applied to different design scales and levels of detail.

Finally, referring to the Project and testing phase, many opportunities have not yet been explored, which allow, among other things, to outline future research. Among

these, given the ongoing consultation with the decision-makers, the discussion of the results with the stakeholders, the acceptance of the proposal with the necessary additions and the stipulation of an agreement between the various actors involved, it is possible to imagine further actions aimed at expanding the network, raising awareness of the local community for the feeling of re-appropriation, experimenting with the chosen uses and, finally, the definitive reactivation of the asset being researched. All these actions (self-construction, competitions of ideas, experimental programming, etc.) find their place in the conceptual framework of the *living lab,* activated in the last phase of the methodological process.

In.Kiostro's decision-making process is based on the interpretation of temporariness as a privileged tool for urban and social regeneration, since it makes it possible to trigger virtuous socio-spatial dynamics that are capable of self-regeneration and, in the long term, of becoming permanent. In this sense, it represents one of the most important partial results of the research carried out so far, since it is confirmed as an indispensable tool for the first and necessary form of reappropriation of the cultural heritage and its reactivation. A critical revision of the tools chosen contributes to support the definition of a new role of the designer-facilitator, who must equip himself with new skills and abilities (technical, relational, etc.) to design, manage and implement a design process capable of producing innovative and operational results.

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Third Places and Transitory Uses: The Experimental Project "Hall - Hemicycle Agrifood Living Lab" in the East of Naples

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Abstract. Buildings and unused spaces, grounds for experimentation for temporary uses, are known in France for years as "tiers lieux", or third places where hybrid programs and incremental processes are experimented with for the transformation of abandoned spaces. Italy, and particularly the city of Naples, has started to take an interest in the experimentation of temporary uses, approving with Municipal Council Resolution No. 30 of 2022 a "Draft Convention for the regulation of temporary uses for public spaces and publicly owned real estate." It is not coincidental that within the framework of the "CA23 Plural Territories Architecture Festival of 2023", the Living Lab "Inhabiting the City in Transition. Evolutionary projects for the reuse of urban buildings" was held in Naples. Evolving projects for the reuse of large abandoned urban containers, focused on the theme of temporary uses. The Living Lab provided the opportunity to test integrated design projects on some of the numerous abandoned buildings that dot the urban landscape of the city of Naples. Among the most interesting cases is the case study of a nineteenth-century building, the head of a now-disused productive urban block, which became the subject of study for the thesis "Hall-Hemicycle Agrifood Living Lab, transitional agritecture for East Naples," following the Festival. The thesis project is based on an experimental methodology that integrates design, economic appraisal and evaluation tools and methods to advance a proposal for incremental and adaptive reuse that unveils the latent potential of the abandoned spaces of the urban block in question, returning meta-processes aimed at demonstrating the feasibility and potential (multivalued) activatable through the experimentation of temporary uses.

Keywords: Transition · Process · Third Places

1 Introduction

Borges, in substantiating his poetics aimed at removing reality from the ontological condition of certainty, instead emphasizes all the charm of the enigma that the "ephemeral" present, even if real, carries within itself. In fact, in "Storia dell'eternità" (1936), he writes: "Time is a problem for us, a disquieting and demanding problem, perhaps the most vital of metaphysics: eternity, a game or a laborious hope." [2].

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The tension between the transient and the eternal is certainly not foreign to the dimension of the project as an act of configuring a space in the present, which through the project is "projected" into the future. Designing implies transforming space, thinking about its configuration, habitability, use, character, etc., simultaneously delivering the project (more or less consciously) to the real conditions of the present time, but also to the unpredictability of the changes and metamorphoses of space over time to come.

This "short-circuit" between designed space and realized space occurs through the practices of use by the "bodies" that experience it, that inhabit it.

The continuity (the perpetuity, the eternity) of architecture does not exactly lie in the infinite possibility of renewal "in form" and "meaning" of space over time? It is not about giving up the perspective of a formal and defined configuration of space, but rather about thinking of the project within an articulated timeline.

Confronting the temporal dimension in design is a fundamental condition, especially in reference to the modification of existing built space, the numerous vacant, abandoned buildings that characterize contemporary urban landscapes, in a context of increasing economic and political fragility where it is increasingly difficult to activate, sustain over time, and manage processes of requalification and reuse of forgotten heritage.

The European panorama, particularly in reference to French experiments, provides some interesting examples of processes of reuse and urban regeneration of abandoned heritage, initiated through the activation of temporary and/or transient uses.

In Italy, a first legislative recognition regarding transient uses was introduced as an amendment to Article 23 quater of DPR 380/2001 and subsequently taken up by some regions, such as Lombardy, Emilia Romagna, and Campania, with Regional Law 13/2022 "Provisions on building simplification, urban regeneration, and the requalification of existing building heritage." Thes are some initial experiments in updating the procedural framework to allow for the temporary use of buildings, disused and/or underutilized areas, through different intended uses than those originally planned and regulated, to try to counteract processes of further obsolescence and activate unused public assets even for limited periods.

The city of Naples approved with Municipal Executive Resolution no. 30 of 2022 the "Draft Convention for the Regulation of Temporary Uses for Public Spaces and Publicly Owned Buildings", demonstrating sensitivity and interest in pursuing temporary reuse experiments. Within the framework of the cultural and scientific debate on these topics, the work developed in the Living Lab "Inhabiting the City in Transition. Evolutionary projects for the reuse of urban buildings" (edited by O. Fatigato and G. Freda) as part of the CA23 "Plural Territories" Architecture Festival in 2023, and subsequently the thesis proposed as a case study in this article, "Hall-Hemicycle Agrifood Living Lab, agritecture in transition for East Naples", is inscribed.

The proposed thesis is based on an experimental methodology, where the interpretative, design, and narrative choices of the process integrate methodological approaches and operational tools of architectural and urban design with those of estimation and evaluation. The thesis develops a proposal for incremental and adaptive reuse over time that reveals, in multi-valued terms, the latent potential of the abandoned spaces of the urban block in question.

2 Theoretical Approach

2.1 Moving Spaces in "Infinite Places"

At the Venice Architecture Biennale 2018, the collective "Encore Heureux" coined the title "Lieux Infinis" for the exhibition they curated for the French Pavilion, presenting ten contemporary French projects that differ from each other in terms of function, typology of space, ownership, and funding for implementation. These projects are all aimed, according to the diversity of cases, at transforming existing abandoned buildings into "spatial" laboratories where different forms can be experimented with over time to come together, inhabit collective and inclusive spaces in the contemporary "moving" city; an important opportunity for reflection on the reuse of vacant, abandoned, and/or disused buildings, and the indispensable relationship between spatial and temporal dimensions in architectural design.

For the curators, these ten "collaborative, ecological, and supportive" places are representative of a possible different way of regenerating abandoned and disused spaces over time, and of experimenting with new "forms" to inhabit the contemporary city, through the initiation of processes that can be implemented over time.

The concept of "pioneering places" in waiting or in becoming, is discussed – such as "le 104" in Paris, "Atelier 6B" in Saint Denis, "La Friche belle de Mai" in Marseille, "Lieu Unique" in Nantes, "La Ferme du Bonheur" in Nanterre, etc. – where the transformation of space is understood as inevitably connected to the transformation of the social bonds that inhabit it. Through the title of the French pavilion, "Lieux Infinis", "Encore Heureux" connects the notion of place and thus of space, with that of the infinite and thus of time, an "infinite time", which is recognized as a fundamental and indispensable paradigm for the conception of a "place". The notion of "infinite place" refers to the idea that if it is true that every spatial phenomenon occurs over time (Pierre Donnadieu and Elizabeth Mazas, 2002), space can only be continually changing (in motion) because it is the field in which relationships, events, uses, forms of connection, most of the time unpredictable, between the "bodies" that use and inhabit space are realized and manifested. The unexpected is therefore considered as an "opportunity" for the unexpected "manufacture" and experimentation of space in relation to time. The notion of "indeterminacy", which this approach to regeneration project implies, challenges design disciplines to prefigure adaptive systems, open to the unpredictable, to act therefore within a problematic oxymoron but capable of opening up numerous possibilities. The sought-after indeterminacy, not to be confused with vagueness or the ephemeral, characterizes interesting design operations coordinated by interdisciplinary collectives and/or cooperatives of designers, with the involvement of heterogeneous operators, in which new forms of governance and public-private alliance are experimented with, for the clear objective of overcoming the obsolescence of the new project through a new way of thinking about the transformation of the "old".

The experiments of the "infinite places" presented at the Biennale indicate alternative paths to rethink the processes of transformation of abandoned places, another way of thinking about the space of architecture and conceiving the project, but also of rethinking the role of the architect in this process.

2.2 Transitory Uses for Experimenting the "Possible Overlooked"

France is one of the most advanced countries in Europe regarding the experimentation of transient uses (*urbanisme transitoire*) as a phase of integration in many urban transformation and regeneration programs, thanks to the support of continuously updated national and local regulatory frameworks.

In France, since 2016, there have been a series of legislative updates to facilitate and allow, within predefined time frames, the initiation of temporary use projects in disused buildings, often starting with exemptions from existing urban planning and building regulations, due to the ability of such experimental projects to generate social, economic, and environmental value.

A precursor to this procedural innovation (and naturally, beforehand, cultural) is undoubtedly Patrick Bouchain, the creator of the "permis de faire" a principle that advocates for the "pleasure of doing" through collective experimentation of new uses in abandoned and/or underutilized buildings. Specifically, the "permis de faire" was introduced in the update of the State Law on the "Freedom of Creation for Architecture and Heritage" (2016). The law recognizes the creative and experimental aspect of architecture and in Article 88 legitimizes the "permis d'expérimenter", as the possibility of giving actors (residents, local authorities, third sector, entrepreneurs, etc.) the opportunity to explore what Bouchain calls the "possible overlooked".

Patrick Bouchain, awarded the *Grand Prix de l'Urbanisme* in 2019, has always directed his work towards the necessity of "faire autrement" (doing differently); he has been a pioneer of an architecture oriented towards reuse, "frugality", and the experimentation of collaborative practices. In 2006, with "Metavilla", Bouchain transformed the French Pavilion (of which he is the curator) into a space of informal living. In response to the theme of the Biennale – City, Architecture, and Society – "Metavilla" ("Mets ta vie là") is conceived as a place inhabited by the curators, intended to welcome the public and passersby. "Metavilla" aims to demonstrate that space is the field of human relations that unfold over time, and that from these relations, it changes, hybridizes, evolves.

Already in "Metavilla", the potential of the temporary space of the French Pavilion as a field of unexpected and unpredictable relations is affirmed: life in the pavilion is showcased as a true resource of inhabited space.

Starting from the pioneering work conducted by Patrick Bouchain, numerous interdisciplinary groups have emerged in the last fifteen years that have contributed to maturing the theme of "urbanisme transitoire" through numerous research and experiences. Just to name a few: Yes We Camp, Plateau Urbain, Encore Heureux, Communa, etc.. These groups have become new "real estate" actors capable of carrying out significant investments for the temporary use of public and private properties, requalifying disused spaces, and generating innovative economies [3].

Buildings and spaces in disuse, which serve as experimentation grounds for transient uses, are known in France as "tiers lieux", or "third places", where beyond living and working, hybrid programs and incremental processes are experimented with for space transformation and the possibility of shaping those "overlooked possibilities".

Indeterminacy becomes a significant aspect in these experiments, attentive to the changing nature of human interactions and the emerging needs over time. Spaces designed for transient uses are often conceived to have the ability to adapt to unforeseen

scenarios and the evolving needs of the community that inhabits them. This indeterminacy can be seen as an opportunity, rather than a limitation in defining space, because it opens up experimentation for creative and innovative solutions.

In summary, the project for transient uses of empty space requires a delicate balance between the precise definition of key elements and the ability to embrace indeterminacy as an integral part of the process. This goal calls for the creation of spaces capable of evolving along with the dynamic movements, allowing for active participation of users in the co-creation of the environments in which they live and move.

2.3 Transitory Space in Naples: Projects, Experimentations, Perspective

Reflections on the experimentation of temporary uses have also begun to interest Italian cities. Several administrations are carrying out significant work on experimenting with temporary (and/or transitory) uses as a strategic tool to reactivate disused buildings owned by the public. Legislative recognition of temporary uses was introduced as an amendment to Article 23 quater of DPR 380/2001 and subsequently adopted by various regions such as Lombardy, Emilia Romagna, and Campania itself, which approved Regional Law No. 13 of 2022, "Provisions on building simplification, urban regeneration, and the requalification of existing building heritage". In general, these are a series of regulatory and procedural frameworks that essentially legitimize the temporary reuse of buildings, disused or abandoned areas, even providing for possible derogations from the intended uses outlined in the reference regulatory framework.

A virtuous example is provided by the Emilia Romagna region, where the "Laboratiry Hub" has been activated - a space designed as a tool for discussion to reflect on the new conditions and demands of contemporary cities, with particular attention to temporary actions for the reuse of places and buildings, not only public ones, through activities that experiment with participatory methodologies to facilitate sharing processes and collective learning.

Even the city of Naples, by approving Municipal Council Resolution No. 30 of 2022, "Draft Convention for the Regulation of Temporary Uses for Public Spaces and Publicly Owned Buildings", aimed to promote processes for the temporary use of public assets. At present, this draft agreement still finds very limited concrete project implementations, also due to the difficulty of collaboration between different public offices, which a temporary reuse project requires.

Within the framework of the CA23 "Plural Territories" Architecture Festival, held in various locations in Campania and Paris in 2023, the theme of temporary uses was addressed through the work of one of the six Living Labs of the Festival. In particular, in Naples, in collaboration with the Department of Architecture of the University Federico II and the ENSA Paris Malaquais, the Living Lab "Inhabiting the City in Transition. Evolutionary projects for the reuse of urban buildings" [4] was organized, focusing on the theme of temporary uses, starting from the important regulatory steps taken by the Campania Region and the Municipality of Naples.

The living lab was conceived and structured as a collective laboratory that investigated the regeneration processes of some large disused containers in the city of Naples, starting from the activation of possible temporary uses. Together, participants discussed

the co-creation of innovative programs, new forms of hospitality to re-inhabit these spaces, proposing open and incremental strategies over time.

During the Living Lab, the specificities, the "stories", and the potentials of some abandoned buildings that populate the urban territory of Naples at different scales were explored.

Living Lab participants, along with community residents, architects, photographers, artists, students, and university professors, reflected on the value of these containers as "places of possible overlooked".

Integrated design projects were tested on some of the numerous abandoned buildings that punctuate the urban landscape of the city of Naples, resulting in meta-processes aimed at demonstrating the feasibility and potential activated through the experimentation of temporary uses.

The integrated methodological approach started from the development of an interactive and expandable map of the disused urban heritage, both public and private, in the area of East Naples [5].

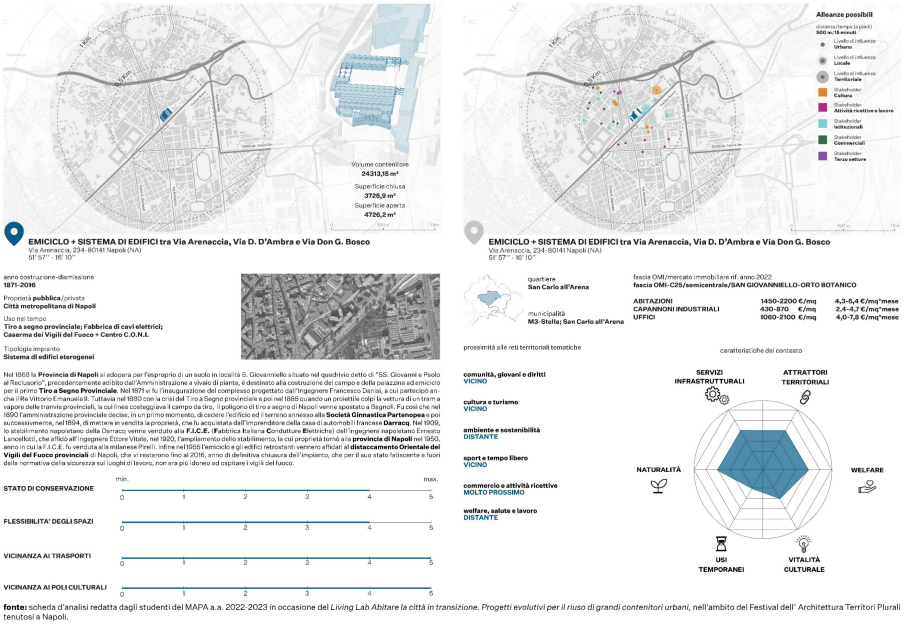
Through this mapping - not exhaustive, partial, and carried out in the short time available during the LL activities - about ninety buildings were identified, for each of which a multi-criteria interpretative card was subsequently developed (see Fig. 1).

The buildings were first divided into three groups according to the recorded square footage. We reasoned in terms of cubic meters rather than square meters to demonstrate the need to think in terms of "capacity of potential habitable space" (cubic meters) with reference to the empty buildings identified and mapped.

The cards were structured into two distinct parts, side A and side B. The front (side A) was conceived as a sort of identity card for the building, where historical, dimensional, and typological information about the building was provided alongside the identification of some useful indicators from the perspective of the temporary reuse of the analysed building, such as: state of conservation, flexibility of spaces, proximity to transportation, proximity to cultural hubs, accessibility. On the back (side B) of the card, the possible networks at different scales, in which to graft the building starting from its reuse, were indicated: stakeholders (cultural, institutional, third sector), hospitality activities, commercial activities, within a walking radius of about 15 min from the building.

The work related to some established indicators, including the level of influence of these stakeholders (urban, local, and territorial), led to the identification and graphical representation of the different degrees of proximity of the surveyed building in relation to the identified territorial and contextual thematic networks.

The experience of the Living Lab concluded with an interesting collaborative workshop coordinated by Mathias Rouet, co-founder of the French cooperative *Plateau Urbain* and one of the leading experts in France on the topic of "urbanisme transitoire" (see Fig. 2). The workshop involved participants from the LL (students, doctoral candidates, professors, collectives, representatives from the Municipality of Naples, and curious citizens), who were divided into groups of promoters, operators, and users. Based on cross-evaluation criteria and a hypothetical budget for investment, they defined which of the mapped buildings was potentially most suitable for reactivation through temporary uses and integrated, incremental methods over time.



fonte: scheda d'analisi redatta dagli studenti del MAPA a.a. 2022-2023 in occasione del *Living Lab Abitare la città in transizione. Progetti evolutivi per il riuso di grandi contenitori urbani*, nell'ambito del Festival dell' Architettura Territori Plurali tenutosi a Napoli.

Fig. 1. Example of a multicriteria evaluation card

Among the buildings addressed in the workshop, was the nineteenth-century hemicycle of the former fire station, which, based on the reflections and outcomes of the workshop, was identified as an interesting case for further research.

Consequently, it became the subject of the experimental thesis work titled "Hall-Hemicycle Agrifood Living Lab: Agritecture in Transition for East Naples" by Simona Capaldo (supervised by Orfina Fatigato and Maria Cerreta).



Fig. 2. Workshop with Mathias Rouet, co-founder of *Plateau Urbain.* During the Living Lab "Inhabiting the City in Transition", in CA23 Plural Territories Architecture Festival

3 Case Study and Methodology

3.1 The Integrated Project "Hall-Hemicycle Agrifood Living Lab, Agritecture in Transition for EastNaples"

The thesis "HALL - Hemicycle Agrifood Living Lab, agritecture in transition for East Naples" by Simona Capaldo develops a structured strategy in different temporal phases for the reuse of the building system, which, along with the hemicycle, an 19th-century building, constitutes the complex block between *via Arenaccia*, *via Domenico D'Ambra*, and *via Don Giovanni Bosco* in Naples.

The project aims to restore to the community a space with an agricultural vocation, where different, incremental uses related to food and based on the principles of the circular economy can be experimented with.

The thesis work is based on an experimental methodology, where interpretative and design choices integrate methodological approaches and operational tools of architectural and urban design with those of economic appraisal and evaluation.

The interpretative elaborations of context knowledge used by architectural and urban design (inter-scalar maps, collages, photographic collections, sections…) are always accompanied by diagrams and organizational charts for the detection of indicators, through quantitative and qualitative data supporting the identification of project objectives and allowing the structuring of a complex decision tree for design decisions.

The project elaborations are approached experimentally: a project "timeplan", replacing the traditional masterplan, constantly interacts with a schedule, developed based on the decision tree and financial analysis, which constantly evaluates the economic advantage of the investment; inhabited perspective sections and storyboards are the drawing and representation tools rethought and used to explicitly demonstrate results and outcomes that propose an incremental and adaptive reuse over time, thus revealing, in multivalued terms, the latent potential of the abandoned spaces of the urban block in question.

The work proposes a strategic schedule where the different temporal phases intertwine space transformations with the identification of promoters, operators, and users as co-activators of the process over time and through a non-linear economic model based on the principles of the circular economy.

An economic model of production and consumption that exploits innovative tools to promote material and immaterial development based on sharing, lending, reuse, repair, refurbishment, and recycling of existing materials and products as long as possible, where extending the product lifecycle not only contributes to minimizing waste but also enables value generation from what, in a traditional linear production process, is conceived as waste.

The experimentation developed through the "HALL" thesis raises some fundamental questions regarding the relationship between spatial and temporal dimensions for the regeneration of urban spaces from abandonment, identifying in transient uses an important tool for the transition project that, surpassing the aesthetics of the ephemeral and/or the provisional, is rather intended as a process that takes into account the evolutionary dimension of time and therefore space in relation to time, in which transient uses serve as a trigger for reuse projects.

In the experimentation work, it is interesting, as an outcome of the integrated methodology, the estimation of the "cost of vacancy" of the building as well as the comparison of the "project scenario" with a "trend scenario" of abandonment and a "restoration scenario" of the building's last active use; the comparison of the respective financial analyses of the three scenarios highlights the economic advantage of the "project scenario" and therefore demonstrates the necessity and urgency of intervening on such a disused building.

The thesis work is structured in three operational phases: immersion, strategy, and experimentation.

The immersion phase, as reading and inter-scalar interpretation of the reference context, is built through heterogeneous materials (collages, cartographies, archival documents, maps, diagrams of space-time evolution of the area).

The strategy phase is articulated, starting from the identification of project objectives and develops through the structuring of a schedule articulated in different phases and time intervals, in which the transformation of space is conceived in relation to time and the different actors (promoters, operators, and users) who, through partnerships of various natures (public-private, public-public, public-private-social), allow triggering the process through experimentation of transient uses: between a prefigured past and a future to be prefigured over time.

The experimentation phase, in which the project proposal is concretized, intended precisely as a proposal for an adaptive and evolutionary architectural and urban project, open to implementation over time and respectful of the "productive unpredictability" that animates contemporary society, in continuous evolution.

3.2 Immersion: The Hemicycle Multidimensional Values

The project area, located in what was originally defined as the *"quadrivio dei SS. Giovanni e Paolo al Reclusorio"*, is situated at the point where *via Foria* concludes, intersecting *via Arenaccia.*

Italo Ferraro, in "Napoli, Atlante della città storica. San Carlo all'Arena e Sant'Antonio Abate" (2002), describes this part of the city as *"costituita da due parti assai differenti tra di loro, collinare quella di San Carlo all'Arena, da Capodimonte a Capodichino, del tutto pianeggiante quella del borgo Sant'Antonio Abate, da porta Capuana all'Arenaccia… E dunque è la storia, ovvero l'evoluzione e la formazione della struttura urbana, a legare queste due parti urbane a monte ed a valle di via Foria, unite da ruoli diversi in relazione allo scorrimento delle acque, e ciò fino ad un tempo non tanto lontano; questo comune legame con l'acqua è una delle caratteristiche generali di Napoli, e riguarda gli aspetti di una forma analoga in parti anche molto differenti tra di esse; a Napoli tutte le strade, spesso nate da antichi corsi d'acqua, portano al mare"* [6]. This area, therefore, conceived as a point of junction and connection between hill and sea, presents countless landscape and strategic positioning potentials (see Fig. 3).

In fact, in addition to *via Arenaccia*, the area borders *via Don Bosco*, originally called *via Nuova del Campo* and conceived to provide the city with a main entrance from the East, intersecting *via Foria* and thus the "Real Albergo dei Poveri". Within a few kilometres, moreover, the project area, already heavily underutilized, is dotted

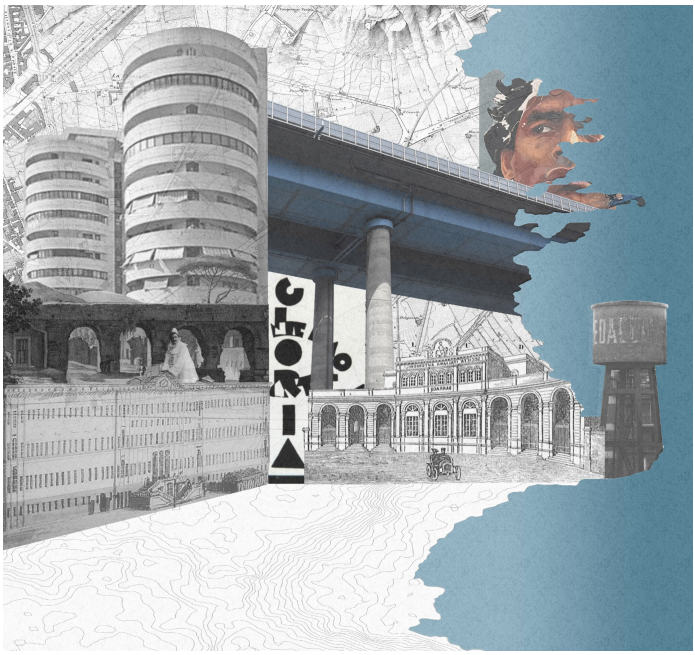


Fig. 3. Interpretative collage of the project: connection between hill and sea.

with a series of other architectures or infrastructures, heterogeneous among themselves, which for different reasons and stories, are unused or otherwise heavily degraded.

"(Re)discover the Hemicycle" means to highlight the complexity and contradiction that characterize this piece of the city, not only through the rewriting of a narrative of events that led to its abandonment but also through the understanding of how temporal evolution of this place has been accompanied by spatial transformation. Originally, the Province of Naples, owner of the area, worked on the construction of the Provincial Shooting Range (1868), which remained in use until 1890, when it was closed and later sold to a private individual in 1894. Following a series of changes in ownership, the area began to undergo transformation, and industrial hangars were built behind the nineteenth-century building, extending across the entire lot, as clearly visible in an aerial photograph from the IGM of 1949. A significant transformation occurred in 1955 when the block was repurchased by the Province of Naples. They demolished some hangars and entrusted the hemicycle and the existing hangars to the eastern detachment of the Provincial Fire Brigade of Naples. However, starting in 2016, the hemicycle and the complex of buildings behind it were closed due to their dilapidated state and non-compliance with workplace safety regulations. They remain awaiting a new narrative even today. From 2016 to the present day, what has been the loss in terms of material (economic) and immaterial (social and cultural) value for the Province of Naples, now Metropolitan City, in keeping this building closed? Is it possible to estimate the "cost of vacancy" to understand even just the economic impact that abandonment has caused?

The first methodological phase of the thesis concludes with an investigation into the management costs that the owning entity faces annually (see Fig. 4), arriving at a "cost of vacancy" of approximately 300,000 € over eight years.

This number represents an initial objective indication of the need to intervene on the property and demonstrates that reuse, if possible, contrary to abandonment, oblivion, and obsolescence, appears necessary, even obligatory, if one aspires to a more sustainable city model and a society more attentive to waste.

EDIFICIO	SPESA di GESTIONE	QUANTITÀ	COSTO di GESTIONE ANNUALE	n. anni dismissione	COSTO di GESTIONE TOTALE	TOTALE
	TARI	mq		(anno 2016-2024) **8 anni**	costo di gestione annuale*8	
Emiciclo	sì	926,7	11084,22	8	88673,76	
Ex cappella	sì	91,1	581,52	8	4652,16	
Hangar 1	sì	959,6	10.989,23	8	87913,84	
Hangar 2	sì	993,9	9208,68	8	73669,44	
Ex palestra	sì	616,3	4656,96	8	37255,68	
						292164,88 €

fonte: https://www.riscotel.it/calcolo/tari/napoli/

Fig. 4. Table of management costs for the abandoned building from 2016

3.3 Strategy: Transitory Uses and Evolutionary Design for "Hall" Activation

"(Re)discover the Hemicycle" first and foremost means restoring its visibility at an urban scale: this second phase of the research is based on the construction of an inter-scalar project strategy to reconnect the hemicycle block to the city through a system of soft mobility (cycling and pedestrian) as a natural connection of the area to the hilly part to the north and towards the sea to the south, building a network of connection between different buildings, abandoned and underutilized areas that punctuate the vast area of East Naples (among others: the "Albergo dei Poveri", the "Fabbrica Redaelli", the "Ospedale psichiatrico Leonardo Bianchi", the "Centro Direzionale"). To rethink the role of the block in its immediate context, four fundamental spatial themes are identified: the retaining wall of the block as a porous margin towards the "Arenaccia" neighborhood; the permeability of internal crossings within the block as a new crossing system; the sequence of squares as a multiplication of public space.

The project's objective, in relation to some of the "Sustainable Development Goals of Agenda 2030" (in particular, No. 2 Zero Hunger; No. 3 Good Health and Well-being; No.11 Sustainable Cities and Communities; No. 12 Responsible Consumption and Production), aims to give back to the community an agricultural space where different, incremental uses related to food and based on the principles of the circular economy can be experimented with.

The project strategy addresses these themes and aims, as evoked by the title of the thesis itself "Hall-Hemicycle Agrifood Living Lab, transitional architecture for East Naples", to experiment with innovative agricultural production systems that interact with the existing architecture.

The term "hall" etymologically defines a large entrance and meeting space in buildings and venues. Conceptually, this meaning is translated into the project's intention to return to the city a permeable space for socializing. Specifically, it refers to an agricultural space where different, incremental uses related to food and based on the principles

of the circular economy can be experimented with, including: local agricultural production, through the installation of urban gardens and experimental hydroponic cultivation systems (hangar 2); processing and selling of products in a hybrid and co-open market space (hangar 1); consumption and relaxation (hemicycle building); research, experimentation, and training in the food and culinary field (newly constructed "Core" building) (see Fig. 5).

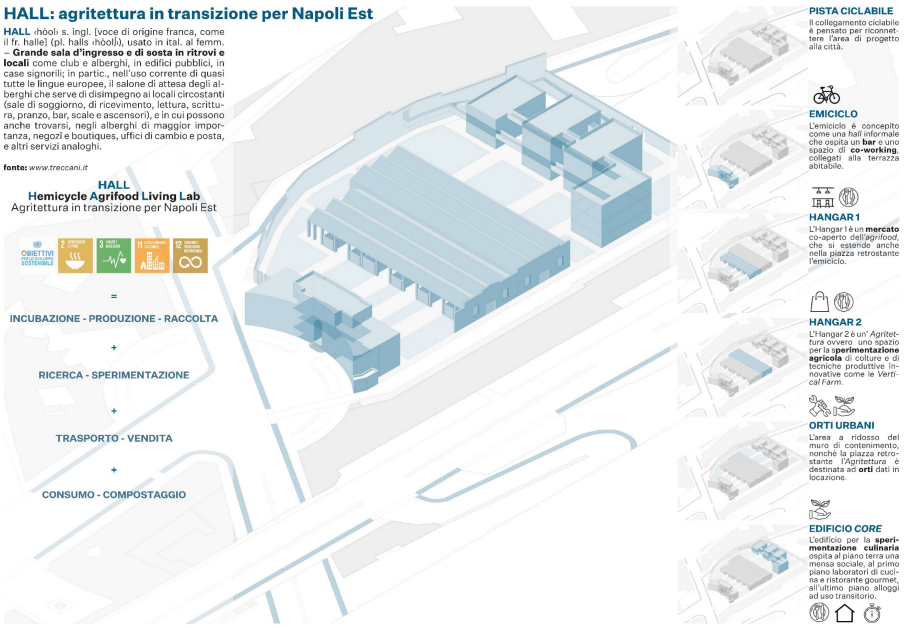


Fig. 5. Goals and Functional Program of the "HALL" project

The strategy emphasizes the innovative nature of the project conceived as an evolutionary process in its spatial and temporal dimensions, structured through a "project space-time line" that clearly associates space and time transformations, defining for each action what is intended to be achieved, who are the involved stakeholders in terms of promoters, operators, and users, and how these actions materialize in terms of "public-private-social partnerships", specifying the spaces involved where actions and intentions are spatialized through the project.

The project strategy is structured into three incremental temporal phases, each lasting 5 years:

The "seeding phase" involves, in parallel with the restoration of the hemicycle and the two hangars, the partial opening of the area through the conduct of temporary use activities (markets, urban gardens, concert space, etc.) in open spaces. These activities require quicker reactivation actions through a construction and management concession between the property owner, namely the Metropolitan City of Naples, and some third-sector entities specialized in organizing events for temporary uses.

This 5-year phase allows, through initial temporary occupation, not only to begin to give visibility to the area through programming based on functional mixity but also, in financial terms, to generate initial revenues that cover the expenses for interventions on existing buildings.

The "growth phase" (5–10 years) involves the simultaneous opening of existing buildings and the reconfiguration of the adjacent open spaces, along with the commencement of the construction of the "Core" building in the area previously occupied by temporary events. For the reactivation of the existing buildings, different models of agreements have been envisaged, ranging from" public-private" to "public-private-social" partnerships. For example, for Hangar 2, intended for the progressive experimentation of new agricultural techniques, a "Build Transfer and Operate" (BTO) partnership has been envisioned. In this partnership, the Metropolitan City of Naples finances the reconfiguration of interior spaces and the provision of facilities, while technicians from the "Real Orto Botanico" and third-sector entities collaborate to establish a network of producers/sellers/buyers (including associations such as "Semenza", "Coldiretti Campania", and the "Dedalus Cooperative"). During this second phase, significant revenues are generated, exceeding the construction and management costs of the completed works, resulting in initial profits.

The "harvest phase" entails the conclusion of this project experimentation, without excluding the possible future evolution of the process. Among the actions of this last five-year period, the most interesting is certainly the realization of the "Core" building, a hybrid structure that embodies the project's overall vision in terms of functional programming, the process of construction interventions, and collaboration among actors of different "public-private-social" nature. Indeed, the "public-private-social" partnership established for the construction of the building, through a "Build Own Operate Transfer" (BOOT) partnership, involves different promoters, operators, and users in the last two temporal phases of the process ("growth phase" and "harvest phase").

This second methodological and strategic phase involves a continuous comparison between proposed spatial reconfiguration designs and the economic sustainability of interventions, taking into account the principles of circular economy highlighted earlier. The design proposals are not seen as fixed answers but rather as incremental and experimental solutions open to possible evolving questions over time, reflecting the complexity and ontological uncertainty characterizing the contemporary city.

3.4 Experimentation: Three Scenarios Compared for the Urban Block of the Hemicycle

The design experiments involve the sequence of buildings that make up the block: the hemicycle, conceived as an informal and "porous hall", almost a threshold element between the block and the city; the "co-open" market composed of movable modules that can extend outside, configuring a constantly variable open space; the "agritecture", a term understood as the art, science, and activity of integrating agriculture into the built environment and in the case of the project, interpreted as a space for experimentation and research into new agricultural techniques capable of addressing environmental challenges and developing systems resilient to climate change; the "Core" building conceived based on various compositional experiments in the design phase and composed

of three buildings, interconnected by a system of walkways, allowing for the opening of a second access to the block at an elevated level and the possibility of dialogue between the block and the system of buildings behind it (see Fig. 6).

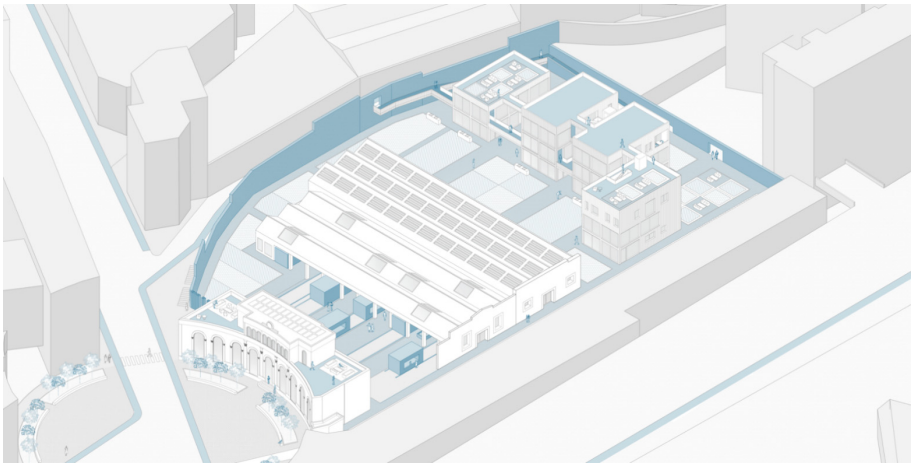


Fig. 6. "HALL - Hemicycle Agrifood Living Lab, agritecture in transition for East Naples"

These design experiments, conceived to conclude within a 20-year process, have been compared to two other possible project scenarios for the subject block, in order to evaluate the actual economic advantage of investing in a design approach that involves experimentation with different and incremental uses.

The methodological interest in comparing the project scenario to two other possible scenarios stems from the desire to address the following problematic question: Is it truly advantageous and therefore desirable to aspire to an innovative and incremental reuse project for this block?

To answer this question, two other possible project scenarios for this isolated complex were hypothesized: a "restoration scenario", in which the block's last function before abandonment in 2016, namely office use, is restored, and a "trend scenario", in which the condition of abandonment, oblivion, and degradation of the facility persists.

Once the three scenarios (project scenario, restoration scenario, and trend scenario) were identified, a financial analysis of revenues and costs was conducted for each of the three scenarios over a 20-year period: revenues were approximated by the revenues obtained from the lease of managed spaces, estimated through consultation of the rental value tables (€/sqm) of the "Osservatorio del Mercato Immobiliare" [7] for the area where the block is located (OMI C-23 range); costs were approximated by the construction and management costs of the works realized, estimated through the comparison of similar works consulted from the catalog of the "ACEN" (Associazione Costruttori Edili della Provincia di Napoli) of 2014 (see Fig. 7).

The financial analysis of the three scenarios allowed estimating the NPV (Net Present Value) and IRR (Internal Rate of Return): indeed, it is from the comparison of the IRR of the three scenarios that it is possible to answer the aforementioned question. From

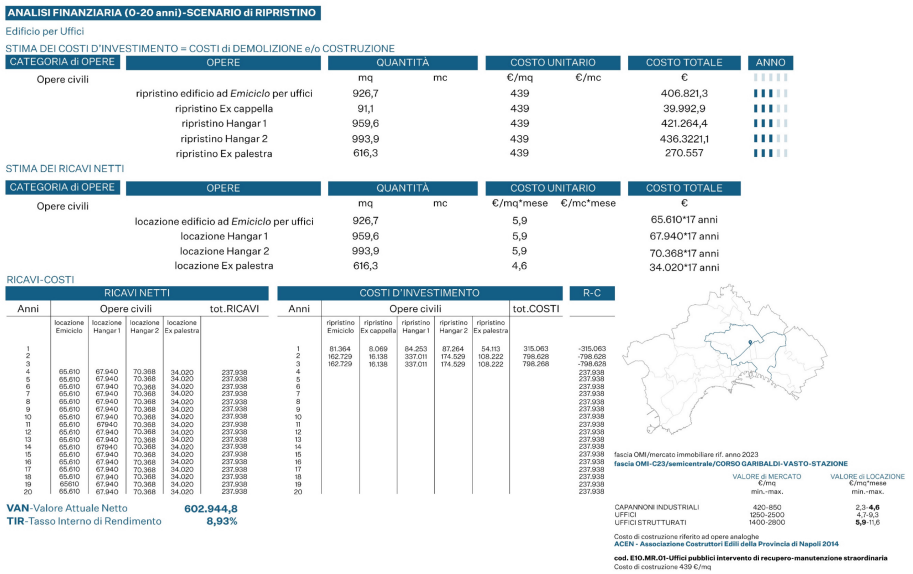


Fig. 7. Financial analysis table of the "Restoration Scenario" (Offices)

the financial analysis, it emerges that the "project scenario" has an IRR of 28.00%, the "restoration scenario" has an IRR of 8.93%, and finally, the "trend scenario" has an IRR of 0%, as the financial analysis shows zero revenues and only a progressive amount of vacant management costs.

So, let's revisit the question: is it really advantageous and therefore desirable to aspire to an innovative reuse project for this area? The comparison of the three scenarios tells us that the answer is definitely affirmative and declares the evidence and urgency of intervening on the property.

To further emphasize this point, another question was addressed: in the case of continued disuse, what is the "economic value of abandonment"?

To answer this, a formula derived from financial mathematics was referenced, where the annual loss in the building's value (Va) is given by the difference between the market value of the project (Vm,prog.) minus the market value of the building in its current state (Vm,today), divided by time (t), the period of abandonment:

$$Va = (Vm, prog. - Vm, today)/t$$

The estimation of the real estate market value, respectively (Vm,prog.) and (Vm,today), was defined by consulting the market value table (€/sqm) of the "Osservatorio del Mercato Immobiliare" for the area where the building is located (OMI C-23 range), referring to the year 2023, which allows us to answer the aforementioned question. Indeed, in the case of continued disuse, the economic value of abandonment is equal to 3.15% of the market value of the project.

The work of experimental design has therefore been substantiated by the estimation of the "vacancy cost" of the building, which was developed in the initial "immersion

phase" and subsequently compared with the financial analysis of the three possible scenarios described above in this final "experimentation phase". The result of this methodological process has highlighted the economic advantage resulting from investing in the experimental, innovative, and incremental reuse of the building. It has also supported the hypothesis regarding the necessity and urgency of intervening on this disused building through an approach that integrates design and economic appraisal and evaluation tools and methods, capable of promoting and enhancing the project's potential.

4 Conclusion

4.1 Transient Uses for Projecting into the "Future Anterior"

The thesis work presented allows for the verification, on one hand, of the proposed theoretical approach regarding the necessary interrelation between space and time to intervene in the processes of reusing abandoned and underutilized heritage, and, on the other hand, to test the integrated methodological approach (between design and economic appraisal and evaluation) proposed.

Referring to the theoretical and scientific debate regarding the theme of reuse and experimentation of transient uses for projects in transitioning cities, it is important to underline how the thesis work, starting from this project approach, aims to focus attention on three main issues:

- A "reuse" project can effectively function in the long term if thought differently, i.e., based on the evolutionary dimension of time and therefore space in relation to time, where transient uses serve as triggers, between a before and an after, of such transformation processes.
- A "transitional" project rejects the aesthetics of the ephemeral or the provisional; it is a project designed to endure over time with the awareness that it does not design on a blank slate or towards a defined future to be prescribed but rather, as Gabriele Pasqui (2019) states: "designing means imagining a future anterior, actions projected into the future but with the awareness that they can occur before others. In this perspective, the project is seen as experimentation because it deals with the world in a context of radical ontological uncertainty" [8].
- A "minor" project, as Camillo Boano (2020) writes, "opens a fracture in the major project where major and minor are not different languages but different uses of the same language" [9]. It recognizes a new figure of the architect, represented not by a single designer but by a collective of interdisciplinary designers, involving heterogeneous and ever-changing operators, implementing new forms of governance and public-private partnerships, aspiring to overcome the obsolescence of the project of the new, so that architecture returns to being a political act aimed at the common good, where aesthetic beauty finds its reason and foundation in ethical beauty.

Referring to the methodological-operational aspect, it is the presented design experience that stands as a demonstration of the necessary integration between design and economic appraisal and evaluation tools and methods. This methodology allowed for the formulation of a proposal for incremental and adaptive reuse over time, capable of integrating multidisciplinary and inter-scale aspects, revealing the latent potential of the

abandoned spaces in the urban block in question, and returning meta-processes aimed at demonstrating the feasibility and the potential (multivalued) activatable through the experimentation of transient uses.

The illustrated design experience highlights and demonstrates the economic advantage of investing in an experimental, innovative, and incremental reuse project over time, and the value and material impact that this project can potentially generate. At the same time, the limitation of this design experimentation is that it is confined, precisely, to a purely methodological-operational dimension, not concretized.

The impossibility to activate the process on the examined artifact does not allow to demonstrate and evaluate the social, cultural (including economic) impacts of the project. Furthermore, in relation to the value of "indeterminacy" as stated in Sect. 1 of this contribution, which is a determining factor in the success of experiments with transient uses of French "tiers lieux", the failure to concretely activate the process does not allow to record "unexpected' effects resulting from the "voluntary" indeterminacy of the process itself. The "possible overlooked", as mentioned by Bouchain, also lies in the unpredictable interaction between bodies inhabiting the space, which can lead to revealing other unexpected material and immaterial potential.

Only the concrete "short circuit" between designed space and realized space can determine the reasons (the necessity) for the real evolution of the process and the additional values it can generate.

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The Dynamics of Containerized Transport in the Mediterranean Sea

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Abstract. The proposed study aims at analyzing the transport dynamics of containerized traffic in the Mediterranean Sea, trying to analyze the main development pathways of the different ports in relation to their geographic location and their afference to the different port ranges present in the Mediterranean Sea and with respect to the different functions they are called to absolve: transshipment hub, gateway or mixed port. Through the use of the Gini Coefficient and to the Shift Share analysis, this study highlights how for different port ranges, transshipment ports are subject to higher traffic volatility. The emerging development trajectories highlighted for the Mediterranean basin imply the strengthening of some gateway ports located in strategic positions with respect to the reference hinterlands, assisted by a growth of the main transshipment hubs located close to the East-West Suez-Gibraltar route, while leading to a loss of traffic shares for smaller ports due to the centralization of flows on a smaller number of ports.

Keywords: Maritime Transport · Transport Dynamics · Shift Share Analysis · Mediterranean Sea

1 Introduction

The Mediterranean port system can be considered as a non-homogeneous set of ports. In fact, we can see how this basin is inter-crossed with a multitude of different ports of call, from established large ones, to a wide range of medium and small ports, each with specific characteristics in which different locational and strategic dynamics intersect within the hinterlands served and the different commodity categories handled. This combination of different types and sizes of ports, supported by the presence of a vast hinterland, has led to the creation of a homogeneous space that is a perfect case study for trying to analyze the factors affecting port hierarchy and competition.

There are numerous studies in the literature that have investigated in depth the dynamics of competition and development of port systems on a regional scale or with reference to individual ports [1–3], and in particular the dynamics of transport flows in the Mediterranean basin have been studied in the works of [4–6]. The contributions just mentioned are the supporting pillars for an in-depth analysis of containerized traffic flows in the Mediterranean Sea area.

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This paper proposes to elaborate a conjunctural analysis about the variation of traffic volumes in relation to the evolutionary arc of different port ranges, considering the strategic role that different ports are called upon to play as gateways for traffic to port hinterlands or transshipment hubs, going beyond the concept of the port as a single node in a transport network, but considering different systems of ports related to each other by geographic location and common hinterlands, finally sketching the evolutionary profiles that different ports are experiencing. As mentioned, the Mediterranean basin is called upon to play a strategic role in maritime transport on a global scale: its location along major east-west trade routes, central to Atlantic, northern European, Asian and African markets offers significant connectivity advantages to shipping companies, allowing for reduced transit times and an important gateway to markets in continental Europe and the Middle East.

However, this contribution was designed and implemented based on the data and geopolitical situation before the crisis that has afflicted traffic transiting the Red Sea and the Suez Canal in recent months since October 2023, due to missile attacks on cargo ships by the Yemeni armed Houthi group in connection with the conflict between Israel and Palestine. As a result, the considerations and results achieved are, at present, obsolete. Given the strategic importance to global-scale traffic of the Suez Canal, however, it is to be expected that the situation can return to near-normality in not too long a time.

This article considers 29 ports located within the Mediterranean Sea basin, with the intention of identifying the main development trends of the region's port system.

2 Literature Review

The analysis of transport dynamics should not disregard the strategic role that different ports are called upon to play. The complex system of transport networks is increasingly articulated, has led to the development of intermediate positions that are called transshipment hubs [7]. These ports are deputed to the function of interface between global and regional routes and represent key nodes in the handling dynamics of containerized traffic. Consequently, container ports occupy two different demand segments from the point of view of transport mode: on the one hand we find sea-sea transshipment cargo handling and on the other hand gateway cargo handling involving a modal shift inland.

In the analysis of transport dynamics, it is crucial to introduce these concepts as it is highlighted in the literature that transshipment hubs are vulnerable to market fluctuations [8]. The possible causes of this vulnerability can be attributed to several factors: the inclusion of transshipment hubs in the transportation network may be only a temporary phase in the development of the port system on a regional basis [5], the strategic choices of shipping lines shift transshipment volumes from one port to another, and competition with gateways that can also handle transshipment traffic volumes [9]. In the opposite direction, gateways represent the main link between regional and global transport systems [10]: these, by nature, will find their geographic location in contexts characterized by a strong development of economic activity within their hinterland [11, 12], assuming a role as logistics "clusters," connecting maritime and land trade flows through the implementation of an infrastructure that is articulated from the waterfront areas to the back-port areas.

Given today's manufacturing environment, articulated along extremely branched production chains, an efficient and well-structured transport system is a factor of strategic importance, linking different modes of transport (maritime rail and road) and offering intermodal services for the distribution of goods. Such infrastructure represents the backbone of a regionalization of different port systems, which originates from the relationship between backport areas, distribution centers and infrastructure [13]. The complexity of the global freight distribution system requires a more pronounced integration between different modes of transport and greater efficiency in the management of supply chains, as well as the increase in freight traffic volumes and the concentration of cargoes on a limited number of ports of call and inland transport corridors, creating conditions for the development of gateway ports in strategic locations along these routes [14, 15].

The increase in traffic volumes on a global scale in the most recent historical period has led to a reorganization of the systemic processes of freight mobility between the port and its hinterland, calling rail transport to play a key function in the dynamics of spatial distribution [16, 26]. The locational characteristics of the various gateways, close to economic hinterlands of reference, determine that the traffic shares achieved by these ports are subject to less volatility than those of transshipment hubs.

3 Data Collection

The Mediterranean Sea plays an extraordinarily important role as a natural thoroughfare for trade flows connecting the Far East to continental Europe. This vast maritime area is bounded by two critical points known as "choke points": the Strait of Gibraltar to the west, which is called upon to fulfill the role of a junction and with the Atlantic Ocean, and the Suez Canal to the southeast, which is the most efficient route for handling the movement of goods on the east-west route. The basin is a key node for global trade, representing an intersection point between intercontinental "pendolum" routes, round-the-world routes, and regional and local flows [17, 18]. Its strategic location within the global macroeconomic landscape makes it a vital crossroads for supplying markets and manufacturing clusters in continental Europe also in relation to the supply markets of the Middle East. The importance of this maritime region is reflected in the complex and intricate port network that has developed in response to this need. The port infrastructure along the Mediterranean coasts has been carefully planned and developed to facilitate the efficient movement of goods and facilitate international trade. The interconnectivity among Mediterranean ports, together with their proximity to the main trade routes, has generated a highly specialized and interconnected port system [19].

These peculiarities have generated a steady increase in traffic volumes operated by the different ports, rising from a share of about 34.9 million TEUs in 2010 to 50.7 million in 2022 with reference to the sample under analysis.

In order to study the evolution of the dynamics of containerized traffic in the Middle-Eastern Sea, the analysis proposes to relate several factors. In addition to the simple quantification of traffic volumes, presented in the summary table below (Table 1), the role of the different ports in relation to the transshipment index was first analyzed, noting that for the macro-region under analysis, the different ports can be divided into 14 gateways, 5 mixed ports and 10 transshipment hubs. Preliminary observations on

traffic volumes and the role of different ports are summarized in Fig. 2. We can see that most of the gateways find location along the northern coasts of the Mediterranean basin while the main transshipment hubs are located along the main east-west route, with particular reference to the major hubs such as Piraeus port, ports located adjacent to the outlet of the Suez Canal such as Port Said and the port of Alexandria, the port of Marsaxlokk on the island of Malta in the center of the Mediterranean, the contenant terminal of the port of Gioia Tauro, and finally the Port of Algeciras near the Strait of Gibraltar.

We must also note how the evolution of mixed ports has led to an increase in transshipment shares for several strategic ports, among which are the ports of Barcelona, Valencia, and Mersin. We can highlight how the gateway function and management of direct trades toward the port hinterland has thus been coupled with the specific functions of transshipment hubs, thus serving as junctions for sea-sea inframodal trades for short- to medium-distance feeder services, effectively assuming a pivotal role in transport dynamics, as confirmed by the steady increase in traffic volumes (Fig. 1).

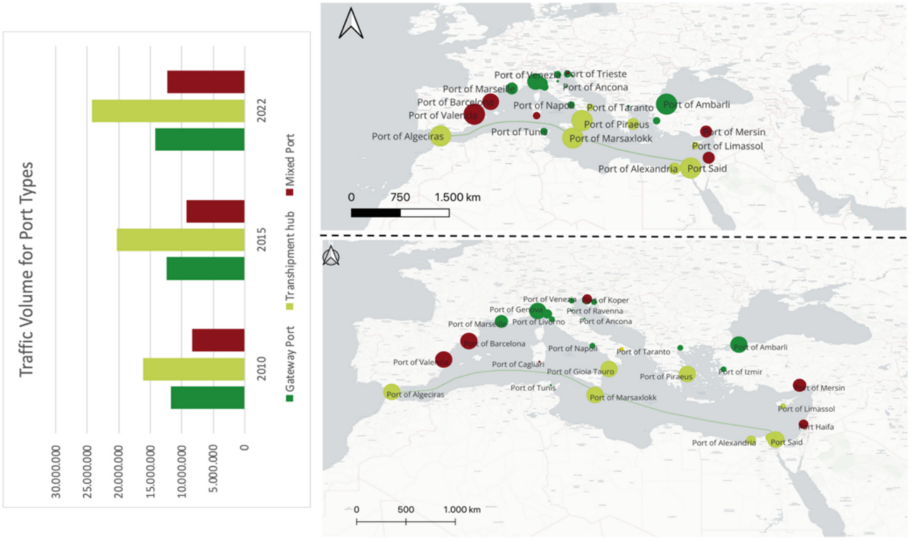

Fig. 1. Traffic volumes for different port types (Gateway Ports, Transshipment Hub, Mixed Ports) in the Mediterranean basin. Source: Personal Elaboration on Port Authorities Data

From this first analysis we can see that transshipment hubs move the largest share of containers, rising from 45% to 48% between 2010 and 2022, while gateways shunted a 32% share of flows to port hinterlands in 2010, falling to 28% in 2022. On the other hand, as far as mixed ports are concerned, deputed to play an ambivalent role in transport dynamics, with reference to flows to hinterlands that in transshipment operations have maintained a traffic share of 23% with some stability.

Table 1. Handled TEU volumes and main port functions by Mediterranean ports.

Country ID	ID	Main Service	2010	2015	2022
EL	Port of Piraeus	Transhipment	885,155	3,327,778	5,311,810
EL	Port of Tessaloniki	Gateway	273,131	351,407	470,645
ES	Port of Valencia	Mixed	4,206,937	4,615,196	5,052,272
ES	Port of Algeciras	Transhipment	2,806,884	4,515,768	4,767,282
ES	Port of Barcelona	Mixed	1,931,033	1,965,241	3,522,944
FR	Port of Marseille	Gateway	953,435	1,223,173	1,530,000
HR	Port of Rjieka	Gateway	137,048	200,102	520,866
IT	Port of Genova	Gateway	1,955,292	2,340,935	2,799,123
IT	Port of Gioia Tauro	Transhipment	2,852,264	2,546,805	3,380,053
IT	Port of La Spezia	Gateway	1,285,155	1.300,442	1,262,496
IT	Port of Livorno	Mixed	628,489	780,874	751,811
IT	Port of Trieste	Mixed	281.643	501.222	877.805
IT	Port of Venezia	Gateway	393,913	560,301	533,991
IT	Port of Napoli	Gateway	534,694	438,280	684,111
IT	Port of Cagliari	Transhipment	629,340	748,647	140,216
IT	Port of Ravenna	Gateway	183,577	244,813	228,435
IT	Port of Ancona	Gateway	110,395	178,476	165,346
IT	Port of Taranto	Transhipment	581,936	0	26,269
ML	Port of Marsaxlokk	Transhipment	2,370,729	3,064,000	2,890,000
SI	Port of Koper	Gateway	476,731	790,736	1,017,798
TN	Port of Tunis	Gateway	420,089	306,931	258,716
IL	Port Haifa	Gateway	1,263,000	1,035,920	1,491,180
TR	Port of Izmir	Gateway	695,799	649,567	390,274
TR	Port of Mersin	Mixed	1,250,873	1,428,300	2,059,309
TR	Port of Ambarli	Gateway	3,023,960	3,061,501	2,867,215
CY	Port of Limassol	Transhipment	382,000	389,000	384,000
EG	Port Said	Transhipment	3,627,813	3,600,000	4,764,583
EG	Port of Alexandria	Transhipment	812,446	978,281	1,488,436
EG	Port of Damietta	Transhipment	1,214,910	1,141,842	1,106,151

Source: Personal Elaboration on Port Authorities Data

It can be seen that the near-totality of the ports under analysis have either maintained their traffic volumes virtually unchanged or are experiencing an expansionary phase. With this in mind, it will be those ports that have seen a drastic reduction in traffic volumes that will be taken into analysis as a specific case study to try to grasp the

dynamics that have led to an almost complete abatement of traffic volumes. In particular, it should be noted how two transshipment hubs located in southern or island Italy have seen an extremely significant collapse in traffic: the port of Cagliari, Sardinia, which went from 748,000 TEUs in 2015 to 140,000 in 2022 and the port of Taranto, which went from over half a million TEUs in 2010 to zero in 2015. We will see below how the reasons for these slowdowns can be attributed to the strategic choices of shipping companies and different terminal operators.

To try to capture the effects of shipping companies' strategic investment choices on the dynamics of traffic volumes, following the general overview presented on the different ports, they were grouped into six different port ranges, presented in Fig. 3 based on geographic proximity.

This categorization divides the different ports into Spanish Med Range (Barcelona, Valencia, Algeciras), Ligurian Range (Genoa and Vado Ligure, La Spezia, Livorno and Marseille Fos), North Adriatic Range (Trieste, Venice, Ravenna, Ancona, Koper and Rjieka), Central Mediterranean Range (Gioia Tauro, Naples, Cagliari, Taranto, Malta Freeport and Tunis (Rades)), East Med Range (Piraeus, Thessaloniki, Izmir, Mersin and Ambarli) and finally South Med Hubs (Limassol, Port Said, Damietta, Alexandria and Haifa).

Considering this local subdivision, the ports of Barcelona, Valencia and Algeciras that make up the Spanish Med Range can catalyze a higher share of traffic than the other clusters, handling 26.3% of total flows in 2022. This subdivision also allows us to note how the northern Mediterranean ports, deputed to gateway functions to the different hinterlands are able to convey on average a more limited amount of containers than the transshipment hubs located along the east-west route. In particular, the ports of Gioia Tauro and Marsaxlokk for the Central Mediterranean Range, the port of Piraeus for the East Med Range, and Port Said for the ports that make up the South Med Hubs, represent the driving forces for the containerized flows of the different clusters.

4 Method

Understanding the dynamics of transportation in the Mediterranean basin must be treated through an organic and systemic analysis of the various ports and its complex set of interactions. With this in mind, the methodological approach taken is marked by two converging trajectories: first, through the application of the Gini coefficient, which is a measure of concentration within the different port ranges and provides useful information for understanding the dynamics of transport for the different ranges [20]. Application of the Gini coefficient suggests that if all ports in a range were of similar size, it would equal zero; conversely, if all traffic volumes were catalyzed on a single port, the Gini index would take a value of 1 [21]. Mathematically, the Gini coefficient is expressed with the following formula:

$$G = \frac{\sum_{i=1}^{n}(2i - n - 1)x_i}{n\sum_{i=1}^{n} f_i} \tag{1}$$

With the Gini Coefficient $= 0 \leq G \leq 1$.

n represents the total number of ports in the sample, f_i represents the frequency, and x_i represents the cumulative frequency.

The two indices just presented represent two fundamental measures for understanding the dynamic evolution of container flows and for trying to capture how localization and geographic components on the one hand, and competitive components among different ports on the other, influence the traffic volumes operated by different ports [19, 22].

In order to try to combine all the different factors highlighted above, however, it will be necessary to flank the two indices just presented with another methodological support capable of providing some more detailed information on transport dynamics, as much by virtue of the variability of traffic volumes in absolute terms as to try to capture the nuances due to the dynamics of development between different ports. For this purpose, as already covered extensively in the literature [23] and in particular by Professor Notteboom [17, 20], the proposal is to adapt the shift-share decomposition applied to ports pertaining to different port ranges.

This methodology approach, which originated in regional economics in the early 1960s, proposed to decompose regional growth, expressed in terms of employment by dividing growth into three different components. The first, named "Share Effect," attributable to national growth, where growth coincides with the growth rate calculated at the highest level of territorial agglomeration. The second component named "Shift Effect" represents how, at the local level, there are some economic activities that grow faster or slower respect to the growth rate of the whole sector at the national level. The third component is named the "Competitive Effect" and represents the portion of a region's growth that is attributable to the better or worse performance of local industries relative to the national average. In other words, it measures how much of the change in employment or economic activity growth can be explained by the relative competitivity of the region's industries relative to the national average [24]. It seems clear that the applicability of this model to our area of study is highly appropriate, by shifting the shift-share model from a regional economy analysis to one devoted to traffic volumes for ports pertaining to the different ranges of the Mediterranean Sea. Employment will be replaced by traffic volumes, the larger spatial unit will cover the total containers handled the Mediterranean area, the different ranges will represent the local level, and finally individual ports will replace industries.

Next, the mathematical formulation of the shift share analysis is presented:

$$v_i^{t+1} - v_i^t = v_i^t \left[\frac{V^{t+1} - V^t}{V^t} \right] + v_i^t \left[\frac{V_r^t - V_r^t}{V_r^t} - \frac{V^{t+1} - V^t}{V^t} \right] + v_i^t \left[\frac{v_i^{t+1} - v_i^t}{v_i^t} - \frac{V_r^t - V_r^t}{V_r^t} \right]. \tag{2}$$

where v_i^t Are the traffic volumes for the i-th port at time t, V Are the traffic volumes for the set of ports under analysis, V_r^t represent the total traffic volumes handled within the individual port range. From this formulation we can then decompose the analysis into the three components observed earlier:

$$\text{Share Effect} = v_i^t \left[\frac{V^{t+1} - V^t}{V^t} \right] \tag{3}$$

$$\text{Shift Effect} = v_i^t \left[\frac{V_r^t - V_r^t}{V_r^t} - \frac{V^{t+1} - V^t}{V^t} \right] \tag{4}$$

$$\text{Competitive Effect} = v_i^t \left[\frac{v_i^{t+1} - v_i^t}{v_i^t} - \frac{V_r^t - V_r^t}{V_r^t} \right] \tag{5}$$

In the application of shift share analysis, we can observe that the "Competititve Coponenet" within the same range is a zero-sum game: thus adding up the individual incremental or diminutive changes will always make the sum zero. The growth of an individual range is then attributable to the "share effect" and/or "shift effect" components.

This empirical application aimed at different ranges is able to highlight the peculiarities in the dynamics of containerized traffic flows, both in reference to growth prospects and to the distribution and concentration of traffic volumes on the various ports (Table 2).

5 Results and Discussion

Table 3 represents the distribution of traffic volumes for the mid-terranean ports within the geographical breakdown for the different ranges proposed earlier. We can first note that between 2010 and 2022, the value of the Gini Coefficient increased from 0.48 to 0.52 for the 29 ports that form the sample: this figure indicates that there is a moderate trend toward a system in which a few ports hold an extremely large share. This trend is practically reflected in the lowering of traffic on a few smaller ports such as the port of Taranto and Cagliari assisted by an expansive phase of the Gioia Tauro transshipment hub, the Port of Piraeus in the east and the ports pertaining to the Spanish Med Range in the west. We can also note that at the range level, the dynamics coerently trace what is expressed by the Gini Coefficient for the set of ports in its entirety, with the sole exception of the Spanish Med Range, which goes from 0.24 to 0.11 by virtue of an extremely balanced distribution of traffic volumes among its three component ports, through a growth phase for the Port of Algeciras between 2010 and 2015 and the Port of Barcelona between 2015 and 2022.

Table 2. Gini coefficient for different port ranges in the Mediterranean basin.

Gini Coefficient	2010	2015	2022
All Ports	0.48	0.50	0.52
Spanish Med Range	0.25	0.24	0.11
Ligurian Range	0.30	0.28	0.34
North Adriatic Range	0.34	0.36	0.37
Central Mediterrean Range	0.48	0.63	0.69
East Med Range	0.49	0.47	0.55
South Med Hubs	0.48	0.46	0.50

Source: Personal Elaboration

The second stage of the proposed analysis comes from the application of the shift-share model adapted to the port area (Table 4). As mentioned, this model allows us to decompose the growth for the different ranges into three different components. The "Share Component," which indicates the potential growth of different ports relative to the entire Mediterranean basin, and the "Shift Component," which represents the potential growth of different ports relative to ports in the same cluster. The third part is the Competitive Component, the sum of which at the range level is always zero, thus being analyzed separately [25].

The trend component (Share Effect) relating to traffic dynamics in the Mediterranean Basin is able to capture in its near totality the growth dynamics of the Ligurian Range in the period between 2010 and 2015 and those pertaining to the Spanish Med Range in the period 2015–2022.

The structural component (Shift Effect), on the other hand, highlights two diametrically opposite trends: on the one hand, that of the Central Mediterrenean Range ports and those of the South Mediterrenean Hubs in the period 2010–2015, which had a loss on potential intra-range growth of 1.53 and 1.38 million TEU, respectively, and on the other hand, we can observe how for the East Med Range this growth component represents potential growth of 1.65 million TEU. By the same token, the Central Mediterrenean Range lost more than 1.14 million TEUs of potential growth in the subsequent period.

The total shift-share component highlights the growth or decrease in traffic volumes for the different areas. As presented above we can see that the Mediterranean port system is experiencing an important expansionary phase, particularly between 2015 and 2022 where all port ranges have significantly increased the volumes of traffic handled, with particular reference to the Spanish Med Range, and South Med Hubs, with an incremental change of more than 2 million TEU each.

The East Med Range, driven by the growth of the Port of Piraeus saw sensational growth for both periods under analysis, translated into an increase in traffic volumes of more than 4 million TEU overall. We can certainly find a correlation between the propulsive drive for growth of Piraeus and the entire range and the strategic choices made by COSCO, by virtue of the commercial agreements initiated since 2008 between the Port Authority and the shipping company, which led to the subsequent acquisition of 51% of the port's shares starting in 2014, arriving in 2021 at the acquisition of 100% of the port of Athens, effectively making the port of Piraeus the nodal hub of maritime traffic transiting the Mediterranean.

The core component of the shift-share analysis, however, is the "competitive components," which can capture how, within the same port range, the distributions of traffic between the different ports have changed. In this sense, we can see how between 2010 and 2015 there was a redistribution of traffic volumes in the transport dynamics of the Spanish Med Range, in which the port of Algeciras absorbed part of the traffic volumes from the ports of Barcelona and Valencia, for an increase of more than 1.03 million TEU. Likewise, we can also observe how, associated with a vertical collapse in traffic volumes from the port of Taranto, these were absorbed by the port of Marsaxlokk. This result is extremely significant when coupled with the strategic investment choices effected by the CMA-CGM Maritime Company, which held control of the Taranto container terminal

until 2015 before deciding to channel most of its traffic in the Mediterranean area precisely to the port of Valletta. Finally, it must be emphasized how, in the traffic dynamics of the East Med Range, the port of Piraeus has assumed an increasingly central role, catalyzing part of the traffic from the Eastern Mediterranean area, and in particular from the port of Ambarli, Turkey.

For the period 2015–2022, on the other hand, we can see how the growth of the port of Barcelona was also determined through a channeling of traffic from the ports of Algeciras and Valencia: this resulted in an increase in intra-range volumes for the port of Barcelona by 1.16 million TEU. Secondly, it is curious to note that between 2015 and 2022, similarly to what happened to the port of Taranto previously, the port of Cagliari saw an almost total slowdown in handled traffic volumes. In this case we can see how this share of traffic has been completely absorbed by the port of Gioia Tauro, which, with the port of Marsaxlokk has assumed a role as a key transshipment hub in the center of the Mediterranean. Also, for the case of Cagliari we can observe how in 2019 the main terminal operator ContShip Italia decided to abandon the Sardinian terminal, effectively decreeing a decrease in traffic.

Table 3. Results of the shift-share analysis

Share Component (‘000 TEU)		2010–2015	2015–2022
	Spanish Med Range	1,513	2,219
	Ligurian Range	816	1,129
	North Adriatic Range	268	495
	Central Mediterrean Range	1,250	1.421
	East Med Range	1,037	1,764
	South Med Hubs	1,235	1,429
Shift effect (‘000 TEU)			
	Spanish Med Range	639	27
	Ligurian Range	7	−431
	North Adriatic Range	625	373
	Central Mediterrean Range	−1,534	−1,146
	East Med Range	1.653	517
	South Med Hubs	−1,390	660
Total Shift-Share component (‘000 TEU)			
	Spanish Med Range	2.151	2.246
	Ligurian Range	823	698
	North Adriatic Range	892	869
	Central Mediterrean Range	−284	275
	East Med Range	2,690	2,281
	South Med Hubs	−155	2.089

(*continued*)

Table 3. (*continued*)

Share Component ('000 TEU)		2010–2015	2015–2022
Highlights from the Competitive Componnet ('000 TEU)		2010–2015	2015–2022
Spanish Med Range	Algeciras	1,034	−663
Spanish Med Range Central Mediterrean Range	Barcellona	−430	1,160
	Valencia	−604	−497
	Cagliari	144	−637
Central Mediterrean Range East Med Range	Taranto	−560	26
	Gioia Tauro	−196	735
	Malta Freeport	785	−292
	Pireo	2,054	1,123
East Med Range	Ambarli	−1,290	−986

Source: Personal Elaboration

6 Conclusion

The Mediterranean port system represents an extremely complex and dynamic ecosystem, influenced by the strategic choices of different market players and geo-economic dynamics on a global scale [16]. The complexity of the shipping network in the Mediterranean basin has meant that individual ports no longer represent simple logistics nodes of modal shift of goods but represent strategic pivots of global networks along major supply chains. The complexity of the market is due to the desire on the part of all market players to want to maximize network effects by exploiting economies of scale wherever possible. These observations justify the trend toward concentration of traffic volumes in a small number of major logistics hubs, which represent the center of gravity of the integrated transportation system not only on a regional scale, but also on a global scale [17].

This analysis reveals how the strategic position of the Mediterranean basin in relation to the dynamics of global transport networks is bound to further increase traffic volumes. We observed how the volatility of traffic volumes for gateways is extremely more limited than for transshipment hubs. For this reason, the development trajectories that the Middle-Eastern basin will experience will involve the strengthening of a number of gateways located in strategic positions with respect to their reference hinterlands, assisted by a growth of the main transshipment hubs located close to the main Mediterranean route. At the same time, we can expect smaller and lesser transshipment hubs to lose their traffic shares due to the centralization of flows to a smaller number of strategic hubs or to gateway ports that are increasing their transshipment share, becoming de facto, mixed ports.

Finally, it must be pointed out that this paper was prepared before the geopolitical situation that has been affecting the Red Sea recently kicked off a major reorganization of sea routes transiting through the Suez Canal. Starting in October 2023 in fact, the Huthi, a Yemeni armed group a began a series of attacks on merchant ships transiting the Gulf of Aden and the Bab El-Mandeb Strait. This event, which is continuing to this day has resulted in a reorganization of the routes followed by the various cargo ships, which to date, for security reasons are circumnavigating Africa, passing through the Cape of Good Hope. These factors, determine that the considerations presented above may be obsolete or at least we are facing a moment of transition waiting for a return to normalcy that nevertheless is significantly affecting containerized traffic flows in the Mediterranean Sea basin.

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Reshoring in Fashion: Overview of Current Trends and Motivation to Production and Re-localisation in the T&A Sector

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Abstract. The phenomenon of reshoring, or the repatriation of previously offshored business operations, has garnered increased attention in recent years. Given its relevance for fashion firms all over the world, this study provides a nuanced understanding of the motivations driving reshoring decisions, while also exploring the potential alternative strategies that organisations may consider. We also explore the nuanced ways in which reshoring impacts sustainability, considering factors such as improved supply chain resilience, and socio-economic implications for local communities.

In this context, this research develops a network analysis through the cartographic processing, connecting the countries in which the various brands/industries had delocalized and subsequently relocated their activities. The goal of the study is to understand and to identify which are the main hubs of offshoring and reshoring globally.

This study contributes to the existing body of knowledge on reshoring by providing a holistic understanding of its potential sustainability benefits for the fashion sector. The findings offer valuable insights for businesses, policymakers, and scholars seeking to deepen their understanding of the interplay between reshoring strategies and sustainable development. As global economic dynamics continue to evolve, a deeper understanding of reshoring and its sustainability implications becomes pivotal for shaping resilient and environmentally responsible industrial practices.

Keywords: Fashion Industry · Reshoring · Sustainable Supply Chains

1 Introduction

The fashion industry, as an economic sector characterised by dynamism and trend-centric nature, assumes a paramount role in the global economic system. Historically, the industry has undergone a notable transformation in its production strategies, with a pronounced shift toward offshoring practices [1] due to the allure of cost efficiency, accentuated by the forces of globalisation, propelling fashion production to dislocate in variegate worldwide locations.

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However, the contemporary milieu has witnessed a paradigmatic shift in production dynamics, marked by an escalating discourse on reshoring—the repatriation of manufacturing activities to domestic or proximate markets [2]. This departure from the traditional offshore production reflects an emerging strategic response to the multifaceted challenges confronting the fashion sector [3]. Reshoring initiatives are increasingly being propelled by imperatives such as bolstering supply chain resilience, enhancing responsiveness, and addressing concerns related to environmental sustainability and ethical production practices [4].

The paper embarks upon a comprehensive exploration of the escalating importance of reshoring efforts within the fashion industry, conducting a critical appraisal of the motivating factors, ramifications, and potential transformative influences on the industry's modus operandi. Furthermore, this investigation scrutinises the association between reshoring initiatives and the overarching pursuit of sustainability objectives.

Therefore, the article aims at exploring reshoring dynamics in the fashion sector and their interplay with sustainability efforts. As it represents a strategic response to evolving consumers' expectations, regulatory frameworks, and a global community increasingly sensitive to its ecological footprint, the aim of this academic investigation is to understand and recognise the main hubs of offshoring and the trends to reshoring globally, unravelling the potential of reshoring to trigger positive transformations within the fashion industry.

The paper is organised as it follows: Sect. 2 The fashion industry: overview and present trends on sustainability; Sect. 3 The fashion industry in Italy: analysis of the economic importance of the sector; Sect. 4 Towards sustainable globalisation: offshoring and reshoring trends; Sect. 5 Methodology and data; Sect. 6 Results and discussion; Sect. 7 Conclusion.

2 The Fashion Industry: Overview and Present Trends on Sustainability

The Textile & Apparel (T&A) sector stands as the world's second most polluting industry, accounting for approximately 1.2 billion tons of greenhouse gas emissions with a consumption growth of +400% in around two decades [1]. This alarming trend has been exacerbated by the proliferation of fast fashion, which not only leads to premature disposal of textile products but also results in heightened waste generation. The expression highlights the industry's rapid turnover, overproduction, and its related massive consumerism. As a matter of fact, brands have gradually overlooked the importance of assessing the negative consequences for local communities and the environment deriving from the production processes of fashion goods, including excessive energy consumption, water contamination, use of highly polluting chemicals, increased textile waste, low wages, and poor working conditions [2, 3].

Evidence of this exaggerated shopping culture is also provided by household spending data collected by the European Commission. The amount of clothes bought per person in the EU has risen by 40% in just a few decades, driven by lowering prices and increasingly fast fashion trends [4].

In response to this ethical fashion movement, not only brands but also suppliers, factory owners, unions, and non-governmental organisations have invested significant resources to promote a sustainable revolution in the industry [5]. However, it seems that industry improvements have not triggered a net positive impact on financial accounts. In fact, it has emerged that while many consumers claim to be motivated by ethical intentions, the translation of this attitude into concrete actions is much less evident, especially when purchasing fashion items [6].

At the heart of the issue lies the unsustainable nature of the entire textile value chain, spanning from raw material extraction to production, distribution, consumption, and end-use [7, 8]. It is evident that environmental repercussions extend throughout the production process, characterised by extensive energy consumption often derived from non-renewable sources, particularly fossil fuels. Furthermore, textile factories heavily rely on water and natural resources, from the cultivation of cotton and natural fibres to their utilisation in production processes [9]. In addition, processes such as printing and dyeing involve the use of chemical substances, whose impact on soil, air, and water quality remains significant despite regulatory limitations over time [10].

Beyond environmental considerations, social and economic dimensions also come into play. Manufacturing operations are predominantly situated in regions where labour rights are disregarded, and the balance between environmental conservation and economic gains is often murky [11]. Moreover, opacity within supply chain stages fosters conditions ripe for illicit activities and exploitative labour practices globally [12].

Apart from consumption and waste generated along the entire fashion supply chain and products distribution, the post-consumption stage warrants closer scrutiny. The advent of fast fashion, indeed, has instigated changes in consumers' behaviour, resulting in shortened product life spans [13].

Although this scenario has also led to new opportunities for reuse, lending, and exchange, consumers' awareness regarding final disposal destinations for discarded fashion items remains low, underscoring the need for education on post-consumption practices [14, 15].

Given these challenges, legislative bodies at national and supranational levels are endeavouring to regulate the fashion industry towards circular practices [16]. Notably, in 2022 the European Union (EU) introduced its Strategy for Sustainable and Circular Textiles, aiming to promote recyclable, safe, and environmentally-friendly products while respecting labour rights [17]. It is in this context that the implementation of the Extended Producer Responsibility is poised to be a cornerstone policy in the EU's efforts to reshape the fashion industry and foster sustainability in the sector, in line with the Circular Economy Package dating to 2018 [18].

3 The Fashion Industry in Italy: Analysis of the Economic Importance of the Sector

The fashion industry in Italy, significantly contributing to the country's economy and cultural identity, has evolved through pivotal moments and influential figures. The landmark high-fashion show in Florence in 1951, organized by Giovanni Battista Giorgini,

marked a turning point for the Italian fashion sector, increasing its importance in international trade and establishing the 'Made in Italy' label [19, 20]. Over the years, the sector's central role for the Italian economy has been underscored by its growing international market diffusion, distinguished by worldwide competitors [21].

Milan, in particular, stands out as a significant 'hub' in the spatial, social, and economic organisation of the Italian fashion industry, characterised by strong local embeddedness and internationalisation. Also, the global resonance of Italian fairs in the T&A, such as the Milan Fashion Week or the Pitti Uomo ones, remark the evolution and importance of the sector in Italy [22]. Therefore, it is evident that the Italian fashion industry, shaped by historical roots in luxury textiles and modern developments in high fashion and ready-to-wear segments, is a key player in the global T&A landscape.

The Italian fashion sector, renowned for its significant economic and cultural impact, stands as witness of both Italy's rich history and dynamic present in the fashion world [19].

The concept of the bazaar economy has been a point of discussion in relation to Italy's fashion sector structure, as several small and independent enterprises buy and sell a wide range of high-quality goods globally and directly, without relying on a centralised mediator. As a consequence, the degree of dependency on foreign markets and the impact of financial crises on its supply chains are higher [23, 24].

In this context, sustainable innovation has become a crucial factor for the competitiveness and the growth of the textile and fashion industry. Several fashion companies have focused on sustainability and innovation, promoting the development of the Italian T&A districts and demonstrating how sustainable innovation can be based on core corporate values and strong territorial relationships [25, 26].

The Covid-19 pandemic accelerated this innovation process further, by forcing Italian fashion brands to restructure their value chains, refine their strategies, and invest in manufacturing, sustainability, and digital technologies, thus demonstrating their adaptability and resilience [27]. Therefore, this has made the need for intellectual property rights instruments all the more necessary, given the common counterfeiting practices in the field [28].

Counterfeiting in the fashion industry presents significant economic and social challenges. Strategies to combat continuous violations and prevent the spread of counterfeiting are essential to safeguard the integrity of the fashion industry [8]. In this context, the role of IT tools and strategies in the T&A sector has been crucial. Companies that effectively use digital communication for online shopping and advertisement better manage to remain competitive and overcome adverse economic cycles [29].

These insights collectively highlight the multifaceted nature of the Italian fashion industry, demonstrating its versatility in front of global trends as the offshoring one.

Beyond any doubt, Italian products in the textile and clothing industry often stand out from the rest due to their renowned style and quality [30]. It is not surprising that four Italian fashion houses appeared in Vogue's best collections in 2023, with Prada, Bottega Veneta and Schiaparelli securing the favour of experts and passionates in the field [31]. Despite the heightened sensitiveness of consumers on sustainability aspects in the T&A sector, the fast fashion trend still prevails over long-term products quality. Due to this tendency, clothing manufacturers strive to meet the diverse needs of consumers

who desire to find the latest fashion trends in stores at reasonable prices immediately after they appear on the runways.

4 Towards Sustainable Globalisation: Offshoring and Reshoring Trends

Sustainability is defined as the ability to meet present needs without compromising those of future generations [32]. This concept is based on environmental, social and economic pillars, as manufacturing activities are recognised to influence all three of these dimensions of sustainability [33].

In recent decades, both insourcing and outsourcing in developing countries have been popular strategies for companies seeking a sustainable competitive advantage [34].

Moreover, economic trends and globalisation have generated complex supply chains, pushing many companies to relocate their production. Delocalisation is defined as the transfer of activities of production, search and development, services and/or supply in a foreign state, outside the company's country of origin. During the first half of the 1990s and the beginning of the 2000s, offshoring increased mainly due to low raw material and labour costs, which offer competitive advantages to businesses [35]. This trend has also been fostered by the reduction of trade restrictions and barriers in developing countries [36].

However, in the current context, sustainable practices and responsible supply chain management are not only indispensable, but also complex. Geographical distance can make it difficult to fully evaluate environmental and social performance and assess suppliers' commitment to sustainability. In fact, reducing environmental impacts and adopting responsible materials and processes require close cooperation with suppliers and ethical treatment of workers [37].

On the one hand, several events, including the economic crisis and globalisation trends, prompted companies to delocate their activities. On the other, growing concerns about the socio-ecological load have led firms to reconsider their shoring decisions. Because of this, several companies have decided to bring production activities back to their home countries. Therefore, researchers face an imperative to conduct more studies on the phenomenon, as it is necessary to better understand the effects of reshoring strategies on sustainability and identify who and what promote them [38].

Current research lacks a clear definition of sustainable reshoring, despite increasing pressure for sustainability-oriented business strategies. Companies, especially Westerners, implement reshoring primarily for economic reasons and to respond to market demand [38].

Reshoring is a phenomenon that has been triggered by several factors, including trade wars, rising labour costs in delocalised countries, concerns about sustainability and supply chain disruptions due to the Covid-19 pandemic [39].

Figure 1 presents 4 acknowledged forms of reshoring:

- in-house reshoring, which consists in the return of wholly-owned offshored activities to wholly-owned local activities. Therefore, a company relocates manufacturing activities performed in wholly owned offshore facilities back to wholly owned State-based facilities;

- reshoring for outsourcing, i.e. the return of wholly-owned offshored activities to local suppliers, according to which a firm satisfies the demand in its local market by relocating manufacturing activities performed in wholly owned offshore facilities back to State-based providers;
- reshoring for insourcing, namely the move from offshore suppliers to wholly-owned home-based facilities, where a firm satisfies its local market by relocating manufacturing activities back to wholly owned local structures;
- outsourced reshoring, according to which a firm relocates manufacturing activities performed by offshore suppliers back to local, State-based suppliers [40].

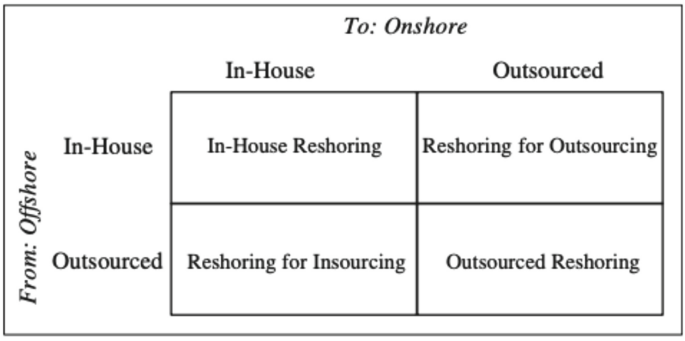

Fig. 1. Different types of reshoring. Source: Gray et al. (2013).

Such a strategy is often adopted in answer to the costs increase or issues in supply chain management. Although it is not a new phenomenon, it has gained importance in recent years, becoming increasingly widespread as a response to changes in the economic landscape and the need for greater control and flexibility in the supply chain [35].

However, although this strategy offered evident competitive advantages, costs and risks have emerged over time such as bureaucratic hindrances, loss of know-how and raise in coordination expenses. Reshoring involves repatriation of activities both internally and externally to the company, while the grounding reasons can differ according to corporate goals and other variables [34].

Reshoring research has identified a wide range of driving factors, including logistical costs, quality, lead time, and emotional motivations. Environmental sustainability also emerges as a key reason for reshoring, although its exact impact remains under investigation [41].

Companies adopt reshoring to reduce both operational and strategic risks and to promote the corporate sustainability agenda. However, little is known about 'resiliently sustainable' supply chains, which is why it is important to investigate these dynamics [42].

Reshoring has emerged mainly in firms with their headquarters in developed countries, for example in Europe and in the United States. Although decisions about the production location may overall seem simple, the underlying complexity of the topic is

intriguing. However, conceptualising this decision-making process is difficult because of its non-linear, dynamic and cyclical nature [39].

In conclusion, before deciding about relocation of corporate activities it is necessary to carefully assess the trade-off between costs and benefits. While reshoring can lead to lower profits and higher production costs, some studies indicate that it can be a profitable strategy, especially considering the higher average return of shares associated with reshoring ads [43]. In particular, it is of utmost importance to consider supply and distribution chains dynamics and mechanisms.

4.1 The Role of Reshoring on Sustainability

As highlighted above, the reshoring of companies' activities assumes an increasingly important role for environmental sustainability. This reflects higher firms' knowledge and awareness on sustainability and the negative impacts of foreign production. Therefore, reshoring shows several advantages that can be pursued and created through reshoring, such as the reduction of emissions associated with international production and transportation, or the promotion of more ethical and safer practices within working sectors [43].

Additionally, it can reduce the use of resource consumption and enhance the use and recycling of ecological materials, thus contributing to circular economy and long-term sustainability. However, in order for reshoring to have a positive impact on sustainability, it is key to implement policies and incentives suitable to the transition to more environmentally responsible models [43].

Supply chains fragmentation, hereby considering the manufacturing industry, attests the vulnerability of global networks. Therefore, the implementation of reshoring strategies allow companies to adapt to unforecast events [44].

To conclude, it is possible to claim that sustainability is a key driver of reshoring decisions at social and environmental levels, although the topic is still under-investigated by current literature [33].

5 Methodology and Data

The data used to apply this methodology have been extrapolated from the European Reshoring Monitor, a database containing fact sheets with data on reshoring events reported by the national media of each member state of the European Union. Active collection of this data for reshoring monitoring began in February 2016, and some previous reshoring cases (2014–2015) were identified by previous data collection activities by the research team. The database was updated monthly until the end of 2018 when the project ended [45].

Within this project, different cases of reshoring have been reported as companies which have brought back (within the EU) value chain activities previously relocated to another country. This project takes into account different sectors but in this research, we decide to put our attention on the sectors related to the fashion industry such as:

- Manufacture of textiles;
- Manufacture of wearing apparel;

- Manufacture of leather and related products.

After a deeper investigation, we found 32 cases of reshoring announced in the period indicated above (Fig. 2).

	RESHORING MONITOR FASHION INDUSTRY						
	Company Name	Company Country	Announcement Date	Offeshored to	Reshored to	Sector	Source
1	Lissau A/S	Denmark	29/04/2017	Lithuania	Denmark	C13 - Manufacture of textiles	European Reshoring Monitor
2	Kiplay	France	07/05/2016	Tunisia	France	C14 - Manufacture of wearing apparel	European Reshoring Monitor
3	Roy Lowe & Sons Ltd	United Kingdom	07/09/2017	Turkey	United Kingdom	C14 - Manufacture of wearing apparel	European Reshoring Monitor
4	Roy Lowe & Sons Ltd	United Kingdom	07/09/2017	India	United Kingdom	C14 - Manufacture of wearing apparel	European Reshoring Monitor
5	Roy Lowe & Sons Ltd	United Kingdom	07/09/2017	China	United Kingdom	C14 - Manufacture of wearing apparel	European Reshoring Monitor
6	Kansas	Denmark	19/02/2018	Sweden	Denmark	C14 - Manufacture of wearing apparel	European Reshoring Monitor
7	Le coq sportif	France	08/10/2017	Vietnam	France	C14 - Manufacture of wearing apparel	European Reshoring Monitor
8	Bomboogie	Italy	12/01/2015	Bangladesh	Italy	C14 - Manufacture of wearing apparel	European Reshoring Monitor
9	Bomboogie	Italy	12/01/2015	China	Italy	C14 - Manufacture of wearing apparel	European Reshoring Monitor
10	Wendre	Estonia	27/06/2017	Sweden	Estonia	C13 - Manufacture of textiles	European Reshoring Monitor
11	Wendre	Estonia	27/06/2017	Finland	Estonia	C13 - Manufacture of textiles	European Reshoring Monitor
12	Diadora	Italy	14/06/2017	China	Italy	C15 - Manufacture of leather and related products	European Reshoring Monitor
13	Pepe Jeans	Spain	02/12/2016	France	Spain	C14 - Manufacture of wearing apparel	European Reshoring Monitor
14	Krys Group	France	08/11/2016	Thailand	France	C14 - Manufacture of wearing apparel	European Reshoring Monitor
15	Benetton	Italy	11/10/2016	NA	Italy	C14 - Manufacture of wearing apparel	European Reshoring Monitor
16	TBA Textiles	United Kingdom	08/09/2016	Netherlands	United Kingdom	C13 - Manufacture of textiles	European Reshoring Monitor
17	Burberry	United Kingdom	14/08/2015	Japan	United Kingdom	C14 - Manufacture of wearing apparel	European Reshoring Monitor
18	Mango	Spain	20/07/2016	India	Spain	C14 - Manufacture of wearing apparel	European Reshoring Monitor
19	Mango	Spain	20/07/2016	China	Spain	C14 - Manufacture of wearing apparel	European Reshoring Monitor
20	Rapanui Clothing	United Kingdom	28/01/2014	India	United Kingdom	C14 - Manufacture of wearing apparel	European Reshoring Monitor
21	Patrona Luggage	United Kingdom	12/11/2014	China	United Kingdom	C14 - Manufacture of wearing apparel	European Reshoring Monitor
22	Damart	France	19/05/2016	Belgium	France	C14 - Manufacture of wearing apparel	European Reshoring Monitor
23	Icab	Italy	03/11/2015	China	Italy	C14 - Manufacture of wearing apparel	European Reshoring Monitor
24	OVS	Italy	25/10/2015	NA	Italy	C14 - Manufacture of wearing apparel	European Reshoring Monitor
25	Falconeri	Italy	23/05/2015	Romania	Italy	C14 - Manufacture of wearing apparel	European Reshoring Monitor
26	Burberry	United Kingdom	03/11/2015	China	United Kingdom	C14 - Manufacture of wearing apparel	European Reshoring Monitor
27	Paul Smith	United Kingdom	05/09/2014	NA	United Kingdom	C14 - Manufacture of wearing apparel	European Reshoring Monitor
28	Safilo	Italy	25/07/2015	China	Italy	C14 - Manufacture of wearing apparel	European Reshoring Monitor
29	Gta Moda	Italy	10/12/2014	Romania	Italy	C14 - Manufacture of wearing apparel	European Reshoring Monitor
30	Ciak Roncato	Italy	23/07/2015	China	Italy	C14 - Manufacture of wearing apparel	European Reshoring Monitor
31	Prada	Italy	03/04/2014	China	Italy	C14 - Manufacture of wearing apparel	European Reshoring Monitor
32	Giorgio Armani	Italy	26/02/2016	Switzerland	Italy	C14 - Manufacture of wearing apparel	European Reshoring Monitor

Fig. 2. Reshoring cases T&A sector 2014 -2018. Source: European Reshoring Monitor.

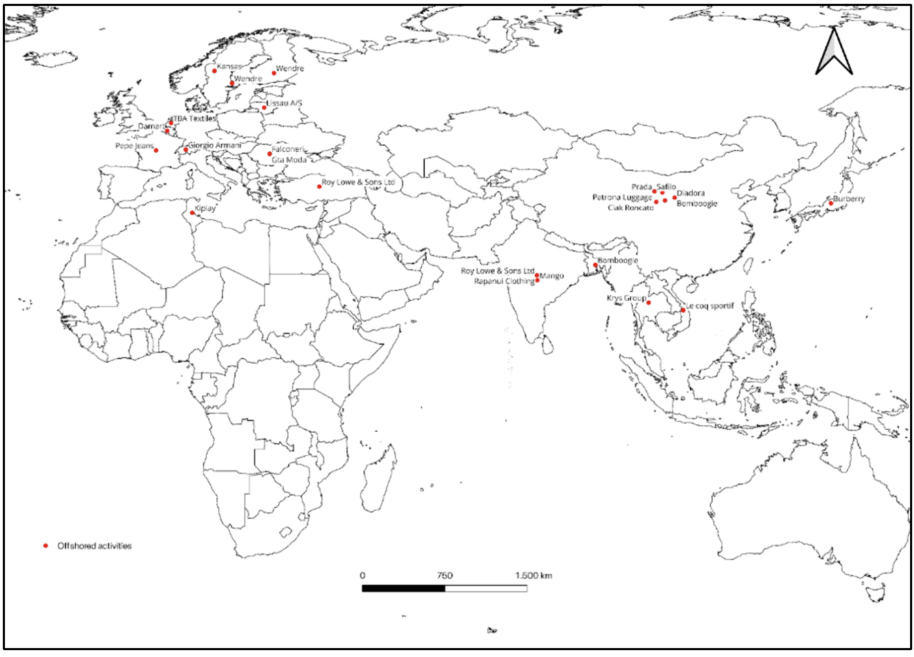

Fig. 3. Cases of offshored activities. Author: F. Sinatra (2024).

After preliminary data analysis, only 29 cases of reshoring were considered, as some data on the relocation of production activities did not clearly indicate the antecedent position to reshoring. Subsequently, the QGIS software was used to more accurately represent this analysis. After setting up the map with the coordinates of the enterprises on My Maps, two distinct analytical levels were applied: one to indicate the original location of the activities (offshored to) and one to represent the place of reshoring (reshored to).

After that, a network analysis was conducted on the repatriation of production activities in a comprehensive manner (not only for the companies under consideration) (Fig. 3).

6 Results and Discussion

Both from the data and the network analysis conducted through QGIS, it is possible to check for the fashion companies conducting reshoring strategies. Our analysis highlights that the T&A firms which started to implement reshoring activities are still a minority worldwide. Particularly, reshoring strategies are mainly conducted by European firms, as they are those which previously delocalised most in South-East Asia States and China. In addition, it is possible to see that Italy and the United Kingdom are the countries where the highest number of cases was attested (Fig. 4).

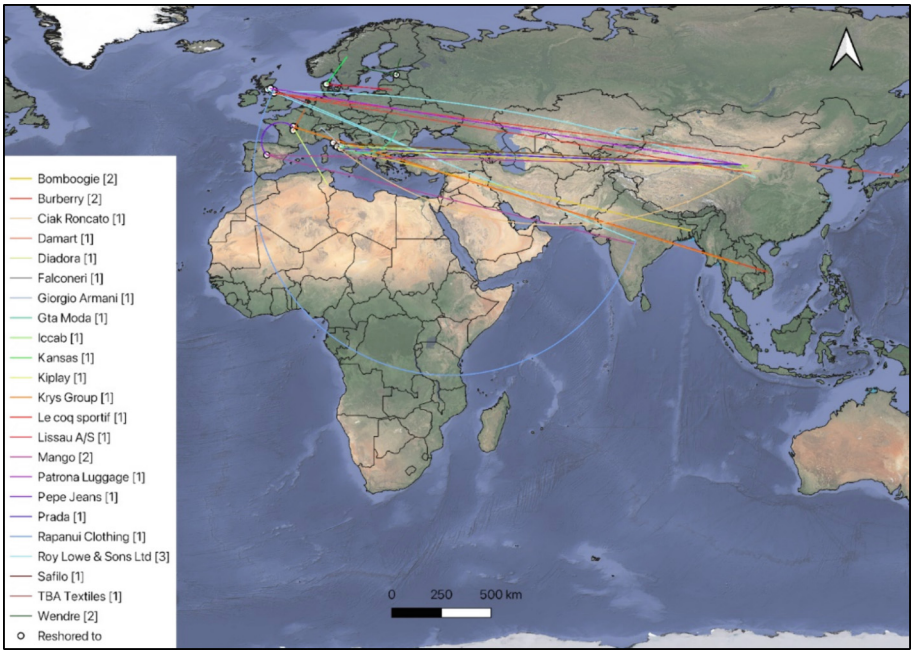

Fig. 4. Reshoring Cases from 2014 to 2018 in the fashion industry. Author: F. Sinatra (2024).

Our analysis demonstrates how companies keen on reshoring can benefit from a reinforced brand identity, mostly from the Italian market standpoint where the 'Made in' is considered as a key qualitative component for products and services.

Consequently, firms choosing this strategy can benefit from added value along the entire value chain, creating a positive impact on social and environmental sustainability [35]. For instance, they can lower global transportation emissions and create social value on local communities.

Nevertheless, our analysis does not allow us to exclude other factors such as normative changes, political reasons or tax incentives pushing companies to adopt reshoring strategies. Moreover, we remark that, along with opportunities, reshoring also shows drawbacks and risks connected to its implementation, such as higher costs, heavier tax burden and readaptation needs [46]. Therefore, reshoring is strongly related to sustainability in its wider meaning, by considering social, environmental, and economic aspects as impactful on corporate performance in the short and long run.

7 Conclusion

The trend of reversing initial offshoring decisions is becoming increasingly common, with some studies reporting that one in every four offshoring firms decides to reshore (or nearshore) manufacturing within the next five years [47, 48]. This phenomenon is particularly relevant in the apparel industry, with the majority of reshoring occurring in Southern Europe, especially in Italy, France, Germany, Spain, and Portugal [49, 50].

Previous scholars have revealed how a key factor behind these decisions consists in consumers' perception, particularly relevant for luxury brands [51]. Additionally, costs reduction plays a significant role. Increasing transportation costs may make producing in distant locations less cost-effective, while proximity to markets can reduce delivery times, offering a competitive advantage in an industry where speed is crucial. While sustainability is an important consideration, research nevertheless suggests it is not the primary driver of these decisions.

Overall, the trend of reshoring or nearshoring production in the apparel industry is driven by a combination of factors. However, we highlight that the reshoring phenomenon is still marginal with respect to delocalisation strategies. This leads to unsustainable supply chains distinguished by low resilience levels, which highlights the need for other strategies enhancing the mitigation of environmentally negative effects.

Our study also suggests a shift away from extensive globalisation efforts, influenced by collateral events such as supply chain disruptions and raising costs. Although complete disengagement from globalisation seems unlikely due to the importance and widespread nature of global value chains, we envision a new equilibrium between offshoring and reshoring in the T&A industry. As firms adapt to external factors, making location decisions that suit their brands assumes higher strategic importance and especially in the period post the Covid-19 pandemic.

To sum up, our paper sheds light into fashion companies which have adopted reshoring strategies at global level. In the context of the fashion industry's heightened consciousness regarding its environmental impact, ethical concerns, and the imperative to maintain economic sustainability, reshoring emerges as a strategic instrument capable of harmonising financial exigencies with social and environmental responsibilities.

7.1 Theoretical and Practical Contributions

Our paper contributes to current literature and practice on reshoring by providing an overview of companies undertaking the decision to relocate in the T&A field globally. Apart from conveying the present trends on this phenomenon, we also provide some reference points to orientate researchers on the grounding reasons for offshoring and reshoring practices by firms, therefore enriching current understanding of these localisation strategies. Therefore, we add to the existing knowledge of reshoring by focusing on the main sustainability factors that contribute to shape and spread this strategy across sectors, to the benefit of the environment and society. While doing this, we enrich the current debate on the drivers to reshoring and their main positive impacts.

Our study also speaks to practitioners and experts of the fashion sector, on the one hand, and of localisation strategies, on the other. The study also aims at providing them with concrete instruments of support that could serve to better orient their actions and guide practice.

Lastly, we acknowledge the limitations of the present study. As we rely on secondary data, their limited timeframe does not allow us to say anything about currently ongoing trends. Moreover, as we limit the reshoring analysis to the fashion field, we do not account for the dynamics occurring in different sectors.

As there is still wide room for academic investigation, we leave to future researchers the opportunity to deepen the episodes of reshoring within different industries. We hope to serve as useful background to theoretical and practical efforts, encouraging further exploration of current and future reshoring dynamics to the benefit of academics and practitioners.

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The Mediterranean Maritime Network of Container Shipping: Spatial Structure and Regional Dynamics

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Abstract. This study proposes to analyze the maritime transport network for container traffic in the Mediterranean Sea basin. For this purpose, the 29 main ports that make up the study macro-region were analyzed by taking into consideration the traffic volumes handled and the main pendolum and round-the-world routes operated by the main shipping companies. These two components represent the nodes and arcs of the studied network, on which a subdivision of the different ports was then made based on their geographical location and different ranges of belonging. To fully understand the transport dynamics, Freeman's centrality indices and Eingivenvector Centrality were successively introduced, which are useful in capturing which nodes are the most relevant within the transport network and in defining possible lines of future development for the sampled ports. In this context, the main transshipment hubs located along the Port Said - Gibraltar backbone assume an increasingly relevant role while, in the face of an increasing decentralization of secondary transshipment hubs. Moreover, this analysis highlights how gateway ports that direct their flows not only to the back-port area but also to other ports, assuming the role of mixed ports, are consolidating an increasingly prominent position of centrality.

Keywords: Network Analysis · Mediterranean Sea · Maritime Transport · Transport Dynamics · Regional Structure

1 Introduction

There are three basic dimensions in the study of transportation geography: flows, nodes and transportation networks. In this complex system, ports represent the fundamental nodes of transport networks [1].

In this paper we propose to analyze network dynamics in relation to containerized maritime transport in the Mediterranean Sea basin, relating the Ports, as nodes in the port system and from the main pendolum and "round-the-world" routes operated by major shipping companies [2]. We can see how the Mediterranean basin is spotted with a multitude of different ports, from established major ones, to a wide range of medium and small ports, each with specific characteristics over which different locational and

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strategic dynamics intersect within the hinterlands served and the different commodity categories handled [3, 4]. This combination of different types and dimensions of ports, aided by the presence of a vast hinterland, has led to the creation of a uniform space that provides a suitable case study for trying to analyze the factors affecting port hierarchy and competition [5]. Several studies have investigated the development dynamics of the different port systems on a regional scale or with reference to individual ports [6], and in particular the dynamics of transport flows in the Mediterranean basin have been studied in numerous works [7, 8]. The contributions mentioned before representing the cornerstones for an in-depth analysis of containerized traffic flows in the Mediterranean Sea area, and in particular, there are several studies that have dealt with the analysis of maritime traffic through complex network analyses: in this sense, the works carried out by Ducruet [9, 10] should be mentioned.

This analysis aims to propose to relate the role that different ports are called upon to play as gateways for traffic to port hinterlands or as transshipment hubs [11]. The second aspect to be considered concerns the relationship between the different port ranges of afferent ports, going beyond the simple concept of a port as a single node of the network, but also taking into consideration the relationships between the different port ranges characterized by contiguous geographic locations and a hinterland sharedness [12, 13]. Finally, the last aspect considered is aimed at taking into account the connections between different ports arising from maritime transport routes, finally sketching the evolutionary profiles that different ports are experiencing. As mentioned, the Mediterranean basin is called upon to play a strategic role in maritime transport on a global scale: its location along the main east-west trade routes, central to the Atlantic, Northern European, Asian, and African markets offers significant connectivity advantages to shipping companies, enabling a reduction in transit time and an important channel of access to markets in continental Europe and the Middle East [14, 15].

However, this contribution was designed and executed using data and geopolitical circumstances prior to the crisis that has affected traffic through the Red Sea and Suez Canal in recent months, beginning in October 2023. In recent months, numerous missile attacks have been launched on cargo ships by the Yemeni Houthi armed group linked to the Israeli-Palestinian conflict. As a result, the considerations and achievements currently seem obsolete. However, given the crucial role of the Suez Canal in global traffic, through which roughly 12 percent of the world's trade was transiting[1], it can be expected that the situation may return to a state close to normal in the near future.

This article considers 29 ports located within the Mediterranean Sea basin, with the intent of identifying the main development trajectories of the port system of the region.

2 Data Collection

The Mediterranean Sea has a role of great importance as a natural artery for trade flows connecting the Far East to continental Europe. This vast maritime area is bounded by two critical points known as "choke points": the Strait of Gibraltar to the west, which is called upon to fulfill the role of a bridge with the Atlantic Ocean, and the Suez Canal to the

[1] Source: https://unctad.org/news/red-sea-black-sea-and-panama-canal-unctad-raises-alarm-global-trade-disruptions, last access: 12 march 2024.

southeast, which constitutes the most efficient route for handling the movement of goods on the east-west route [16, 17]. Its strategic position within the global macroeconomic landscape makes it a vital crossroads for supplying markets and manufacturing districts in continental Europe, even in relation to supply markets in the Middle East. The importance of this maritime region is reflected in the complex and intricate port network that has developed in response to this need. The port infrastructure along the Mediterranean coast has been carefully planned and developed to facilitate the efficient movement of goods and smooth international trade.

These characteristics have generated a steady increase in the traffic volumes operated by the different ports, rising from a share of about 34.9 million TEU in 2010 to 50.7 million in 2022 with reference to the sample under analysis.

To study the evolution of the dynamics of containerized traffic in the Mediterranean Sea, the traffic volumes for individual ports, presented in the summary table below (Table 1), were considered, and a categorization of the 29 nodes in six different port ranges was subsequently made:

- Spanish Med Range (Barcelona, Valencia, Algesiras);
- Ligurian Range (Genoa and Vado Ligure, La Spezia, Livorno and Marsille Fos);
- North Adriatic Range (Trieste, Venice, Ravenna, Ancona, Koper and Rjieka);
- Central Mediterrean Range (Gioia Tauro, Naples, Cagliari, Taranto, Malta Freeport and Tunis (Rades));
- East Med Range (Piraeus, Thessaloniki, Izmir, Mersin and Ambarli);
- South Med Hubs (Limassol, Port Said, Damietta, Alexandria and Haifa).

Table 1. Transport Volume and Main Services and Range of affiliation for Mediterranean Ports.

Port ID	Main Service	Range	2010	2022
Port of Piraeus	Transshipment	East Med Range	885,155	5,311,810
Port of Tessaloniki	Gateway	East Med Range	273,131	470,645
Port of Valencia	Mixed	Spanish Med Range	4,206,937	5,052,272
Port of Algeciras	Transshipment	Spanish Med Range	2,806,884	4,767,282
Port of Barcelona	Mixed	Spanish Med Range	1,931,033	3,522,944
Port of Marseille	Gateway	Ligurian Range	953,435	1,530,000
Port of Rjieka	Gateway	North Adriatic Range	137,048	520,866
Port of Genova	Gateway	Ligurian Range	1,955,292	2,799,123
Port of Gioia Tauro	Transshipment	Central Med Range	2,852,264	3,380,053
Port of La Spezia	Gateway	Ligurian Range	1,285,155	1,262,496
Port of Livorno	Mixed	Ligurian Range	628,489	751,811
Port of Trieste	Mixed	North Adriatic Range	281,643	877,805
Port of Venezia	Gateway	North Adriatic Range	393,913	533,991

(*continued*)

Table 1. (*continued*)

Port ID	Main Service	Range	2010	2022
Port of Napoli	Gateway	Central Med Range	534,694	684,111
Port of Cagliari	Transshipment	Central Med Range	629,340	140,216
Port of Ravenna	Gateway	North Adriatic Range	183,577	228,435
Port of Ancona	Gateway	North Adriatic Range	110,395	165,346
Port of Taranto	Transshipment	Central Med Range	581,936	26,269
Port of Marsaxlokk	Transshipment	Central Med Range	2,370,729	2,890,000
Port of Koper	Gateway	North Adriatic Range	476,731	1,017,798
Port of Tunis	Gateway	Central Med Range	420,089	258,716
Port Haifa	Gateway	South Med Hubs	1,263,000	1,491,180
Port of Izmir	Gateway	East Med Range	695,799	390,274
Port of Mersin	Mixed	East Med Range	1,250,873	2,059,309
Port of Ambarli	Gateway	East Med Range	3.023.960	2.867,215
Port of Limassol	Transshipment	South Med Hubs	382,000	384,000
Port Said	Transshipment	South Med Hubs	3,627,813	4,764,583
Port of Alexandria	Transshipment	South Med Hubs	812,446	1,488,436
Port of Damietta	Transshipment	South Med Hubs	1,214,910	1,106,151

Source: Personal Elaboration on different Port Authority Data

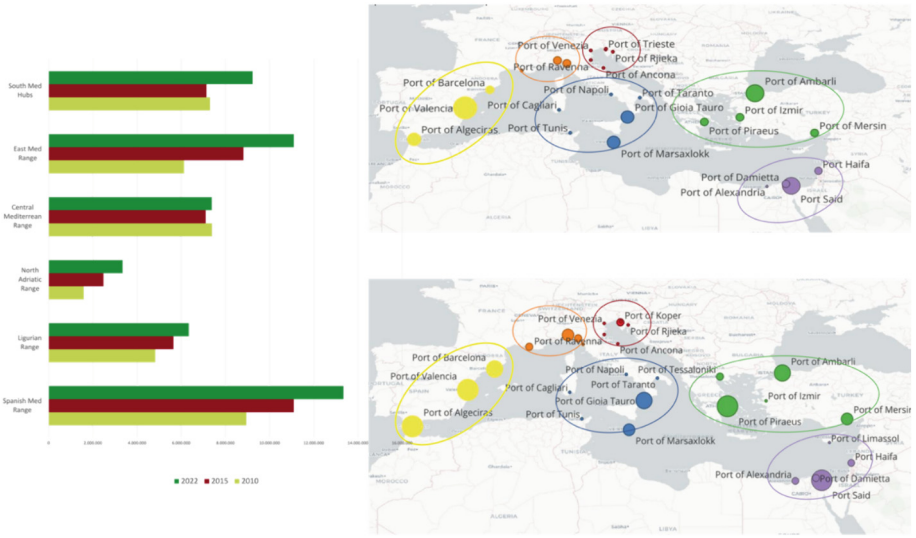

Fig. 1. Different Port Ranges and traffics in Mediterranean Basin. Source: Personal Elaboration

Finally, the last aspect to be considered in this analysis concerns the main routes operated by the major shipping lines. At this juncture, the information provided by the reports of the major Shipping Companies regarding pendolum routes aimed at linking continental European markets with key destinations in the Far East and North American markets in relation to continental flows in the Mediterranean Sea has been summarized [2] (Fig. 1).

This analysis is structural in order to try to understand there is a relationship between the strategic investment choices in the different terminals and the choices proposed by the different Shipping Companies regarding the choices of ports on which to call.

The main routes operated are presented in the figure below (Fig. 2).

As extremely complex as the transport network appears, we can see that the Port of Piraeus is included by only one of the ocean routes under analysis with regard to MSC trades while it is completely excluded with regard to the main routes operated by Maersk. In contrast, the trades operated by the 2M alliance make extensive use of the Algeciras and Gioia Tauro container terminals. Another relevant consideration is related to the strategic importance of the port of Marsaxlokk with regard to the main routes operated by CMA-CGM, which, however, tend to avoid pendolum connections with the port of Algeciras [2, 18]. Conversely, the port of Gioia Tauro is not included in the calls operated by Cosco and Evergreen. We can also observe that there is an important concentration of traffic volumes on the port of Piraeus by the three Ocean Alliance member companies such as CMA-CGM, Cosco and Evergreen. These considerations, however, are treated in the light of evidence related to the Mediterranean trades as a whole: the transport network appears to be extremely dense and complex for the entire Mediterranean region, in which the different shipping companies try to exploit the synergistic advantages derived from a complex system of gateway and transshipment nodes [19].

3 Method

Understanding the dynamics of transportation in the Mediterranean basin must be treated through an organic and systemic analysis of the different ports and its complex set of interactions. With this in mind, the methodological apparatus used requires, first of all, that the proximity matrix W be constructed for the different nodes of the transport network: this binary matrix represents the proximity relationship between the elements of the system. However, it must be specified that at this juncture, the adjacency matrix was not constructed using the geographic proximity criterion [20]. The W matrix we are going to use was constructed from the analytical reconstruction of the routes proposed in Fig. 4, through which the proximity between two nodes in the network was determined on the basis of a second-degree k nearest neighbor. This thus implies that node Ni and node Nj will have a value of 1 if in one of the routes proposed by the shipping companies, the two nodes can be reached within two calls from the route. In case the distance is greater than the two ship stops, the value will be 0. Thus, this analysis makes it possible to relate what are the main nodes in the system (ports) and the different arcs (routes), from which the proposed methodological apparatus can be expanded [21].

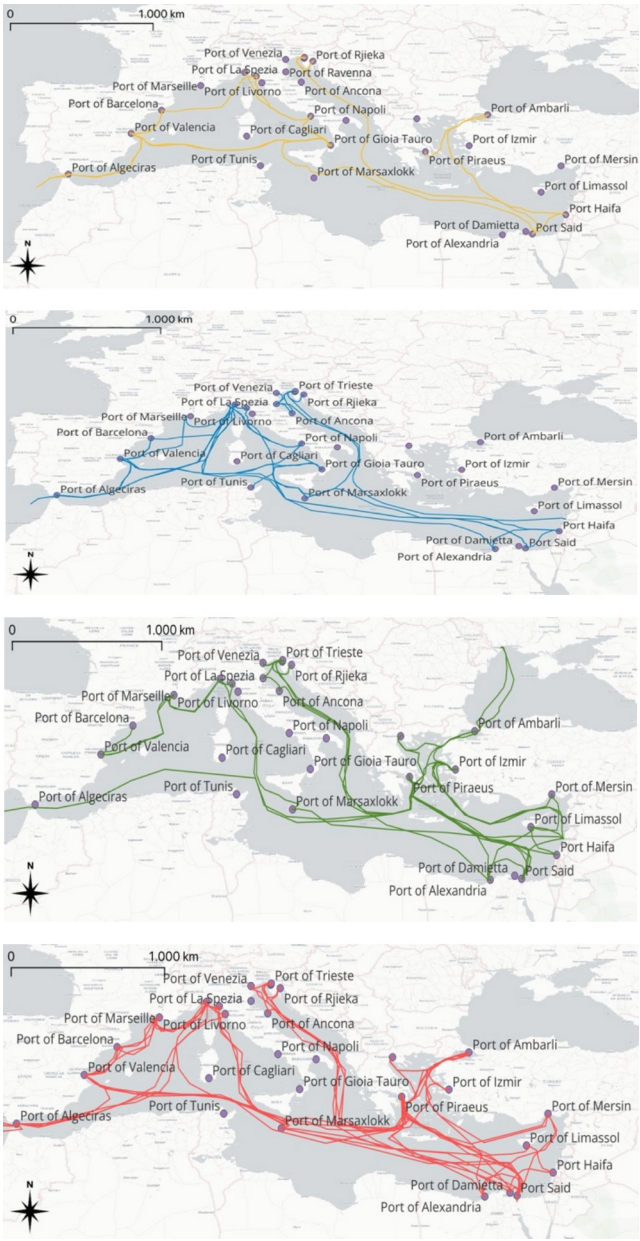

Fig. 2. Main "Pendulum" and "Round the World" routes of the main shipping companies (MSC routes - Fig. 2A), (Maersk routes - Fig. 2B), (Evergreen routes -Fig. 2C), (COSCO routes - Fig. 2D), (CMA CGM routes - Fig. 2E), (Overall routes - Fig. 2F). Source: Author's personal elaboration on Personal elaboration on shipping companies report (Data collected from the web pages of different port operators: https://ss.shipmentlink.com/tvs2/jsp/TVS2_LongTermMenu.jsp?type=L Evergreen; https://www.msc.com/-/media/files/msc-cargo/msc-solutions/trades/transatlantic-med.pdf, https://www.msc.com/-/media/files/msc-cargo/msc-solutions/trades/east-west-network/asia-europe-network_may-2023-cii.pdf MSC; https://lines.coscoshipping.com/home/Services/route/16 COSCO; https://www.cma-cgm.com/products-services/line-services/ CMA CGM; https://www.maersk.com/local-information/shipping-from-europe-to-asia-pacific Maersk.).

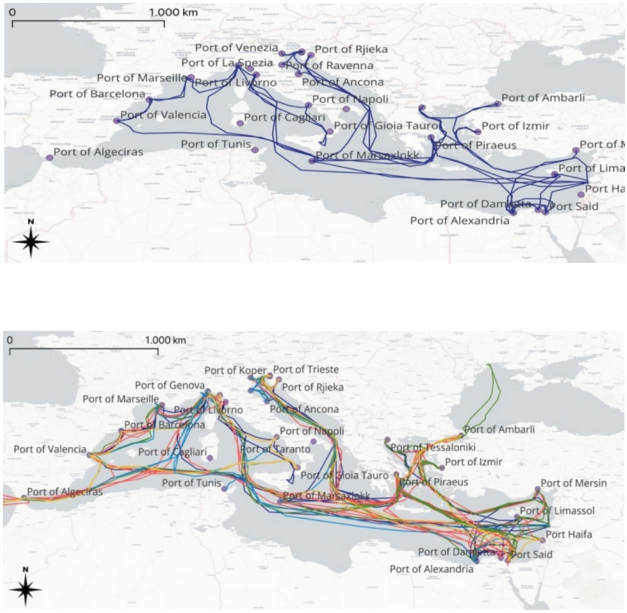

Fig. 2. (*continued*)

By first obtaining the contiguity matrix that determines network development, it is possible to go on to develop Freeman's Degree Centrality Index using the following formula [22]:

$$DG = \sum_{k=1}^{N} \frac{\alpha(n_i; n_j)}{N-1} \tag{1}$$

In this equation n_i and n_j represents two nodes of the network, and, on the other hand, a represents the arc connecting these two nodes. If the arc is present, and thus the two nodes will result connected to each other, α will have a value of 1, in the case where the two nodes are not connected the arc will have a value of 0.

A second centrality index used is the Eigenvector Centrality Index. This index represents a second measure of centrality used in network analysis to assess the importance of a node within a network. This metric is based on the mathematical concept of eigenvectors of a matrix [23]. The main idea behind Eigenvector Centrality is that nodes connected to important nodes are themselves important. The Eigenvector Centrality algorithm assigns each node a score proportional to the sum of the scores of its adjacent nodes, weighted according to their importance, through an iterative process. In more simple terms, a node has high centrality according to Eigenvector Centrality if it is connected to other nodes that are also central. Therefore, the centrality of a node depends not only on the number of connections, but also on the quality of those connections.

The mathematical form for calculating the Eigenvector Centrality of a node in a network is the following:

$$p_i = \frac{1}{\lambda}\sum_j W_{ji}p_j \tag{2}$$

In this case, p_i, p_j represent the centrality of the eigenvector for the i-th and j-th nodes, while the term W_{ji} represents the element in the i-th row and j-th column of the adjacency matrix W.

The key idea is that the centrality score for a node is proportional to the sum of the centrality scores of the other nodes to which it is directly connected, weighted according to their centrality. The estimation of Eigenvector Centrality was done through the network analysis software Gephi.

Traffic volumes, Freeman's Index of Centrality and Eigenvector Centrality are the main indicators on which to build the network analysis hierarchy highlighting the strategic importance and marginality of different ports within the network.

A further elaboration of the indices just used is given by the introduction of graph diagrams, in which the different ports (nodes) and routes (arcs) will be summarized. The first graphs presented were developed from the Fruchterman-Reingold layout [24], defined through a positioning algorithm whose main objective is to arrange the nodes of a graph in such a way that the nodes connected by an arc are arranged close to each other, while the unconnected nodes are evenly distributed in space, introducing forces of attraction between the nodes connected by an arc and forces of repulsion between all the nodes of the unconnected graph. As a result, connected nodes should be attracted close together, while unconnected nodes should repel outward. In fact, the arrangement that is being created is one in which the most central nodes are represented in a more central area, and as the interactions between different nodes decrease these will be arranged in progressively more peripheral areas.

The last step proposed in this paper is to take advantage of a geographic node distribution layout, in which, through the use of latitude and longitude, it is possible to georeferenced the graph in a cartographic environment, effectively giving the graph a spatial dimension that can be imported into common geographic information tools.

4 Results and Discussion

The preliminary analysis on traffic volumes within the Mediterranean Sea immediately highlights some extremely interesting dynamics regarding the dynamics of containerized traffic in the Mediterranean Sea. Considering the initial clustering of the 29 ports in the sample in the different ranges, it can be seen that the ports of Barcelona, Valencia and Algeciras that make up the Spanish Med Range handle a higher share of traffic than the other clusters, handling 26.3% of total flows in 2022. This subdivision also allows us to note co-me the northern Mediterranean ports, deputed to gateway functions to the different hinterlands are able to convey on average a more limited amount of containers than the transshipment hubs located along the east-west route. In particular, the ports of Gioia Tauro and Marsaxlokk for the Central Mediterranean Range, the port of Piraeus for the East Med Range, and Port Said for the ports that make up the South Med Hubs, represent the driving forces for the containerized flows of the different clusters [25, 26].

It can be seen that the near-totality of the ports under analysis have either maintained their traffic volumes virtually unchanged over the past 10 years or are experiencing an expansive phase.

With this in mind, we can immediately see how two transshipment hubs located in southern or island Italy have seen extremely significant traffic slumps: the port of Cagliari, Sardinia, which has gone from 629 thousand TEUs in 2010 to 140 thousand in 2022 and the port of Taranto, which has gone from over half a million TEUs in 2010 to about 26 thousand in 2022. The reasons for these slowdowns can be attributed to the strategic choices of shipping lines and different terminal operators; however, we can already have indications about the extremely more significant volatility of transshipment hubs compared to gateway ports [18]. This dynamic can be attributed to the very nature of the various gateways serving the production-industrial fabric in the port hinterland areas, thus resulting in the fashion-le shift node of sea-land flows [27, 28]. Next, the network analysis of traffic volumes is presented (Fig. 3) carried out using the methodology presented earlier by utilizing the Fruchterman Reingold layout and using the contiguity matrix and weighting for traffic volumes as the first proxy for the realization of the graphs. This layout emphasizes the centrality of the four main transship-ment hubs located near the pivotal east-west Mediterranean route, Suez-Gibraltar, placing the ports of Gioia Tauro, Marsakloxx, Piraeus, and Port Said in the most central positions.

We can also see that the ports of the Spanish Med Range, despite extremely large volumes of traffic, hold a slightly more defiladed position than the ports mentioned earlier, as does the port of Genoa. This dynamic can be explained by the fact that transshipment hubs handling sea-sea flows will indicatively be characterized by a higher number of

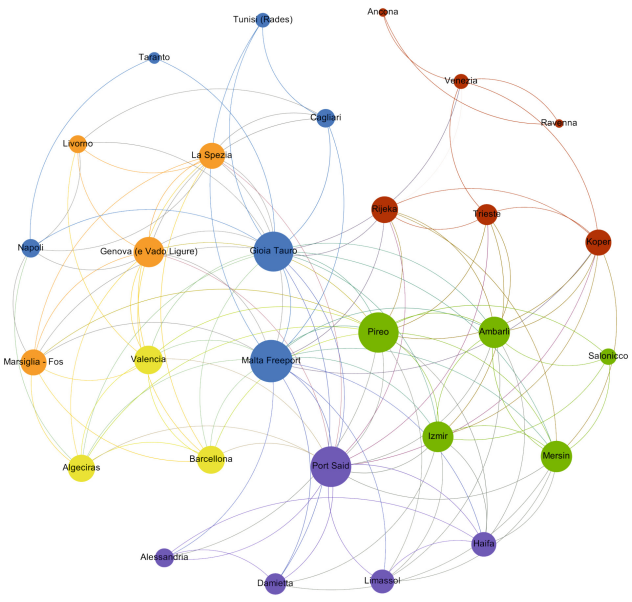

Fig. 3. Network representation of volume of TEU handle per port under the Fruchterman Reingold layout. Source: Personal Elaboration in Gephi.

maritime connections than mixed ports or gateways will move cargo to backport areas [29, 30, 36].

The network analysis was subsequently extended by computing the Freeman centrality index, calculated using Formula (1). Using this indicator, we can see from the graph depicted below (Fig. 4) how there is basically an overlapping with regard to the most central nodes within the port network, but it is interesting to observe how the ports of Algeciras (Spain), Damietta (Egypt) and Ambarli (Turkey) hold rather marginal positions in the face of extremely significant traffic flows. These dynamics are due to different reasons: as far as the port of Algeciras is concerned, infra-Mediterranean routes were considered and not Atlantic ones, nor were the transport dynamics linking the Spanish port of call to that of Tanger Med, a key hub for traffic between the Americas and Europe, and subsequently, for all these ports it must be pointed out that feeder services were not taken into account [31, 32]. Consequently, despite the extremely significant critical mass of these ports, their location within the graph is feeble.

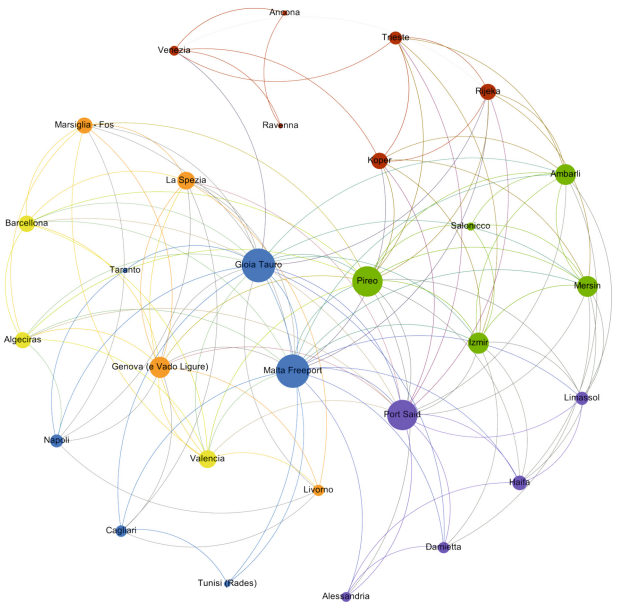

Fig. 4. Network representation of the Freeman Index for the different port under analysis represented with the Fruchterman Reingold layout. Source: Personal Elaboration in Gephi.

Finally, the Eingivenvector Centrality Index provides the extremely accurate representation of the network analysis. This indicator highlights how, partly because of their geographical location, some port ranges play more or less marginal roles within the network, as in the case of the Ligurian Range and North Adriatic Range ports.

In addition, the Eingivenvector Centrality Index highlights how for all the different port ranges, with the exception of the Adriatic range,as presented in Fig. 5, are characterized by the presence of central nodes, represented by transshipment hubs or mixed

ports capable of handling important volumes of traffic, and representing the hub of the transport system on an inter-regional scale [33–35].

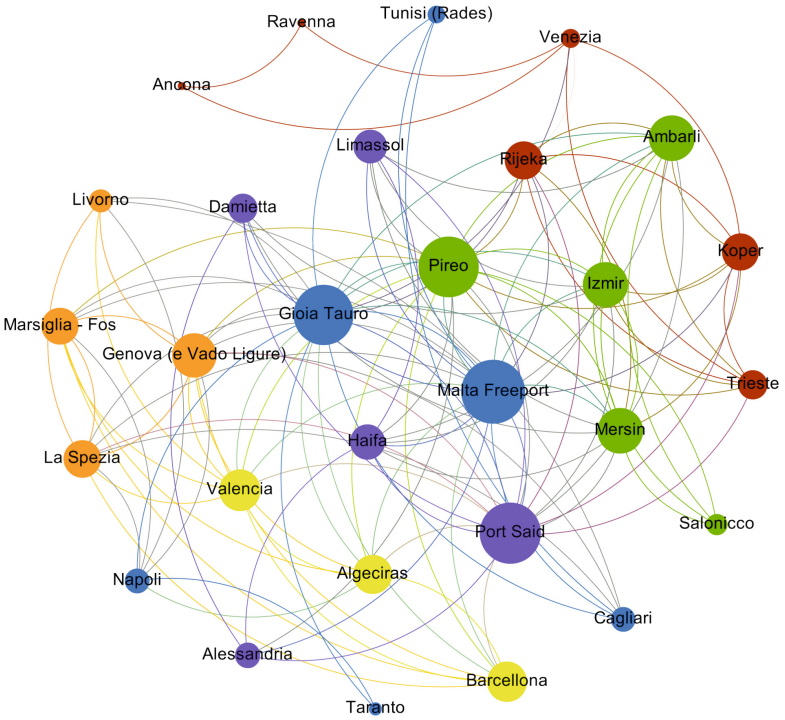

Fig. 5. Network representation of the Eingivenvector Centrality for the different port under analysis represented with the Fruchterman Reingold layout. Source: Personal Elaboration in Gephi.

Finally, using the geo-referenced layer of the network analysis, it is possible to translate these considerations from an abstract Cartesian plane to a map plane. Indeed, in Fig. 6A we find the representation of eingivenvector centrality through the geo-referenced layer, while in Fig. 6B the network analysis related to traffic volumes has been imported onto a thematic map [37].

The map analysis further highlights the ongoing trend of channeling an increasingly significant percentage of traffic shares to strategically located transshipment ports [6, 9]. The strengthening of these ports is also determined at the expense of some hubs, such as the ports of Cagliari and Taranto.

On the other hand, as far as the main gateways are concerned, the overall trend is that of an increase in traffic volumes, but ports capable of conjunctively handling both hinterland and other port traffic, i.e., those ports characterized by the presence of both of these services that take the name of mixed port, are surely destined to assume more central roles within these com-plex networks. This case study certainly includes the port of Valencia, and, to a less marked degree, the port of Trieste [34].

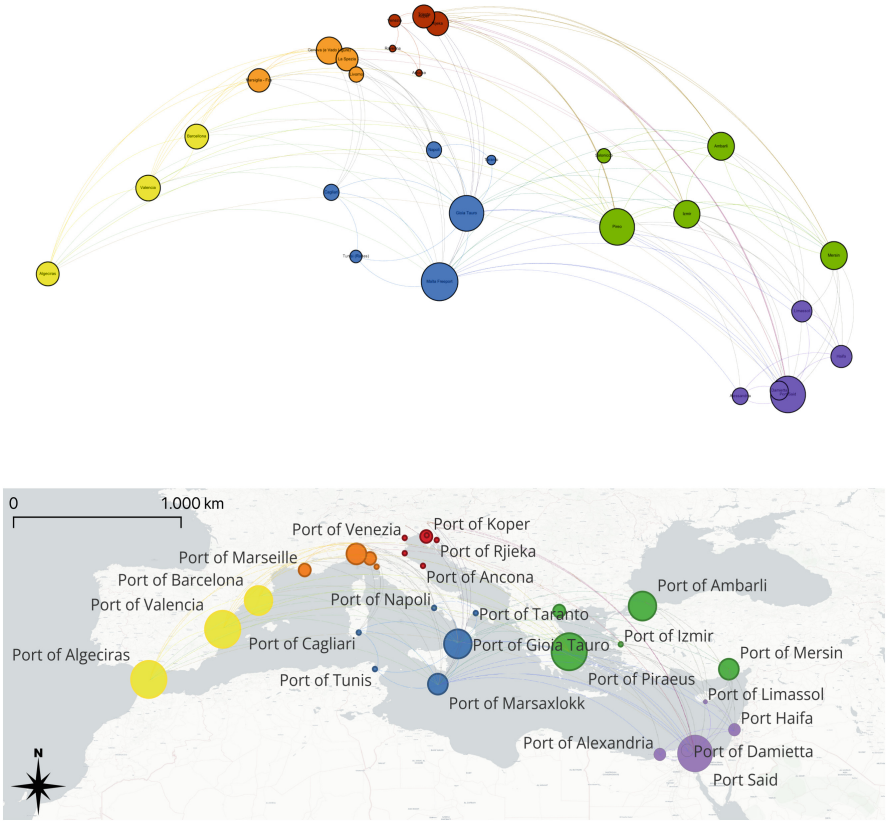

Fig. 6. Network representation of the Eingivenvector Centrality index for the Mediterrenean ports represented by the Geo-Spatial layout (Fig. 6A) and Geo-Spatial layout of the volume of TEU handle by the different ports, imported in a cartographic environment. Source: Personal Elaboration in Gephi (Fig. 6B) and then geo-referenced in QGIS.

5 Conclusion

The Mediterranean port system represents an extremely com-plex and dynamic ecosystem, influenced by the strategic choices of different market players and geo-economic dynamics on a global scale [36]. The complexity of the shipping network in the Mediterranean basin has meant that individual ports no longer represent simple logistics nodes of modal shift of goods [19] but represent strategic pivots of global networks along major supply chains [9]. Market complexity is due to the desire on the part of all market players to want to maximize network effects by exploiting economies of scale wherever possible. These observations justify the trend toward concentration of traffic volumes in a small number of major logistics hubs, which represent the center of gravity of the integrated transportation system not only on a regional scale, but also on a global scale [10].

This analysis shows how the strategic position of the Mediterranean basin in relation to the dynamics of global transportation networks is bound to further increase traffic volumes. We observed how the volatility of traffic volumes for gateways is extremely more limited than for transshipment hubs [14]. For this reason, the development trajectories that the Mediterranean basin will undergo will involve the strengthening of some gateways located in strategic positions with respect to their reference hinterlands, assisted by a growth of the main transshipment hubs located close to the main Mediterranean route, which are characterized by the highest centrality in the transport network. At the same time, we can expect smaller and lesser transshipment hubs to lose their traffic shares due to the centralization of flows to a smaller number of strategic hubs or to gateway ports that are increasing their transshipment share, becoming de facto, mixed ports [19].

The final consideration of this paper regards the actual geopolitical situation that is affecting in this period the Red Sea and the Suez Canal. In fact, since October 2023, the Houthi, an armed group from Yemen, started a series of attacks on merchant vessels navigating into the Gulf of Aden and the Bab El-Mandeb Strait. This ongoing event has led to a restructuring of shipping routes, with cargo vessels now opting to circumvent Africa via the Cape of Good Hope for security reasons. These developments set the considerations presented in this paper outdated, or at least indicative of a transitional period until a return to normal situation. Nonetheless, this events significantly impacts containerized traffic flows within the Mediterranean Sea basin.

Appendix

See Table 2.

Table 2. Freeman Degree of Centrality Index and Eigenvector Centrality Index of the Mediterranean Ports.

Port ID	Degree Centrality Freeman	Eigenvector Centrality	Port ID	Degree Centrality Freeman	Eigenvector Centrality
Ravenna	0107	0.020	Barcellona	0.357	0.579
Ancona	0.107	0.020	Marsiglia - Fos	0.357	0.529
Taranto	0.107	0.107	Rijeka	0.357	0.545
Tunisi (Rades)	0.143	0.194	Koper	0.357	0.524
Salonicco	0.179	0.256	Valencia	0.393	0.603
Venezia	0.214	0.210	La Spezia	0.393	0.533
Alessandria	0.214	0.327	Genova (e Vado Ligure)	0.464	0.652
Livorno	0.250	0.289	Izmir	0.464	0.666
Cagliari	0.250	0.312	Mersin	0.464	0.679

(*continued*)

Table 2. (*continued*)

Port ID	Degree Centrality Freeman	Eigenvector Centrality	Port ID	Degree Centrality Freeman	Eigenvector Centrality
Damietta	0.250	0.394	Ambarli	0.464	0.678
Trieste	0.286	0.390	Pireo	0.679	0.937
Napoli	0.286	0.312	Port Said	0.679	0.949
Limassol	0.286	0.468	Gioia Tauro	0.75	0.929
Haifa	0.321	0.494	Malta Freeport	0.75	1.000
Algeciras	0.357	0.562			

Source: Personal Elaboration

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Urban Regeneration: Innovative Tools and Evaluation Model (URITEM 2024)

Assessment Approaches for Rent and Sales Price Control in Social Housing

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Abstract. The lack in the direct participation of the public sector (including Local Authorities) in the implementation of new initiatives of Social Housing that has been recorded since the 1990s has been countered by an increasing involvement of the private sector also by virtue of density bonus, fiscal, economic and financial nature leverage in order to make Social Housing initiatives operationally and financially feasible. This contribution reports the results of a Reresearch financed by the National Association of Builders, Lazio section and by the Department of Architecture of the University of Florence, which is aimed at defining a procedure for the identification of capped rents and sales prices and lower than the free market, but contextually able to guarantee the break-even point for the promoters of Social Housing initiatives of a private nature. In order to meet the aims of the Research, to determinate rents, it has been decided to deepen the use, in this case, of the Break-Even Analysis (BEA) proposing an operational declination specifically calibrated on the case study; for the sales price, an experimental and specially procedure to verify of their suitability is proposed, based on specif case study of Lazio Region.

Keywords: Break-Even Analysis · Social Housing · Rent/Sales Price Control

1 Introduction

Since the 1990s in Europe, there has been a growing involvement of the private sector in public housing policies, i.e., aimed at providing access to housing to those who lack the income/wealth capacity to access the free market. In fact, albeit with different declinations and audiences from state to state, there has been a steady decrease in the direct participation of the public sector (including Local Authorities) in the implementation of new public housing initiatives, with a greater concentration of energies and resources on the management of existing assets, to the benefit of private initiative. It is precisely this case that is of particular interest today in the very broad field of so-called "Social Housing" (SH). Despite the broad perimeters of the SH terminology, analyzing the different interpretations in the European Union, however, one can recognize a target that accumulates the policies on the subject of the various member states, which in short consists of promoting interventions and initiatives finalized to make available housing with rents (or purchase prices) below free market thresholds [1].

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However, it should be noted at the outset that the potential audience of SH recipients takes on different characterizations from state to state (in short, it depends on the income thresholds for access to SH). According to the 2005 CECHODAS (European Federation of Public, Cooperative & Social Housing) definition, this term refers to "housing solutions for those households whose needs cannot be met under market conditions and for which there are allocation rules" [2]. Similar definition, with more emphasis on the organizational and management profile of the interventions and aspects of social cohesion and integration of SH users, is the European Commission's 2010 definition: "the development, rental/sale and maintenance of affordable housing and its allocation and management, possibly including the management of housing complexes and neighborhoods; […] may include support services involved in housing programs or the rehousing of specific groups or debt management of low-income households" [3].

The constant need for housing by families/subjects unable to access housing in the open market (for rent or for sale), which according to Housing Europe [4], albeit to an extent varying from member state to member state, ranges between 10% and 20% of the population, makes the topic particularly topical and in particular becomes the subject of scientific interest the study of SH-related values, in particular related to the rent or sale of assets within this perimeter.

The present contribution reports the results of a Research that benefited from a dop-first funding: (i) an initial funding was first provided by the National Association of Building Constructors (ANCE), Lazio section; (ii) a second funding was provided by the Department of Architecture of the University of Florence as part of the allocation of University Funds, and which pursues the aim of identifying and/or defining methodologies and tools for the identification of controlled rents and purchase prices that are lower than the free market, but still able to guarantee minimum operating conditions for the promoters of SH initiatives, of a private nature.

To meet the aims of the Research, with reference to the determination of rents, the use, in this case, of Break-Even Analysis (BEA) is explored in depth, proposing an operational declination of it specifically calibrated on the case study; with regard to transfer prices, an experimental and specially constructed model of verification of their suitability is proposed.

In the following: in Sect. 2 a summary is proposed of how SH has been interpreted in Italy in particular in the last 15 years, since the definition of SH appeared in the legislation; in Sect. 3 the methodological aspects related to the techniques to be used because of the purpose of the Research are explored in depth; in Sect. 4 the case study is illustrated and, having carried out the experimentation, the results obtained are discussed; in Sect. 4 the conclusions of the present work are drawn.

2 Social Housing in Italy

In Italy, with the "Piano Casa," introduced by Article 11 of D. L. June 25, 2008, No. 112, a new era began as far as social housing is concerned: it is a parallel model to the traditional model of Public Residential Housing, endowed with copious literature-professional, juridicial and economic. Elaborated between 2007 and 2008, the Piano Casa was grafted into an economic and social framework of housing that, as of 2005, was now showing the first signs of breaking with the previous fifty years.

It was precisely with the Piano Casa that, in Italy, the definition of SH (or Edilizia Privata Sociale - EPS) was established. The Italian declination of the European definition of SH includes the following three elements: i) focus on that segment of citizens who are disadvantaged because they are unable to sustain a market rent, but who are not so disadvantaged as to be able to access ERP (so-called gray band); ii) interest and commitment to combine social, economic and environmental objectives; iii) allocation criterion based on the so called "targeted" model [1]. This approach is based on the assumption that the objectives of housing policies are predominantly achieved by the market with identification of households for whom the market is unable to provide decent affordable housing as beneficiaries, with no special restrictions beyond income level and the setting of a capped rent for rents (with which a public subsidy may be associated) [5].

The Housing Plan was followed by the approval of the "National Housing Plan," consisting of six lines of action: (i) establishment of an integrated national and local system of real estate funds for the construction of residential housing properties; (ii) increase of the public housing stock; (iii) financial promotion also at the initiative of private parties (project financing); (iv) facilities to housing cooperatives established among the recipients of the intervention; (v) integrated programs for the promotion of residential housing including SH; (vi) interventions within the competence of the former IACPs (to which the resources identified during the previous legislature by D. M. Infrastructures 28 of December 2007).

With the 2009 National Housing Plan, therefore, a further new taxonomy is developed based on the distinction between housing built only through public funds and managed by public entities (typically, the former IACPs) and various types of Public-Private Partnerships. In fact, it is worth mentioning that SH differs from ERP: i) in that it is aimed at a specific target of recipients, characterized by certain income conditions (the oft-mentioned "gray area"); ii) for the mechanism of calculating rents (lower than market rents, but determined in consideration of the economic-financial sustainability of the initiatives); iii) leaving uncovered a large segment of the population, whose demand can only be met with subsidies from central and local governments.

Against this backdrop, with the enactment of the first Housing Plan, the national housing framework has undergone, at least at the regulatory level, a change from the previous static period. Allocations at the central level and a new paradigm for the selection of interventions stimulated the co-involvement of private investors and the mobilization of different levels of government, in a public-private partnership perspective aimed at the realization of SH [5].

Regulatory evolution, therefore, has resulted in the expansion of intervention tools, graduating their intensity according to the goal of social inclusion of different categories of end users. The overall redefinition of the sector's structure, however, has marked the pace due to both the cumbersome nature of administrative processes and the extreme territorial heterogeneity in the transposition of national regulations and the actual implementation of interventions.

In this area, there remains a wide range of critical issues, the resolution of which is the basis for a genuine revitalization of the sector. In particular: i) the more effective link between the role of the state, regions and local authorities to provide timely and

efficient responses; ii) the identification of a budget of subsidies and compensation in line with that reserved for the sector by the main European countries; iii) the effective development of projects for the renovation and enhancement of existing real estate assets as opposed to new construction; and iv) greater attention to the rental market, the real node for restoring liquidity to the market [6, 7].

Since 2009, de facto, control of SH has shifted to the regions; within the perimeter traced by the Piano Casa, in fact, each region has constructed an interpretation of SH according to a principle of complementarity and, only rarely, of alternative to its own programming (mainly carried out by employing the traditional tools of subsidized, facilitated and conventional housing) to meet housing needs. An examination of the regional legislation, therefore, does not allow the definition of a univocal characterization, but only the placement of the new instrument in a position of intersection between subsidized and subsidized housing, with a greater inclination toward one or the other depending on the degree of public financial involvement, the nature of the interventions and the characteristics of the housing recipients. However, it is possible to identify at least four common aspects relatively the ERS, as interpreted by the Regions: i) the presence of a more articulated and varied housing demand, which cannot be satisfied only with traditional tools and in the absence of integrated projects; ii) the consequent desirability of fractionating supply into different lines of interventions and the identification of two macro-categories for the provision of residential services: the general interest (i.e., the specific role of a universal and solidaristic public service) and the general interest with economic relevance (i.e., the prevision of a correlation between performance and tariffs, albeit lower than free-market sales); (iii) the scarcity of public financial resources and the preference of using them to respond to the provision of housing services of general interest; (iv) the acquisition of proposals at the local level by private operators, considered most capable in identifying sustainable and innovative solutions, with prior evaluative responsibility of municipalities.

Again from the examination of regional experiences, it is possible to construct a synopsis of the measures, or levers/facilities, by which they have involved the private sector in the implementation of SH initiatives:

1. economic leverage characterized: in the start-up phase by free of charge or low-cost area rent or sale, capital or interest subsidies for co-construction of housing units; in the operation phase by grants to managers and tenants, rent support vouchers; in the decommissioning phase: grants to tenants for purchase;
2. financial leverage characterized: in the start-up phase: capital underwriting, subsidized financing for area acquisition or initial investment, public guarantees; in the management phase: guarantee funds on risks linked to contracted debts (manager or tenants); in the divestment phase: subsidized loans to tenants for redemption, sale options, guarantee funds on tenants' mortgages/rents;
3. regulatory/urban planning leverage or density bonus [8] characterized: in the start-up phase: granting of land/area rights, volumetric premiums, urban equalization or compensation, exemption or reduction of construction charges.
4. fiscal lever characterized by: in management phase: relief on property taxes on the value of rental apartments.

In what follows, we will dwell on an issue that affects a specific lever, that of legislation/urban planning just mentioned, with specific reference to the case of the Lazio Region in Italy. In Latium, the concept of SH in conformity with the provisions of the Ministerial Decree of April 22, 2008, enters into the regional system with Regional Law August 11, 2009, no. 21 "Extraordinary measures for the housing sector and interventions for SH." To the extent of interest in this Research, we dwell in particular on the provisions of Art. 3b "Interventions aimed at the finding of housing at a lowered rent through the change of use from non-residential to residential," by which the regional legislature imposes on operators in the sector the realization of housing at a lowered rent in exchange for the possibility granted to them to change the use of buildings or areas and cubature premiums.

3 Methodologies for Defining Rents and Sales Prices

3.1 Break-Even Analysis to Assess Rents

BEA allows the verification of the conditions of financial viability to intra-take an investment or rectify, for example, one already undertaken.

It is a tool for assessing the economic-financial feasibility of an investment/industrial project, a key factor in its success that depends not only on the availability of allocable resources on the part of the proposing parties, but above all on the ability of the work to be carried out to generate revenue to offset the costs of implementation and also, in certain cases, to maintain its efficiency.

It is recognized in the scientific literature that BEA presents utility in identifying the extent and magnitude of the economic-financial problems that a company faces and in identifying their solutions.

The main utility of the BEA lies in its ability to examine the impact of prices and costs in relation to profit [9]. Indeed, BEA summarizes the effects of changes in an organization's volume of business on its costs, revenues, and profits [10]. It can be extended to cover the effect on profit of changes in sales prices, service rates, costs, income tax rates, and the organization's product or service mix. It is thus an evaluation tool that can provide a company's management, a comprehensive overview of the effects on revenues and costs of all types of short-term financial changes. Although the word profit often appears in the scientific literature associated with BEA, this technique can also be effectively used for the evaluation of social-impact initiatives that are not focused, preliminarily, on the pursuit of profit, but on the practicality and therefore feasibility of the programmatic/planning forecasts associated with a productive-industrial initiative [10].

The subject of BEA, is in fact the study of the composition of an enterprise's economic and financial items in order to understand the break-even point, or break-even point. The break-even point originates from the economic concept of "point of indifference." From an economic point of view, the break-even point indicates the quantity of certain assets at which the decision-maker would be minimally, but sufficiently, satisfied with the results of an industrial venture, thus being able to undertake it. At this quantity, the costs and benefits, including an ordinary (minimally acceptable) profit are, in fact, exactly balanced. In other words, the break-even point defines when an investment will generate

a positive return using a given price necessary to cover all the costs, including that ordinary minimum profit that prompts a given operator to "take a risk" to undertake an economic-productive activity [10].

Break-even point analysis is a useful tool for short-term planning and decision-making and is most relevant when the proposed changes in the activity are therefore relatively small and thus established patterns and cost relationships are likely to hold over time. If the amount of fixed costs and marginal cost per unit change, the risks of BEA failure increase [10].

Fixed costs are generated by the acquisition of the area and/or real estate of intervention, their suitability and eventual reclamation, the rehabilitation of pre-existing buildings, and the construction of works and buildings related to the infrastructural system (urbanization works) and/or collective level standards and equipment.

Variable costs, on the other hand, are associated with the factors of production, available in variable amounts, of the production process and depend on the volume of production: they increase as it increases and, conversely, decrease when the quantity produced contracts.

The sum of fixed costs and variable costs consequent to each volume of production gives total costs [10].

Against the production costs, the sale at market prices of the goods and/or services produced by the intervention determines the firm's returns, or, depending on the volume of production, the total revenue.

Total profit can be positive, return, or negative, loss, or, again, zero, and the budget then is balanced.

In technical terms, "break-even" is an unknown q*, i.e., the minimum amount needed to repay fixed and variable costs, thus ensuring ordinary profitability in market terms for a project proponent [11, 12].

In short, the BEA allows the initiative to be valued by considering its implementation costs and the property values (to be rented) of income-generating assets or disposals.

In traditional BEA, known fixed costs, unit variable costs and unit revenues, the quantity of q, which becomes q* by which equilibrium in the composition of fixed and variable costs and revenues (without extra-profits) is achieved, can therefore be estimated through (formula 1):

$$q^* = \frac{CFt}{Pu - CVu} \tag{1}$$

Putting Pu as the unknown and considering this datum as the relationship between income I and cap rate r, formula 2 will result in:

$$I = P_u * r \tag{2}$$

According to cost approach, Pu is derived from the sum of all settlement costs and area value. Therefore, the formula above can be articulated by considering all fixed and variable costs [13], as per the scientific literature, but considering the applicative specificity of BEA if a unit product is considered, fixed costs can be considered as an incidence to variable costs; therefore, formula 2 can be transformed into formula 3:

$$I = (C_a + C_{te} + C_{ia} + C_{sa} + C_{up} + C_{us} + C_{cc} + C_{tc} + C_{st} + C_{oc} + C_{oc} + C_{ai} + C_{of} + C_{up} - RC) * r \quad (3)$$

dove:

- Ca related to the market value, if any, of the buildings/intervention area;
- Cte related to the technical costs of constructing saleable buildings;
- Cia related to the costs of suitability of the area;
- Csa related to the costs of outdoor private area development;
- Cup related to urbanization costs (equal to or higher than primary urbanization charges);
- Cus relating to secondary urbanization charges;
- Ccc related to contribution on construction cost;
- Ctc related to costs of works to be surrendered, non-locatable/saleable;
- Cst related to technical expenses related to fixed costs;
- Coc related to marketing charges;
- Cai related to other costs, including contingencies;
- Cof related to financial charges;
- Cup related to the profit of the promoter;
- RC related to grant funding.

With reference to Ca, i.e., the market value of the area, it is represented that if the intervention derives from building bonuses on areas that have already been transformed, and where therefore the incidence of the land has already been absorbed by the realized buildings, this component may not be considered in the BEA.

Unit sales prices (Pu) are concerned with the proceeds from the sale of buildings that can be disposed of with the intervention (or even rented out, if rental income is capitalized). For a quick and still effective implementation of the model, they are estimated in a synthetic-direct manner taking into account data provided by databases that reveal sales prices. Thus, the implementation of formula 3 makes it possible to estimate the break-even rental canon of real estate initiatives; it seems clear that, qua-lore the real estate initiative is SH, this case will have to be considered in the estimation of costs.

3.2 Methodological Approach to Verify the Sale Prices

On the other hand, regarding the verification of the impact of Article 8 of R.R. No. 18/2012, it should be preliminarily considered that:

- the housing can be alienated after 15 years from the terms of Article 2 paragraph 3 of the aforementioned R.R. No. 18/2012 (alienation price not exceeding the average OMI quotations of the six months prior to the sale);
- the alienation of the housing to the tenant can be anticipated after 7 years from the commencement of lease considering as the maximum alienation price 70% of the average OMI quotations of the semester prior to the alienation;

– even before the expiration of the term referred to in Article 2 of R.R. No. 18/2012 (15 years), the owner may, at the sale price referred to in Article 8, paragraph 2 (alienation price not exceeding the average OMI quotations of the six-month period preceding the sale), alienate en bloc or fractionally or transfer the reserved housing to a real estate fund or other private entity for management.

In the first instance, it should be noted that the suitability of such sale values defined by R.R. No. 18/2012, once the 15-year rental constraint has elapsed, will depend on the performance of the OMI quotations taken as a reference for the sales compared to the actual market values that will be substantiated at the time of the alienation. It should be noted that once the 15-year rental lien has expired from the terms set forth in Article 2, Paragraph 3 of R.R. no. 18/2012, the real estate units may present themselves, likely, in an average to fair condition of maintenance and efficiency, and that therefore, in this case, the use of the average parameter of OMI quotations may appear fair, both for the seller and for the buyer-re; it should be noted that OMI quotations that are not aligned with market values would produce conveniences for one party and inconveniences for the other (in the case of OMI quotations below market values, conveniences for the buyer and inconveniences for the seller; conversely, with OMI quotations above market values, inconveniences for the buyer and conveniences for the seller).

On the other hand, with regard to the verifications related to the early alienation to the tenant after 7 years from the terms referred to in Article 2 paragraph 3 of R.R. No. 18/2012, it is intended to put in place verifications on the suitability of the values provided by R.R. No. 18/2012 also combined with the effects produced by the rents defined by Article 6 of the same regulation.

Since what is contemplated in Article 8 paragraph 4 of R.R. No. 18/2012 is an option, it is intended to construct some scenarios from which to extrapolate data to assess the balance of the measure. Using procedures inferred from financial mathematics to calculate prepaid and deferred annuities, we proceeded to associate the regulatory forecasts with a financial structure structured on the basis of the assumption that the rents paid for the duration of 7 years are discounted and can be "virtually" considered as an advance on the purchase price, however, to a partial extent with respect to the capped rent (in fact a gross income for the implementing party) having to consider the "part-ownership expenses" that remain with the landlord. Given the nature of housing with purposes that have social impact, any further curtailments that in the free market are generally practiced in contracts that take the form of rent to buy are not considered.

This discounting of rents, operated by considering a discount rate that is considered to be assumed to be equal to the risk free rate practiced at the Research start date (October 2023), equal in round figures to 4.5 percent, is therefore interpreted as a "down payment on the price" [14].

The scenarios are constructed by simulating average OMI quotations, based on which to consider 70 percent as the purchase amount, varying from €1,000/sqm to €2,500/sqm (interval every €250).

The findings of this analysis brings out data that is believed to be indicative for understanding the viability of the regulatory measure.

In fact, the proposed methodology, aims to define an equivalent quotation in terms of alienation price, "simulating" a contract – "fictitious" - which provides for the capping

rents on account of price (which is allowed to be revalued pursuant to Article 6 paragraph 1 of R.R. No. 18/2012) and at the end of the 7th year, the balance in the amount established by Article 8 paragraph 4 of R.R. No. 18/2012, equal to 70% of the average OMI quotations of the six months prior to the alienation.

The calculation is made considering the current OMI quotations; therefore, a linear trend of OMI quotations with respect to the relationship with market values and inflation must be admitted as a condition to postulate the reasoning. It is worth noting that even in this case, affordability depends on the relationship between OMI quotations and market values actually re-discounted at the end of year VII.

4 Case Study: Social Housing in Lazio Region

The outcomes expected from the experimentation pursue the purpose of verifying the congruity of the related regulatory provisions (R.R. no. 18/2012) in terms of the capped calmierated rent and sales price of SH resulting from the conventional obligations assumed following the application of the oft-mentioned art. 3 ter, observed from the point of view of economic-co-financial feasibility for operators who would be in the administrative condition to be able to activate initiatives for the realization of housing at a capped rent, but who nevertheless are inhibited by rents deemed no longer consistent with the current economic context (2024) with suspected risks of economic-financial losses to implement interventions that although of social impact, are to all intents and purposes private in nature.

The BEA, appropriately declined because of the principles inferable from Article 3b of Regional Law No. 21/2009, was applied with the aim of determining the rents that allow the implementation of initiatives that, while providing for capped rents, are implementable by private operators, without the support of public contributions. In addition to the BEA, checks were carried out regarding the fairness of the amounts of housing alienation, according to the terms of Article 8 paragraph 4 of R.R. No. 18/2012.

The experimentation was extended to the entire territory of the Lazio Region; in this regard, a database was constructed containing about 100,000 data, taken from institutional and/or recognized scientific sources such as the Revenue's Agency Real Estate Market Observatory (OMI), the Ministry of the Interior, and ISTAT. The construction of the database was carried out by taking the micro-zones of the OMI as basic cores; for each micro-zone, with respect to the data made available by the Internal Revenue Service, additional data were integrated, which allowed to prepare sets of attributes the implementation of traditional, large-scale estimation procedures as a basis for being able to apply the BEA.

Specifically, the database was constructed considering the following data:

(a) geographic/demographic: territorial area, Region, Province, Municipality (and category), resident population (if greater than 10,000 inhabitants), band, zone, microzone;
(b) estimative: type description, state of preservation, maximum, average and minimum quotations, type of area considered for quotations, maximum, average and minimum rents, type of area considered for rents, master party expenses (value and percentage), capitalization essay, construction cost (referred to settlement production).

Geographic data were extracted from the Internal Revenue Service's OMI, the Ministry of the Interior and ISTAT.

Data of an estimative nature, on the other hand, were extrapolated by taking as reference data from the Internal Revenue Service's OMI and any appropriate reworkings.

Particular attention was given to the cost of construction (settlement production), which was specially estimated by considering:

(a) as direct costs: i) Technical Costs of Building Renovation, taken as a reference from the "Prices Building Types" (edition 2024) published by DEI, Tipografia del Genio Civile of RomeIn particular, the comparables were taken from typologies B5 and B7, which were considered to be those most consistent with the design types of Social Housing implemented under Article 3ter of R.L. no 21/2009. Data have been elaborated considering adjustment coefficients aimed at recording the recurring differences between the data of the Province of Milan and/or the Region of Lombardy to which "Prices Building Types"refer and homologous data instead referring to the five Provinces of Lazio;
(b) as indirect costs: i) suitability of the area, assumed to the extent of 2.50% of the technical cost of construction; ii) primary and secondary urbanization costs/charges according to the average rates practiced in the Lazio Region, also assuming that, given the nature of the interventions referred to in Art. 3ter of R.L. no. 21/2009, no further urbanization costs are to be expected since they are already included (and amortized) within the exclusively private component of the interventions; iii) contribution on the construction cost, not considered for the effects of art. 6 paragraph 5 of R.L. no. 21/2009; iii) costs due to works to be divested, non-locatable/non-saleable, not provided for; iv) technical costs, assumed at the rate of 8% of the Technical Construction Cost; v) marketing charges, not provided for; vi) other costs, including contingencies, assumed at the rate of 2% of all proceeding items, including technical costs; (vi) financial charges, provided for by considering a share of debt capital (debt) equal to 100% and assuming as the reference rate the IRS, calculated by the "European Banking Federation" plus spread (referring to ordinary contractor), or the additional delta that banks add to the index defined above to determinate the rate at which they grant loans. The repayment plan is assumed to be seven-year; vii) profit of the real estate developer (general manager of the transaction), considered by assuming two scenarios, as outlined above: 1) an initial scenario in which the developer's profit is assumed to be 10% of the total post-transformation Market Value; this amount of profit is lower than what is ordinarily considered in real estate development (15–25%) and is expected in the consideration that the real estate development initiative aimed at the production of housing to be subjected to subsidized rent produces risks that must be remunerated also in the consideration that it is profit related to the ""management" of the operation, as distinct from the return on capital profits, contemplated in the profitability essay of the operation (see below), which is generally used to estimate the incidence of the area/goods on which to intervene; 2) a second scenario in which the developer's profit is not considered, on the assumption that the rewards in Art. 3b can produce can produce a profit (which cannot be estimated since it differs from intervention to intervention) that is in any case capable of also absorbing the risks arising from the real estate development of

housing to be allocated at a lowered rent; viii) non-repayable financing, which is not provided for.

The results of the estimation related to construction costs (settlement production) were, through the elaborated regrouping coefficients, estimated with reference to the five Latium Provinces and also considering the differences related to costs due to the positioning of the intervention in the central area. In view of the processing of a large number of data on a large scale (approximately 100,000 data) and the differences in the results of the present elaboration, which are considered negligible (less than 1 percent between the various Provinces), it is considered appropriate to adopt, in each of the two scenarios, a single average regional figure for the non-central areas and a single average regional figure for the central areas. As of now, it should be noted that this differentiation is performed for methodological rather than practical reasons, as the inter-vents referred to in Article 3b of Regional Law No. 21/2009 fall exclusively not in the historic settlements as identified by the Regional Landscape Territorial Plan. Table 1 shows the outcomes of the estimates, under the two scenarios assumed.

Table 1. Estimated unit costs of settlement production of SH initiatives in the five provinces of Lazio - scenarios 1 and 2

Unit costs assessment of settlement production of Social Housing initiatives in the five provinces of Lazio Region						
Area type	U/M	Frosinone	Latina	Roma	Rieti	Viterbo
Scenario 1						
Total non-central areas	€/sqm	1,964	1,955	1,950	1,936	1,920
Total central areas	€/sqm	2,072	2,063	2,057	2,045	2,028
Scenario 2						
Total non-central areas	€/sqm	1,803	1,795	1,790	1,774	1,760
Total central areas	€/sqm	1,911	1,903	1,897	1,883	1,868

4.1 Data Elaboration: Scenarios 1 and 2

The data in the database were processed to identify sustainable rents in scenario 1, i.e., considering an albeit minimum profit and the incidence of the area. In the calculation it was necessary to put in place some operational simplifications: although aware of the applicative limitations of art. 3 ter of R.L. No. 21/2009 about the historical settlements identified in the Regional Territorial Landscape Plan, since it was not possible to verify on the coincidences of said landscape classification with the perimeters of the OMI

micro-zones, it was decided, for operational reasons related to the management of a particularly large database with about 100,000 data, to consider in the elaborations all the OMI micro-zones where data were available. On the other hand, from the calculation of municipalities with a population of less than 10,000 inhabitants, the parameters relating to the islands (Ponza and Ventotene) were excluded, as they were considered misleading for the purposes of the present application, considering these territorial realities not affected by the dynamics referred to in Art. 3 ter of Regional Law No. 21/2009. Having estimated the incidence of the area (the data were entered into the database), it was finally possible to implement the BEA.

A second processing of the data in the database was carried out to identify the sustainable rents in scenario 2; in this case, the profit of the developer of the initiative was not considered; the incidence of the area is considered equally as in scenario 1. What has already been explained above about area value, storic settlements and islands also applies in this case. Based on these considerations, the BEA was applied.

Table 2 shows the results of the experimentation; the data processing was aimed at searching for the rent that would allow the implementation of housing initiatives with subsidized rent in the territory of Roma Capitale (result 1), in the remaining municipalities of the Lazio Region with a population of 10,000 or more (result 2) and with a population of less than 10,000 (result 3).

Table 2. BEA scenarios 1 and 2

Rents (results)				
			Scenario 1	*Scenario 2*
1	*Rome*			
	Value	€/sqm for month	10.50	9.90
2	*Municipalities with population greater than 10.000 inhabitants*			
	Value	€/sqm for months	9.90	9.10
3	*Municipalities with population lower than 10.000 inhabitants (islands excluded)*			
	Value	€/sqm for months	10.20	9.40

The results generally refer to non-core areas (consolidated fabrics, expansion, renovation/transformation). The data resulting from the experimentation are to be considered "average," that is, generically referring to the macro-territorial areas considered (Roma Capitale, Municipalities with a population of 10,000 inhabitants or more, and Municipalities with a population of less than 10,000 inhabitants); it is evident that, if referred to more circumscribed areas, variations with respect to average rents could occur depending, in particular, on the Market Values found in the aforementioned areas. The proximity of the values of Lazio municipalities above or below 10,000 inhabitants suggests that this distinction could be, without consequence, overcome.

4.2 Verification of the Impact of Article 8 of R.R. No. 18/2012

Using the data in the database, in accordance with what is illustrated in Sect. 4, scenarios were constructed with the aim of verifying the impact of Article 8 of R.R. No. 18/2012. Table 3 shows the outcomes of the application illustrated in Sect. 4.4: rents were discounted and 7 scenarios were assumed for as many hypothetical OMI quotations (from € 1,000/sqm to € 2,500/sqm with inter-values of € 250).

On the other hand, with regard to the check on alienation prices after the 7 years of lease, contemplated by art. 8 c. 4 of R.R. no. 18/2012, it is noted how this optional measure results, with the rents referred to in art. 6 of the aforementioned regulation, and with the 30% deduction from the OMI quotations (always of the semester prior to the sale) of doubtful practicability for the owners of the housing, since at increasing quotations, even considering "virtually" the amounts disbursed during the lease as a down payment on the price, the equivalent paid decreases, with ratios compared to the average OMI quotations, which reach even below 80%.

It is considered useful to reiterate that the proposed applications and simulations refer to the case study provided in art. 3 ter of R.L. n. 21/2009; the determination of rents for additional forms of SH production, can avvenire always using the proposed procedure but must be considered input data specifically referred to the characteristics of the form of SH to which the application of the procedure is referred.

Hence it should be considered that the outcome values of the conducted experimentation cannot be generically applied to estimate sustainable rents for operators and/or as a starting point for capping, for different forms of SH than the one on which the present Research activity is focused.

Table 3. Sales prices verify according to art. 8 c. 4 del R.R. n. 18/2012

Fairness verification of alienation prices art. 4 c. 8 Reg. Reg. Lazio n. 18/2012								
Hypothesis 1: rent art. 6 Reg. Reg. Lazio n. 18/2012 - Roma Capitale - €/sqm 5 per month								
Discounted net income (tot.)	€	282						
OMI listings	€/sqm	1,000	1,250	1,500	1,750	2,000	2,250	2,500
Art. 8 c. 4 R.R. n. 18/2012	70%	700	875	1,050	1,225	1,400	1,575	1,750
Discounted net income	€	282	282	282	282	282	282	282
Sales price	€	982	1,157	1,332	1,507	1,682	1,857	2,032
Sales price/listings	%	98.20%	92.56%	88.80%	86.12%	84.10%	82.53%	81.28%

(*continued*)

Table 3. (*continued*)

Fairness verification of alienation prices art. 4 c. 8 Reg. Reg. Lazio n. 18/2012								
Hypothesis 2: rent art. 6 Reg. Reg. Lazio n. 18/2012 - Other municipalities with a population of 10,000 inhabitants or more - €/sqm 4 per month								
Discounted net income (tot.)	€	225						
OMI listings	€/mq	1,000	1,250	1,500	1,750	2,000	2,250	2,500
Art. 8 c. 4 R.R. n. 18/2012	70,00%	700	875	1.050	1.225	1.400	1.575	1.750
Discounted net income	€	225	225	225	225	225	225	225
Sales price	€	925	1,100	1,275	1,450	1,625	1,800	1,975
Sales price/listings	%	92.56%	88.05%	85.04%	82.89%	81.28%	80.03%	79.02%
Hypothesis 3: rent art. 6 Reg. Reg. Lazio n. 18/2012 - Other municipalities with population under 10,000 inhabitants - €/sqm 3 per month								
Discounted net income (tot.)	€	169						
OMI listings	€/mq	1,000	1,250	1,500	1,750	2,000	2,250	2,500
Art. 8 c. 4 R.R. n. 18/2012	70,00%	700	875	1,050	1,225	1,400	1,575	1,750
Discounted net income	€	169	169	169	169	169	169	169
Sales price	€	869	1,044	1,219	1,394	1,569	1,744	1,919
Sales price/listings	%	86.92%	83.54%	81.28%	79.67%	78.46%	77.52%	76.77%

5 Conclusions

The experimentation was intended to pose mainly from the perspective of the private operator. The results obtained from the experimentation mentioned in the previous chapter are sustainable rents for private SH operators; further and future studies will have to verify, beyond the break-even point of SH initiatives but not necessarily for the citizens for whom social housing is intended, i.e. those who do not qualify for ERP but also have difficulty accessing the free market [15].

The fees resulting from the experimentation can already be considered in part "capped": in fact, they are "break-even fees" with which to repay the costs of the initiative, with reduced profits (scenario 1) or even no profits (scenario 2) unlike therefore what is generally expected from initiatives in the free market; as already illustrated, in detail in scenario 1 it is a fee that also considers a profit, albeit minimal; in scenario 2

it is assumed that the completely free market component of art. 3b of R.L. No. 21/2009 compensates for the assumed absence of profit.

Finally, it should be noted that, from the reading of the results of the experimentation in the light of the findings of the Research, in the present case referred to the capped rents referred to in R.R. No. 18/2012, but also in general in social housing, based on the actual condition of the construction sector, a diachronic situation is presented characterized by the size of the identified rents that if on the one hand would ensure the implementation of the initiatives, on the other hand could exceed the threshold of sustainability for low-income households.

A further calming operation, by decreasing the identified rents, on the other hand, if on the one hand it would broaden the audience of possible beneficiaries of the initiatives, on the other hand it could condition the activity of private operators.

Further investigation, to overcome some "rigidities" related to the choise of economic and assessment parameters in the proposed methodology, may involve the implementation of sensitivity analyses aimed at identifying not a single output value (in the case of rents), but multiple output values dependent on the change in the economic-context underlying the assessment.Ultimate aim of the work should be aimed to define a balance that avoids situations of ""non-intervention" and that at the same time has a social rents affordable to the families on the basis of their income.

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Medium- to High-Resolution Integrated Geophysical Surveys to Reconstruct an Archaeological Settlement: New Perspectives from the Ancient Town of Nora, Southwestern Sardinia (Italy).Preliminary Results

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Abstract. Non-invasive and wide-area geophysical prospections are an important scientific tool for investigating ancient settlements. Through the integration with historical reconstruction studies, they allow a "highly probable" visualization of signs left under the ground by ancient civilizations. This is demonstrated once again by the application of integrated geophysical methods to the wide archaeological area of Nora: the preliminary results of electrical resistivity tomography (ERT), multichannel ground penetrating radar(GPR)-in customized or standard towed configuration-, and electromagnetic (EM) applications to the site are presented and interpreted here as a tool for the reconstruction of ancient settlements urban structures, even if a detailed analysis of the correspondences between archaeological and geophysical findings is left to a more mature work. The geophysical discovery of new neighborhoods, expected from the site location and archaeological expeditious surveys, opens new frontiers in the archaeological study of the area. The non-trivial data-based geophysical results suggest the opportunity for fruitful further analyses and development indicated at the end of the present manuscript.

Keywords: Applied Geophysics · Preventive Archaeology · Multichannel GPR · ERT · EM · Roman settlements · Nora

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1 Introduction

The archaeological site of Nora is localized on the southern coast of the Gulf of Cagliari, Italy, in the proximity of the city of Pula (southwestern Sardinia, Fig. 1(a)). The ancient town was built on a little peninsula, the isthmus of Capo Pula, and occupied a central strategic position as a fundamental maritime crossroads in the ancient Mediterranean Sea (Fig. 1(b)).

The geological features of the area comprise different lithologies derived from past volcanic manifestations, including volcanic breccias, conglomerates, and massive effusive lavas. Quaternary deposits, composed of beach sands (Olocene-Present) and locally sandstones and conglomerates of Thyrrenian, are present in the northern area of the ancient town. The sedimentary deposits overlay the substrate with a variable thickness. These materials are characterized by abundant content of fossils and organogenic components [1]. The stone materials utilized for the construction of numerous archaeological structures are volcanic rocks outcropping in the Sarroch-Pula district [2].

"The first settlements date back to the Nuragic period, as evidenced by the discovery of ceramics. The presence of the Phoenicians (VIII to VI century B.C.) is well documented with important findings of epigraphic documents and features related to the late Phoenician age [3]. The ancient town of Nora was the center of important trade routes, as demonstrated by its three ports, now mostly submerged. The town, already flourishing in the fifth century, underwent further development in the fourth century thanks to the contact with the Italian world and especially Rome. The Roman domination began in 238 B.C. and lasted until 456 A.D., when pirate raids and Vandals invasions resulted in the rapid decay of Nora. The "coup de grace" was the Arab raids on the southern coast of Sardinia in the early VIII century. The area was then abandoned, but sporadic traces of life have been found in higher levels of the collapsed Roman buildings" [4]. Furthermore, many ruins of ancient buildings are visible in the waters around the peninsula and various findings were discovered in the sea and lagoon waters [5].

The archaeological excavations started in 1889 when the Punic tophet appears after an intense coastal storm. The archaeological surveys carried out in the 1952 by the superintendent Gennaro Pesce allowed to dig part of the ancient city consisting of structures pre-existing the Roman city [6]. After sporadic interventions during the 1970s and 1980s, since 1990, searches on the site have continued steadily up until today.

Previous geophysical investigations carried out in the northern area of the open archaeological digs have highlighted the traces of the buried perimetral constructions of the ancient Roman amphitheater of the town. The buried sub-elliptical structures were identified through a GPR survey performed in the narrowest part of the isthmus, in an area devoted to parking for visitors of the archaeological site [4]. The presence of the buried monumental structures is confirmed by subsequent recent direct excavations [4] and by archive research on historical pictures of other historical excavations [7, 8].

In the months of June and July 2013 a joint campaign of study started in the area formerly devoted to military uses on the small hill just northern to the archaeological park (Fig. 1b and c), [9, 10]. Since then, the archaeological excavations have gone on, revealing many important elements of the ancient city stratification, and an integrated cross-disciplinary prospection is planned for the next future in the remaining free area.

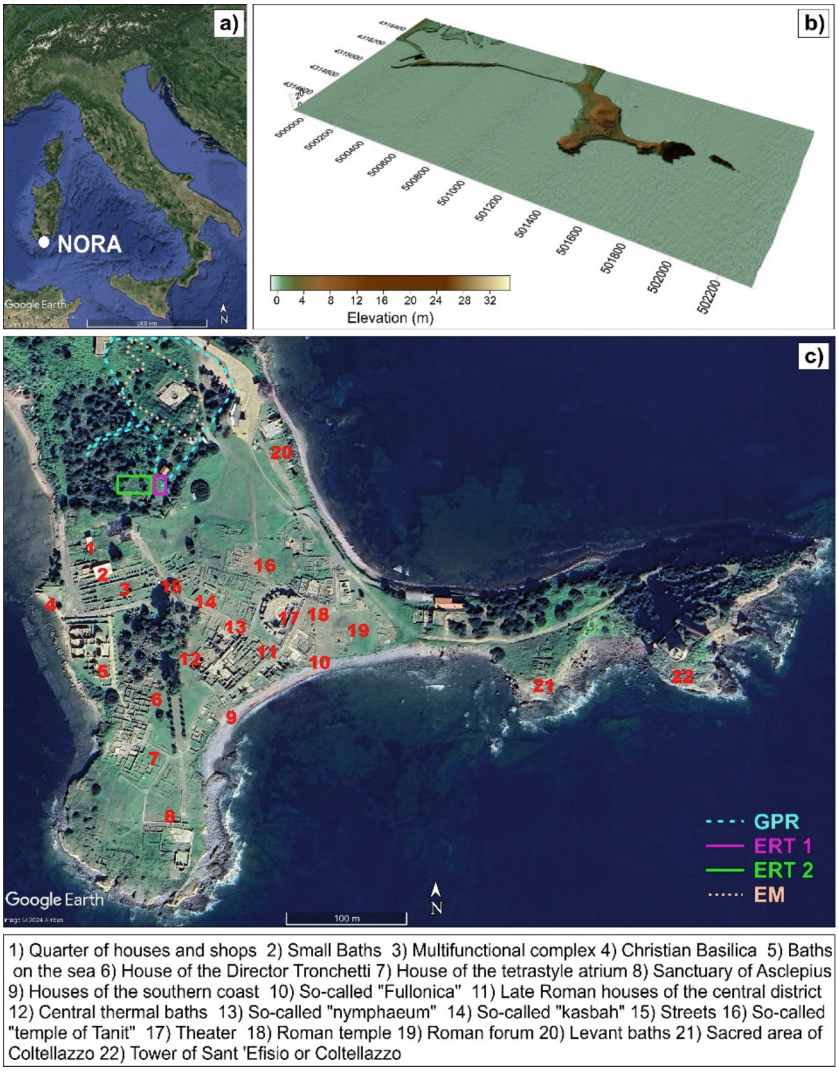

Fig. 1. Geographic location of the archaeological site of Nora in Southwestern Sardinia, Italy(up-left pane), Digital Terrain Model (DTM) of the Peninsula of Nora (up-right), andaerial view of the investigated area and the archaeological park with theindication of ground penetrating radar (GPR), electric resistivity tomography(ERT), and induction electromagnetic (EM) surveys with respect the archaeological remains (bottom).

The preliminary experimental results of the geophysical surveys are presented here, even in the light of the first results from the archaeological findings.

Integrated geophysical surveys have been widely and successfully utilized to study different archaeological settings worldwide, such as buried prehistoric structures [11–14], temples [15, 16], theatres [17], amphitheaters [18], basilicas [19–21], complex

ancient towns [22–24], water systems and underground aqueducts [25, 26], necropolis [27–29]. More recently, traditional geophysical techniques have been integrated with remote and proximal sensing ones to perform non-destructive inspections of historical and monumental structures [30–35] and to study static and dynamic behavior of ancient valuable buildings and archaeological remains [36–38].

2 Geophysical Datasets

The methodological approach for the acquisition of the geophysical datasets was based on the complementary use of fixed arrays and mobile measurement systems for a fully non-invasive inspection of areas with different irregular macro- and micro-topography of the ground surface (Fig. 2). The multichannel GPR survey was performed using a mobile radar system towed by an off-road vehicle; for uneven and small areas the system was customized to be pushed by a walking operator. This instrumental equipment is suitable to explore wide areas with the main advantage of collecting big datasets through a relatively high speed of acquisition. The EM was implemented to integrate GPR survey and cap no-data sectors. The 2D-ERT surveys were focused on two southern zones of the site of study and were designed to highlight shallow-to-mid-depth geophysical anomalies. In order to improve the archaeological interpretation of the experimental outcomes, underground models of ERT, GPR, and EM anomalies have been derived from the measurements.



Fig. 2. The Stream-X array system towed by the off-road vehicle (top, left), the half-battery Stream-X arraycustomized for small subsets (top, right); example of FDEM acquisition (middle-left) and view of the archaeological park from the investigated area (middle-right); ERT profile (bottom, left) acquired using the Syscal Pro–10 channel multi-electrode resistivity imaging equipment (bottom, right).

2.1 GPR

Ground Penetrating Radar is considered a very effective geophysical method to identify shallow archaeological structures with high spatial resolution. GPR methods comprise numerous techniques of measure which mainly differ for the use of reflected or transmitted electromagnetic signals to study inaccessible domains of the medium. GPR surveys could be performed to find buried objects [39–42] and to evaluate the status of integrity of materials at different working scales [43, 44]. The great interest in archaeological geophysical prospection has encouraged the development and improvement of several high-resolution geophysical methods. These techniques utilize both new instrumental configurations and unconventional layouts of acquisition to reliably collect high-density datasets and are suitable to detect underground structures and buried remains with centimetric precision. At the same time, the large extension of many archaeological sites suggests the use of mobile acquisition systems, permitting exploration of wide areas within a few hours [45].

In the case study investigated, a multichannel high-resolution radar system, just acquired to the laboratory assets, was tested on the most accessible (but still rough) surfaces of the site to address the specific challenge of an extensive investigation in a fast and precise way over quite irregular surfaces and areas. The GPR survey was carried out by the Subsurface Tomographic Radar Equipment for Assets Mapping (STREAM X by IDS Ingegneria Dei Sistemi, Italy) (Fig. 2). This system, initially designed to map buried pipes and to inspect subgrades and roads pavements, has quickly found application for archaeological surveys [45, 46]. The acquisition instrument was equipped by sixteen parallel dipoles, oriented along the forward direction of the profile (vertical polarization) and arranged inside two boxes. The electromagnetic signals are emitted by the transmitter unit and are characterized by a central frequency band of 200 MHz. The electromagnetic antennas are positioned inside two boxes with a reciprocal distance of 12 cm. The spacing between two adjacent radar profiles corresponds to the distance between the radar dipoles, and the measurement conventionally positioned in the middle of each couple, working as a transmitter and a receiver. The measurement equipment was trained by means of a vehicle moving on the ground surface with a velocity mainly depending on the topographic features of the area and the related local roughness. The GPR data were geo-referenced in real-time by means of a differential GPS system directly connected to the acquisition unit. A Radar Doppler system allowed to real-time measurement of the covered distance during the acquisition of the radar profiles. A customized acquisition system was specifically arranged for the most challenging sub-areas of the site by using only one of the two boxes containing the antennas; assembled with the same positioning technologies of the towed full-system, the customized apparatus was controlled and pushed by a walking operator.

The raw GPR data are collected into acquisition missions, inside which they are available as swaths, the 15 parallel channels of each acquisition profile (for the full-system). After georeferencing calibration and data normalization, raw data have been processed with standard 2D steps as it follows: De-wow; Soil sample; Background removal; Band-pass filtering; Gain amplifying.

The resulting GPR data were then processed using the 2.5-D Kirchhoff migration procedure [47, 48]. Considering the typical EM velocity on materials similar to Nora

shallowest subsoil layers, and after evaluating its compatibility with the radar events recorded on the radargrams, a homogeneous velocity of 0.10 m/ns was chosen for the 2.5D migration and for the time-to-depth conversion. Finally, depth-slices by means of the planar interpolation of signal parameters were extracted from thickness-defined slices of the migrated radargrams. Figure 3 reports some results from the GPR survey: A-to-D letters indicate some subsets characterized by a certain coherence of the recorded and processed signals.

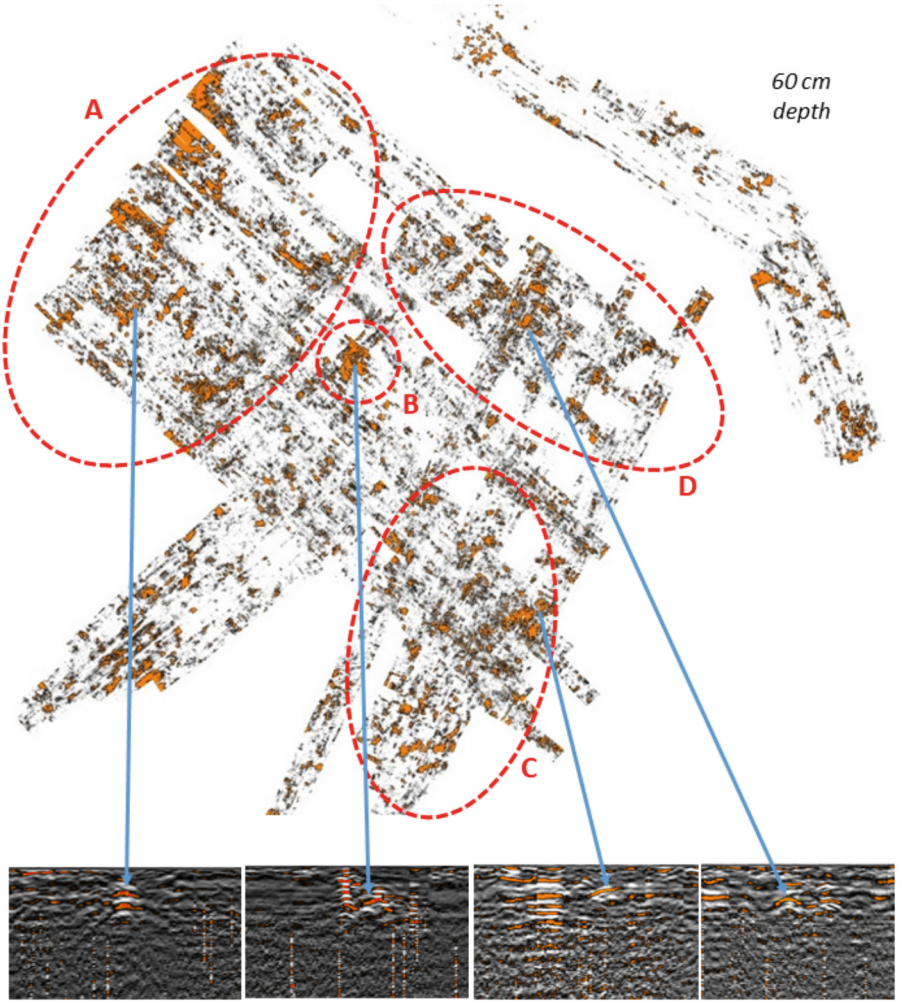

Fig. 3. Georadar multichannel survey on the flattest slope of the hill just outside the archaeological park: depth-slice at 60 cm (top section of the image), with identification of most interesting areas depending on density and coherence of reflected signals, and samples of the radargrams crossing most intense radar events.

2.2 EM

Frequency-domain electromagnetic (FDEM) is a method based on the induction of low-frequency alternating currents through a transmitting coil underground by a primary electromagnetic field. It spreads in the ground and therefore also through target bodies, inducing eddy currents which generate a secondary electromagnetic field perceived by a receiving coil. The secondary field can be decomposed into the in-phase (real) component, sensitive to metallic objects, and the quadrature (imaginary) component, related to conductive materials, expressed in parts per million (ppm), [49, 50].

In this site, data acquisition was carried out using the CMD-1 antenna by GF instruments (10 kHz, 0.98 m coils offset, sampled at 10 Hz), which automatically converts the quadrature component of the recorded signal into apparent electrical conductivity at a specific depth for each instrumental configuration (Fig. 4). The preliminary analysis of the EM results leads to the recognizance of two very conductive linear patterns most probably attributable to a modern net of technological services of the military area but anyway to be verified in terms of exclusion from possible clay- and water-rich pipes eventually datable back to the ancient settlements of the area. Some further interesting EM pieces of evidence, to be jointly investigated with the other geophysical and archaeological information, are constituted by soft dynamics of spatial variability of the apparent conductivity (in combination with variations of the in-phase values), possibly related to the variation of the fine-to-coarse composition of the filling sediments or presence of sparse archaeological remains. Finally, some saturating events were detected that are possibly linked to archaeological values like for example tombs, voids, or tanks. Processing and interpretation of the EM data is very preliminary and needs to be

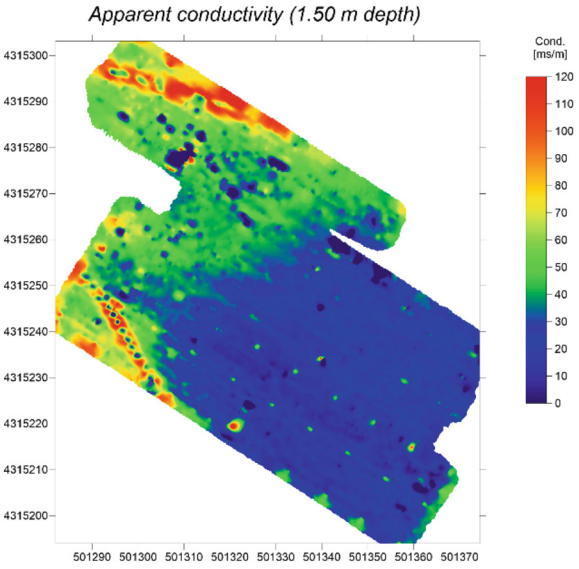

Fig. 4. Apparent conductivity map at a nominal depth of 150 cm.

further investigated against GPR, subsequent geophysical surveys, and archaeological contextualization based on the literature and the diggings within the project.

2.3 ERT

Electrical Resistivity Tomography allows the identification of main anomalous bodies perpendicular to the direction of the profile and is an effective method to highlight both vertical and lateral electrical resistivity heterogeneities of the underground layers. The method is widely utilized for archaeological investigations but is also considered more expensive and time-consuming than other ground-based geophysical techniques [51].

The electrical Resistivity Tomography method allows to derive the apparent electrical resistivity of the underground materials by using a set of fixed-surface steel electrodes. The electrical current flows in the ground through a transmitter dipole (current dipole) and the electrical potential is measured by a second dipole (potential dipole). Two-dimensional electrical resistivity tomographies usually use linear equally-spaced electrode profiles with different quadrupolar configurations of acquisition. The use of the electrode array is suggested based on the purpose of the survey (e.g. depth of investigation, signal decay, special resolution, etc.). The sensitivity function of the array allows the evaluation of the reliability of the experimental measurements [52]. The electrical model of the subsurface is derived from the inversion of the experimental data of apparent resistivity [53].

Two sets of Electrical Resistivity Tomographies were acquired at the site of study (see Fig. 1). The first group of ERT profiles was localized in the southern sector of the surveyed area, in the zone indicated with *ERT2*(green rectangle) in Fig. 1, and included thirteen parallel profiles forming a grid with 2-m of profile spacing, oriented in easting direction. The ERT profiles were designed (done) using forty-eight steel surface electrodes with 1-m electrode spacing. The second group of measurements was acquired in the higher part of the hill and covered a rectangular surface, indicated with *ERT1*(magenta rectangle) in Fig. 1. Twenty-three parallel ERT tomographies were oriented in northing direction. In order to collect a high-density dataset of apparent resistivity measurements, the second group of tomographies was designed to improve the effectiveness and the resolution of the method with the purpose of detecting also small archaeological structures and little resistivity anomalies. The electrode spacing and the distance between adjacent ERT profiles were set equal to 0.5 m. A Syscal Pro–10 channel multi-electrode resistivity imaging equipment (by Iris Instruments, France) was utilized to record the apparent resistivity data with an accuracy of 0.1 Ω·m. The measurements were performed by using Wenner (W) electrode array. The minimum dipole spacing was set equal to the electrode spacing of the ERT profiles. The second configuration provided to obtain high-resolution measurements up to 2 m of depth.

Raw data of apparent resistivity were filtered to remove outliers and data points affected by high contact resistance. The filtered data were processed through a two-dimensional inversion algorithm (Res2DInv, [54]). The inversion procedures allowed the definition of 2D and 3D electrical resistivity models of the underground structures. The package used for the processing of ERT data, implements the smoothness-constrained least-squares inversion, based on the Gauss-Newton optimization technique [55], and is based on finite-element discretization to take into account the topographic profile. In

most cases, the acceptable inverse models were obtained after five or six iterations with a final percentage Root Mean Square (RMS) error lower than 5%.

The following Figs. 5 and 6 show 3D axonometric views and location of the two ERT datasets and their tomographic reconstruction, evidencing the main alignments potentially related to architectonic/urbanistic elements like buried walls, roads, tanks, or pipes, to name some.

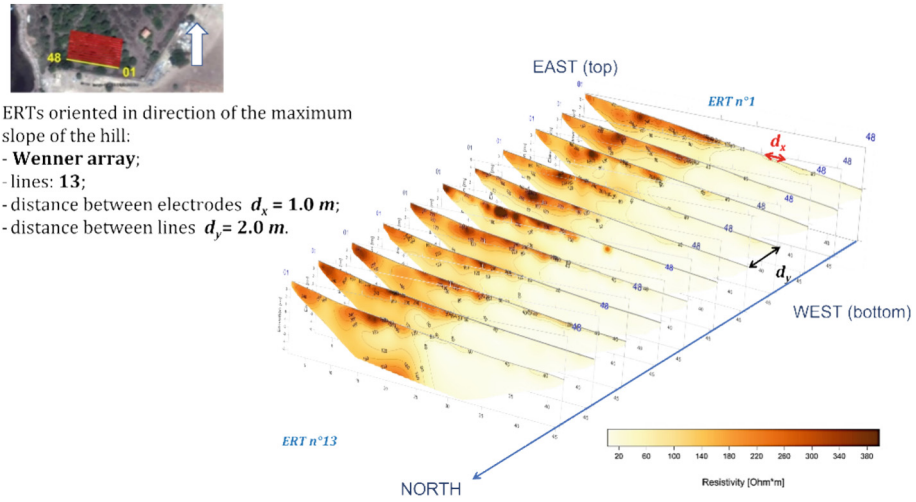

Fig. 5. 3D view of ERTs oriented in direction of the maximum slope of the hill (E1).

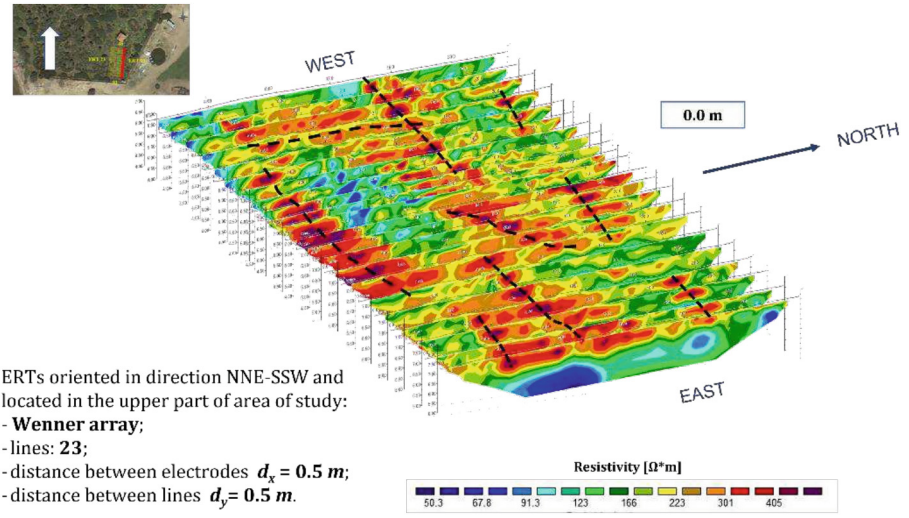

Fig. 6. 3D view of ERTs oriented in direction NNE-SSW and located in the upper part of the study area (E2).

3 Archaeological Results

The excavations carried out by the University of Cagliari at Nora, which began in 2013, are concentrated in an area of approximately 15,000 square meters, located in the north-eastern sector of the promontory and part of an area for a long time occupied by an Italian Navy base [10, 56, 57]. The area is set in a sector that, starting from the north-western slopes of the so-called Colle di Tanit, extends to the limits of the archaeological area, in the direction of the modern access road to the site. The analysis of the urban spaces of the southern sector has made it possible to highlight the presence of a series of buildings and finds that, through a topographical analysis of the area and of the elements of material culture, make it possible to advance hypotheses on the use of this area. We find ourselves, in fact, in the sector facing the so-called Cala di Libeccio, in an area gravitating around the western harbor berth and which has yielded numerous features that make it possible to highlight aspects strongly connected with the sea and related activities.

The northernmost sector of the investigated parcel has instead returned to a context of considerable importance for the definition of the urban spaces of the city of Nora and their distribution in the imperial age, with phases of abandonment of the area marked by ceramic materials with a chronological span that reaches the 5th-6th century AD. In particular, an open area paved with local purple andesite stones [58] has been brought to light, created using the same technique as the arterial roads that run through the whole settlement, probably a public space of a city that seems to denote its polycentric nature. This sector is notable for the presence of buildings on the eastern side, still under excavation. The structures present masonry built by laying large irregular blocks and reused elements, with rooms characterized inside by the presence of materials and artifacts related to wheat processing and bread baking.

The open space presents a circular basin with a diameter of approximately 6 m and an exedra structure, located in correspondence to the GPR anomaly indicated with B in Fig. 3, built with deliberate decorative intent, seeming to depict a situation relative to a monumentalized square certainly connected to important civil and religious functions [58–60]. In the center of this sector, a portion of a circular facility on the level of the pavement has come to light, and a trench relating to a pipeline with a slight slope towards the semicircular structure. The channel carved out below the level of the paving, filled with compacted earth and whose trajectory joins the exedra and the southern sector of the excavation area, ends in a circular open space (diameter hypothesized to be between 5.50 and 6 m.), characterized by the presence of hydraulic mortar elements and negative traces of metal structures pertaining to the channeling of water. The internal profile of the basin, where the presence of hydraulic mortar is evident, is marked by a row of large rectangular blocks with visible face dimensions of 40x40 cm.

In fact, the exedra is unique in the panorama of Roman-age cities in Sardinia. The monument (approximately 2.8 x 1.9 m, preserved in height from the floor level at 1.7 m) is set on a space partly spared of the paved surface and located to the east of a large building with a quadrangular plan and separated from it by a kerbstone made of elongated monolithic quadrangular blocks, of the same local andesite and entirely similar to those found in the other sectors of the city served by the arterial roads. The exedra structure consists of a core of rubble and mortar, reshaped by bessales bricks cut in half diagonally and inserted in such a way as to leave the longest side exposed, with several layers of

mortar also covering patches of the surrounding paving (Fig. 7). The residual mortar is mainly concentrated near the paving level, with a clear waterproofing intent, so as to form a kerbstone that ran along the entire lower external side of the structure, adhering to the andesite paving stones on which the structure is set, in order to create invitations for the outflow of water towards the sides of the road.

On the eastern side of the exedra, there is a monolithic quadrangular basin, heavily damaged in the central part and characterized by sharp corners on the outside and rounded corners on the inside. The basin rests on a plinth consisting of three blocks of local biocalcarenite that rest directly on the paved road surface, a fact that would lead one to hypothesize the construction of this forepart in a second phase.

This wide public area, marked by elements related to water supply in the city in the imperial age, seems to be part of an impressive single project connected with the construction of a portion of Nora's main road network.



Fig. 7. The monumental exedra excavated (Archivio UniCa).

4 Discussion and Concluding Remarks

Although the joint analysis of the geophysical datasets and archaeological findings is very preliminary and a specific and deeper cross-interpretation is planned to be performed on both these datasets and new ones we expect to collect over specific regions, some brief considerations are already possible. The three geophysical methods adopted in different sectors of the area of study were mainly chosen to take into account the surface roughness, the presence of trees, the soil acclivity, and the presence of possible external noise and interferences.

ERTs in two different configurations were implemented over the less accessible sectors, allowing for the recognition of some alignments in the 3D electrical resistivity patterns, probably related to some primary (like possible roads, large pipes, and bordering walls of urban blocks, in the case of the lowest spatial resolution setup) and secondary urban elements (like walls differentiation inside buildings, small dry or humid sediment filled cavities, in the case of the highest spatial resolution setup). The low-resolution ERTs, collected over the slope of the hill, allowed to detection of a ramp of the electrical resistivity potentially linked to the underground intrusion of seawater in the lowest layers of the subsoil.

FDEM data were acquired with the two orthogonal positions of the transmitting and receiving coils. The investigated area was smaller than the GPR one and was chosen by keeping in mind the necessity to walk far from the metallic wire mesh on the border of the area of study and small piles of rubbish, known sources of heavy noise on induction EM measurements. Nevertheless, the investigated area was sampled continuously (differently from what happened with the GPR, limited by the off-road car practicability), and some important features were recognized and preliminarily interpreted as possible archaeological values.

Automated and customized GPR acquisition covered the widest areas with the highest 3D spatial resolution in a relatively short collection time. Some features have been recognized with exceptional detail, like in the case of the exedra monumental fountain reported in Fig. 7 (picture) and anomaly B in Fig. 3. The site is known to be challenging for GPR investigations [61], and this is confirmed by our preliminary results that evidenced different diagnostic performances over archaeological features even very close to each other: this aspect will be further investigated in the context of the planned deepening of the cross-check of the archaeological-geophysical results and new multimethod acquisitions (and integrated excavations) over sample areas.

Finally, the preliminary results of the integrated geophysical-archaeological investigation of the ex-military areas in the promontory of Nora are very promising in terms of both specific and general remarks related to the archaeological site and the effects that background elements (e.g. filling soil stratifications, sea proximity) introduce on the recognizability of archaeological and non-archaeological features. Further investigation is planned in the next months to perform a more detailed critical comparison of the geophysical results against the archaeological findings and documented stratigraphies. This will be done in parallel to the development of additional processing and positioning strategies aiming at the extraction of the most diagnostic information possible from the experimental dataset. New acquisitions are also planned to better constrain the geophysical study.

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Integration of Geomatic, Geophysical and Chemical Data in a GIS Environment for Monitoring Contaminated Soils

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Abstract. This paper presents a GIS-based integration of a multidisciplinary dataset concerning a heavy metal contaminated soil. The case study is an area extending for about half a hectare where nearly 600 young trees have been planted to carry out a phytostabilization treatment. Three different plant species have been used for the experiment, lentisk, poplar and oleander, with different characteristics in terms of foliage and mean heights. The area has been monitored by exploiting geomatics, geophysical and chemical techniques, to acquire a comprehensive dataset able to describe the vegetation health status and the soil pollution levels. Low-cost UAV flights, GNSS surveys, and geophysical and chemical investigations have been performed in the area at four different epochs. The different acquisitions were elaborated resulting in specific products (point clouds, DSMs, specific maps) and the related quantitative and qualitative parameters. All the available data have been managed in a GIS project to provide a broad description of the site and to ease the understanding of complex dynamics. The presented analysis belongs to a wider project, aiming at defining monitoring procedures for soils contaminated by heavy metals, using a combination of geomatics, geophysical, and chemical derived parameters. The final purpose will be the definition of algorithms implemented in the GIS environment, specific for different soils, plant species and microbial populations allowing the identification of the optimal conditions for the contaminated site's restoration.

Keywords: GIS · Monitoring · Geomatic survey · UAV · Geophysical survey · Contaminated soil · phytostabilization

1 Introduction

Sardinia (Italy) is the second Italian region in terms of contaminated areas occurrence: in 2018 the Regional Agency for Environmental Protection pointed out a total of 1.411 sites [1]. These have been grouped into different categories, in particular: industrial sites,

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mining sites, landfills, military sites, general sites, fuel-selling sites, and accidental event sites. Nevertheless, only a few of these contaminated sites saw the conclusion of any remediation intervention [1]. The highest number of contaminated areas, equal to 207, is related to mineral sites, namely areas where millions of cubic meters of mineral residuals with high metal concentrations have been released over time. In addition, these areas are usually characterized by rough terrain and are generally hard to access, making impossible their reclamation and restoration over the years. Among the 207 sites, 180 are in southwestern Sardinia (Fig. 1), where indeed minerals like zinc, lead and silver have been mined since the mid-1800s.

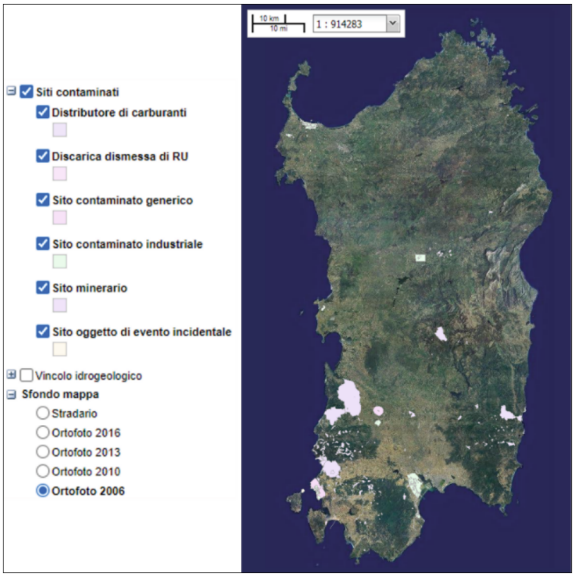

Fig. 1. The cartographic geoportal of the Sardinia region (https://portal.sardegnasira.it/cartografico).

While, from a purely economic point of view, mining sites contributed to the local economy and provided jobs for local people, after the mines' closure during the 1980s-1990s, the areas and the associated buildings were abandoned. This led to a gradual spreading of the metal extraction's wastes, making these lands unsuitable for other activities and potentially dangerous to the population's health. Moreover, all these general considerations should be framed in the regional context, in which mining areas are side-by-side with untouched nature and white beaches of remarkable beauty. In this context, in 2003 Sardinia region promoted a Plan for the reclamation of contaminated sites, although most of these are still pending reclamation [2].

Several approaches and techniques are currently available for the remediation of such sites, involving multidisciplinary expertise such as engineering, geophysics, geotechnics, chemistry, etc. As a result, this kind of analysis commonly requires the proper integration of a significant amount of data, with a challenging interpretation process. In the range

of possible remediation techniques for contaminated sites, phytoremediation is convenient both from an environmental and economic perspective, since it exploits green plants to limit or detoxify contaminants in soil and water [3]. Phytoremediation includes several strategies and procedures to degrade, remove, or immobilize pollutants including degradation (rhizome degradation, phyto-degradation), accumulation (phytoextraction, hemofiltration), dissipation (phytovolatilization), and immobilization (hydraulic control and phytostabilization) [4]. Different mechanisms are exploited by the plants depending on the specific pollutants to reduce their concentrations in soil and water. For example, plants can absorb and accumulate heavy metals in their tissues [5] or degrade organic pollutants [6] to reduce their toxicity level thanks to soil and water resources. Moreover, different plant species can use combinations of reclaim methods for different types, forms, and contamination media. Contaminations of soils, sediments, or muds are treated through phytoextraction, phytodegradation, phytostabilization, rhizodegradation or phytovolatilization [7].

The present description is meant as a general synthetic background as a detailed discussion of phytoremediation techniques is way beyond the scope of this paper. Indeed, this study focuses on the actual management and analysis of the different data sources required for a comprehensive monitoring of the soils' remediation level after these treatments. Consistently, we focus on geomatics, geophysical and chemical data processing, management, and interpretation strategies.

In this context, Geographic Information Systems play a fundamental role since they allow the storage, management and integration of both spatial and non-spatial data (e.g., social, demographic, economic), and they offer many possibilities in terms of processing tools [8, 9]. In fact, in a GIS environment, geospatial information can be processed following a wide range of different operations, which always include merging, querying, and data visualization at different levels of detail [10, 11]. Generally, the analytical processes enabled by GIS systems improve the comprehension of complex dynamics easing decision-making processes. Indeed, when dealing with multidisciplinary studies, spatial information is essential for a proper evaluation of the possible correlation between chemical, physical, and environmental factors, and their impact on environmental sustainability.

The ongoing technological advancements offer several geomatic instruments and techniques able to provide high-resolution digital spatial data [12]. In particular, the monitoring of vegetated areas mainly involves the use of remote sensing techniques to acquire images using sensors (e.g., LiDAR, multispectral, optical cameras) which can be embedded on different platforms such as satellites, aircraft, and drones. Recently, there has been a widespread use of Unmanned Aerial Vehicles (UAVs) due to their flexibility to carry different types of sensors with rapid performance and lower costs than other geomatics techniques [13].

Geophysical analyses allow the assessment of the physical characteristics of the soil at depth (compared with the more standard remote-sensing techniques). These kinds of investigations require the use of specific instruments, such as electromagnetic induction (EMI) tools [14–16].

This paper presents a GIS-based methodology for the integration of data from different geomatics, geophysical and chemical techniques to evaluate the health of plants

in the context of contaminated soils undergoing phytostabilization processes. The presented analysis belongs to a wider project, aiming at defining monitoring procedures for soils contaminated by heavy metals, using a combination of geomatics, geophysical, and chemical-derived parameters. The final purpose is the definition of algorithms implemented in the GIS environment, specific for different soils, plant species and microbial populations allowing the identification of the optimal conditions for the contaminated site's restoration.

The case study consists of a contaminated area of about half a hectare where nearly 600 young trees have been planted to carry out a phytostabilization treatment. Three different plant species have been used for the experiment, lentisk, poplar and oleander, with different characteristics in terms of foliage and mean heights.

Low-cost UAV flights, EMI and chemical surveys have been carried out at different epochs over the area to evaluate the evolution of both the plants' health parameters and the soil's pollution levels. All the available data have been included in a GIS project to find possible correlations and create maps describing the site's characteristics.

2 Monitoring Technologies and Techniques

To gain a multidisciplinary and complete knowledge of contaminated lands and to evaluate the effectiveness of the reclamation approach, different technologies should be mutually used. These include geospatial techniques, and geophysical and chemical investigations [17].

Concerning the first category, GIS and several geomatic techniques should be mentioned. In particular, GIS deserve a separate description as they serve as platforms to merge and jointly analyse all the different kinds of available data [18]. Among the geomatic techniques, Global Navigation Satellite Systems (GNSS) and UAV surveys are usually employed for applications like the one presented in this paper. Data acquired using such instruments provide an accurate metric description of the surveyed areas, from which quantitative parameters can be deduced [13]. On the other hand, qualitative parameters describing the vegetation and the soil are the result of complex geophysical and chemical surveys.

The following paragraphs provide a more detailed description of the mentioned technologies and the commonly implemented procedures for land monitoring activities.

2.1 Geographic Information Systems (GIS)

GIS are likely the major players in multidisciplinary studies involving environmental monitoring since they allow both effective data visualization and a wide range of spatial analysis and tools [10, 19]. Thanks to these instruments, the products of geomatic surveys can be integrated with more specific information, such as geophysical or chemical data, providing comprehensive maps which make the available information easily understandable. This aspect becomes fundamental in the specific context of the considered study, involving different types of technicians and decision-making politics.

In addition, GIS-based spatial analysis allows to easily manage the geomatic products obtaining maps and fundamental parameters describing the vegetated areas [20]. Moreover, these operations can be also carried out by merging or overlaying data acquired

with different instruments, at different spatial scales and relying on different reference systems. This is one of the main potentials of GIS instruments, especially considering the related opportunity of using publicly available datasets such as inventories and indicator maps, to give context and background to more specific information on the study areas. Thus, overall, the use of Geographic Information Systems leads to a smarter and more effective administration of the available resources.

2.2 Geomatic Surveys

Geomatic surveys are designed to acquire all the quantitative information on the soils, and they become essential to ensure that comparisons are accurately performed when combining data from different sources or conducting monitoring operations which extend over time. This is also true considering that, usually, other investigations such as the geophysical soundings should be attributed to specific positions in the final maps, and this is possible only through proper management of the data spatial reference.

Together with the advancement in technologies, nowadays, we are experiencing a shift towards low-cost, user-friendly and more time-efficient geomatic instruments [21]. However, it is not possible to define a single technique and measuring approach usable for different applications or contexts. Indeed, the size of the area, the cost of the surveys, the availability of instruments and tools, and the precision required for the final products are strictly dependent on the specific case [22].

Regardless of this, we will refer to the most common practices employed in contexts like the analysed one. As mentioned, for similar applications, geomatic surveys mainly involve the use of Unmanned Aerial Vehicles. Indeed, drones carrying specific types of sensors are a strategic solution considering cost, usability, and field times. Digital Surface Models (DSMs) and orthophotos can be easily obtained by exploiting large sets of RGB images covering the study area. This three-dimensional information represents the basis for the extraction of the quantitative parameters (trees' heights, crown volume). Furthermore, the use of multispectral and thermal sensors results in different products, such as maps of vegetation indexes describing the state of health of the vegetated areas or the amount of water in the soil. The ordinary processing of the UAV images exploits the Structure from Motion (SfM) algorithm which is currently implemented by open-source software packages following guided workflows [23].

On the other hand, GNSS are fundamental at least as a supporting technique to give the spatial reference for accurate surveys' alignment. In fact, GNSS surveys may involve both the overall study area, meaning the production of Digital Terrain Models (DTMs), or the acquisition of specific points, such as the trees' positions and the coordinates of Ground Control Points (GCPs) for the georeferencing processes. In particular, Real-time Kinematic (RTK) and Network RTK (NRTK) approaches are used to obtain coordinates in real time with centimetre-level accuracy.

2.3 Geophysical Analysis

In this Section, we will refer to the frequency domain electromagnetic (EMI) technique as the geophysical methodology used for the characterization of the subsoil's first few

meters. Indeed, this technique is best suited for sites with terrain roughness like those of our site or for practical considerations.

In this case, during the survey, a time-varying magnetic field is generated by the transmitter; such a primary varying field induces eddy currents in the subsurface, which, in turn, originate a secondary magnetic field that can be recorded by the receiver. Clearly, the recorded signal is a function of the physical parameters of the soil. In particular, the signal at the receiver depends on the electrical resistivity of the subsurface and can be effectively used to reconstruct the 3D volume of that physical property across the investigated domain. In fact, the original transmitted signal consists of several frequency components and the response at each frequency is sensitive to a different depth range.

EMI techniques allow data collection over very large areas, in a very short time, with a high spatial sampling density [24]. On the other hand, EMI measurements are sensitive to electromagnetic noise, and dedicated data processing is required in order to remove, for example, anthropic disturbances. In addition, even if the measurements can be potentially used immediately to infer possible lateral heterogeneities, more advanced inversion techniques are usually required to associate the precise resistivity values to the corresponding depths [25, 26]. However, the translation of the measurements at different frequencies into the resistivity values at different depths is an ill-posed problem and regularization strategies are necessary to tackle the associated non-uniqueness and instability of the solution [27, 28].

EMI surveys result in continuous acquisitions. The inverted resistivity volume can provide information on the spatial distribution of the different lithology/materials, varying water content, and, possibly, the contaminant presence and dynamics (in case the geophysical data are acquired in time-lapse).

2.4 Chemical Investigations

As mentioned, among the wide range of possible reclamation techniques, we dealt with phytostabilization. The concept underlying this treatment is that the existent pollutants are not completely removed, whereas they are constrained, i.e., stabilized, in a reduced layer between the roots and the subsoil. Indeed, thanks to this process, pollutants are prevented from flowing either downward toward the water table, or upward along the plant. This is also the main benefit of phytostabilization since plants are not classified as dangerous wastes [29].

When dealing with this kind of soil treatment, chemical analyses commonly consist of three main steps:

- Soil characterization before planting (T_0) in terms of metal content.
- Planting of the area following defined configurations.
- Sacrifice of sample plants and chemical analysis on the whole plants and their foliage.

In particular, the effectiveness of the treatment can be deduced by comparing values related to the pre-treatment situation with the ones deduced from the sacrifices. Indeed, the chemical analysis provides a quantitative evaluation of the metals' interaction dynamics in the soil-plant system. Thus, it is possible to understand the metabolization status of the different plant systems and the rhizospheric soil.

3 Materials and Methods

3.1 Study Area

The chosen case study is an area of about half a hectare, located in the South of Sardinia, Italy (Fig. 2). The site was involved in a project named "Tecnologie di CARatterizzazione Monitoraggio e Analisi per il ripristino e la bonifica (CARMA)", aiming at the integration of geometric, chemical, and geophysical data in a single workflow to assess the trees' health condition and rates of growth [30]. Indeed, the chosen area suffered from heavy metals contamination (zinc, lead, arsenic, and cadmium) due to the coal spilling in some close extractive areas.

The site was divided into two sectors: most of the area was treated with organic soil conditioners (substrate) while a small part was maintained without any treatments, named the "witness area" (black area in Fig. 2). Then, different species of plants were planted to carry out phytostabilization, thus, to be used as indicators of the soil's state of health after the treatment. In particular, nearly 600 young plants have been placed following a precise configuration along 26 rows with 2–3 m of inter-distance. The geometric setup allowed an efficient management of both the in-situ surveys and the irrigation operations. Poplar, lentisk and oleander have been chosen for the experiment, having different typical characteristics in terms of height and foliage.

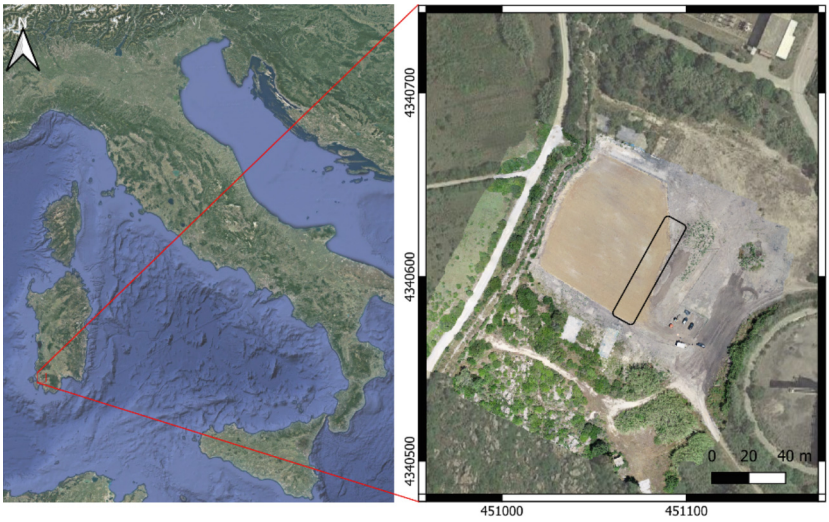

Fig. 2. Study area located in the South of Sardinia, Italy. The black area identifies the sector maintained without any treatments. Base map: Google Satellite. Map generated using Qgis software; coordinates aligned to the ETRS89-ETRF2000-UTM32 reference system (EPSG: 6707).

3.2 Field Surveys and Analysis

The field surveys involved geomatic, geophysical and chemical investigations. Four temporal epochs have been identified for the field operations: hereafter called T_0 to T_4,

where the T_0 epoch refers to the situation before the area plantation, used as a reference for the following evaluations.

Besides the mentioned campaigns, direct measurements of the trees' heights have been performed at epochs T_1, T_2 and T_3 using a metric rod. Table 1 reports the timeline of the performed survey campaigns.

Table 1. Epochs, dates, and survey campaigns performed in the study area.

Epoch	Date	Height measurement	Geomatic survey	Geophysical survey	Chemical analysis
T_0	May 2020		X		X
T_1	August 2020	X	X		X
T_2	January 2021	X	X	X	X
T_3	March 2021	X	X	X	

UAV Surveys

The UAV campaigns involved the use of three different sensors, namely digital RGB cameras, and multispectral/hyperspectral cameras, embedded in different platforms. Table 2 summarizes the main parameters of each UAV flight. Note that, in the case of using different sensors (e.g., RGB and multispectral), multiple columns refer to the same measurement epoch.

For all the UAV survey, overlapping of 80% and 70% forward and side, respectively, were ensured by auto-planning the flights. Furthermore, the accurate georeferencing process was performed by exploiting 8 GCPs. These benchmarks have been surveyed using a Trimble R8 GNSS receiver operating in NRTK mode (SARNET network [31]) obtaining coordinates aligned to the ETRF2000-UTM32N reference system (EPSG: 6707).

Acquired images have been processed using Metashape software (version 2.0.4) [32] following the embedded Structure from Motion workflow. Then, dense point clouds have been elaborated selecting high-quality parameters and the related orthophotos have been produced. Afterwards, the Digital Surface Models processing was carried out using CloudCompare software (version 2.12.14) [33]. In particular, the dense point clouds have been processed through the Rasterize tool choosing 20 cm of pixel dimension, resulting in the associated DSMs.

A filtering operation on the point clouds was necessary to produce the DTMs, leading to the non-ground points removal. This was performed thanks to the Cloth Simulation Filter (CSF) in CloudCompare. Then, the availability of both DSM and DTM related to the same survey epochs allowed the Canopy Height Models (CHMs) computation through a simple operation using the Raster Calculator tool in QGIS software (version 3.34) [34]:

$$\mathrm{CHM} = \mathrm{DSM} - \mathrm{DTM} \tag{1}$$

Table 2. Summary of the sensors' parameters for each UAV flight.

Flight	Sensor, focal length, pixel size, frame dimension	Relative h (m)	GSD (cm)	n. frames	Outputs	Indicators
Zero-RGB	FC6310, 8.8 mm, 2.41 μm, 5472*3648	42	1.0	308	DSM, orthophoto	Trees heights
Zero-Multispectral	Survey 3W_RGN, 3.37 mm, 1.4 μm, 4000*3000	47	1.9	613	NDVI/GNDVI/ CCC maps	NDVI, GNDVI, CCC
1-RGB	FC6310, 8.8 mm, 2.41 μm, 5472*3648	42	1.0	345	DSM, orthophoto	Trees heights
1-Multispectral	Survey 3W_RGN, 3.37 mm, 1.4 μm, 4000*3000	49	2.0	728	NDVI/GNDVI/CCCC maps	NDVI, GNDVI, CCC
2-RGB	FC330, 3.61 mm, 1.56 μm, 4000*3000	30	1.0	313	DSM, orthophoto	Trees heights
3-RGB/Multispectral	RedEdge-M (5 bands), 3.7 μm, 1280*960	57	3.9	189	DSM, orthophoto NDVI/GNDVI/CCC maps	Trees heights, NDVI/GNDVI/CCC

Thereafter, individual trees' heights were obtained from the CHM maps, exploiting a local maxima approach implemented in the GIS environments. This operation allows the identification of the maximum values of CHM pixels within selected trees' neighbourhoods, able to represent the height values.

In order to properly elaborate the vegetation indexes, multispectral acquisitions have been carried out between 9.30 a.m. and 11.30 a.m. The acquired images have been also processed using the SfM algorithm implemented in Metashape software, after properly verifying the camera's calibration. In fact, Metashape enables the calculation of NDVI, and other vegetation indixes based on the multispectral input imagery. Furthermore, the vegetation index formula can be set by the user, thus allowing for great flexibility in data analysis [19]. Raster maps related to three main indexes were obtained using the "*Raster Calculator*" tool, in particular:

- Normalized Difference Vegetation Index (NDVI)
- Green Normalized Difference Vegetation Index (GNDVI)
- Canopy Chlorophyll Content (CCC).

NDVI can represent the vigour of vegetation, regardless of the plant species, with values ranging between 0 and 1 for vegetated and cultivated areas. The GNDVI can be used to identify the presence of water, humidity, and nitrogen absorption. Finally, the CCC index measures the amount of chlorophyll in the vegetation and provides information on the nitrogen amount. In general, there is a direct dependence between the CCC and the vigour of the plants. Equations of the NDVI, GNDVI and CCC are reported in Eqs. (2), (3) and (4):

$$\mathrm{NDVI} = (\mathrm{NIR} - \mathrm{RED}) \big/ (\mathrm{NIR} + \mathrm{RED}) \tag{2}$$

$$\mathrm{GNDVI} = (\mathrm{NIR} - \mathrm{GREEN}) \big/ (\mathrm{NIR} + \mathrm{GREEN}) \tag{3}$$

$$\mathrm{CCC} = \big((\mathrm{NIR} - \mathrm{RE}) \big/ (\mathrm{NIR} + \mathrm{RE})\big) \big/ (\mathrm{NIR} - \mathrm{RED}) \big/ (\mathrm{NIR} + \mathrm{RED}) \tag{4}$$

Geophysical Surveys

The first step of the geophysical investigations involved a preliminary analysis of the site's condition, evaluating possible issues due to the presence of anthropic noise sources. In this regard, the portion of the test area adjacent to the wire fences has been excluded from the measurements. Then, the geophysical data acquisition was performed with the ground-based system GEM-2 [28] and by using 5 different frequencies ranging from 5825 to 80225 Hz. A collection of one sounding every 25 cm was possible. Actually, for effective monitoring of the possible evolution of the electrical resistivity of the subsurface (potentially associated with water content dynamics and pollutant migration), several acquisition campaigns have been performed (a few months apart).

Chemical Investigations

The in-situ chemical analysis performed at epoch T_0 served to verify the preliminary state and homogeneity of the site's contamination level. The effectiveness of the phytostabilization process has been quantified by comparing values related to the untreated soil with the ones related to the conditioned soil.

Pointwise samplings were conducted at defined depths to assess the average level and/or variability of the soil characteristics in terms of pollution. Then, the concentration variation of four analytes (Zinc, Lead, Cadmium and Arsenic) was evaluated from the experimental results at epochs T_1 and T_2. In particular, three biological indicators have been defined, as shown in Eqs. (5).

$$\mathrm{BAC} = \frac{[\mathrm{M_{ep}}]}{[\mathrm{M_s}]};\ \mathrm{BCF} = \frac{[\mathrm{M_r}]}{[\mathrm{M_s}]};\ \mathrm{TF} = \frac{[\mathrm{M_{ep}}]}{[\mathrm{M_r}]} \tag{5}$$

where M_{ep}, M_a, and M_r represent the metal's concentration in the epigean parts, in the soil, and the roots, respectively.

Since the sacrificed samples belong to different plant species, it was also possible to separately define the behaviour of poplar, lentisk and oleander during the treatment. In this regard, "accumulators" and "excluders" were identified as the extremes of the physiological plants' response to the presence of heavy metals in the soil, whereas "indicators" were considered as an intermediate behaviour not completely able to reflect the direct link between absorption and metal tolerance.

3.3 GIS Data Integration

As mentioned, the focus of the presented study consists of integrating all the available data into a GIS project, to provide a comprehensive and multidisciplinary description of the site. All the presented results were obtained using Qgis software.

About this, the first operation involved the joining of the GNSS-derived plants' positions with the related information in terms of plant species, manually acquired on the field (Fig. 3). This was possible thanks to the careful definition of the planting configuration in terms of rows and related id, allowing to match the corresponding data simply.

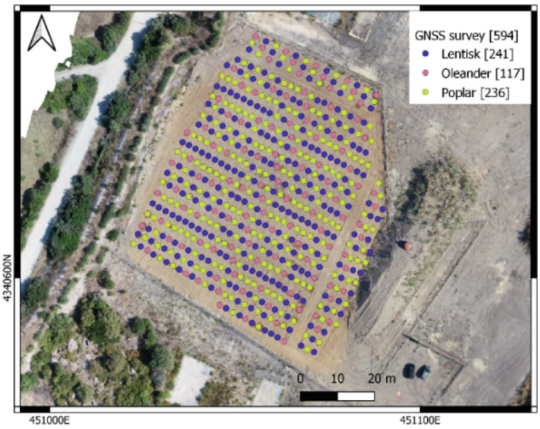

Fig. 3. Qgis Project: GNSS survey on the area and information about the plant species.

Thereafter, all the UAV-derived products were imported into the Qgis project, namely the point clouds (.las), the orthophotos and DSMs (.tif) and the maps obtained from the multispectral acquisitions (.tif).

As mentioned, the extraction of the UAV-derived plants' heights (see Sect. 3.2) has been performed, leading to an automatic matching of the obtained values with the other information. In addition, the available field measurements of the plants' heights (see Sect. 3.2) were associated with the trees' positions and ID, through a GIS-based procedure, allowing the validation of the UAV-derived heights.

The dense geophysical acquisitions (1 point every 25 cm) available as text files have been also imported. Thus, it was possible to view the geophysical data for the whole area and to resample the specific values at the plants' positions.

Concerning the chemical investigations sacrificed plants were identified in the GIS project using their IDs, integrating the attribute table with the related biological indicators. This allowed the possibility to observe the chemical analysis from a pointwise perspective and to produce continuous maps representing the overall trend in the area.

4 Results

This chapter reports the results of the integration of all the data collected in the different survey campaigns with different methodologies, within a comprehensive GIS project. As mentioned, for each type of acquisition or investigation, specific maps and indicators have been obtained. Figure 4 shows an example of a dense point cloud obtained by processing the RGB images acquired during the UAV flight at epoch T_2.



Fig. 4. Example of a UAV point cloud in RGB natural colours, related to T_2 flight.

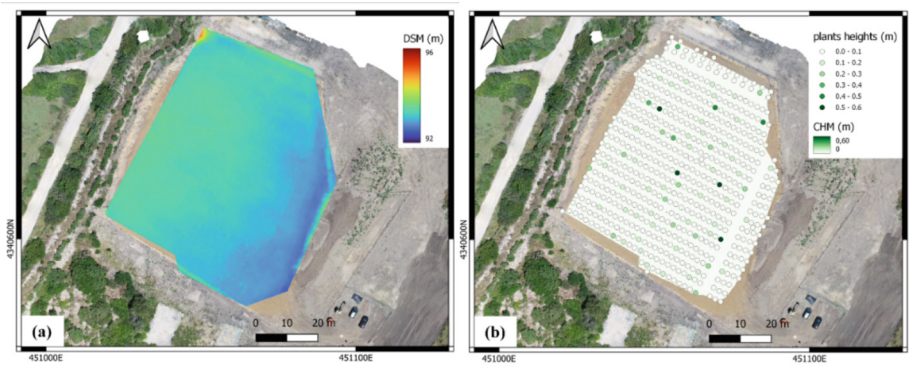

Fig. 5. DSM (a), CHM and extracted plants' heights (m) related to T_2 flight.

The results in terms of Digital Surface Model, related Canopy Height Model and extracted plants' heights are shown in Figs. 5 (a,b), for example case of flight T_2. Note that, since the last two surveys (T_2 and T_3) were performed 8 and 10 months after planting the area, extracted heights exhibit very low values. This made the processing quite challenging, compared to cases where plants are higher and with well-defined crowns. Extracted heights have been compared with the direct in-field measurements for

validation. Nevertheless, this kind of analysis goes beyond the presented study, where the focus is the acquisition of several data sources, that is, the plants' heights at different epochs in this case.

Regarding the analysis of the multispectral acquisitions, obtained maps show the plants' health status in the area handled with substrate compared with the higher stress in the witness area (black area in Fig. 6). However, overall, the vegetation parameters exhibit values below 0.30, mainly due to the low presence of plant biomass. In fact, the reclamation process started a few months before the geomatic surveys, thus resulting in very low plants heights ranging between 10 cm and 140 cm and sometimes with leaf-off conditions. For this reason, the vegetation indexes did not allow the evaluation of the plants' vigour, even considering the last survey epoch T_3. The maps of the NDVI, GNDVI and CCC index related to the T_3 epoch are reported in Figs. 6 (a,b) and Fig. 7 as an example.

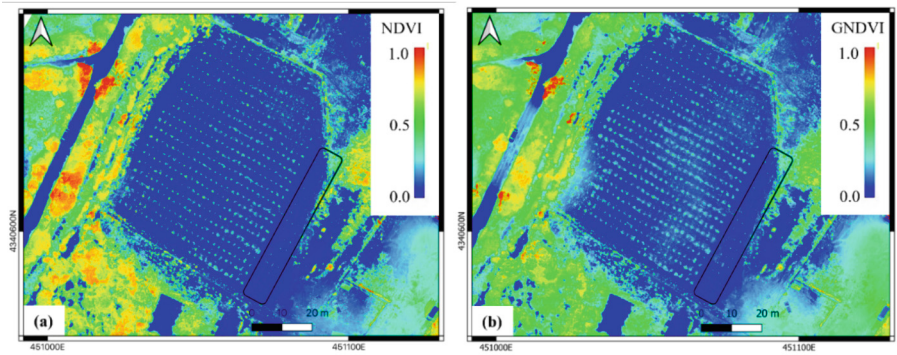

Fig. 6. Map of the NDVI (a) and GNDVI (b) indexes at the T_3 epoch. The black area identifies the witness sector.

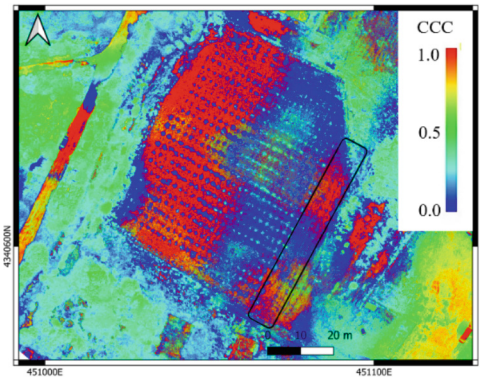

Fig. 7. Map of the CCC index at T_3 epoch. The black area identifies the witness sector.

Figure 8 shows a plan view of the raw data acquired at 15325 Hz during the geophysical surveys. It is clearly visible, not only the NE-SW resistivity trend but also the

more subtle associated with the subsurface heterogeneities. In addition, on the east side, the sharp electrical anomaly due to the unexpected presence of a pipeline can be easily seen. That anomaly was confirmed by direct inspection afterwards.

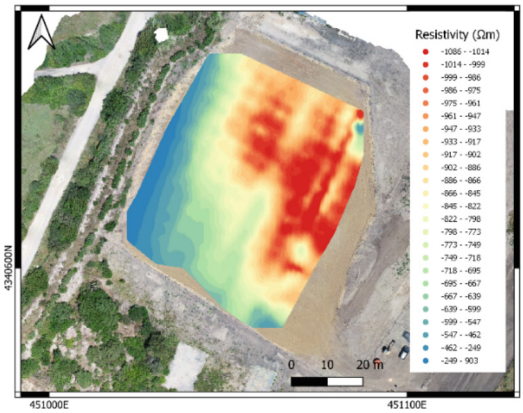

Fig. 8. Map of the geophysical measurements collected at 15325 Hz.

After the data collection and processing, the EMI measurements have been inverted. In this respect, an example of the data inversion is shown in Fig. 9: there, a vertical NE-SW vertical resistivity section is plotted. The actual depth of investigation depends not only on the frequency range but also on the local resistivity values. In particular, less resistive soil prevents to reach deeper layers. That is why the columns in Fig. 9 are not equally long.

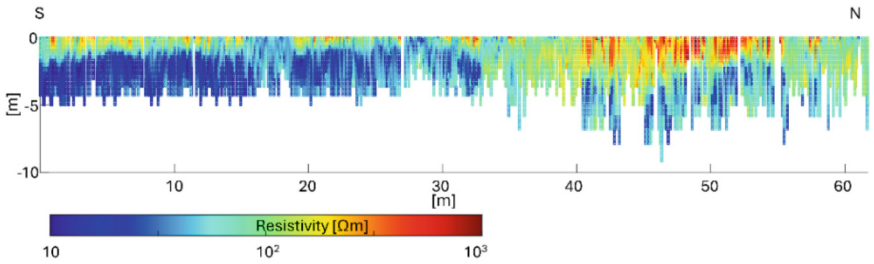

Fig. 9. Vertical section of the geophysical inverted resistivity model.

Tables 3 shows the chemical characterization of the selected samples in terms of biological indicators (see Sect. 3.2), related to epoch T_2. Overall, the accumulation of metals was bound mainly into the root system, without flowing to the stem and leaves, thus without affecting the plants' vigour. However, the different species acted as accumulators, indicators or excluders depending on specific conditions of existence (differences in substrate, presence of microorganism colonies, etc.). Indeed, a multiple

relationship between clone substrate and microorganisms arose, leading to different interactions between plants and pollutants.

Table 3. T_2 Chemical investigation: metals concentrations (mg/kg) of the rhizospheric soil, roots, and stem leaves, in terms of biological indicators.

	Pb			Zn			Cd			As		
Plant ID	BAC	TF	BCF	BAC	TF	BCF	BAC	TF	BCF	BAC	TF	BCF
T1–11 O	0,29	0,25	1,13	0,73	0,62	1,18	2,60	2,00	1,30	0,01	0,01	1,22
F1–10 O	0,57	0,26	2,15	0,62	0,30	2,10	0,87	0,20	4,33	0,01	0,05	0,29
T2–7 P	0,68	0,38	1,80	0,77	0,81	0,95	0,76	0,30	2,52	0,02	0,01	1,46
F10–6 P	0,77	1,06	0,72	1,71	0,41	4,13	5,00	1,00	5,00	0,02	0,02	0,86
T1–5 L	0,28	0,27	1,06	1,20	0,53	2,27	0,63	0,70	0,90	0,02	0,02	1,16
F20–15 L	0,07	0,15	0,47	0,43	0,66	0,65	0,39	0,43	0,91	0,02	0,04	0,91

An example of chemical data examined in the GIS environment is shown in Fig. 10, where the sacrificed plants are displayed together with their associated values of BAC for Pb and Zn analytes, respectively.



Fig. 10. Sacrificed plants: location, and values of BAC indicator for Pb and Zn analytes at T_2.

5 Discussion and Conclusion

This paper presents a comprehensive multidisciplinary analysis of a contaminated area treated through phytostabilization. The general characteristics of these treatments are given to better understand the main purpose of the analysis. Indeed, the chosen case study

is a contaminated area, located in the south of Sardinia in Italy, where phytostabilization has been performed by planting 600 young trees belonging to three different species. The area has been monitored by exploiting geomatics, geophysical and chemical techniques, to acquire a multidisciplinary dataset able to describe the vegetation health status. Indeed, low-cost UAV flights, GNSS surveys, field measurements of the plants' heights, and geophysical and chemical investigations have been performed on the area at 4 different epochs. All the acquisitions were properly elaborated resulting in specific products (point clouds, DSMs, specific maps) and the related quantitative and qualitative parameters.

Throughout the paper, the fundamental role of the GIS is highlighted. Indeed, GIS allowed the combination of both spatial and non-spatial data, thus ensuring the possibility of understanding complex processes including different data sources at different spatial scales. Secondly, they offered the possibility to easily perform a wide range of operations, such as the ones that allow obtaining the main quantitative parameters of plants, i.e., the plants' heights.

Finally, bearing in mind that commonly such studies, like the one presented in this paper, involve not only technicians but also authorities engaged in the decision-making processes, the use of GIS provided maps and reports for straightforward comprehension. Finally, it is worth noticing that the chosen site is part of ongoing research to define a GIS-based algorithm combining geomatic, geophysical and chemical data capable of defining specific procedures of soil reclaim in different conditions.

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Towards the Construction of a Hypothetical Map of Santa Maria de la Antigua del Darién (Colombia), The First Spanish City in the American Mainland. An Overview of Ten years of a Communitarian and Multidisciplinary Archaeological Project

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Abstract. The archeological site of the city of Santa Maria de la Antigua del Darién is located in Colombia, within the municipality of Unguía, in the Chocó Department, on the western coast of the Gulf of Urabá. In 1510, Santa Maria de la Antigua del Darién was the first Spanish city to be founded on the American mainland. A multidisciplinary community archeology project supported by remote sensing and geophysical prospecting has been underway since 2013. Here the preliminary results are presented, also focusing attention on their social consequences.

Keywords: Santa María de la Antigua del Darién · Archaeology · Geomatics · Geophysics · Community Archaeology

1 Introduction

Santa María de la Antigua del Darién, in the north of the Chocó Department of Colombia (Fig. 1a), was the first city founded by Spanish on the American mainland. In its fourteen years of existence (1510–1524) it went from a fortress ruled by Vasco Núñez de Balboa to a city with a bishop, a cathedral church, a second church, a hospital, a Franciscan monastery, a trading house, a foundry house, a prison, and everything a Castilian city needed in the early 16th century [1]. Santa María constitutes a milestone in historical and archaeological studies of the Americas for several reasons [2, 3]:

– It is the missing link of the first Spanish colonial urban planning, in a chronological space between Santo Domingo and Panama, with completely peculiar characteristics such as having been created by an indigenous village.

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- It is the starting point from which the main directions of the Spanish conquest were launched, with the European discovery of the Pacific Ocean, the foundation of Panama, Acla and Nombre de Dios and the expansion towards Peru, Nicaragua and Costa Rica.
- In its stratigraphy, the example of the contact between the Spanish world and the Amerindian world is evident, and almost unique, with the diachronic overlap between the pre-Hispanic settlement and the Spanish city, but with the synchronous alternation of spaces lived by masters and servants, as well as evidence of an indigenous presence following the abandonment of the city.
- It is a perfect example of the failure of a project of conquest conceived in a European court and tested in a tropical environment. Captains and advisors experimented with completely inadequate forms of confrontation in the new lands and quickly led to the near extinction of the Cueva-speaking people, the first population to receive the European impact on the American continent.
- It is an example of indigenous resistance, since the massacre of the last Spanish inhabitants and the burning of the city in 1524 are an emblematic point of the opposition to the Spanish conquest of the region, which began in San Sebastián de Urabá in 1509 and was maintained until the beginning of the 20th century by the indigenous Guna.
- It is a turning point, one of those key moments in history in which we can say that there is a "before" and an "after", with continental and regional consequences that continue today.

Today the area where Santa María de la Antigua del Darién was founded is located in the north of Chocó in Colombia, about 500 m from the Tanela River, a tributary of the Atrato, through the Marriaga Swamp (Fig. 1b). This area of low hills, the last offshoots of the Darién mountain range, is today characterized by the presence of large cattle ranches, evidence of territorial occupation by a few large landowners, sometimes a direct or indirect consequence of conflicts and violence lived in this part of the country between 1997 and 2005 [4]. The state presence in this part of the country is minimal and in fact the area is still under the control of armed groups, called BaCrim (Criminal Gangs), which represent the continuation of the paramilitary groups that preceded them. The appropriation of lands in the region by families linked to paramilitary groups generated serious phenomena of violence and displacement between the end of the 1990s and the first decade of this century. Many of the inhabitants of Tanela and Santuario, where the archaeological site is located, were direct victims of these dynamics [5].

Carrying out archaeological research work in this socio-political context, where the social problems are very serious and the lack of basic services in most of the villages and townships is absolute, has involved trying to understand how, from a process linked to archaeology, contribute to the social development of this place. There are currently 10 settler communities in the region, including cities and villages, made up of settlers originally from Córdoba, Chocoana, Antioquia and Old Caldas: five Emberá Dobida communities, one Emberá Katío community, one Gunadule community, three coastal Afro-descendant communities and two Afro-descendant wetland communities.

In this socio-political context, the Santa María de la Antigua del Darién Project promoted by the Ministry of Culture of Colombia and the Colombian Institute of Anthropology and History (ICANH) was launched in 2013. The initial objective was to locate and

delimit the city, and then propose to the Ministry a Special Management and Protection Plan that would protect the first Spanish city in continental America and promote serious and lasting scientific research. The research activities involved different Institutions (see Acknowledgments) with expertise in different disciplines and the following workflow was considered: study of historical sources, collection historical plans, archaeological survey, remote sensing, photogrammetry using drones, geophysical prospections, archaeological excavations, restoration, community archeology, community museology and museography. In this paper, an overall view of the main results are presented.

During ten years of activity, has effectively identified and located the colonial city (2013–2014), coming to formulate a Special Management and Protection Plan (2014), to achieve the recognition of Santa María de la Antigua as an Asset of Cultural Interest of the Nation (2015), to carry out the creation of the fifth Archaeological Park of Colombia (2016), the construction of the Heritage House (2017), the inauguration of the Museum (2019), the creation of the Community Hall with the temporary community exhibition "Maternidades" (2020), the realization of three museographic routes in the Archaeological Park with a strong community presence (2020–2023) and the creation of four museographic structures in the Park and two temporal community exhibitions, "Caminos de Agua" and "Cimarronajes" (2022–2024).

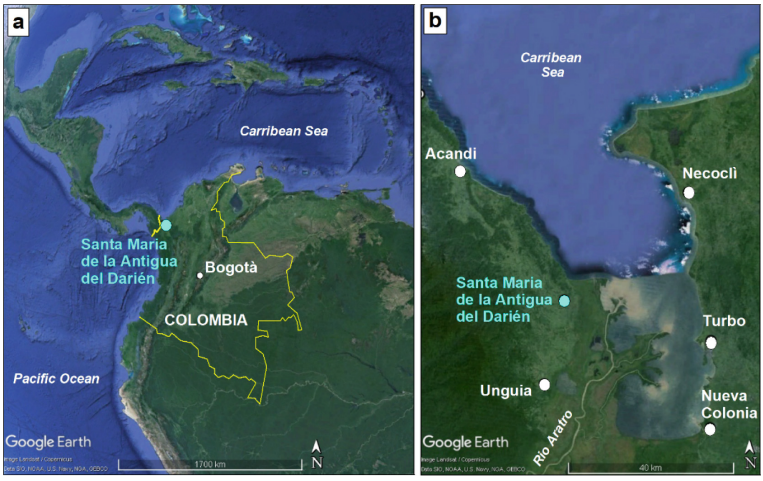

Fig. 1. Location of Santa Maria de la Antigua del Darien (4554450 E, 2467300 N) in northern Colombia (a) and a detailed view of the Gulf of Urabà on the Carribean Sea (b).

2 Historical Background

The expansion of the first stable colony in the mainland of América was carried out towards the west, in the direction of the new sea, the South Sea. It was discovered by Balboa in 1513 precisely from Santa María de la Antigua, where at that time he was the mayor elected by the inhabitants of the settlement (which became a city the following

year, when Pedrarias Davila arrived with 2,000 Spanish colonists). Acla (1515), Nombre de Dios (1519) and Panama (1519) are "daughter" cities of Santa María de la Antigua, founded and populated by its inhabitants who gradually moved into them following the course of the new routes of conquest. At first with the conquest of Nicaragua and then with the exploration of the Pacific and the conquest of Peru, the new axis of the trans-oceanic trade between Nombre de Dios and Panama were determined. Santa María de la Antigua became the first Spanish "foot" in the new continent, the first foundation that managed to survive in a lasting way from where those who would be the protagonists of the early conquest passed through.

However, the "first city in continental America" was founded in a territory densely populated by people who had the same language and similar customs; a territory that stretched from the Gulf of Urabá to the Chame River in the Gulf of Panama. This population, with a strong inclination towards exchange, had wide connections, reaching at least as far as the Mompox depression to the east, the Dabeiba mountain chain and the Gulf of Cupica to the south and Nicaragua to the west and north-west, although it is quite possible that their range reached the Mesoamerican and Peruvian areas. We know very little about this population, as it disappeared very quickly in the first twenty years of the Spanish conquest, decimated by disease, slavery and forced labour. The little we know is thanks to the descriptions of chroniclers such as Gonzalo Fernández de Oviedo or Pascual de Andagoya, who lived in Santa María de la Antigua for several years. In seven years of archaeological work in Santa María de la Antigua, we have been able to identify around 30 archaeological sites in the region, belonging to different chronological periods, from the pre-ceramic to the 17th century, only two of which have been known and studied previously [6–8]. In general, the region has been little studied, by both the Colombian and the Panamanian side, due especially to the difficulties of access caused by the jungle environment and the control of the area by armed groups, since it became a site of illegal routes far from the institutional centres of the two countries.

The short time that the Darien was the centre of the new colonial empire was followed by a period of abandonment by the Spanish, with the destruction of Santa Maria de la Antigua in 1524, the abandonment of Acla in 1552 and Nombre de Dios in 1596. The abandonment by Spain did not mean in any way a generalized abandonment of the territory, quite the contrary. The very end of Santa María Antigua is testimony to an indigenous tenacious resistance struggle, which had begun since the Spanish had set foot on the eastern coast of the Gulf, in San Sebastián de Urabá. Since 1600, the Kuna or Guna-dule groups, as they call themselves, have been continuing this anti-Spanish resistance, based on the Atlantic coast of the Darien, the Chucunaque River, parts of the Tuyra River and the Gulf of Urabá, in other words, a territory almost as large as that formerly occupied by the Cuevas. This transition between Cueva and Guna-dule is unclear, always due to the lack of exhaustive research (archaeological, historical, genetic, ethnographic). In addition to the indigenous resistance, there was a strong fight for freedom by several groups of African Maroons, who were fleeing from the slave labour of the gold mines and the pearl harvest. Between 1550 and 1600, wars broke out between the Spanish and their former slaves, who settled in the mountains of inland Panama, especially in the area of the Gulf of San Miguel, the Chepo River and the surroundings of Nombre de Dios. The Darien region, particularly on its Pacific side,

but also in the area of the Gulf of Urabá, also became a territory of African palenques, inhabited by people of various origins attested to by their surnames, such as Congo, Mandinga, Biafara, Yolofo, Mozambique, Bran and some born free, on American soil, in these decades of flight and resistance [9, 10]. Both the African Maroons (at least in the initial stages between 1550 and 1579) and the Guna-dule made alliances with English and French corsairs in an anti-Spanish function. In the 17th century, Franco-Guna communities were not uncommon, just as it was not uncommon to find Guna chiefs visiting Jamaica in the 17th and 18th centuries [9].

In 1700, there was a Scottish attempt to colonize the Caledonian Bay where the Cueva chiefdom of Careta and the city of Acla were formerly located. The Scottish fort of New Caledonia was settled near the important Guna settlement of Sasardi, with which it had friendly relations. The Spanish reaction, the environmental difficulties and the lack of support from the English, caused the project to fail and led to the rapid abandonment of the new colony, with disastrous consequences for the mother country.

The Guna-dule managed to maintain control of the territory, at the cost of an almost uninterrupted war, until the end of the 19th century when the new colonizing impulse of the post-colonial nation of Colombia, managed to get there where the Spanish had not managed. The new markets for wood, tagua and caucho encouraged new entrants from the departments of Atlántico and Chocó, followed by the people of Córdoba and Antioquia, when the old gold market and the new cattle market were retaken. In this movement of people that made the Gunas withdraw from much of their territory, the Embera also moved from the south, occupying part of the old Guna territory. However, the Gunas managed to keep at least part of their land, thanks to their incredible strength of resistance that was evident in the 1925 "Tule revolution" against the Panamanian authorities who were threatening the very existence of their communities [11]. Today the Guna-dule maintain a semi-independent territory in the Panamanian regions of Guna Yala, Wargandi and Madugandi. In Colombia, only the communities of Arquía and Caimán Nuevo, located on both sides of the Gulf of Urabá, remain.

3 Methods

The first phase of the project involved the study of historical sources starting from the study of the historical cartography of the maps of America. The research was concentrated in the search for the toponym "Darien". In the cartography of the new American lands, there is a genesis of the name, which appears in different forms in nine maps drawn up from 1531 to 1764. Subsequently, the results of previous archaeological expeditions were analyzed with particular reference to the expeditions of King Leopoldo in 1956 [12] and by Graciliano Arcila in the period 1948–1977 [5]. Both provide general plans with the location of the excavation trenches and pits but the precise location and identification of the city and its limits was not detected.

Since the official cartography of this region is not very detailed, in 2013 high definition satellite images were acquired [13]: Panchromatic (0.5 m World View 1 and 2; 0.6 m Quickbird) and multispectral (1.8 m World View 1 and 2; 2.4 m Quickbird) images. In the early stages of the project, they were used as a basis for georeferencing the information that was progressively collected in a Geographical Information System (by

using the software QGIS). This ensured the possibility of performing spatial analyzes and obtaining thematic maps. The satellite images were studied and interpreted in order to identify archaeological traces over an area of about 45 km. Particular attention was given to the mapping of principal paleohydrography, agricultural divisions, soil and crop marks present across the area.

In 2013 and 2014, a systematic archaeological survey was started over an area of approximately 8 km^2. Since the area is not affected by intensive cultivation, the collection of surface materials was inhibited. For this reason, it was chosen to carry out hand-dug test pits, measuring 1 m × 1 m with a maximum depth of 1 m, for a total of 980 units. For each test, archaeological materials were detected, cataloged and studied distinguishing indigenous materials from Spanish ones. The investigations involved eight areas around some modern points of interest shown in Fig. 2 and allowed to drawn a map of the density of the findings, according to the quantity of pottery shards/artefacts found per test pit.

In 2016, a photogrammetric survey carried out via drone was carried out with the aim of obtaining a high-resolution orthophoto and a Digital Elevation Model (DEM). Data processing of images was performed with Agisoft Metashape software (LLC. St. Petersburg, Russia) using the Structure from Motion (SfM) technique [14]. Thanks to the topographic survey, it was also possible to approximately georeference the plans of previous excavations, taking the heights indicated therein as a reference.

In 2016, considering the areas with major concentrations of finds, geophysical prospections were planned in order to produce an extensive map of hidden structures to guide future archaeological excavations. In the early stages of the project, the strategy of integrating methods was adopted implementing the resistivity tomography, the induced electromagnetic method and the Ground Penetrating Radar (GPR) technique. Since the archaeological evidences (cobblestone pavements, post holes, canalizations) were found to be very superficial and characterized by low contrast from a geophysical point of view, in 2017 it was decided to proceed only through GPR prospecting. All possible areas of the village of Santuario, under which approximately one third of the ancient city lies, are being studied. During data acquisition, measurements were performed using a SIR-3000 GPR (GSSI) in grids in which GPR profiles are half meter equally spaced.

For each grid, ground control points were surveyed using a GNSS antenna in RTK (Real Time Kinematic) mode. All sections were processed together in order to obtain 2D horizontal maps at a different range of depth (GPR-SLICE 7.0 software) [15] using standard methodological approaches: data conversion subtracting out the dc-drift (wobble), timezero correction, bandpass filter, background removal, application of the automatic gain function. Thus, horizontal sections were processed and data were gridded using the inverse distance algorithm, using a fixed radius of interpolation of 0.75 m, a smoothing factor of two, and grid cell size of 0.01 m.

Since 2013, considering the results of all the research applied to the project, nine stratigraphic excavations have been carried out.

During the project, the relationships with local communities was crucial. In 2013, only few families from two settler communities supported the work, a community from Emberá Dobida and a community of Afro-descendants from the coast, in a general lack of interest on the part of the other indigenous communities and the hostility of the main organization of Afro descent. Activities were conducted only with local workers and

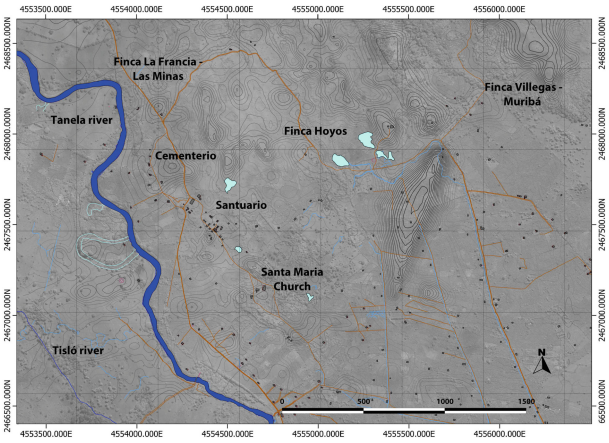

Fig. 2. Location of the surveyed areas with the main places of interest [3, 13].

finds were left on site, kept by the inhabitants in a cabin rented for this purpose. It is necessary to highlight a significant presence of women in archaeological work (more than 50%), which is unusual in the area, where women generally do not work outside their homes or farms.

From 2014, courses on archaeological and restoration techniques were organized for local workers, strengthening awareness of the work carried out and a greater sense of belonging to heritage and the past. The collaborative work with the community and the archaeology classes continued until today, involving more than 150 people from 5 communities and managing to create a group of at least 15–20 local people trained in stratigraphic excavation techniques, graphic documentation and photography in the field, in the design of ceramics, in the collection of plant macroremains and in the restoration of ceramics. This occurs in a place where school offerings are basic.

4 Results

In the cartography of the new American lands, the name of the site appears in different forms in nine maps drawn up from 1531 to 1764 [3]: “El Dariem” places the city in the port map of the Hergoz Bibliothek (before 1531) (Fig. 3a); “Dariem” locates it in Alonso de Chaves’ Map of the New World (1533) (Fig. 3b); “Darien” defines the city in the Map of Diego Gutierrez (1562) (Fig. 3c); “Rio Darien” is reported in the map 329 of the Indias Archive of Panama (1597): for the first time the city is not indicated but only the name of the river; “Rio Grande del Darien” is used again to locate the river in the map 23 of the Indias Archive of Panama (1600); “Rio Darien” is also in the map of Choco (1610); “Darien” places the city in the Atlas of Janssonius (1646) (Fig. 3d); “S. Maria la Antigua” indicates the city and “Darien” locates the region in the map of the Isthmus of Panama and the Gulf of Darien (1730) (Fig. 3e); “S. Marie l’Ancienne” defines the location of the city and “Darien” and the “Golphe de Darien” respectivetly define the region and the gulf in the map of Isthmus of Panama and the Povinces of Veragua (1764) (Fig. 3f).

The analysis of historical maps shows that the city was initially indicated in cartography up to forty years after its abandonment. Then it disappears and the name Darien is often associated with the River. Afterwards, the toponym is used to indicate the region or the Gulf until today and the name S. Maria de la Antigua begins to appear with a meaning of cartographic memory of a place of historical importance. In any case, historical maps do not provide an exact and univocal location of the city even though they always place it west of the Gulf of Urabà.

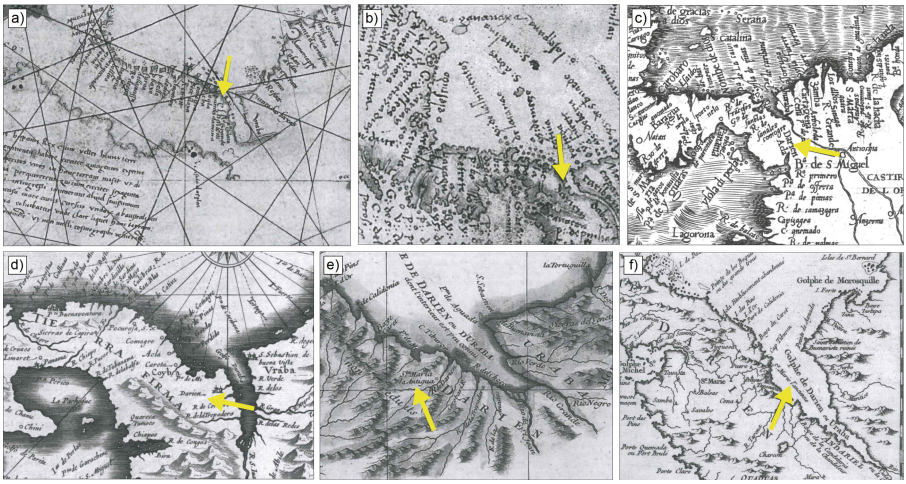

Fig. 3. The Toponym "Darien" in historical maps: map of the Hergoz Bibliothek (before 1531) (a); Alonso de Chaves' Map of the New World (1533) (b); Map of Diego Gutierrez (1562) (c); Atlas of Janssonius (1646) (d); map of the Isthmus of Panama and the Gulf of Darien (1730) (e); map of Isthmus of Panama and the Povinces of Veragua (1764) (f) (Modified by [3]).

The study of satellite images, supported by fieldwork over an area of about 45 km, permitted to reconstruct the principal paleohydrography, particularly regarding the original course of the Darién River (today the Tanela) (Fig. 4a), and to distinguish the regular grid agricultural divisions (Fig. 4b).

The most recent documentation relating to archaeological excavations constitutes effective proof of the identification of the city. The plans indicate the passage of the current Rio Tanela, the heights and the location of the excavations (Fig. 5a,c).

The topographic survey carried out in 2016 allowed the production of a high-resolution orthophoto, the basis on which to implement all the data in GIS (Fig. 6a). The area was limited to a strip of land west of the river Tanela, in the center of which the village of Santuario is located. As a further processing, a DEM was produced from which the topography was derived (Fig. 6a). Thanks to the highlighting of the hills, it was possible to georeference the plans of Arcilla Velez [5] and Verlinder [12], specifying the sites where excavations were carried out in those years (Fig. 6b,d). From this, it was possible to understand that the two archaeological expeditions concentrated on the southern part of the city, thinking that it was contained to that area. In return, the current

investigations have been able to define the real size of Santa María de la Antigua, which is about twice the size assumed by the two scholars.

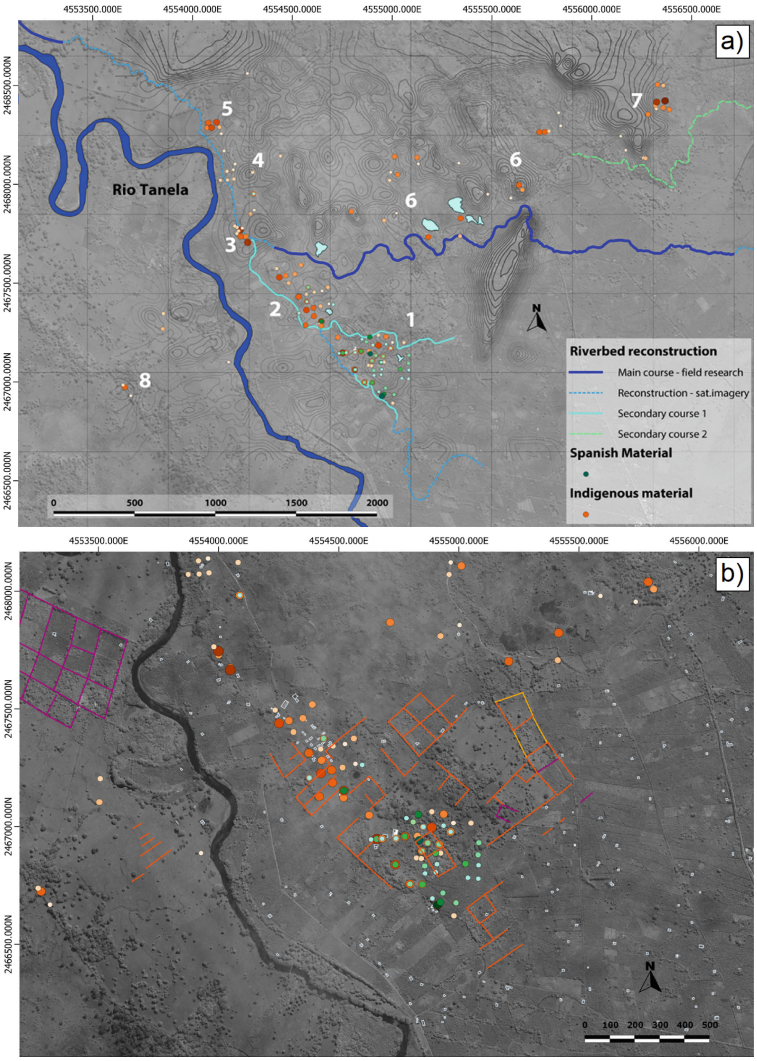

Fig. 4. Reconstructive hypotheses of paleohydrography (a) and agricultural divisions in the Santa Maria/Darién area. In the figures, the numbers indicate the following places: 1. Santa Maria de la Antigua; 2. Darién; 3. Cementerio; 4. Tanela Viejo; 5. Las Minas; 6. Hoyos; 7. Muribá; 8. Tisló (Modified by [13]).

In Fig. 7, the density of the findings of the archaeological prospections, according to the quantity of artefacts found per test pit, is reported. The circles with shades of green indicate Spanish finds, the circles with shades of orange indicate indigenous, pre-Hispanic finds, negative tests (lacking archaeological material) are marked as black

triangles. In the figure, two large main areas with high densities of materials, one near the Catholic church (1 in Fig. 7) and one in the inhabited area of Santuario (2 in Fig. 7), can be observed. Indigenous archaeological material was present with a great degree of density in whole areas in which surveys resulted positive. Spanish material instead appeared to be concentrated in these two areas with higher density. In addition, other archaeological pre-Hispanic sites in the analyzed territory can be clearly distinguished: the area of Los Laureles, investigated in 2016, which proved to be an indigenous, short-lived site from a post-abandonment phase of the colonial city (3); the Las Minas area, in the territory of the La Francia Estate, a site probably related to a settlement (5); the Muribá area, in the territory of the Villegas Estate, with a very high materials concentration, almost certainly related to a pre-Hispanic settlement (7); a vast area in the territory of the Hoyos Estate, in which the findings were more scattered, evidence of small housing units strewn on the heights of the zone (6); the area surrounding the Tisló river, on the western bank of the Tanela river, where a layer of anthropogenic origin, about 0.94 m deep and 0.4 cm thick, was found (8). In the remaining parts of the western area of the Tanela river, surveys have had little effect, probably because of the high levels of relatively recent alluvial origin; the area of the old village of Tanela Viejo, probably to be related to the ancient Guna Dule village of the 17th–19th century (4).

Based on these indications, geophysical surveys were planned. A first area was investigated in the village of Santuario. The GPR result highlights a series of very shallow NEE-SSW aligned anomalies within half a meter of depth (Fig. 8a). Subsequently the archaeological excavation (Tests B and F) linked these anomalies with canalization of the indigenous period (Fig. 8b). On the upper levels, Hispanic material and post holes from a probable house were found.

From 2014 to 2021, stratigraphic investigations have been carried out in 9 large areas and 31 sections (2 m × 2 m) in which several places in the colonial city and important features of the pre-Hispanic phase have been revealed (Fig. 9). From the colonial phase, of which the sub-phases of foundation (apogee, pre-abandonment and destruction) were recognized, the following elements were found: patios in boulders of Spanish houses (Área M17 2019), the western street of the city (Area J 2017–2018 and Area L9 2019), a house for indigenous servants next to a Spanish lot (Area F 2015), a water intake site (Area C 2014), a workshop for the preparation of bullets for firearms (Area H 2016), a blacksmith's workshop (Area K2 2019) and the southern River Wharf (Área A 2014–2023), with a large number of material culture objects.

From the pre-Hispanic phase a foundation phase, dated to 1106 AD. ±/−78, was recognized. Homes and family gardens, a long phase of movements and seasonal presence, a pre-contact phase and a contact phase characterized it. Three important burials from this phase (Areas F 2015, I 2016 and M1 2019), a house and some channels for water control (Areas B 2014 and F 2015) were excavated. A typology of pre-Hispanic ceramics also began to be generated based on stratigraphic excavations. The post-abandonment phase, characterized by ritual offerings with a "cleansing" nature, was recognized in Areas A 2014 and H 2016, as well as in the nearby Los Lureles site (Area G 2016).

Subsequently, the museum building was built in the area surveyed by geophysical prospecting and interested by B and F test pits. The geophysical research, starting from the feedback obtained at this point, continued in the northern and eastern areas. In Fig. 10, the first results are presented inserting dotted lines to facilitate interpretation. From the analysis of the anomalies, a regular distribution of the maximum amplitudes of the detected electromagnetic signal emerges. In the figure, considering the archaeological data coming from the excavations carried out beneath the current museum, two typologies are distinguished: in yellow medium-sized anomalies attributable to the pre-Hispanic phase (1100–1400), in red large-sized anomalies attributable to the colonial phase (1500–1524). This consideration derives from the comparison be-tween the features identified and the orientation and distribution of the archaeological evidence. In particular, the pre-Hispanic phase is characterized by the presence of shallow canalizations, as demonstrated by previous excavations (Fig. 8).

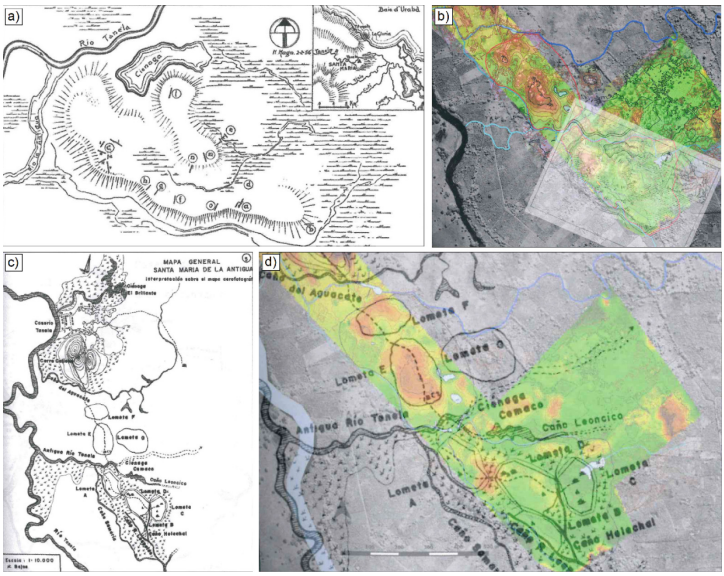

Fig. 5. Plan of archaeological excavations conducted by Arcila Velez (a) and Verlinden (c) and their overlap on the DEM (b and d) (Modified by [3]).

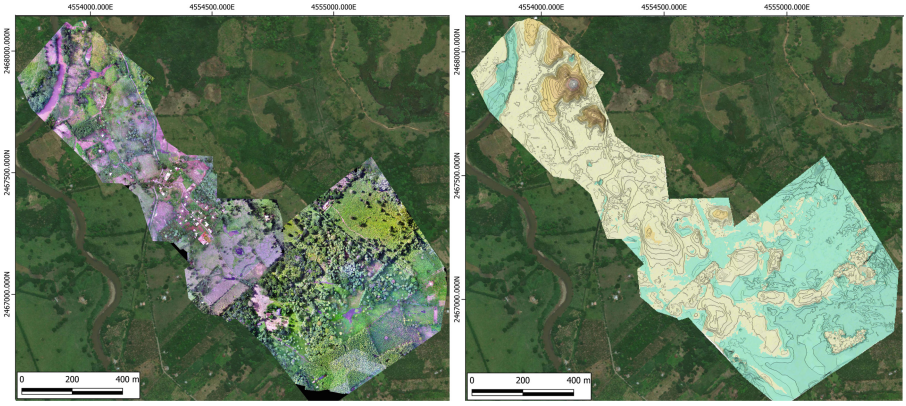

Fig. 6. Orthophoto (a) and Digital Elevation Model (b) produced in 2016.

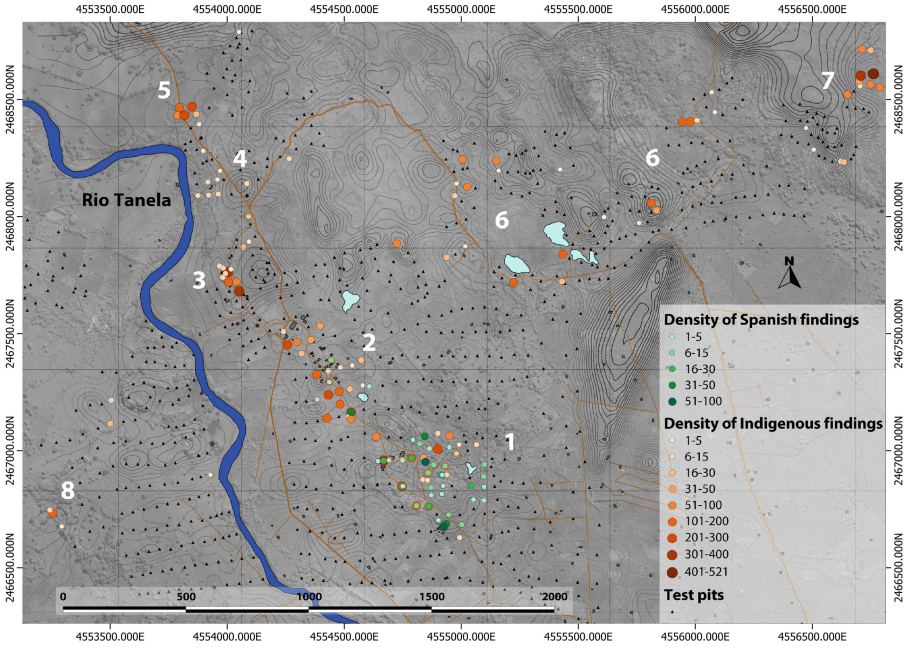

Fig. 7. Density map of archaeological finds (Modified by [3, 13]).

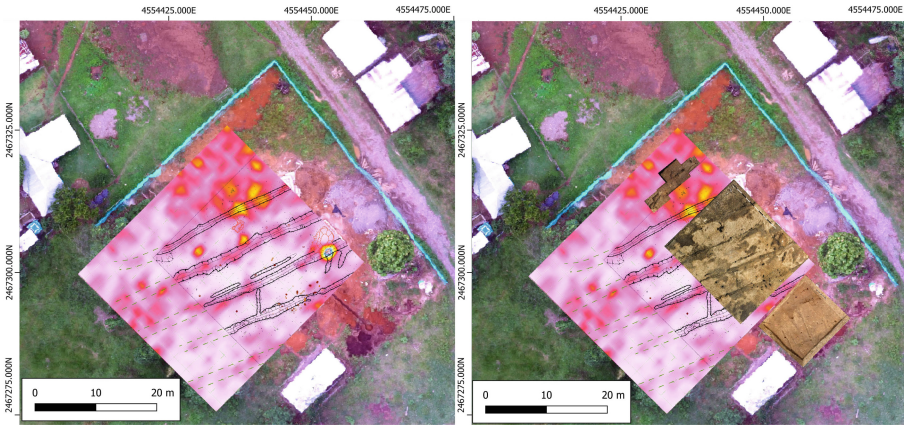

Fig. 8. GPR results (a) and orthophoto of archaeological excavation in test pit B and F (b).

5 Final Remarks

In the last ten years, since its beginning in 2013, the project has succeeded first of all in the important achievement of creating an Archaeological Park, thanks to the support of the Colombian Institute of Anthropology and History. This happened in one of the most complex regions of Colombia, recently further complicated by the passage of thousands of migrants on their way to the United States, giving permanent employment opportunities to nine men and women workers and three guards, in addition to the hundreds employed in the archaeological excavations.

The Museum and the Archaeological Park have had a considerable impact at regional level, constituting "the Museum" of the area, meaning the point of reference for reporting finds or donating objects encountered by inhabitants on their land, which has greatly expanded the archaeological collection contained in its storehouse.

Thanks to state funding and the support of international cooperation projects (see Acknowledgements), an almost constant level of research has been maintained, which the recognition of important parts of the colonial city, its phases and the pre-Hispanic phases that preceded it has enabled, through different forms of investigation, including the use of technology applied to archaeology.

In addition, the research also extended to the region, with the aim of clarifying the chronology of cultural and social events in the area, trying to answer important questions, such as the apparent disappearance of the "bays society", which formerly settled on both sides of the Gulf of Urabá, but by the time of the arrival of Europeans had long since abandoned most of the coastal sites where it had developed.

Among the most important results of the project, however, the gradual rapprochement of the communities and its increasingly strong integration into the activities must counted transforming this experience more and more from an institutional to a community project.

The completion of the Archaeological Park (2016) and, above all, the construction of the Heritage House (2017), a place of storage and exhibition of archaeological finds and a place for community meetings and gatherings, have given new impetus to relationships with communities. Here we began to support community projects that sometimes

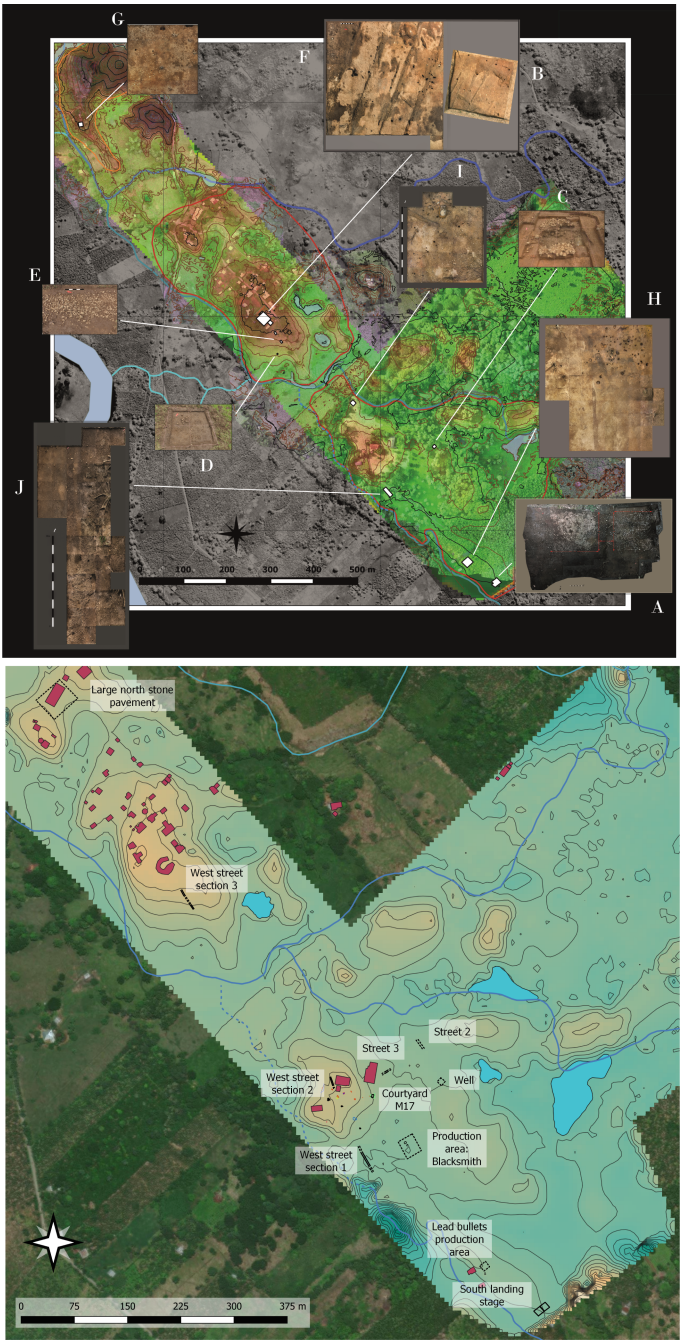

Fig. 9. Stratigraphic excavations carried out from 2014 to 2017 in the archaeological areas of Darien (B, D, E and F), Santa Maria de la Antigua (A, C, H, I and J) and Laureles (G) [3] (top) and preliminary archaeological map (bottom).

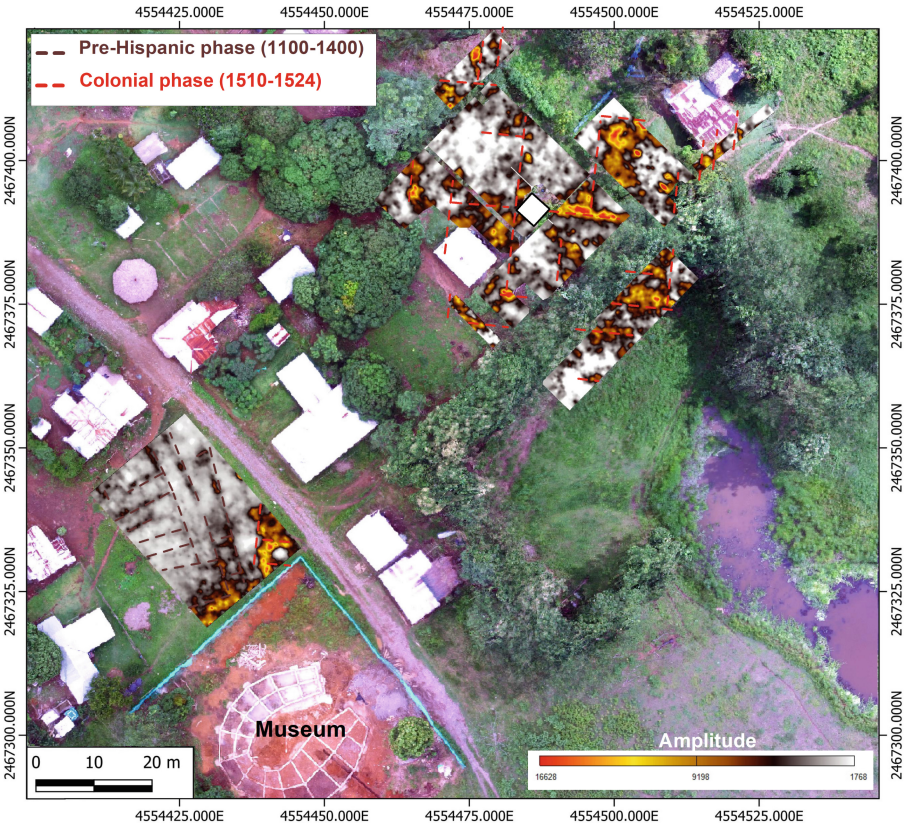

Fig. 10. GPR slice relative to 0.3 m in depth.

went beyond the institutional scope of ICANH, but which were nevertheless vital for the community, such as the rural housing project of cultural interest or the Territorial Development Plans. This openness, this ability to leave the institutional track and to listen to and support the concrete needs of the communities beyond the cultural proposals that are part of our mission, has brought even more families from the two villages in which the Park is located to the project.

The intuition that radically changed the relationship with the communities was the constitution of a Cultural Proposals Committee for the Heritage House and the Park (which was later simply called the Darién Cultural Committee). The idea was that the cultural events would not be organised from the capital, but would have a local root and matrix, conceived by a group of local representatives interested in the cultural aspects of the region. In 2018, the first meeting of the Committee was held, where most of the participants arrived without a clear understanding of what it was all about.

As time went by, the Committee gained strength, always maintaining a horizontal, equal and democratic form of relationship between the participants. Very quickly, even communities that had always been distant or opposed to the project, such as the Afro-descendants of the Major Council of Bajo Atrato or some of the Embera communities

and the Guna Dule community, approached the Committee. Talking about the culture of the communities and working to value it, in a territory where violence and paramilitary control incline people to lock themselves in their homes and villages instead of meeting and exchanging the different forms of their knowledge, proved to be a powerful trigger that has brought together most of the communities of the region in the Committee. From an initial participation of 9 communities, today the Cultural Committee comprises 21 communities in the region, belonging to the Embera Dobida, Embera Katio, Gunadule, Afrodescendent and settler populations.

The Committee is a meeting place between communities that rarely meet to dialogue. Culture is a neutral territory, in a context where paramilitary control prevents daily and normal forms of expression in other parts of the country and the world: talking about culture, creating and managing cultural spaces, is a form of rapprochement and mutual recognition that can open previously unexpected relationships.

For us it has been important, from the beginning, to move towards a decolonising archaeology, from research to musealisation, integrating all the communities of the territory in an integral multivocal approach. This is especially true for a site like Santa María de la Antigua, which represents the first step on the American mainland of the European colonising conquest at the expense of indigenous peoples and African populations transported as slave labour. A territorial reality such as an Archaeological Park, a Museum or an Archaeological Protected Area cannot be unrelated to all the communities that inhabit that territory, to their history and to their interpretation of the archaeological site and the findings. To paraphrase Iñaki Díaz Balerdi, we want to go beyond the physical limits of the Museum and the Archaeological Park to speak of territory [16]. In the case of Santa María de la Antigua, which with its colonial history encompasses indigenous, Afro-descendant and settler communities, there are different degrees of rootedness in the territory starting with the Guna, who have been present for at least 400 years (and probably much longer), the Embera, who arrived in the south of Darién around 1700 and in the Santa María area around fifty years ago, the Afro communities of the coast who arrived from the department of Bolívar in the late 1800s, those of the ciénagas, who arrived from the south along the Atrato around the early 1900s, and the Cordovan and Antioquian communities who have also been present for around fifty years. Each of these communities has a story to tell, a point of view as valid as the others.

By the way, those of Santa María de la Antigua del Darién are neither a community museum nor a community park, since "a community museum is created by the community itself: it is a museum of the community, not elaborated externally for the community" [17]. An archaeological park and its museum, in Colombia, cannot be, at least at this time, created and managed by the community. Our Park and our Museum have a community voice, they have community spaces, they carry out the community creation (and partly the management) of cultural events, but for the moment they are not a community Park and Museum.

The Santa María de la Antigua project was born out of an initiative that was previously a university initiative (the initial elaboration of the project is due to historian Paolo Vignolo of the National University, former ICANH director Ernesto Montenegro and the archaeologist Alberto Sarcina), on the part of the National University, and later a state initiative, on the part of ICANH and the Colombian Ministry of Culture. Likewise,

those of us who were leading this process were always clear about the importance of multivocality in all phases of the project. The empowerment by the communities of their own heritage, in our case, is a process that took and will take some time, and it is desirable that at some point a shared management of the Museum and the Park between ICANH and the communities, through the Cultural Committee, will be achieved.

Our proposal is to bet on archaeology, on the valorisation of the archaeological site as the detonator of a process of dialogue, of redefinition of a common territory based on the study of its history, of its ancestral roots, of the critical and proactive discussion of a history that has been divisive and violent since the arrival of the Spaniards. Undoubtedly, the Darién is a space where the memory of conflicts is reflected in the stories of indigenous resistance and Spanish atrocities, passing through the permanent war between the Guna and the Government of Panama, until reaching the current conflict, with an incredible continuity.

There is no doubt that in Santa María de la Antigua, peasant memory, indigenous memory and Afro-descendant memory are probably antagonistic to each other, on the one hand, and surely minority and excluded from the national historical narrative, on the other. We could define these narratives as "marginalised memories" (what Moshenka defines as "sectional memories" in [18]) as opposed to the national hegemonic memory.

The site of the first Spanish city founded on the continental land of America cannot exempt itself from being a stage for the articulation of all the stories and all the forms of memory present in the territory, and to place them on an equal footing with the hegemonic narrative. Our endeavour is to create the space, as welcoming and open as we can, to accommodate these stories and harmonise them in a decolonising narrative that is as multivocal as possible, while at the same time trying to generate a cultural fabric for peace.

Acknowledgments. About 300 local workers, who have specialized in stratigraphic archaeological research techniques. In addition, we have had the collaboration of: prof. Juan G. Martín (Universidad del Norte) for underwater research in Bahía la Gloria (2013), prof. Javier Rivera (Universidad del Norte) for research in Excavation Area A in 2014, prof. Rocío Salas and Prof. Pedro Botero (National University) for the study of soils and research in paleochannels (2013–2014), ArcSat satellite images of Padua for remote sensing in 2013, prof. Paolo Vignolo (National University) for historical research (2012–2020) and for being one of the creator of the project, Archaeologist Ernesto Montenegro for being one of the creator of the project and for impelling it since its beginnings (2012–2018), prof. Sneider Rojas (University of Antioquia) for the study of plant macroremains (2015), the geophysicists Julián Gallego, Davíd Tabares, César Ardila and Carlos Reina for investigations with profiler and GPR (2015–2023), the Bogotá Workshop School for the construction of the Heritage House (2016–2017), Drone Metrum SAS for topographic surveys in 2016, the museologists Carolina Quintero and Paula Torrado for the creation of the permanent exhibition in the Archaeological and Historical Museum and for contributing in the creation of the museography of the Park, the temporary community exhibitions "Maternidades" and "Caminos de Agua" (2017–2022), the Faculty of Heritage Studies of the Externado University for the restoration of metal pieces (2018), the Faculty of Education of the University of Antioquia for accompaniment in the realization of the community booklets (2018–2019), the restorers Pablo Obando and Tabita Serrano for the restoration of the metal and ceramic pieces (2014–2023), the Master's Degree in Museology at the National University of Bogotá, to accompany the realization from the museology of the Community Room (2019), William López, director of the National

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Author Contribution A. Sarcina is the archaeological project manager; M. Cozzolino, V. Gentile and P. Mauriello are responsible of the geophysical researches (MAECI Project “Large scale geophysical prospection for the knowledge of the Santa María De La Antigua Site, Colombia”, Grant number 1470, Director P. Mauriello).

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Joint Use of Geomatic and Geophysical Methods for the Survey and Documentation of the Vespasian's Thermal Baths (Cittaducale, Rieti, Italy)

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Abstract. The paper is related to the in-depth study of the route and characterization of a stretch of the ancient Via Salaria, an ancient Roman consular road, which connected Rome with Porto d'Ascoli on the Adriatic Sea. Researches were focused in the archaeological area of the Baths of Vespasian, also called Baths of Cotilia, in Cittaducale near Rieti in central Italy. The study of the sources, the analysis of the wall palimpsests and the interpretation of the results carried out return a much more articulated overall picture than what is currently visible, entirely resembling a territorial compartment characterized by a scattered settlement. A 3D laser scanner and digital photogrammetric survey of the structures was carried out, supplemented with a campaign of geophysical surveys (GPR). The results show interesting anomalies related to the roadway and adjacent structures, taking into account the transformations that the whole system must have undergone in subsequent epochs.

Keywords: Laser scanning · photomodeling · historical maps · GPR · Vespasian's Thermal Baths · Ancient Salaria road

1 Introduction

The research activity at the Baths of Vespasian in Cittaducale (RI) originated as a case study of the Project "Stone road paving. History, conservation, valorization and project", funded in 2017 by the Italian Ministry of University and Research in the frame of the action "Projects of Relevant National Interest (PRIN)". The research was developed with the analysis of the construction and execution techniques of stone roads through the comparative study of the works, based on what their function was supposed to be and the historical-geographical and political-cultural contexts of reference.

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In cases where the road infrastructure are no longer present, the study continued with the collection of information derived from toponymy or through iconographic sources.

The present work was aimed at carrying out survey operations, bibliographic research and direct analysis in order to evaluate different types of road pavements made through the centuries, also intended as covering architectural artifacts related to road routes such as: archaeological substructure works and ancient bridges. In order to compare the identity elements of different contexts, case studies were chosen on national territory, in urban and suburban areas, taking into account the function and historical-geographical and environmental characteristics of the sites.

The contribution summarizes the results related to in-depth studies on the route and characterization of the ancient Via Salaria near Rieti, through an interdisciplinary methodological approach based on integrated survey systems and the documentation and analysis of visible archaeological evidence.

The subject of the investigation was the archaeological area of the so-called Baths of Vespasian in Cittaducale (RI) where, following recent excavation campaigns carried out by the then Soprintendenza Archeologica del Lazio, a glare section of the ancient Via Salaria, about 30 m long, was found (Fig. 1a).

The architectural complex, placed in close relation to the road, was part of the infrastructure of one of the most important stopover stations in central Italy, witnessed, among other sources, by the representation on the *Tabula Peutingeriana* (*Aquae Cutiliae*); it was articulated, not surprisingly, around a monumental basin.

The study of the sources, the analysis of the wall palimpsests, and the interpretation of the first survey and diagnostic results carried out return a much more articulated and complex overall picture of what is currently visible, entirely resembling a territorial compartment characterized by a scattered settlement. The structures show not only a large number of construction phases, but also a high variety of functions. Given the geomorphological characteristics of the site and the distance of the other coeval sites along the ancient route, it is believed that the bath complex must have played a landmark role in the surrounding area.

This project had three main objectives: the first was to develop a study model based on a multidisciplinary, multi-scale approach to archaeological investigations and to map the invisible. This is a model that many scholars in the field of archaeology have been using and refining for some time now with some excellent results, and which makes use of instrumentation capable of representing in different forms and with common visualization systems the results of an approach at different levels of knowledge. The second was to test different diagnostic techniques whose results are useful precisely to calibrate the methods of investigation on a particularly interesting and probably still under-investigated case study. The last one was to link under homogeneous reference systems the results of the investigations done, integrating them within a GIS platform to define different geomorphological analyses and the definition of thematic cartographies specific to the research results.

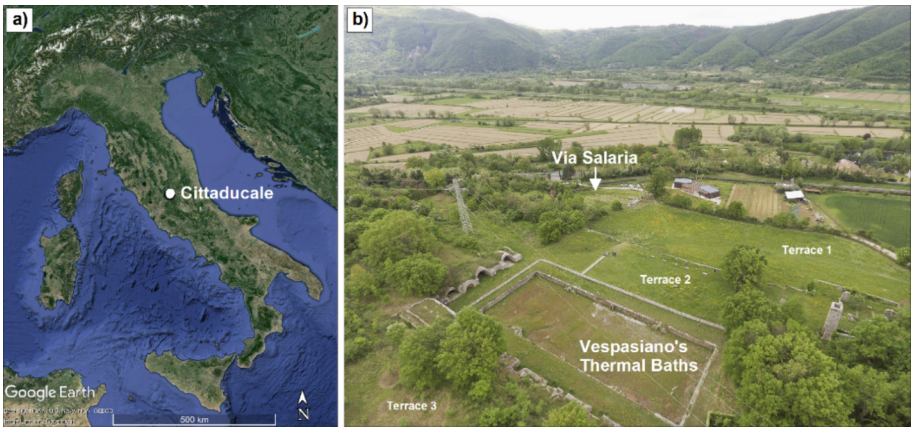

Fig. 1. Location of Cittaducale in central Italy (a) and aerial view of the thermal baths of Vespasian and Via Salaria (b).

2 Archaeological Background

The architectural complex of the Baths of Vespasian is structured around a first structure dating back to the second half of the 2nd century BC and the first half of the 1st century BC, which was followed by multiple construction phases both in the imperial age and in the late ancient and medieval eras [1]. In the *Tabula Peutingeriana*, a 12th-13th century copy of an ancient Roman map showing the routes of the Roman Empire, the site of Cotilia is localized with the symbol used for thermal structures in the variant with a *quadriporticus* and two-tower façade, indicating the presence of the complex which probably also constituted a resting place for travelers [2]. The site also seems to correspond with the toponym *Aquae Cutiliae* of the *Itinerarium Antonini*, a register of stations and distances between localities located on the various roads of the Roman Empire, which was located along the Via Salaria nine miles from *Reate* (Rieti) and seven from *Interocrium* (Antrodoco). This location currently corresponds to the district of Paterno in the municipality of Castel Sant'Angelo, near which there are some modest-sized lakes, one of which could correspond to the *lacus Curiliae* [3]. In this area, numerous terraces and substructures of the Via Salaria and infrastructures connected to it are documented and, in the past, notable discoveries have occurred during agricultural and road works reported mainly in the Italian periodical dedicated to archaeology *Notizie degli Scavi dell'Antichità* (News of the Excavations of Antiquity) as early as 1878.

From a geomorphological point of view, it is a territory in which, due to the solubility of the rocks, karst phenomena occur (F.I.G.M. n. 1939 IIISO; Geological Map of Italy, f. 139 [4]). In some underground cavities originating in ancient and recent times, there are springs of sulphurous or highly mineralized water, accompanied by manifestations attributable to secondary volcanism to be related to the existence of the very ancient Coppaeli volcano north-east of Rieti. The sulphurous water springs were also known to the ancients who took their healing properties into consideration [5–7]; the emperor Vespasian, native of *Falacrinae*, used to go to *Aquae Cutiliae* during the summer period.

The first excavations at the site date back to the years 1890–1891 [8]. The works began south-east of the *natatio*, where numerous walls, traces of marble and mosaic floors and a room identified with the *laconicum* of the baths were found. The investigations then restarted during the 1970s with tests in the central and northwestern areas, during which the thermal use of the buildings was confirmed [9, 10]. From 1982 to 1984, the excavation of the *natatio* continued and the north façade and the rooms behind it were highlighted and restored [11]. Only during the excavations directed by the Superintendency from 2010 to 2012, the remains of the stretch of road believed to belong to the ancient Via Salaria were found (Fig. 2).

The structures belonging to the thermal complex are mainly positioned on three terraces approximately 100 m long (Fig. 1b). At the second terrace, there is a *natatio* with a rectangular plan, which can most likely be identified with the *natatio*, accessible by stairs positioned symmetrically on the long sides. On the north and east sides of the pool there are various rooms characterized by a composite front with structures that reach approximately 5 m in maximum height. On the northern façade, there are alternate niches with rectangular and semicircular sections arranged on the sides of a rectangular room with an apse on the rear side. The eastern façade preserves large rectangular rooms alternating with small apses and in the northeastern corner a staircase is still visible which must have served as access to the upper floor, which branches off from a pillared portico where remains of mosaic flooring have been recovered. Furthermore, to the west of the basin and the architectural structure that surrounds it, there is the church of S. Maria di Cesoni, dating back to the 12th century due to its typology and construction techniques, but probably founded in an older era. The structure was entirely built with materials recovered from the Roman baths in continuity with the pre-existing walls. In the first terrace, the remains of what has been interpreted as a stretch of the ancient Via Salaria are currently visible.

Today the road has been excavated for a length of only 30 m and it seems clear that new excavation campaigns could bring to light even larger portions. In this stretch, the roadway of the ancient Via Salaria is made of crushed stone and gravel, delimited by stones arranged in cuts, and has a wall structure in blocks along the north side (Fig. 2). The path of the road and the wall end abruptly to the east, probably due to the cut made in the fascist era for the construction of the canal of the nearby hydroelectric power station. The presence of a structure made of large blocks of very compact limestone with a northeastern trend perpendicular to the road is a peculiarity of the site and is unique considering its typology. This structure, already partially identified in 2010, was interpreted as a sewer pipe, a hypothesis also confirmed by the latest excavation campaign [12]. Numerous questions remain open regarding the relationship between the road and the possible sewer and the dating of the conduit itself. Considering what emerged from the excavation documentation and the materials found in the abandoned layers of the structure it's not possible to advance a precise dating of the structure.



Fig. 2. A view of Via Salaria from west to east showing the hypothesis of sewer pipe, perpendicular to the road in the middle of the image.

3 Methods

The objective of this work was to represent at the appropriate scale the set of visible structures and the environmental context in consideration of the strong vegetation that characterizes the area and for a timely and accurate description of the territory on which archaeological structures stand.

Operating in a heterogeneous context and with different levels of detail has led to the integration of various relevant instruments. It was therefore decided to operate on three different levels: one relating to aerial vision using historical images and new acquired images by drone, another relating to the architectural scale with the use of laser and photogrammetric instrumentation, the last relating to the visualization of what is below the ground through geophysical diagnostics.

As part of the documentary analysis activities, various online digital archives were examined to verify the aerial coverage of the area from the years of the Second World War up to the most recent images downloadable from Google Earth. The objective was to analyze historical images that could provide further information on the area and identify possible anomalies in the territory based on sharpness, the camera model used and the acquisition altitude. The investigation area is very small compared to the extension of the images available and the resolution has not allowed accurate detailed analyses so far. Various digital archives were viewed, including for example that of the IGM, the National Aerophoto Library, the National Collection of Aerial Photography (NCAP) and The Library of Congress [13].

In particular, several shots taken in 1943 in the Rieti area were examined from the IGM website. The images had not a high resolution; however, among those available, there were some with higher definition. Taken from 9000 m above sea level, the area of the baths of Vespasiano was very small compared to the viewable territory. The methodology involved the use of available high definition images and their georeferencing on a Google database through the QGIS GDAL georeferencer. This operation allowed to project historical images onto the digital terrain model (DEM) of the available area taken from TIN Italy [14, 15]. The main difficulty consisted in identifying the homologous points between what is visible today and what was visible at the time of the shot. Furthermore, the difference in resolution between the images affected the accuracy of the process. Anyway, with six homologous points, it was possible to resolve projection ambiguities.

Regarding on-site surveys, part of the work was carried out using SfM-based digital aerial photogrammetry systems. The surveying was aimed to reach a large scale knowledge of the site and was carried out using a remotely piloted aircraft. Data processing of images was performed with Agisoft Metashape software (LLC. St. Petersburg, Russia) [16] using the structure from motion (SfM) technique [17, 18].

The area of the pool and the surrounding structures was surveyed with a laser scanner (Faro Scan S350 +, Faro Company, Lake Mary, FL, USA); in this case, it was necessary to use a long-range instrument to record both the elevated structures and the context relating to the terrain, to precisely describe the geomorphological trend with high resolutions. About 40 high-resolution scans were performed on the area. Particular attention was given to the enormous *natatio*, which occupies almost the entire upper terrace. The part of structures relating to the medieval church was also surveyed with laser scanner to have an accurate geometric description of the western part of the site.

The ancient route of the Via Salaria was the subject of more in-depth analysis concerning the general objectives of the project and it was surveyed both with laser scanners and with a photogrammetric system hooked to a carbon pole. In this case, the use of a reflex camera (Canon 5D Mark II with a focal length of 28 mm) mounted on a carbon telescopic pole of 6 m allowed several high resolution shots to be taken which were subsequently oriented using and integrating the laser scanner data.

The amount of data produced was processed according to widely standardized protocols in different application sectors for the management and restitution of point clouds [19, 20]; the latter were also georeferenced within a topographic network built *ad hoc* to organize the data in a single reference system aimed at an overall vision of the area within GIS platforms or data viewers. Since the area is characterized by a strong presence of vegetation at the limits of the archaeological structures with particular concentration in the northeastern area and in consideration of the morphological complexity of the site, it was also decided to use the LiDAR information of the integrated online services of the Lazio Geoportal to those obtained directly with a flight performed in April 2022 [21]. From the WMS services of the geoportal it was possible to visualize on Google mapping both the DSM and DTM of the Reatino area from LiDAR, excluding the predominate vegetation. As visible in the figure (Fig. 3), although the scale of representation is high and the resolution of the data is 1 m, it is possible to observe some very interesting anomalies of archaeological nature. The most obvious one is the continuation of the

substructure wall of the second terrace in an easterly direction for at least another 50–60 m, where it is also possible to see the corner that turns to the north. This discovery makes it possible to reestablish the correct extent of the terrace by decentralizing the reading of the infrastructure just to the east. A little further north it is possible to identify other small anomalies of an archaeological nature probably related to the structure of the baths. Only a field analysis will clarify the real nature of these anomalies referring them to ancient structures.

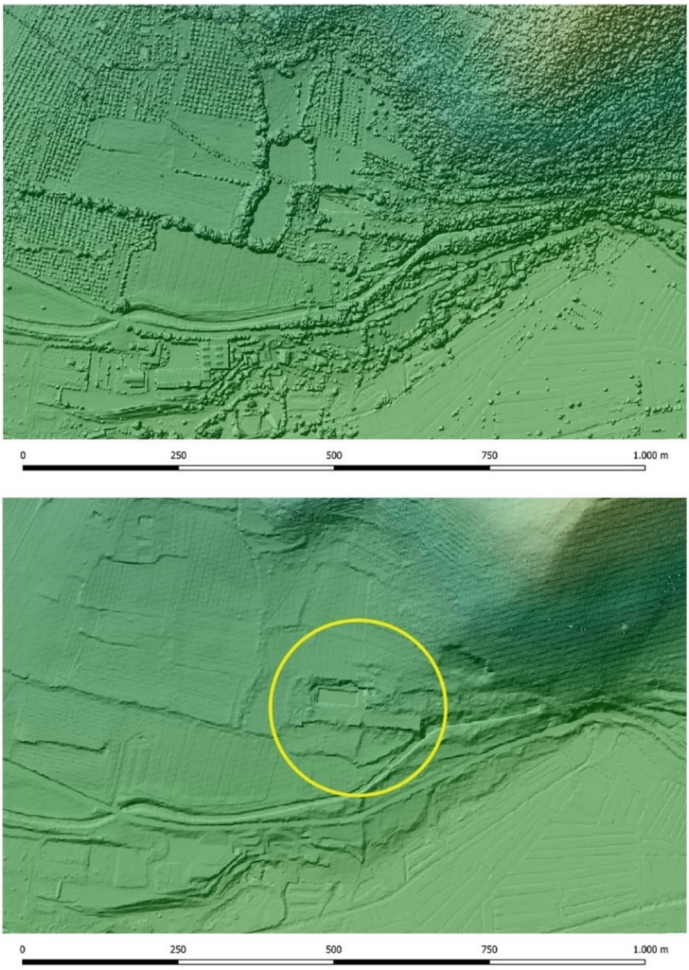

Fig. 3. DSM First and DTM Last LIDAR with 1 m of resolution (Ministero dell'Ambiente e della Sicurezza Energetica, WMS service http://wms.pcn.minambiente.it/ogc?map=/ms_ogc/WMS_v1.3/servizi-LiDAR/LIDAR_LAZIO.map&version=1.3.0)

Lastly, preventive non-invasive geophysical surveys were carried out on the first terrace with the aim of outlining in detail the route of the Via Salaria, partially identified southeast of the area. The investigations were partly overlapped with the areas investigated in 2020 by the British School at Rome, in collaboration with the Saint Mary's University of Halifax and McMaster University, using magnetometry and Ground Penetrating Radar (GPR), equipped with an antenna with a frequency of 400 MHz. These data show a complex range of structures between the road and the northern medium terrace. The continuation of the Via Salaria is clearly visible in the dataset towards west, while on the same east-west alignment a significant dividing wall is detected, behind which there are traces of some buildings [22]. In 2021, GPR surveys were repeated, as part of this project, with the aim of increasing the depth of investigation and qualitatively correlating the data with the distribution of the elevations of the entire surface. During data acquisition, the RIS K2 Georadar (IDS GeoRadar s.r.l., Pisa, Italia) was used, equipped with a 200 MHz antenna. The choice of the antenna frequency was dictated by the need to reach an investigation depth of approximately 3 m given that the road route was identified at an altitude of approximately −2.40 m from the plateau to be investigated. This, however, discriminated against the high-resolution identification of any more superficial structures. The survey covered an area of approximately 4400 m^2 through a regular grid of profiles spaced 1 m apart considering the overall size of the investigation area and the investigative purposes. In this way, the most useful detail resolution for data processing and their interpretation was obtained.

Radar reflections on each line were recorded as 16-bit data in a time window of 90 ns, acquiring 512 samples per radar scan at 25 scans per mark (unit/marker, 1). Raw data were processed using the IdsGred [23] and GPR − SLICE 7.0 software [24] using standard methodological approaches: data and trace editing, subtraction of the dc-drift (wobble) in the data, time-zero correction, bandpass filter, background removal and automatic gain. The entire data set was used to extract horizontal sections relating to different time windows equal to 4 ns with an overlap of 1–2 ns. By combining an average speed of 100 m/mm with some diffraction hyperbolas identified near specific objects, the estimate of the depth of the expected buried elements was found to be confined to the volume of soil included in the 0–3 m interval. This assessment is in agreement with the archaeological data considering that the structures excavated in the area appeared in the ground a few decimeters from the surface up to 3 m deep.

4 Results

From a preliminary analysis of historical aerial images, no elements suggesting important evidence have been identified in the excavation area. However, in the surrounding area, the presence of rather regular geometries could reflect ancient structures facing the ancient road route or simply be related to the growth of local vegetation. In particular, on the continuation of what may correspond to the route of the ancient section of the Via Salaria in the directions of Rieti (west), a rectangular-shaped anomaly of about 25 m × 35 m, overlooking the ancient route, has been identified. It is not possible to determine whether this anomaly constitutes the presence of an ancient structure or simply traces the growth of local vegetation (olive trees), but it is interesting from a topographical point of

view the correspondence of one side of this figure with what could represent the ancient route, a few hundred of meters from the area of the Baths. In Fig. 4, a high-resolution orthophoto of the currently visible thermal complex characterized by three terraces is reported. The image is georeferenced and represents the most accurate documentation of the whole structures reached until today. Both the structures pertaining to the baths and the medieval ones in the western area are recognizable. Figures 5, 6 and 7 show, respectively, the high-resolution point cloud of the thermal complex, the Via Salaria and the medieval structures coming from laser scans. Data processing is still ongoing and it is regarding the productions of horizontal plans relative to different heights and the drawing of vertical sections and side elevations.

The integration of laser scanning and photogrammetry at the via Salaria site was obtained through the projection of the images of the photogrammetric survey onto the laser model. This allowed the representation of this stretch of road through the restitution of plans, elevations and sections in different areas to have a complete documentation of a road stretch that continues below the current first terracing (it is located at a lower level than approximately 2.40 m) (Figs. 8 and 9).



Fig. 4. North-oriented high-resolution orthophoto of the archaeological complex.



Fig. 5. High-resolution point cloud of the thermal complex. The *natatio* measures a total of 60 m long, 22 m wide and 2 m high.



Fig. 6. High-resolution point cloud of the Via Salaria. The surveyed section of road measures about 30 m long by 5 m wide



Fig. 7. High-resolution point cloud of the medieval structures. The tower has a height of 10 m.

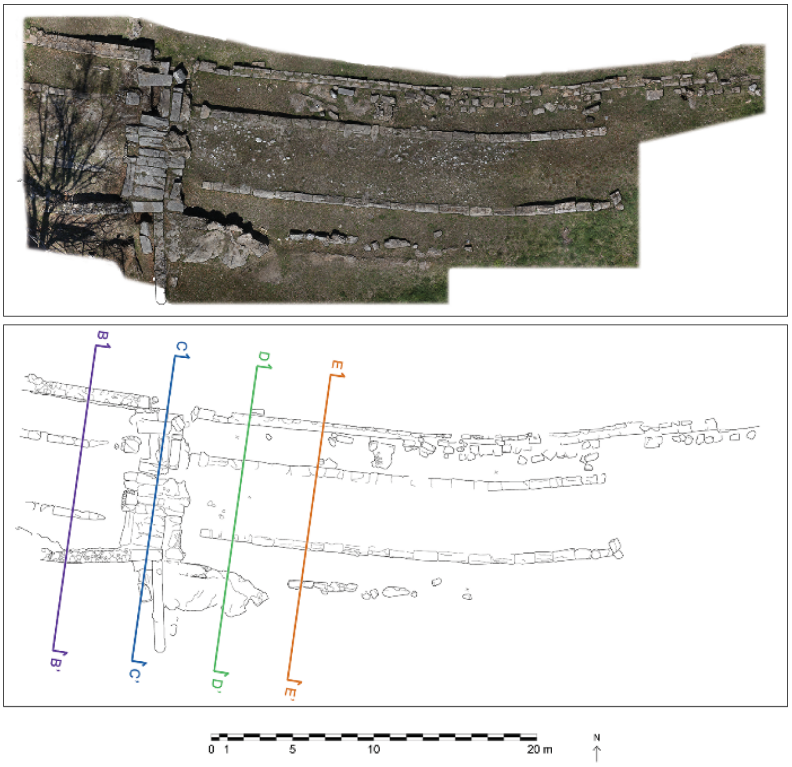

Fig. 8. Model obtained with the integration of laser scanner and photogrammetrc acquisition (top) with relative representation of the plan (bottom) of the ancient stretch of the Via Salaria. The location of the sections shown in Fig. 9 is indicated with colored lines.

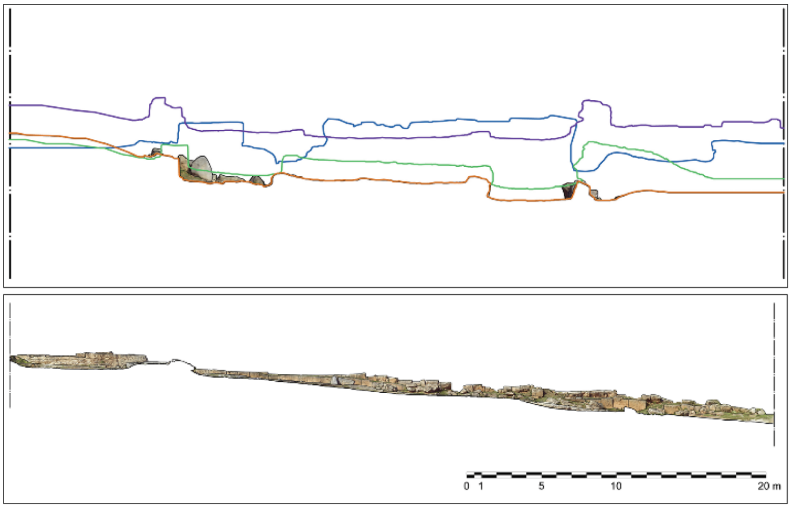

Fig. 9. Cross sections extracted by the numerical model and a longitudinal section (bottom) of the Via Salaria. The location of the sections is indicated with colored lines in Fig. 8.

Figure 10 shows some more significant horizontal sections. Image analysis allows the recognition of a complex regular system of maximum amplitudes of electromagnetic signals. Starting from the most superficial horizontal section, some anomalies with NNE/SSW orientation are noteworthy, which are most likely attributable to recent agricultural channels (two of them are partially visible in the field). From a depth close to 1 m onwards, alignments begin to be noticed which, with variable intensity, persist up to a depth of 2 m. Segment AA' appears to be the continuation of the curb of Via Salaria. However, there is an interruption about 25 m from the excavation trench, which shows the road. To the north, some probable walls can be identified that enclose large rooms. Focusing attention on the Via Salaria, the analysis of radargrams provided the approximate section along each transect. Five meters from the edge of the archaeological excavation, the profile of the road is very clear (Fig. 11, n. 1). The localization depth of the road pavement at this point is approximately 2 m. The anomaly is also visible at 11 m and 15 m (Fig. 11, n. 2 and n. 3) from the edge of the trench. Here, in the initial part of the profile, the anomaly corresponding to what could be a structure to the north of the road is also evident. At 31 m from the edge, while the hyperbola representing the wall parallel to the road appears clear, there is no clearer evidence of the Via Salaria (Fig. 11, n. 4). This interruption is approximately 30 m and it could indicate the absence of paving stones and curbs in that strip of land. Continuing towards the west, the road is detected again although at a lower altitude (Fig. 11, n. 5).

The numerical data resulting from the LIDAR and Laser Scanner detection were used for a methodological comparison with the results derived from the geophysical acquisitions. The overall and unstructured LIDAR point cloud was compared through the DSM inspection filter of the JRC 3D Reconstructor 4.4.2 software with the laser scanner data, acquired some time before at a time when no vegetation was present (Fig. 12) [25, 26].

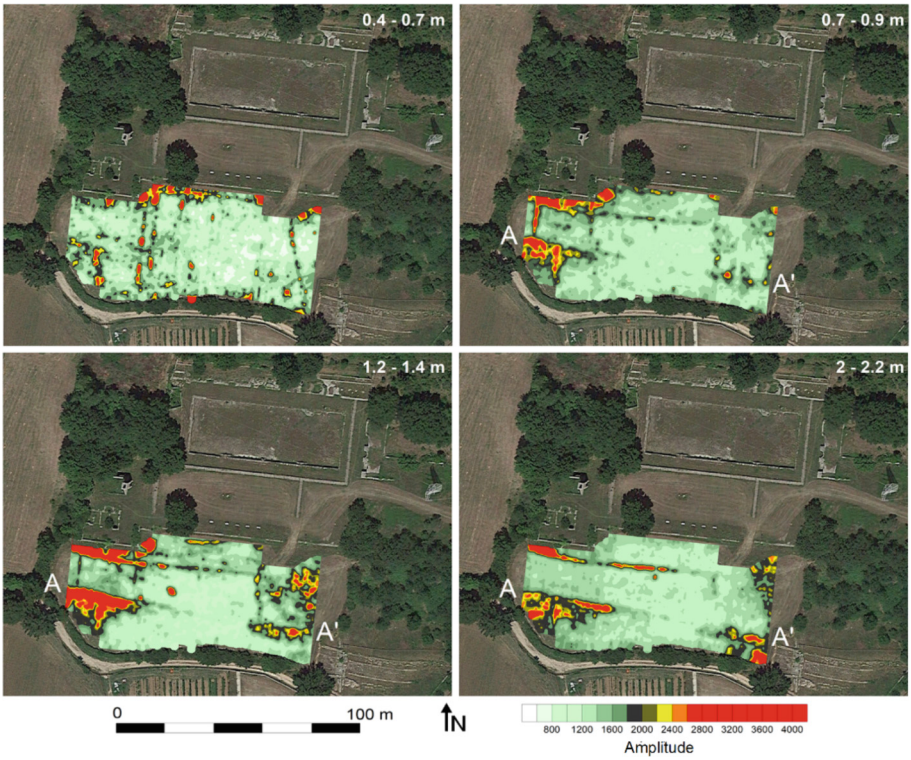

Fig. 10. Horizontal sections relating to various depths overlapped on Google EarthTM satellite image.

This filter was used on some specific areas, in particular the lower terrace and the large basin in order to better define the anomalies present in the area. The filter is based on the analysis of the differences in the relative altitudes of the part examined and is therefore able to clearly highlight what is on the ground from what is vegetation.

Once an auxiliary plane placed at a predetermined distance has been created, the relative elevation values with respect to the plane are associated and the differences are calculated. Usually the inspection filter is based on the definition of a plane positioned at a predefined distance; the reference numerical model is subtracted from this plane. From this subtraction, a false color map is obtained with respect to the elevations. The choice of the position of the plane strongly influences the result of the final map.

In this case, however, it was decided to use the inspection filter by subtracting from the LIDAR numerical model the one acquired from the ground with the laser scanner in the same area. In this way, the displayed map corresponds to the difference in height of the vegetation present in the area.

The available data made it possible to use this filter in an experimental configuration for which it was possible to identify the different relative heights of the surrounding vegetation in false colors.

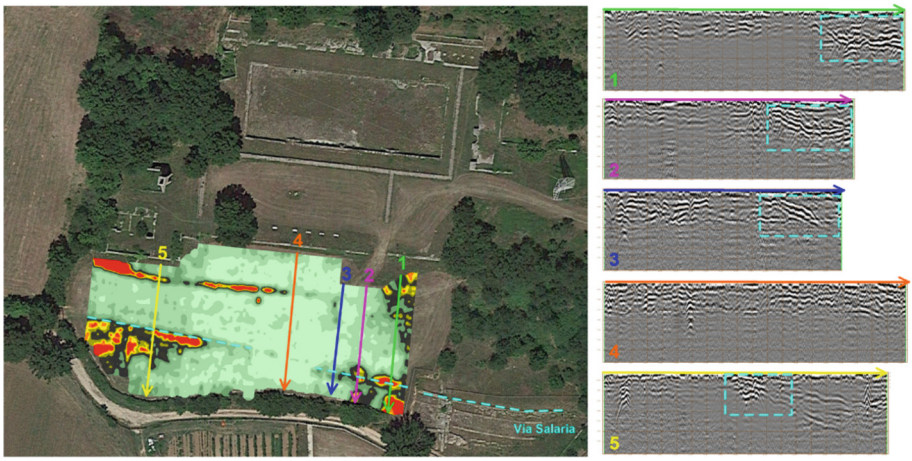

Fig. 11. Examples of radargrams, the location of which is shown on the section relating to the depth of 2–2.2 m, with indication of the anomalies attributable to the presence of the Via Salaria (in blue).

The growth of vegetation on the lower terrace is particularly interesting when compared to the anomalies found in the geophysical results (Fig. 12). The comparison between the two images of the figure suggests an affinity between what is visible on the surface and what is below the walking surface up to a height of −0.9 m. The direction and some forms of the vegetation give us indications on how the road axis must have developed in this part of the terrace.

This experimentation certainly allows us to analyze the methodologies used in greater detail and see for example, based on vegetative growth, how much anthropic material we should expect below and possibly at what altitude.

The same experiment was also conducted inside the large *natatio*. In this case, the area was not investigated with geophysical surveys, but the result of the anomaly is clearly visible (Fig. 13). In the figure, inside the basin, it is possible to find an off-centre rectangular shape of more than 25 m on a side in the south direction, located at a lower level than the surface of the basin, which suggests older phases or buried structures.

Other areas have also been further mapped with this processing to give greater prominence to possible anthropic anomalies invisible on the raw data. The analysis performed in this way was particularly effective not so much on wooded areas but on those where the grass grew in a differentiated manner. In other cases, it will be necessary to have further confirmation with the results of the geophysical activities.

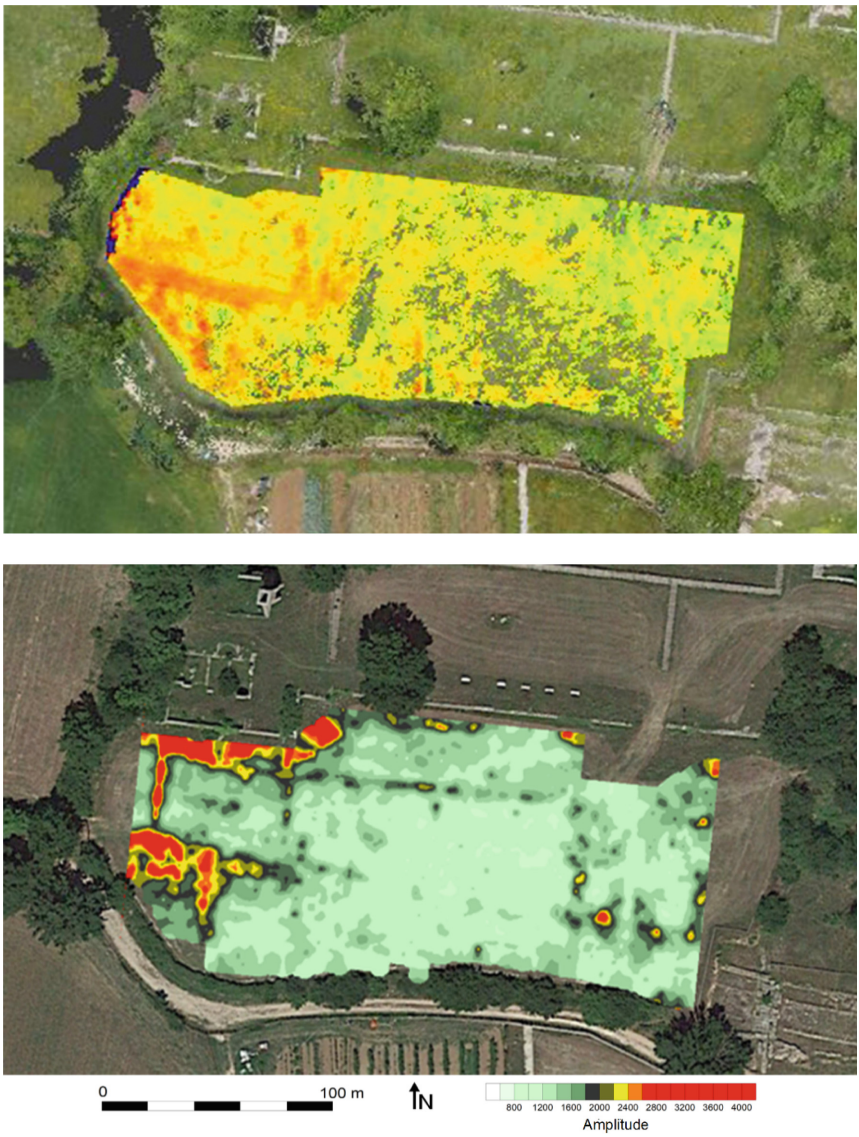

Fig. 12. Comparison of the geophysics results (bottom) and those deriving from the inspection filter (top) which shows an affinity in the representation of the anomalies.

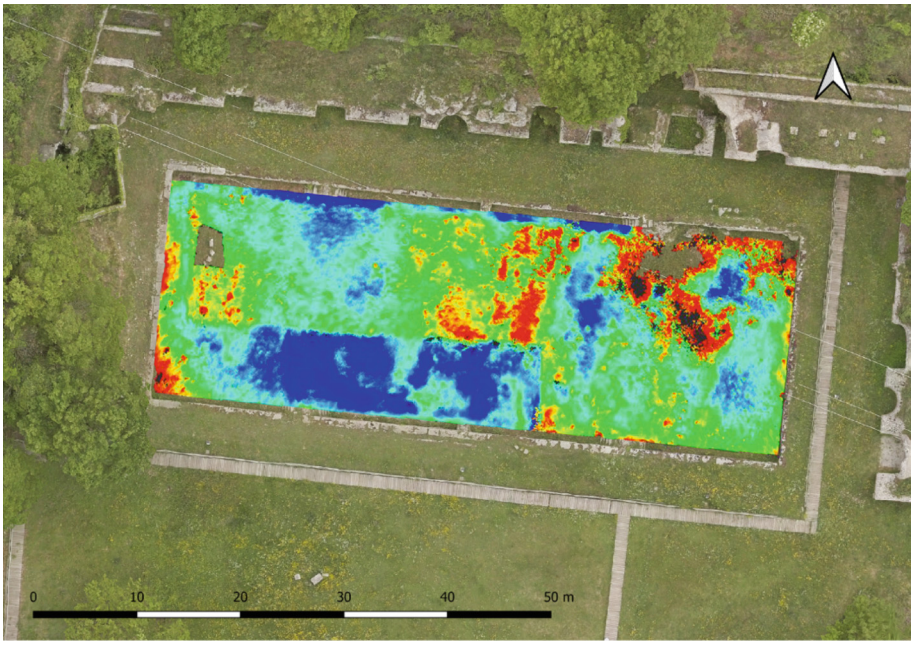

Fig. 13. Application of the inspection filter on the area of the *natatio*, which highlighted a possible rectangular anomaly inside the *natatio* itself.

5 Conclusions

The integrated reading of the territory on a large scale is now necessary for any archaeological study through the use of aerial, drone or LIDAR images, but above all numerical data present in different databases or acquired at the moment. The numerical data available, combined with zenithal and oblique shots, allow an interpretation of anomalies that has never been achieved, and to identify archaeological structures or real inhabited centers that are in fact not visible.

The contribution of new technologies has actually paved the way for the use of instruments capable of mapping a large area and the surrounding territory directly from below, which was unthinkable until a few years ago. The same applies to photogrammetric processes, which moreover now also benefit from drone acquisitions at very low altitude, as well as geophysical systems that have been mapping the territory below ground level for many years.

The acquisition of millions of pieces of information during survey campaigns allow us to position ourselves at an advantageous point for the final interpretation of the data, and from which we can associate different levels of detail and heterogeneous data as long as they are in the same reference system.

This is what was pioneered at the Baths of Vespasian and is often applied in the survey of ancient centers. The reading of a territory can now make use not only of images from above but also from diversified multiscale territorial analysis systems that concur toward the same result.

The research work highlighted the importance of cross-skills and diverse approaches in calibrating study methodologies and obtaining more information about the territory under investigation.

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