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Computational Science and Its Applications – ICCSA 2024 Workshops

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





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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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Sustainable Digital Circular Economy (DiCE 2024)

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Enrico Dagostini	University of Malta, Malta
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Marco Naseddu	University of Cagliari, Italy
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Maria Ronza	University of Naples, Federico II, Italy
Massimiliano Bencardino	University of Salerno, Italy

Evaluating Inner Areas Potentials (EIAP 2024)

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Manuela Rebaudengo	Polytechnic of Turin, Italy
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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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Kazuaki Tanaka	Kyushu Institute of Technology, Japan
Toshihiro Uchibayashi	Kyushu University, Japan
Toshihiro Yamauchi	Okayama University, Japan
Fenghui Yao	Tennessee State University, USA

Geographical Analysis, Urban Modeling, Spatial Statistics (Geog-An-Mod 2024)

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Andreas Fricke	Hasso-Plattner-Institut für Digital Engineering, Germany
Rodrigo Tapia McClung	Centro de Investigación en Ciencias de Información Geoespacial, Mexico

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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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Francesca Moraci	Mediterranea University of Reggio Calabria, Italy
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Antonella Versaci	University of Enna Kore, Italy
Celestina Fazia	University of Enna Kore, Italy
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Clarastella Vicari Aversa	Mediterranea University of Reggio Calabria, Italy

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

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Roberto De Lotto	University of Pavia, Italy
Caterina Pietra	University of Pavia, Italy

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

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Francesco Piras	University of Cagliari, Italy
Tanja Congiu	University of Sassari, Italy
Mara Ladu	University of Cagliari, Italy
Martina Sinatra	University of Cagliari, Italy
Ginevra Balletto	University of Cagliari, Italy

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Marco Mazzarino	IUAV Univeristy Venice, Italy
Maria del Mar Munoz Leonisio	University of Cadiz, Spain
Veronica Camerada	Univeristy of Sassari, Italy

Brunella Brundu	Univerisity of Sassari, Italy
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Enrico Dagostini	University of Malta, Malta
Giovanni Mauro	University of Campania Luigi Vanvitelli, Italy
Maria Ronza	University of Naples, Federico II, Italy
Massimiliano Bencardino	University of Salerno, Italy

Development of Urban Mobility Management and Risk Assessment (MAINTAIN 2024)

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Tiziana Campisi	University of Enna Kore, Italy
Massimo Di Gangi	University of Messina, Italy
Antonio Comi	University of Rome Tor Vergata, Italy
Grigorios Fountas	Aristotle University of Thessaloniki, Greece
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Orlando Belcore	University of Messina, Italy
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Borja Alonso	University of Cantabria, Spain
Luigi Dall'Olio	University of Cantabria, Santander, Spain
Kh Md Nahiduzzaman	UBC, Canada

Multidimensional Evolutionary Evaluations for Transformative Approaches (MEETA 2024)

Workshop Organizers

Maria Cerreta	University of Naples Federico II, Italy
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Ludovica Larocca	University of Naples Federico II, Italy
Maria Somma	University of Naples Federico II, Italy
Gaia Daldanise	National Research Council, Italy

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Sveva Ventre	University of Naples Federico II, Italy
Caterina Loffredo	University of Naples Federico II, Italy
Giuseppe Ciciriello	University of Naples Federico II, Italy
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Benedetta Grieco	University of Naples Federico II, Italy
Simona Panaro	University of Sussex, UK

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

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Federico Dell'Anna	Politechnic of Turin, Italy
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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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Lucia Saganeiti	University of L'Aquila, Italy
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Angela Pilogallo	University of L'Aquila, Italy
Francesco Zullo	University of L'Aquila, Italy
Alessandro Marucci	University of L'Aquila, Italy

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Ilaria Del Ponte	University of Genoa, Italy
Carmen Guida	University of Naples Federico II, Italy
Chiara Di Dato	University of L'Aquila, Italy

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

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Davide Cerotti	University of Piedmont Oriental, Italy

Scientific Computing Infrastructure (SCI 2024)

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Alexander Degtyarev	St. Petersburg State University, Russia
Alexander Bogdanov	St. Petersburg State University, Russia
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Downscale Agenda 2030 (SDGscale 2024)

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Francesca Sinatra	University of Trieste, Italy
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Salvatore Dore	University of Trieste, Italy
Maria Attard	University of Malta, Malta
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Maria Ronza	University of Naples, Federico II, Italy
Massimiliano Bencardino	University of Salerno, Italy

Socio-Economic and Environmental Models for Land Use Management (SEMLUM 2024)

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Elena Fregonara	Polytechnic of Turin, Italy
Paola Amoruso	LUM, Italy

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

Workshop Organizers

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Patrizia Serra	University of Cagliari, Italy
Silvia Battino	University of Sassari, Italy
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)

Workshop Organizers

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Marco Mazzarino	IUAV University Venice, Italy
Enrico Dagostini	University of Malta, Malta
Marco Naseddu	University of Cagliari, Italy
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Giovanni Longo	University of Trieste, Italy
Luca Toneatti	University of Trieste, Italy
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Maria Ronza	University of Naples, Federico II, Italy
Massimiliano Bencardino	University of Salerno, Italy

Smart Tourism (SmartTourism 2024)

Workshop Organizers

Silvia Battino	University of Sassari, Italy
Francesca Krasna	University of Trieste, Italy
Maria del Mar Munoz Leonisio	University of Cadiz, Spain

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Brunella Brundu	University of Sassari, Italy
Maria Attard	University of Malta, Malta
Tu Anh Trinh	College of Technology and Design for UEH University, Vietnam
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Maria Ronza	University of Naples, Federico II, Italy
Massimiliano Bencardino	University of Salerno, Italy

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

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Antonio Comi	University of Rome Tor Vergata, Italy
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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)

Workshop Organizers

Francesco Scorza	University of Basilicata, Italy
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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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Contents – Part VIII

Socio-Economic and Environmental Models for Land Use Management (SEMLUM 2024)

Values and Prices in the Historic City. Divergences and Value Creation 3
Maria Rosa Trovato and Vittoria Ventura

The Optimal Functional Mixture for Student Housing Initiatives: An Italian Case Study 21
Pierluigi Morano, Francesco Tajani, Marco Locurcio, Debora Anelli, and Felicia Di Liddo

Impacts of Urban Decay on the Residential Property Market: An Application to the City of Rome (Italy) 36
Debora Anelli, Pierluigi Morano, Francesco Tajani, and Emma Sabatelli

An Analysis of the Airbnb Market: A Detailed Look at Four Italian Cities 49
Francesco Paolo Del Giudice, Benedetto Manganelli, Pierfrancesco De Paola, Francesco Tajani, and Federico Amato

A Rational Method for the Quick Assessment of the Areas' Weights Applied to the Italian Context 66
Francesco Tajani, Benedetto Manganelli, Francesco Sica, Pierfrancesco De Paola, and Davide D'Ugo

Assessing the Value of Cultural Landscapes Through the Integration of Biophysical-Economic Valuation, Risk Assessment and Cost-Benefit Analysis 78
Vanessa Assumma and Claudia De Luca

A Systematic Analysis of the Scientific Literature on the Relationships Between Urban Redevelopment Initiatives and Property Market Dynamics 94
Francesco Tajani, Pierluigi Morano, Felicia Di Liddo, and Federico Stara

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

Exploring the Privacy Horizons: A Survey on HCI & HRI 113
Antonio Saporito, Parinaz Tabari, Mattia De Rosa, Vittorio Fuccella, and Gennaro Costagliola

A Tool to Support Automation of Risk Assessment 126
Mauro Iacono, Michele Mastroianni, Francesco Palmieri, and Antonio Saporito

Preventing Data Tampering in Smart Grids: A Blockchain-Based Digital Twin Framework 144
Biagio Boi, Christian Esposito, and Jung Taek Seo

Sustainable Evolution of Long-Distance frEight paSsenger Transport (SOLIDEST 2024)

A Preliminary and Aggregate Analysis Relating to the Italian and Balkan Intermodal Corridors for the Development of International Freight Trade 159
Antonio Russo, Giovanni Tesoriere, Socrates Basbas, Efstathios Bouhouras, Marios Miltiadou, and Tiziana Campisi

Railway Demand Evaluation: HSR Induced Component 173
Francesco Russo, Marialuisa Moschella, and Giuseppe Musolino

Dynamic Structure of Fares for High Speed Rail Services 188
Francesco Russo, Domenico Sgro, and Giuseppe Musolino

State of the Art of Sustainable Development of Railway Nodes: The High Speed Rail (HSR) 202
Paola Panuccio

A Network Analysis for HSR Services in the South of Italy 217
Corrado Rindone and Antonio Russo

Framework for Life Cycle Railway Sustainability Assessment: A Methodological Approach Based on Advanced Methods and Tools 233
Marinella Giunta and Giovanni Leonardi

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

A Selection of Sustainability Parameters for a Comprehensive Assessment of Urban Transformations 247
Sara Bianchi, Anna Richiedei, and Maurizio Tira

Supporting Sustainability: The Case Study of the Abruzzo Regional Sustainable Development Strategy 268
Federico Falasca, Carmen Ulisse, and Alessandro Marucci

Enhancing Vulture's Territorial Assets Through Tourism Ecosystems for Spatial Development 285
Rachele Vanessa Gatto, Giovanna Andrulli, Francesca Perrone, Simone Corrado, Erika Cerra, and Francesco Scorza

"Ecomuseo dell'Acqua": An Indivisible Unit of Strategic Sustainable Planning 293
Francesca Perrone and Rachele Vanessa Gatto

Territorial Regeneration in the Crater Municipalities After the Earthquake of L'Aquila: Social Challenges and Innovative Approaches 302
Carmen Ulisse, Raffaello Fico, and Alessandro Marucci

Specifics of Smart Cities Development in Europe (SPEED 2024)

Can Be Small Municipalities Smart? 317
Darina Rojíková, Katarína Vitálišová, Anna Vaňová, Katarína Sýkorová, and Mária Vavrúšová

Planning Sustainable and Resilient Waterfronts in the Mediterranean _ Insights from Athens and Lisbon 335
Yiota Theodora and Eleni Spanogianni

Evaluation of Geometric and Photometric Data Augmentation for Pedestrian Detection with Thermal Cameras 353
Marco Fanfani, Matteo Marulli, and Paolo Nesi

Smart and Sustainable Island Communities (SSIC 2024)

Spatial Data Management and Scenario Planning for Paving Sustainable Future Trails in Insular Territories - Case Study Milos Island, Greece 369
Akrivi Leka, Yiota Theodora, and Anastasia Stratigea

Assessing the Tourism Footprint in Dodecanese Complex, Greece – An Islands' Typology Approach 388
Dionisia Koutsi, Apostolos Lagarias, and Anastasia Stratigea

Planning Strategies and Practices for Accessibility in Peripheral Sparsely Populated Areas (SPA). A Spatial Knowledge Interpretation Approach 407
Tanja Congiu, Viola Fonnesu, Chiara Garau, and Alessandro Plaisant

Relevance of Structural Conditions in the Sustainable Management and Reuse of Historical Military Buildings: An Interdisciplinary Approach 421
Elisa Pilia, Giovanna Concu, Donatella Rita Fiorino, Emanuele Reccia, and Daniel Meloni

Author Index 435

Socio-Economic and Environmental Models for Land Use Management (SEMLUM 2024)

Values and Prices in the Historic City. Divergences and Value Creation

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Abstract. Analyses of the property market in the historic city often reveal heterogeneous, inconsistent or weak results as to the relationship between property characteristics and ask prices, even in homogeneous neighbourhoods. This phenomenon in the historic city is closely related to the existence of an imperfect real estate market, in which properties are often demanded and offered not only by families, but also by tourists as holiday homes and/or by students. The study proposes a model for analysing the residential property market in the historical centre of Syracuse, namely Ortigia, developed with reference to the Theory on sub-markets analysis. The structure of the model is characterised by spatial clustering based on quartiles of property characteristics, an exploration of the relationship between an aggregate quality index and price/sqm based on simple linear regression, spatial clustering based on the aggregate quality index, and fuzzy clustering. The model found a segmentation of the Ortigia property market based on three sub-markets, which provide details on the relationship between property characteristics and price formation, and between groups of property characteristics that contribute to price formation. Fuzzy clustering helped to highlight the dynamics of an imperfect market such as that of the historic centre of Ortigia.

Keywords: Imperfect market · Real estate sub-markets · Fuzzy clustering

1 Introduction

Analyses of the property market in the historic city often reveal heterogeneous, inconsistent or weak results in terms of the relationship between property characteristics and asking prices, even in neighbourhoods that are homogeneous in terms of location and context. In some cases, this is due to the fact that within the same segment, e.g. residential, some properties are intended for personal use, others for productive investment, and still others for speculative investment, thus obscuring the actual market segment to which they refer. These conditions should place these properties in different segments because the preference systems of the economic actors involved are different, which should therefore have different effects on the relationship between the asking price and the characteristics of the property.

This phenomenon, in the historic city, is closely linked to the fact that there is an imperfect property market, in which properties intended as residences are in demanded

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and are offered not only by families but also by tourists as holiday homes and/or by students. This opacity in the true state of properties leads to a blurred characterisation of properties within the same market. In order to achieve a better characterisation of the market, it is necessary to deepen the level of analysis in order to identify potential submarkets.

In other cases, all things being equal, the preferences of the economic actors may be more nuanced and weaker, leading to an overall low significance of the relationship between asking price and property characteristics. This could be tentatively highlighted in the pre-analysis phase of the data with the detection of numerous outliners.

Further research could support the identification of specific sub-markets for the property market under analysis.

There are several methods in the literature to detect significant factors influencing property prices, such as Hedonic models [1] or Automated valuation models (AVM) [2], which can support a robust analysis and characterisation of the market.

There are also numerous filtering models in the literature, developed within the framework of the Theory on sub-markets analysis proposed by William Grigsby, which can support the identification of sub-markets [3].

These models make it possible to identify and characterise sub-markets for apparently homogeneous property markets, i.e. those identified on the basis of spatial segmentation. Due to its complexity the property market in the historic city centre is difficult to describe in terms of sub-markets defined a priori on the basis of its spatial segmentation, since neighbouring units, even if they belong to the same residential segment, can be very different in terms of property characteristics, preference structures of the subjects and actual destination.

The study proposes a model analysis of the residential property market in the historical centre of Syracuse, namely Ortigia, with the aim of identifying and characterising its sub-markets. The model develops several analyses: spatial clustering of properties on the basis on property characteristics; estimation of an aggregate index of overall quality; relationship between aggregate index of overall quality and asking price per square metre; fuzzy clustering. The paper is divided into the following sections: Sect. 2 illustrates the state of the art in the theory of sub-market analysis; Sect. 3 introduces the case study; Sect. 4 illustrates the methodological approach; Sect. 5 reports the results; Sect. 6 proposes some reflections on the results and a summary of the proposed research.

2 Theory on Sub-markets Analysis

“Filterng models”, which aim to study the functioning of local housing systems have been proposed since the 1940s and 1950s [4]. The main assumption of “filtering models” is the existence of real estate submarkets characterised by specific dynamics of house prices, levels of property characteristics and preferences of economic agents.

There is no single concept of property market filtering in the literature [5]. In the field of urban economics, the concept of filtering has developed into two main lines of research: one aimed at analysing processes related to the life cycle of housing units, i.e. changes in the level of property characteristics affecting changes in real house prices;

and another aimed at analysing processes related to the life cycle of households, i.e. changes in their real income level and changes in real house prices.

The empirical research that has developed on the basis of filtering models has mostly focused on analyses aimed at assessing a specific indicator of change: house prices, in order to measure their variation [6], housing turnover [7], household mobility [8]. On the one hand, researchers agree on the existence of real estate submarkets, but on the other hand they do not propose a single empirical dimension to identify them.

A sub-market could be defined on the basis of the location of dwellings in the urban context, creating a spatial sub-market, or on the basis of property characteristics, creating a structural sub-market. Some researchers have found the empirical dimension for the identification of property sub-markets in a division of the market into areas, socio-economic characteristics of households and environmental characteristics [9–11]; others on the basis of neighbourhoods [12–14]; others on the basis of administrative boundaries [15–18]; others on the basis of population data; others identify the sub-market as the result of an in-depth knowledge of the market [19]; others on the basis of property prices defined by professionals [20, 21].

Other researchers consider as a sub-market to includes all properties, regardless of their location in the urban context, that have similar physical characteristics and are identified by economic agents as "close substitutes" [3, 4, 22, 23]. The first researcher to define sub-markets in terms of "close substitutability" of housing was William Grigsby [3]. In terms of strict substitutability, the property sub-market consists of a number n of "close substitutes" that belong to the same group but are "imperfect substitutes" for those belonging to other sub-markets [24–27]. Other research belonging to the nested spatial/structural and demand group-based submarkets sub-markets approach has highlighted the importance of spatial and structural characteristics in definition sub-markets.

Property market analysis aimed at identifying possible sub-markets can be carried out approaches. The academic literature produced over the last few decades has proposed numerous studies on market analysis aimed at the identification of sub-markets on the basis of real estate characteristics.

These studies have highlighted the role played of property characteristics in identifying sub-markets: Rapkin, Winnick and Blanck [3, 28] emphasised the influence of the "unit location within the building" characteristics of properties on the identification of sub-markets; Goodman [21, 29] emphasised the influence of "location and overall accessibility of the building and neighbourhood characteristics" of properties on the identification of sub-markets; Adair, Berry and Mc Greal W.S. [30, 31] emphasised the influence of "location and overall accessibility of the building and neighbourhood characteristics" and "unit location within the building".

Although there is no clear definition of a sub-market in the literature, based on the theoretical framework developed by Grigsby [3] and on the empirical basis that sub-markets can be identified by reference to certain characteristics of properties, several models for identifying and analysing sub-markets have been proposed in the literature: Hedonic pricing models [32, 33]; Factorial Analysis [23]; Cluster analysis [16, 34–36]; Geostatistical Models [37–41]; Hard clustering with the k-means analysis clustering algorithm [42]; Soft clustering with the Fuzzy clustering algorithm [43–48].

3 The Case Study

Situated on the south-eastern coast of Sicily, the island of Ortigia rises a few hundred metres from the mainland and extends into the Ionian Sea, creating two natural harbours, the Small Harbour to the north and the Large Harbour, bordered to the south by the Maddalena Peninsula (Fig. 1).



Fig. 1. Geographical framing of the studied urban context.

The ancient core of the historical centre of Syracuse, Ortigia, covers an area of 45 hectares and is connected to the mainland by two bridges spanning the narrow "Darsena" canal.

The present urban fabric of Ortigia is the result of a complex historical and urban stratification, the fruit of an evolutionary process that has taken place over a long period of time since the Greek colonisation in the 8th century BC. Its millenary history can be seen in the signs and traces that have been preserved over time.

The rebuilding of Ortigia after the devastating earthquake of 1693 in the late Sicilian Baroque style, which that incorporated the remains of previous eras in a harmonious union, has contributed to the creation of an architectural and urban context of absolute value, in which strong identity and cultural characteristics emerge.

On the threshold of the modern age, the Ortigia, still enclosed by the confines of the Spanish fortifications, grew on itself, making hygienic and sanitary conditions critical. From 1870, with the demolition of the fortifications, Ortigia was gradually transformed from the nerve centre of Syracuse to the outskirts.

The city of Syracuse, which had not left the island for many centuries, began to expand on the mainland and the population began to migrate in search of better living conditions. From the second half of the 20th century, the island was abandoned to neglect and decay, with only the poorest classes lived there, leading to progressive social and physical degradation.

Since the end of the last century, however, thanks to an intense process of restoration and improvement that has radically transformed it, Ortigia has once again become a site of primary historical and cultural importance and a strong point in the city's tourist development. In addition, the inscription in the UNESCO World Heritage List-WHL in

2005 has raised Ortigia's profile worldwide, attracting increasing interest from national and international investors.

As a result, a process of gentrification was set in motion, which has transformed Ortigia into a cultural, tourist and leisure centre, but also gradually causing the local population to move to other parts of the city.

In fact, the resident population fell from 27,000 in 1950 to 3,889 in 2020.

The population density is not high and varies according to the tourist season. Ortigia, in fact, is now overcrowded from spring to autumn and depopulated in the winter months.

As for the property market in Ortigia, which was dormant until the early 2000s, it has experienced an unexpected boost since the first decade of the 21st century, with a progressive increase in demand and prices, driven by the presence of a university campus and the development of tourism. The island, now transformed into an "exclusive location", is in fact today the area with the highest unit prices in the city.

4 Method

The methodological approach used to identify and characterise the submarkets for the Ortigia property market consists of the following steps:

- Create a database containing the property characteristics of the sample to be analysed;
- Spatial analysis of the sample of properties based on the quartiles of property characteristics in order to identify sub-markets (spatial segmentation using QGIS);
- Estimation of an aggregate k^* index of the overall quality of properties and spatial analysis of the sample of properties based on its quartiles by using QGIS.
- Analysis of the relationship aggregate k^* index of overall property quality with asking price per square metre.
- Cluster analysis of the property characteristics data of the sample and identification of submarkets (fuzzy clustering).
- Spatial analysis of submarkets identified by fuzzy clustering by using QGIS;
- Local analysis of submarkets.

4.1 Database Real Estate Characteristics

The database, based on the approach of Carlo Forte [49], includes the survey for the sample of the following property characteristics: k_e Location and overall accessibility of the building, and neighbourhood characteristics; k_i Position of the unit within the building; k_t Technological characteristics about building and unit; k_p Income/capital gain; k_a Architectural quality of the building and unit; P_{sqm} Asking price per square metre.

The six real estate characteristics are broken down into sub-characteristics, which are scored on a six points ranging from 1, indicating poor quality, to 5, indicating excellent quality. The main property characteristics are rated based on the aggregation of scores for the sub-characteristics. Table 1 shows the hierarchy of sub-characteristics for the k_e, k_i, k_t, k_p and k_a.

Table 1. Database structure of the property characteristics

k_e- Location and general accessibility of the building and characteristics of the neighbourhood	1. Complexity and urban shape	1. Location and settlement quality; 2. Mix of functions; 3. Social status (occupation type, income level, etc.) of the area; 4. Level of public space maintenance
	2. Urban facilities	1. Public facilities; 2. Public services
	3. Accessibility	1. Mobility to/from the area by private transport; 2. Mobility to/from the area by public transport; 3. Mobility within the neighbourhood
	4. Micro-environmental characteristics	1. Functional and 2. Symbolic characteristics
k_i- Building unit location		1. Panoramic quality; 2. View; 3. Brightness; 4. Orientation; 5. Security;
k_t- Technological characteristics	1. Building	1. Quality of the building structure; 2. Quality of the installations; 3. Quality of the finishes and windows; 4. Maintenance levels
	2. Unit	1. Finish; 2. Quality of the installations; 3. Maintenance levels
k_p- Income / capital gain		1. Income gain; 2. Capital gain
k_a- Architectural quality	1. Building	1. Use suitability; 2. Integration of structure and installations; 3. Finish and technology; 4. Morphological consistency; 5. Space decorum; 6. Maintenance levels
	2. Unit	1. Size, functionality and distribution; 2. Additional surfaces; 3. Quality of finish
$P_{sqm}-$ Asking price		Price per square metre

4.2 Fuzzy Clustering

Cluster analysis is a well-known multivariate statistical technique that can be used to derive a group structure, consisting of several similar units, can be derived from a given

Table 2. Sample of the database.

id	ask price	price/sq	ke	ki	kt	kp	ka
1	400,000	3809.52	4.26	4.35	3.13	5.00	4.06
2	175,000	2333.33	2.03	2.00	3.71	3.50	3.52
3	128,000	2560.00	2.03	2.00	4.31	4.50	3.94
4	150,000	2371.54	2.08	2.30	4.66	4.50	4.44
5	300,000	2857.14	3.17	3.00	3.71	4.50	4.08
6	200,000	2312.14	2.21	4.25	2.17	5.00	3.38
7	215,000	2330.62	1.70	2.60	3.31	4.00	3.92
8	195,000	1361.26	4.37	2.75	1.70	3.00	2.42
9	290,000	2426.78	4.81	4.15	2.42	4.00	3.30
10	308,000	2415.69	3.38	3.05	3.39	3.50	2.78
11	210,000	1564.25	2.03	3.15	1.83	3.00	3.68
12	198,000	2828.57	2.43	2.45	4.48	3.50	4.02
13	130,000	2549.02	2.85	2.40	3.92	3.50	3.60
14	268,000	2977.78	3.06	3.45	1.39	4.00	3.66
...	...	...	...	...	...	...	...
50	540,000	2160	2.515	2.95	4.79	3.5	3.72

population of data. The groups identified are characterised by internal homogeneity and external heterogeneity, assessed with reference to a defined set of variables.

There are several approaches to cluster analysis in the literature, those in which the objects belonging to a given group are selected by similarity, i.e., "similar" objects fall into the same cluster, referred to as hard clustering; those in which the objects belonging to a given group are selected on the basis of modulation of the degree of similarity (even partial), referred to as soft clustering. The fuzzy clustering algorithm belongs to of the soft clustering approaches. Given the imprecision of the data, a soft clustering approach can provide more information than a crisp approach.

There are several approaches to fuzzy clustering, in the literature, hierarchical or non-hierarchical [50]. The latter directly provide an a priori fixed number of clusters using iterative procedures aimed at optimising an objective function [51]. For each solution, an error measure is provided based on the distance between the data and the representative elements of the cluster. Among the fuzzy clustering algorithms proposed in the literature, the one proposed by Kaufman and Rousseeuw [52] is widely used, which proposes the following objective function:

$$C = \sum_{k=1}^{K} \frac{\sum_{i=1}^{N} \sum_{j=1}^{N} m_{ik}^2 m_{jk}^2 d_{ij}}{2 \sum_{j=1}^{N} m_{jk}^2} \tag{1}$$

where m_{ik} represents the unknown membership of object i to the cluster k and d_{ij} is the dissimilarity of object i to the cluster i, evaluated as the Euclidean distance or Manhattan distance.

Goodness-of-fit statistics are important in selecting the number of clusters.

The amount of "fuzziness" in a solution can be measured by Dunn's partition coefficient, which measures how to close the fuzzy is to the hard solution. Dunn's partition coefficient is given by the following formula:

$$F(U) = \frac{1}{N} \sum_{k=1}^{N} \sum_{i=1}^{N} m_{ik}^2 \tag{2}$$

This coefficient varies from $1/K$ to 1. Its value is $1/K$ when all memberships are equal to $1/K$. Its value is one when, for each object, the value of a membership is unity. The normalised version of Dunn's partition coefficient, i.e., so that it varies between 0 (completely fuzzy) and 1 (hard cluster, can be represented by the following formula:

$$\mathrm{F_c(U)} = \frac{\mathrm{F(U)} - (\frac{1}{\mathrm{K}})}{1 - (\frac{1}{\mathrm{K}})} \tag{3}$$

Another partition coefficient that helps verify the goodness of the model is the one proposed by Kaufman (Kaufman1990), which can be expressed by the following formula:

$$\mathrm{D(u)} = \frac{1}{\mathrm{K}} \sum\nolimits_{\mathrm{k=1}}^{\mathrm{N}} \sum\nolimits_{\mathrm{i=1}}^{\mathrm{N}} (\mathrm{h_{ik}} - \mathrm{m_{ik}})^2 \tag{4}$$

this coefficient varies in the range from 0(hard clusters) to $1 - (1/K)$ (completely fuzzy).

The normalised version of this coefficient is given by the formula:

$$\mathrm{D_C(U)} = \frac{\mathrm{D(C)}}{1 - \left(\frac{1}{\mathrm{K}}\right)} \tag{5}$$

Dunn's normalised partition coefficient and Kaufman's normalised partition coefficient provide good guidance for identifying the optimal number of clusters, in particular the criterion of selecting the solution with $F_c(U)$ the largest and $D_C(U)$ the smallest.

In this study, we used the NCSS software for fuzzy clustering. It allows us to minimise the objective function C of Kaufman and Rousseeuw [52] and check the goodness of fuzzy clustering, i.e. the number of clusters, based on the values of the normalised partition coefficients of Dunn and Kaufman.

5 Results

We surveyed a sample of 50 properties in the historic centre of Syracuse, i.e. Ortigia, net of outliers.

The property sample data were organised in a database based on the hierarchy identified and presented in the section for the six characteristics: k_e, k_i, k_t, k_p, k_a.and P_{sqm}. A summary of the aggregated data is presented in Table 2.

The spatial analysis of the property sample based on the quartiles of the property characteristics k_e, k_i, k_t, k_p, k_a and P_{sqm} can support an initial exploration of the property market aimed at identifying spatial submarkets. Analysis based on of the quartiles of different property characteristics shows how properties are redistributed according to their level.

Figure 2 shows the spatial distribution of the properties in Ortigia based on the quartiles of property characteristics k_e, and k_i.

For property characteristic k_e, 22% of the properties in the sample belong to the first quartile, 28% to the second quartile, 20% to the third quartile and 30% to the fourth quartile. Properties that fall in the first quartile of k_e are mostly located in the central belt of Ortigia. Those belonging to the second quartile are located partly along the perimeter

but in side streets, and partly in the central strip of Ortigia. Those belonging to the third quartile are mostly located in a perimeter strip that extends inwards to the east and west of the island of Ortigia. Those belonging to the fourth quartile are mostly located along the perimeter strip of the island of Ortigia and along its main street axis, Corso Matteotti.

For the property characteristic k_i, 28% of the properties in the sample belong to the first quartile, 22% to the second quartile, 22% to the third quartile, and 28% to the fourth quartile.

Properties that fall in the first quartile of k_i are mostly located in the central belt of Ortigia. Those in the second quartile are located along the innermost perimeter strip and in the central belt of Ortigia.

Those belonging to the third quartile are mainly located in the central strip and the southern and northern perimeters strip of Ortigia. Those belonging to the fourth quartile are mainly located along the central and western perimeter strip of Ortigia Island.

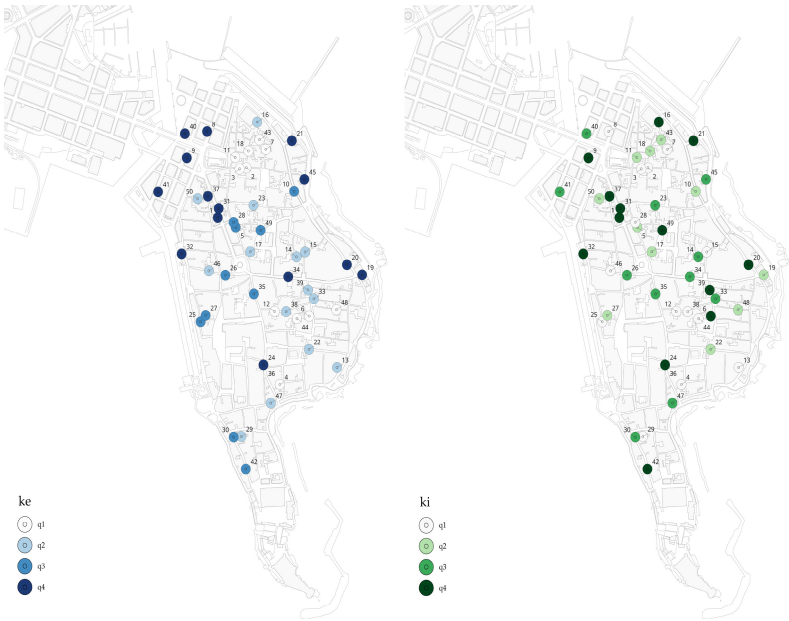


Fig. 2. Spatial distribution of properties in Ortigia based on the quartiles of property characteristics k_e, and k_i.

Figure 3 highlights the spatial distribution of properties in Ortigia based on the quartiles of property characteristics k_t and k_p.

For the property characteristic k_t, 26% of the properties in the sample belong to the first quartile, 22% to the second quartile, 24% to the third quartile and 28% to the fourth quartile. Properties that fall into the first quartile of k_t are mainly located in the central belt of Ortigia.

Those belonging to the second quartile can be found in the northern part of Ortigia. Those belonging to the third quartile ds are mostly found in the northern and southern

areas of the island of Ortigia. Those belonging to the fourth quartile are mostly found along the central strip of the island of Ortigia.

For the property characteristic k_p, 10% of the properties in the sample belong to the first quartile, 28% to the second quartile, 20% to the third quartile and 42% to the fourth quartile. The properties belonging to the the first and second quartiles of k_p are mostly located in the central belt of Ortigia. Those belonging to the third quartile are mostly found along the south-western and northern belts of the island of Ortigia. Those belonging to the fourth quartile are mostly found along the central belt of the island of Ortigia and along the main road axis system.

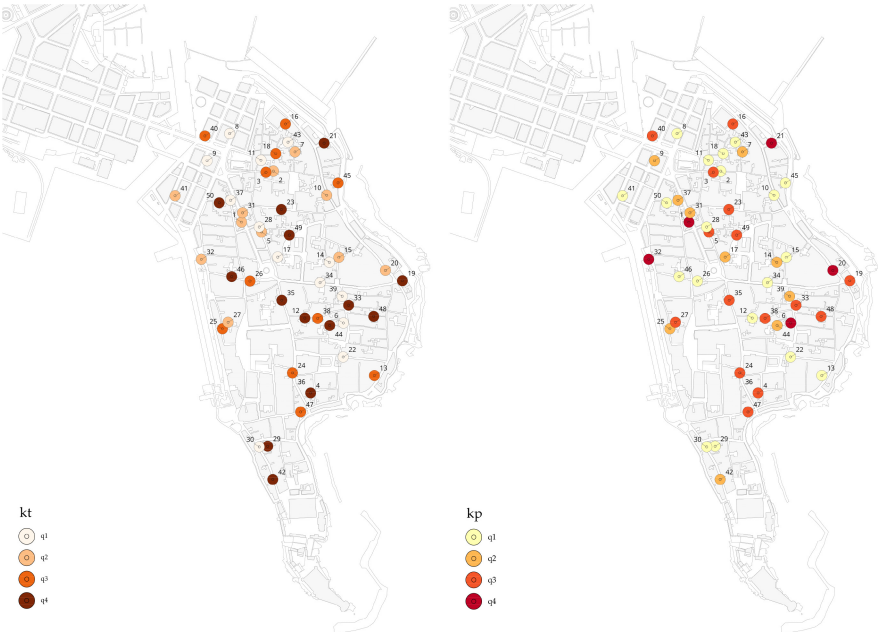


Fig. 3. Spatial distribution of properties in Ortigia based on the quartiles of property characteristics k_t and k_p.

Figure 4 shows the spatial distribution of properties in Ortigia based on the quartiles of property characteristics k_a and P_{sqm}.

For the property characteristic k_a, 26% of the properties in the sample belong to the first quartile, 20% to the second quartile, 28% to the third quartile and 26% to the fourth quartile. Properties in the first quartile of k_a are mainly located in the central belt of Ortigia. Those belonging to the second quartile are mainly located in the central belt of Ortigia and the western perimeter belt. Those belonging to the third quartile are mainly located in the central belt and along the south-western perimeter strip of the island of Ortigia. Those belonging to the fourth quartile are mainly located along the diagonal band in the east-west axis and in the north-western part of the island of Ortigia.

For the property characteristic P_{sqm}, 24% of the sample properties are in the first quartile, 26% in the second quartile, 26% in the third quartile, and 24% in the fourth

quartile. Properties that fall in the first and second quartiles of P_{sqm} are mainly located in the central belt of Ortigia consistent with the spatial analysis of other property characteristics. Those belonging to the third quartile are mainly located in the eastern part of the island of Ortigia. Those belonging to the fourth quartile of P_{sqm} are mainly located in the central and northern areas of the island of Ortigia and along the main axis system.

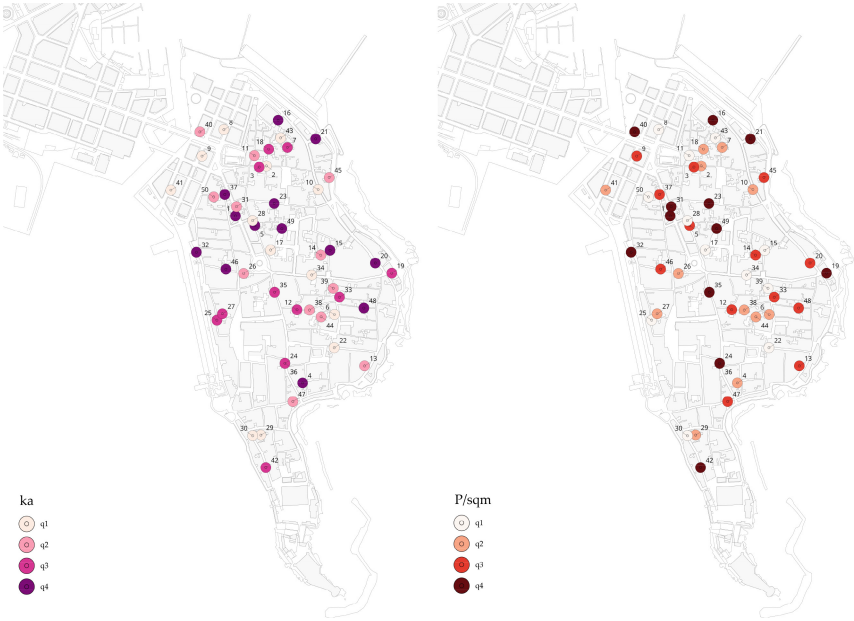


Fig. 4. Spatial distribution of properties in Ortigia based on the quartiles of property characteristics k_a and P_{sqm}.

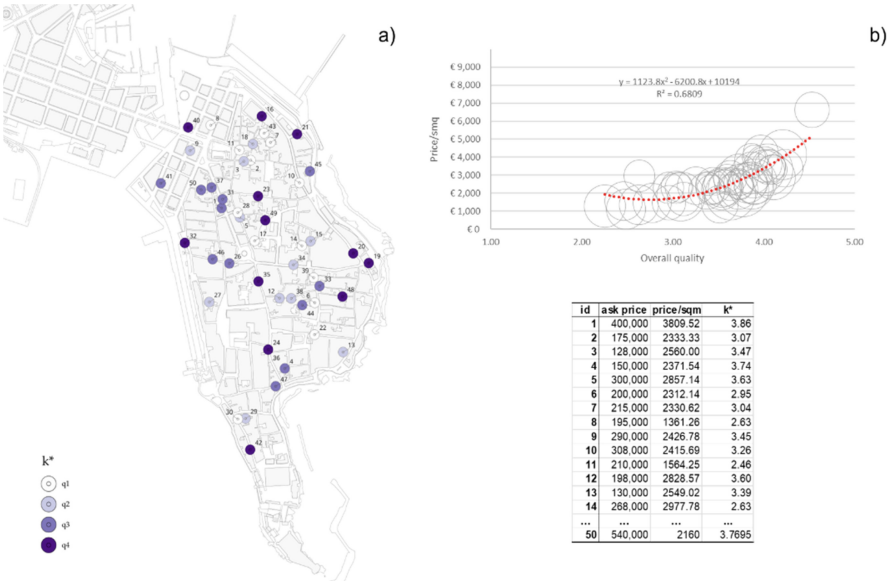
Estimating an aggregate index k^* of property characteristic scores for k_e, k_i, k_t, k_p and k_a provides a measure of overall property quality.

Spatial analysis of the sample of properties based on the quartiles of the aggregate index e k^* provides a map of propriety quality in Ortigia (Fig. 5a). Figure 5a highlights the spatial distribution of properties in Ortigia and the quartiles of the aggregate quality index k^*. For the property characteristic k^*, 26% of the properties in the sample belong to the first quartile, 24% to the second quartile, 24% to the third quartile and 26% to the fourth quartile. Properties in the first quartile of k^* are mainly located in the central belt of Ortigia. Those belonging to the second quartile are present, some along the perimeter but in side streets and and others in the central strip Ortigia.

Those belonging to the third quartile are mainly located in a perimeter strip that extends inwards to the east and west of the island of Ortigia. Those belonging to the fourth quartile are mainly located along the perimeter strip of the island of Ortigia and along its main street axis, Corso Matteotti. Figure 4b highlights a section of the database and the graph showing the relationship between P_{sqm} and overall quality identified by k^*, estimated on the basis of a simple linear regression. The relationship showed in the

graph shows an increase in price as the aggregate quality index k^* increases. The size of the bubble represents the area of each property. The graph shows a smaller bubble for smaller properties, which in most cases corresponds to a lower P_{sqm} and a larger bubble for larger properties, which generally corresponds to a higher P_{sqm}, in line with the typical relationship between P_{sqm} and property quality.

This graph also shows smaller properties with higher P_{sqm} corresponding to higher overall quality, this concerns in some cases buildings of higher historical-architectural value, and therefore consistent with the typical relationship between P_{sqm} and property quality. In other cases the direct proportionality between P_{sqm} is not confirmed even in the face of a pre-analysis led to the identification and removal of outliers based on the R^2 value of the simple linear regression between k^* and P_{sqm} (Fig. 5b). This highlights the likelihood that the sample of properties analysed do not all belong to the same market segment, and thus there is a need to integrate further analysis aimed at identifying and characterising potential submarkets.



id	ask price	price/sqm	k*
1	400,000	3809.52	3.86
2	175,000	2333.33	3.07
3	128,000	2560.00	3.47
4	150,000	2371.54	3.74
5	300,000	2857.14	3.63
6	200,000	2312.14	2.95
7	215,000	2330.62	3.04
8	195,000	1361.26	2.63
9	290,000	2426.78	3.45
10	308,000	2415.69	3.26
11	210,000	1564.25	2.46
12	198,000	2828.57	3.60
13	130,000	2549.02	3.39
14	268,000	2977.78	2.63
...	...	...	...
50	540,000	2160	3.7695

Fig. 5. a) Spatial distribution of properties in Ortigia based on the quartiles of the aggregate index of overall quality k^* state characteristics; b) Relationship between k^* and P_{sqm}.

5.1 Identifying Real Estate Submarkets in Ortigia Based on Fuzzy Clustering

Analyses of the functioning of local housing systems based on filter models aim to identify property submarkets. A sub-market is characterised by properties that can be considered as close substitutes for those belonging to the same group and imperfect substitutes to those belonging to different groups. The identification of sub-markets can be done in terms of spatial characteristics or in terms of property characteristics. Since

our data sample was collected in a relatively small area, the filtering model based on property characteristics is certainly more meaningful. The filtering model proposed in this research is based on fuzzy clustering based on the six property characteristics k_e, k_i, k_t, k_p, k_a. and P_{sqm} of the sample under analysis. In this research, NCSS software was used for fuzzy clustering of the property sample based on the six property characteristics. This software integrates a fuzzy clustering tool that allows us to identify clusters by minimising the objective function C and allows us to identify the significant number of clusters through two goodness-of-fit measures, namely the two normalised Dunn's and Kaufman's partition coefficients. Based on these coefficients we selected the number of clusters, specifically the best configuration is the one that maximises the average Silhouette $F_c(U)$ and minimises the partition coefficient $D_C(U)$. Based on these two selection criteria, three clusters, i.e., three sub-markets, were identified. The presentation of the centroids for the three clusters with reference only to the five property characteristics k_e, k_i, k_t, k_p and k_a, shows that the properties falling in Cluster 3 are those that globally have the highest levels of the six characteristics, the properties falling in Cluster 2 are those with the lowest levels of k_a, k_t and k_p the properties falling in cluster 1 are those with the lowest k_a, k_t (Fig. 6).

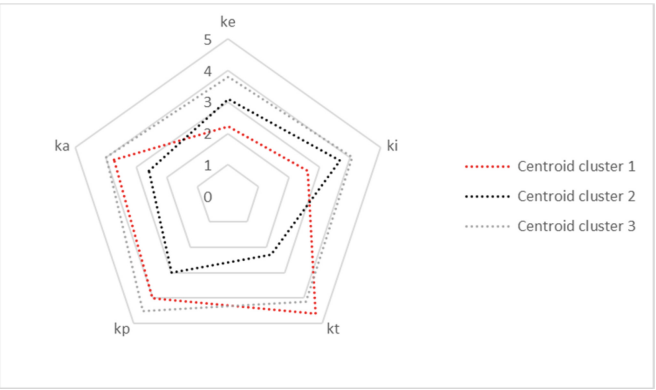


Fig. 6. Comparison between the centroids of the three clusters

The centroid of cluster 1 is represented by the property with id 44 in the data sample, that of cluster 2 by the property with id 30, and that of cluster 3 by the property with id 24. Cluster 1 includes the properties with the following ids. 2, 3, 4, 7, 12, 13, 15, 18, 25, 26, 29, 33, 38, 44, 46, 48 and 50. Cluster 2 contains the properties with the following ids. 6, 8, 9, 10, 11, 14, 17, 22, 28, 30, 34, 39, 41, 43 and 45. Cluster 3 contains the properties with the following ids: 1, 5, 16, 19, 20, 21, 23, 24, 27, 31, 32, 35, 36, 37, 40, 42, 47 and 49. The three clusters identify three sub-markets: the first sub-market identified by cluster 1 is characterised by the properties with lower k_e and k_i, the second sub-market identified by cluster 2 by the properties with lower k_a, k_t and k_p, and the third sub-market identified by cluster 3 by the properties with the best ratings for all six property characteristics. This last submarket is characterised by a slightly higher numerosity than the others, in particularly the numerosity of Cluster 1. The properties

in the original sample are distributed 34% to the submarket of properties with low k_e and k_i identified by Cluster 1, 30% to the submarket with low k_a, k_t and k_p identified by Cluster 2, and 36% to the submarket of properties with one the best ratings for all six property characteristics, identified by Cluster 3. The comparison between the first and second submarkets, shows that properties characterised by a lower level of k_e and k_i and higher level of k_a, k_t and k_p (Cluster 1) have a higher P_{sqm} than those in the submarket characterised by properties with a lower level of k_a, k_t and k_p and higher level of k_e and k_i (Cluster 2). This highlights how economic agents prefer to forego a better location and general accessibility of the building, as well as neighbourhood characteristics or the location of the unit within the building for properties with a higher level of technological characteristics, architectural quality and income/capital gain.

This is consistent with the general characteristics of Ortigia, the historic centre of Syracuse, connected to the mainland only by two bridges. Such a settlement location condition reduces the influence of k_e and k_i characteristics in the formation of the P_{sqm} and increases the influence of k_a, k_t and k_p characteristics in its formation.

The greater importance of k_a characteristic in the formation of P_{sqm} indicates a greater preference for properties with higher historical-architectural value. The greater importance of k_t in the formation of the P_{sqm} indicates a greater preference for properties in good condition and with adequate facilities.

The greater importance of k_p in the formation of the P_{sqm} indicates that the properties are demanded by economic entities for the purpose of production or speculation.

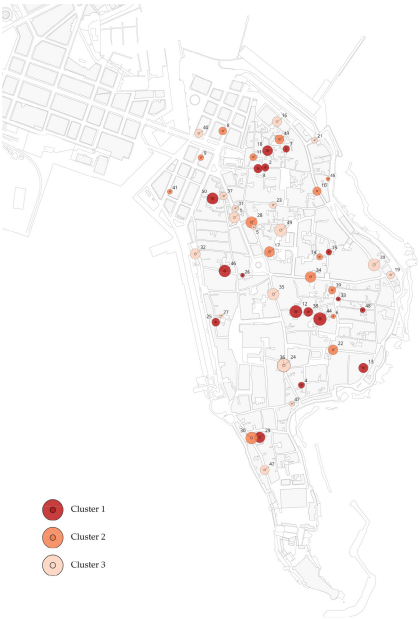


Fig. 7. Spatial analysis of three sub-markets. The size of the bubbles measures the degree to which the element belongs to the cluster.

A local analysis of the three identified submarkets can be carried out on the basis of the membership function of the properties in the clusters.

The spatial analysis of the three clusters shows not only the location of the properties in Ortigia, but also their membership function in the three submarkets, represented by the bubble size in Fig. 7.

The local submarket analysis on the basis of the degree of cluster membership of the properties, shows a more nuanced cluster membership, i.e., below 70% for the Cluster 1 of the properties with id 15, 26, 33 and 48, for the Cluster 2 of the properties with id 6, 8, 9, 11, 14, 39, 41 and 45, for the Cluster 3 of the properties with id 5, 19, 21, 23, 27, 31, 37 and 47.

6 Conclusion and Discussion

The analysis of the residential property market in the historical city of Syracuse, namely Ortigia, was developed in this study with reference to a first spatial clustering of properties based on the quartiles of property characteristics k_e, k_i, k_t, k_p, k_a.and P_{sqm}, which highlighted areas with different characterisation of the levels of property characteristics. A second analysis involving a spatial analysis of properties based on an aggregate index k^*, which highlighted areas with different overall property quality. The study examined the relationship between the aggregate index k^* and P_{sqm}, based on a simple linear regression model, in order to verify not only the robustness of the sample, but also the presence of soft and weak relationships that indicate the need for further research on the Ortigia property market. A third analysis consisted in the fuzzy clustering of the sample of properties on the basis of the six property characteristics k_e, k_i, k_t, k_p, k_a.and P_{sqm}, in order to carry out a more in-depth investigation aimed at highlighting dynamics that were difficult to detect with the previous analyses proposed in this study, which led to the identification of three sub-markets. The three sub-markets highlight information of interest in order to capture the complex dynamics of an imperfect market such as that of a historic city [53]. The sub-market identified by Cluster 3 consists of properties that confirm the natural dynamics between property characteristics and price formation, i.e., a higher level of characteristics k_e, k_i, k_t, k_p and k_a corresponds to a higher P_{sqm}. The two submarkets identified by clusters 1 and 2 provide details on the relationship between property characteristics and price formation, and between groups of property characteristics that contribute to price formation. A comparison of the two submarkets 1 and 2 shows that to the former includes properties with a higher level of k_t, k_p, k_a and P_{sqm} property characteristics and a lower level of k_e and k_i, while the latter includes properties with a lower level of k_t, k_p, k_a and P_{sqm} property characteristics and a higher level of k_e and k_i. These submarkets show a greater dependence on the characteristics k_t, k_p, k_a and a lesser dependence on the k_e and k_i in the formation of P_{sqm}. The lower importance of characteristics k_e and k_i is fully in line with the peculiarities of the property market on the island of Ortigia. It is still possible to highlight a direct relationship between characteristics k_t, k_p, k_a and P_{sqm}, which is confirmed in both sub-markets 1 and 2. This relationship shows a greater preference for properties with a higher historical-architectural value, a greater preference for properties in a good state repair and with adequate facilities, and a greater desirability of such properties for productive or speculative investment [54]. In particular, for the purpose of an in-depth study that highlights

dynamics that are difficult to detect with the previous analyses proposed in this study, the fuzzy clustering has highlighted two sub-markets that can be considered of greatest interest in order to detect the complex dynamics of an imperfect market such as that of a historic city namely Clusters 1 and 2.

These clusters showed fuzzy or inconsistent relationships as to the dynamics between property characteristics and P_{sqm}, and they indicate little apparent consistency in the relationship structure between of economic agents' preferences and P_{sqm}. The identification of fuzzy or opaque dynamics, as well as the identification of submarkets, can improve the quality of property market analyses, especially for historic centre properties. Our data sample consists of data collected through real estate agencies. A pre-analysis this data revealed many outliers, which significantly reduced the number of properties in the sample to be analysed. Comparing the data from real estate agencies with those from some specialised tourist and student websites, we found that in some cases the same properties were offered to different segments. Further research will be carried out to refine the analysis of the property market in Ortigia. The methodological approach proposed in this study can support the analysis of imperfect real estate markets and therefore its implementation can be extended to other contexts with similar characteristics.

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The Optimal Functional Mixture for Student Housing Initiatives: An Italian Case Study

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Abstract. Student housing is one of the main alternative asset classes within the real estate sector. In Italy, this sector is experiencing rapid growth and presents an excellent opportunity for attractive returns. However, the gap between the demand and supply of student accommodations remains substantial, therefore, the spread of student housing initiatives is supported by National Recovery and Resilience Plan dispositions that foster its application. The aim of the work is to define a goal-programming based model able to maximize the profit of the private subject involved into the initiatives that concern the enhancement of student housing accommodations. It concerns the definition of a management model that provides for the possibility of allocating part of the rooms to tourist hospitality. Starting from these considerations, in this paper an operations research problem whose objective is to identify the optimal mix of functions that allows the maximization of the profit of the structure manager is proposed. The obtained results show interesting margin of profit in the case for which the integration with the National Recovery and Resilience Plan are considered.

Keywords: student housing · operative research · scenario analysis · profit maximization

1 Introduction

Independently living university students traditionally choose between two types of accommodation: on-campus dormitories and private housing (rooms) near campus. Since the mid-1990s, purpose-built student accommodation (PBSA) has emerged as an alternative to traditional types of private housing and has become an increasingly important source of housing for students. PBSA share some features with dormitories: they are designed for student needs and the rooms are generally shared, but unlike dormitories, it is a service provided by market operators and it is based on the rent of bed. The level of quality varies, but it often includes higher quality services than those provided by dorms.

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Among the several drivers of the PBSA spread, the number of international students seeking education abroad is relevant. It has been on rise, especially in countries like the United States, the United Kingdom, Australia, and Canada. This trend has led to an increasing demand for student housing, particularly in major university cities. Students are ever more concerned about environmental issues, and developers are responding to this demand by providing sustainability features such as energy-efficient appliances, eco-friendly building materials, and waste-recycling systems. The technological enhancement for students living experiences has led to include online rental payments, mobile apps for communication and maintenance requests, and high-speed internet access. The COVID-19 has significantly affected the dynamics of the market giving the possibility to offer more flexible leasing options, such as shorter lease terms and ability to cancel or modify leases with minimal penalties. This flexibility has become crucial for students who may need to adjust their living arrangements due to changing circumstances.

Many students and investors consider PBSA market as a safer and more convenient option compared to traditional rental housing. However, student housing has become less affordable since 2013, leading to widespread public concern. The determinants of PBS housing affordability, which is a large component of college costs, are key policy interest. From 2013–2020, the effective rent per bed increased by about 25% higher for purpose-built student housing and 30% for student-competitive housing (defined as conventional apartments within three miles of a campus). A natural explanation for the rise in housing costs is represented by the growing demand from university students. This contingence would seem to fit in with the fact that student housing became less accessible just as university enrolments increased. When universities increase their enrollment, more student housing units are built. However, if there are changes in the traditional housing rental market, specially built student housing rents increase more than proportionally. It is sometimes the case that tax relief or regional subsidies lead to higher rents for student housing.

As total student numbers increase, notably international students who often maintain higher budgets and are less familiar with local housing, it is expected to see a rise in demand for PBS housing. The OECD predicts that the number of globally mobile students will increase to around 8 million by 2025, compared to 5 million in 2019. The growing middle class is driving demand for goods and services across various sectors, including higher education. Current annual average occupancy rates are high across Europe, ranging from 95% to 98%.

1.1 Italian Student Housing Market

Italy has a significant student population, with over 2 million students enrolled in higher education institutions across the country. This includes both domestic and international students pursuing undergraduate and postgraduate degrees. Major cities in Italy with renowned universities attract many students. These cities include Milan, Rome, Florence, Bologna, Padua, Turin, and Pisa, among others. The demand varies depending on factors such as the reputation of the university, the availability of programs, and the city's attractiveness for students.

After several years, the completion of the first modern assets is possible to observe, some of which are already operational. The *Aparto Giovenale* in Milan was sold by

Hines to an Italian pension fund for over € 100 M, completing in the first quadrimester of 2023. The project repositioned an obsolete property through complete refurbishment and is in an established residential area nearby Bocconi University, providing a new international campus with 600+ high quality beds, completed in 2022. To these three other properties of international target are added, for a total of 2,000 beds in 2022 in the city of Milan. Moreover, in 2022 *Patrizia AG* invested 70 million of euro in the forward purchase of a new-build PBSA in Turin, strategically located in Via Frejus to the west of the city center, which is within 1 km of Polytechnic of Turin, household to 33,000 students and 3.5km from the University of Turin. The transaction closed as envisioned in 2022 and the asset was inaugurated in September 2023 without the sale conditions changing. Rome, on the other hand, remains an exception, being the European city with the lowest coverage and a very low number of projects due to various reasons, mainly related to the difficulty of realize new buildings and converting existing ones.

The supply of student accommodation in Italy falls significantly short in meeting the escalating demand from both international and national students. Italy and Portugal, in comparison to Denmark and the UK, show the most inadequate provision rates with 1/10 of the latter's availability. In order to bring the offer of student housing to the standards of the best European peers (coverage rate of at least 20% of off-site students), it is necessary to increase the current allocation of about 100,000 beds. The future student housing supply in the main Italian cities will see over 23,600 beds to be completed by 2027. The current bed supply in Italy is almost 65,500 units: most of them (61%) are regional facilities under the Right to University Education, whilst 20% are managed by private operators, 12% are directly managed by universities, and the remaining 7% are legally recognized private and public student housings.

This suggests promising prospects for investment growth potential in Italy, to fulfil the rising demand from students pursuing tertiary education outside their home cities and from abroad. Milan (12,400 beds) and Turin (3,300 beds) record the highest bed completion rate by 2027, followed by Rome (2,300 beds), Florence (around 2,300 beds) and Pavia (507 beds). Of these additional 23,600 beds by 2027, 32% of them are already under construction, and more than half are concentrated in Milan. The total student housing availability by 2027, across the main cities, will total nearly 61,000 beds assuming the planned ones complete as anticipated and construction commences without delay across the pipeline.

Several large PBSA transactions has taken place and investment volumes remain high in the sector. The total investment volume reached €11.7 billion in the first three quarters of 2022, a 130% increase on the same period in 2021 and a record high. Forecasts of investment volumes up to 2024, which will gradually increase with the addition of new assets, will record between 800 million and 1 billion euros invested between Milan, Bologna and Florence.

The types of student accommodation in Italy vary, including dormitories, PBSA, shared apartments, and private rental properties. While some students prefer the convenience of dormitories or PBSA, others opt for shared apartments for reasons of affordability, independence, and cultural immersion.

The student housing sector in Italy presents investment opportunities for developers, investors, and real estate companies. There is potential for the development of new

student accommodation properties or the renovation of existing buildings to cater to the needs of students. Investors, especially institutional and international ones in the Italian market, are increasingly requiring ESG (Environmental Social and Governance) compliant assets: if LEED or BREEAM certifications criteria are not satisfied, the assets are generally less liquid. Appetite for low-cost rental accommodation is growing because of its social impact and because of virtually guaranteed occupancy. Currently, it represents a 30% share of the pipeline market. Single rooms have been always the most popular accommodation type, and this is even more true after COVID-19: this type is the first to be "sold out" during allocations, followed by double rooms. Those students who live in a double room during their first academic year, usually upgrade to a single room, the next year. High quality amenities in student housing and in campuses, create a premium on rental levels. The units are highly sought after by students, creating over-demand for prime assets and full occupancy. Incorporating high quality amenities into an asset generally has an overall minimal impact on refurbishment and running costs and can be absorbed relatively fast through cashflows.

The higher priced rooms are significantly more than the city average which breaks back to about 850 €/bed/month for Milan and Florence, 700 €/bed/month for Rome, followed by Turin and Bologna that are slightly lower. The average prices comprise both free-market rent and low-cost rental accommodation. On the private free-market rent, high quality amenities and connectivity to the local University, are currently driving demand leading to strong levels of rental growth.

2 Aim

The work is part of the outlined framework. The aim of the present research is to define a goal-programming based model able to maximize the profit of the private subject involved into the initiatives that concern the enhancement of student housing accommodations. It concerns the definition of a management model that provides for the possibility of allocating part of the rooms to tourist hospitality, especially for those structures that are situated in a location with a good tourist vocation, which takes the form of hybrid structures for mixed use "studentate-hotel". Starting from these considerations, in this paper an operations research problem whose objective is to identify the optimal mix of functions that allows the maximization of the profit (U) of the structure manager is proposed. Moreover, on the basis of the existing national incentives in the field of student housing, two scenarios are hypothesized in the present work: the first, called "Business As Usual (BAU)" provides for the resolution of the operational research problem previously introduced by establishing a sustainable rent equal to 25% of the total revenues associated with management; the second scenario, called "project scenario", provides for the identification of the functional mix capable of maximizing the operator's profit while keeping the rent defined in the BAU scenario unchanged, providing for a loan equal to 75% of the rent and adding the constraint previously described to ensure the prevalence of the student residence function over the tourist-accommodation function.

The reminder of the paper is as follows: in Sect. 3 a literature review is presented concerning the applications of optimization models to profit maximization and to the issue of student housing; In Sect. 4 the proposed model is described; In Sect. 5 the

application of the model to the case study is described and in Sect. 6 the conclusions of the work are drawn.

3 Background

Several Authors have studied the student housing market in the reference literature. For example, Ong, Petrova and Spieler (2013) [1] study the determinants of students' housing demand. Levy and Tucker (2006) [2] assess the business cycle vulnerability of student housing. Newell and Marzuki (2018) [3] study the characteristics of student housing from a portfolio perspective.

In the field of the student housing issues, among the several employed techniques, the goal programming-based ones are developed in order to achieve specific objectives related to several issues, such as (i) the housing units allocation by considering factors as room assignments, roommate compatibility and preferences (Rashidi, 2020; Hassan, 2016; Min, 1988) [4–6]; (ii) the assignment of housing units through the balance between maximizing student satisfaction, minimizing costs and ensuring equitable distribution of resources (Deliktas and Ustun, 2017) [7]; iii) the identification of a balance between affordable housing options and high-quality living standards (Li et al., 2023) [8]. Other studies are focused on the improvement of campus facilities and the prioritization of the related interventions according to several constraints, such as student needs, available budget and sustainability goals (Xu, 2022; Legorburu and Smith, 2020) [9, 10]. Within this application field, goal programming techniques have been applied to optimize how institutions can assign faculty members to classes, set objectives related to service quality, accessibility, and effectiveness in order to better meet the several needs of their student population are other relevant application fields of optimization models (Ding et al., 2019; Ascione et al., 2017; Al-Yakoob and Sherali, 2006) [11–13]. Promoting diversity and inclusion is another topic addressed through the development of goal programming models for increasing representation of underrepresented groups, fostering a welcoming campus environment, and implementing inclusive housing policies. The management of the optimal enrollment strategies has been studied by Aulck et al., 2020 [14] in order to set objectives related to student diversity, academic achievement, graduation rates, and alumni success, by guiding decision-making in enrollment-related activities.

Overall, the literature on the application of goal programming to the student housing market demonstrates its potential to address complex decision-making problems and optimize outcomes in various areas.

The development of profit maximization models based on goal programming techniques can be identified in several applications fields. For example, Mohajan and Mohajan (2022) [15] discuss profit maximization policies for the sustainable production by using four variable inputs, such as capital, labor, principal raw materials and other industry-related data where mathematical economic models are applied by considering budget constraint. Maximizing profits in a highly competitive cloud market is a huge challenge for cloud providers. Ganushchak-Efimenko et al., (2020) [16] develop an algorithm for making the optimal decision on the feasibility of implementing a particular innovation project. Liu (2006) [17] employs geometric programming technique to derive the objective value for the long-run profit maximization. Baki and Cheng (2021)

[18] aim for profit maximization of a small-medium enterprise company in Malaysia by using linear programming model. Tyapkina et al. (2017) [19] provide for an optimization model a model for profit maximization of production and products selling procedures. Nordin et al. (2021) [20] maximize the total return of the total amount invested with a different percentage of annual return by proposing a linear programming model. Oikonomou et al. (2018) [21] investigate the impact of the choice of optimization technique when constructing Socially Responsible Investment (SRI) portfolios and compare their performance along the dimensions of risk, risk-return trade-off, diversification and stability.

4 Methodology

In recent years, the students have seen an evolution of their management model, including the possibility of allocating part of the rooms to tourist hospitality, especially for those structures that are located in locations with a good tourist vocation. This business model, which is embodied in hybrid structures for mixed use student-hotel, allows at the same time to increase revenues and contain the rates for room rental to students. This approach is particularly performant where the maximum demand for rooms with accommodation function occurs in the periods of the academic year in which there are no lessons, and therefore students are more likely to vacate the room against a reduction in the annual rent. On the other hand, this model complicates the management of the structure making it necessary to pay attention to varied users with different needs and standards. Obviously the costs and services offered to tourists are different from those of students, and often the management model is further complicated by the possibility of obtaining public funding for operators who reserve a portion of their rooms at a reduced fee for deserving students and deprived of financial means to access free rental market.

In the structures for student-hotel use there are different types of rooms (single, double, mini-accommodation, etc.) which can carry out various alternative functions, that is *(i)* throughout the year for student use at an ad hoc fee or *(ii)* at a market fee, or *(iii)* for part of the year for student use and for receptive use, or *(iv)* exclusively for receptive use.

Starting from these considerations in the present research a problem of operative research is structured whose aim consists in the identification of the mix of optimal functions that allows the maximization of the profit (U) of the private manager of the structure. The profit of the involved private subject is determined as the difference between the revenues (revenues from the rooms, rent of the conference room, catering, bar, canteen, etc.) and all related costs (cleaning, utilities, purchases of food & beverage, staff, rent, ordinary maintenance, etc.) estimated using the same approach as the Uniform System of Accounts for the Lodging Industries [22].

Defined the aim of the problem of operative research, the variables are represented by the number of rooms ($N_{i,j}$) relative to the i-th type afferent to the j-th function. The only constraints consist in the imposition that $N_{i,j}$ belongs to the set of natural numbers and that the sum of the number of rooms for each type is less than the number of rooms belonging to that type present in the structure.

Hence, $N_{i,j}$ is the number of rooms of the property, where i = single, double, mini-accommodation, etc. represents the room type, and j = 1,2,3,4 indicates one of the alternative functions described above, for each type (T_i) we have:

$$N_{i,j} \in \mathbb{N} \cap \sum_{i,j} N_{i,j} \leq T_{i,MAX}$$

where $T_{i,MAX}$ represents the maximum number of rooms associated with the i-th type.

In some cases, better described below, there is a system of incentives where priority is given to the student function, especially if the fee is subsidized; in this case the predominance of the student function over the tourist function-requires compliance with the following inequality:

$$\forall i : N_{i,1} \geq N_{i,2} \geq N_{i,3} \geq N_{i,4}$$

The described problem of operative research summarized in Table 1, is solved through the implementation of the simplex algorithm [23], particularly suitable for solving linear programming problems.

Table 1. Goal, variables and constraints of the algorithm

Category	Formula	Meaning
Goal	$U := MAX$	Maximization of the profit
Variables	$N_{i,j}$	Number of rooms relative to the i-th type afferent to the j-th function
Constraint	$N_{i,j} \in \mathbb{N}$	$N_{i,j}$ belongs to the set of natural numbers
Constraint	$\sum_{i,j} N_{i,j} \leq T_{i,MAX}$	Sum of the number of rooms for each type lower than the number of rooms belonging to that type present in the structure
Constraint	$\forall i : N_{i,1} \geq N_{i,2} \geq N_{i,3} \geq N_{i,4}$	Predominance of the student function over the tourist one

5 Case Study

The operational research problem described above is implemented in a case study on the development of a building located in the center of a medium-sized city in southern Italy to be used as a hybrid student residence, identifying the optimal functional mix that can maximize the profit of the store. The project involves the renovation of an existing property with the creation of a structure that can accommodate a maximum of 72 users divided into 40 rooms (8 single, 28 double and 4 mini-apartments). Inside the property it is also planned to build a bar a restaurant/canteen and a conference room.

5.1 Analysis of the Market Demand

To characterise the demand for beds, a comparative analysis is carried out of the number of students enrolled, registered students and foreign students enrolled by A.A. 2010/2011 at A.A. 2022/2023 with reference to the university located in the city where the intervention is located (henceforth briefly "the university"), the region and Italy. In order to make the data relating to the three geographical scales easily comparable, the diagrams have been constructed on a 100 basis (registered, enrolled and foreigners A.A.2010/2011 = 100).

The analysis of the trend associated with the trend of enrollment for A.A. shows in the last A.A. a growth in the student population attending the university, growth in line with national data and more pronounced than regional data. Despite this, the analysis of the number of students on a 100 basis shows that the university's student population has fallen more sharply than at national level, in line with the average regional trend. The enrolment trend shows, starting from A.A. 2019–2020, a marked growth of new students in the university, reflecting national data and exceeding regional ones. Finally, if we focus exclusively on the number of enrolled foreigners, there is a constant increase in enrollment both in the university and at regional and national levels, with higher in the university than regional and national (Figs. 1, 2 and 3).

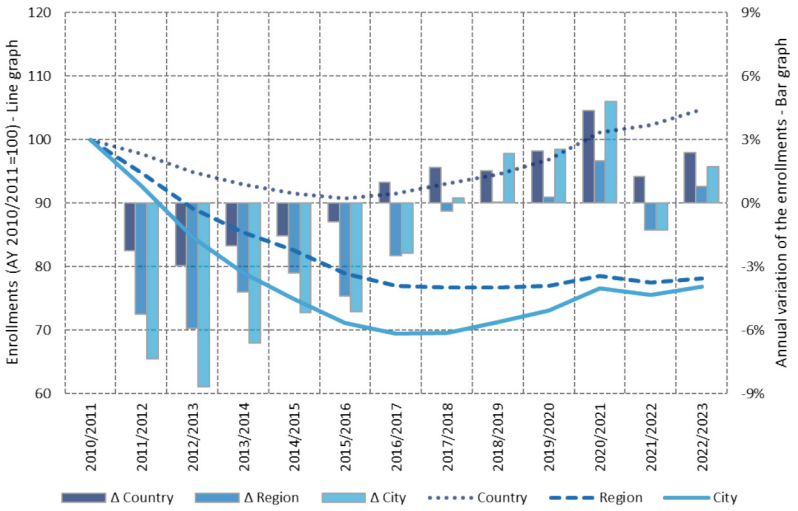

Fig. 1. Enrollments trend and annual variation of the enrollments in Italian universities

The increase in beds that would materialize downstream of the transaction would bring the ratio of beds and students enrolled from 0.9% to 1.1%, well below the Italian and regional average. This observation allows to assume a vacancy almost nothing of the rooms intended to accommodate the function student residence [24]. The hypothetical occupancy of the rooms used for tourist-receptive function has a strongly seasonal trend, as found by the monthly ratio between the attendance and the number of beds in hotel establishments built from ISTAT data for the city of analysis; starting from this

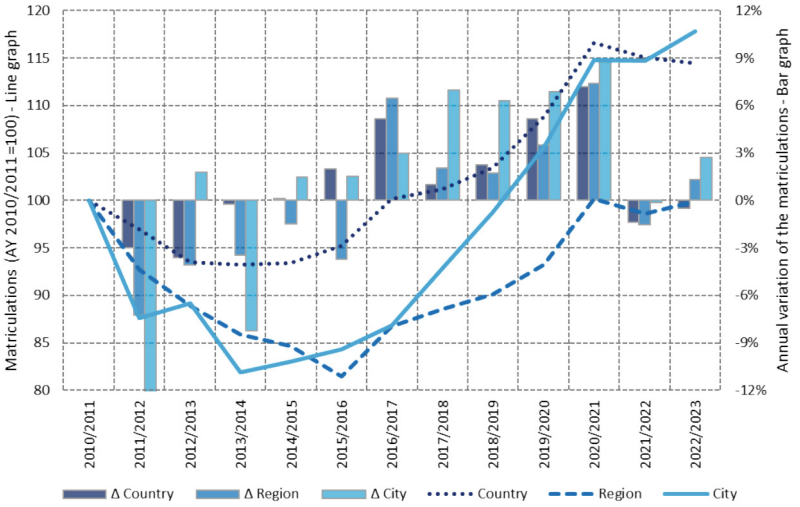

Fig. 2. Matriculations trend and annual variation of the matriculations in Italian universities

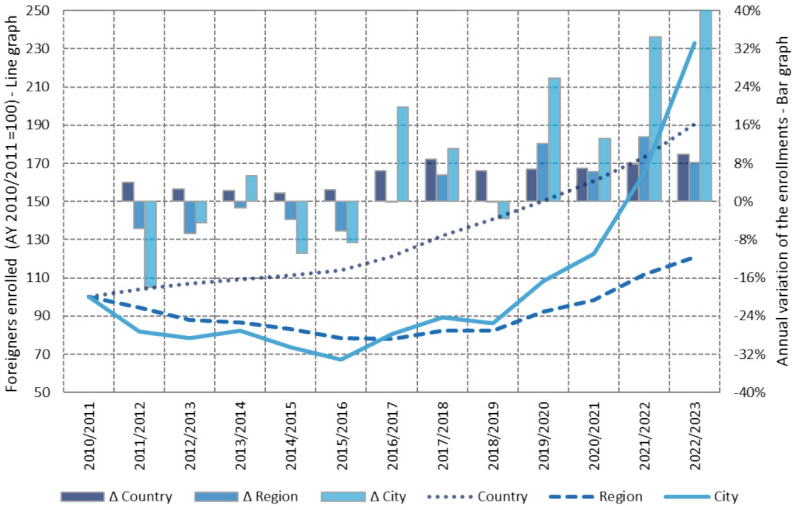

Fig. 3. Enrollments trend of foreigners and annual variation of the foreigner's enrollments in Italian universities

consideration in the hypothesis of mixed management of the rooms (function j = 3 - part of the year for student use and part for accommodation) it is assumed that in the high season (15 June–15 September), coinciding with the interruption of classes, the rooms are used with tourist-receptive function (Fig. 4).

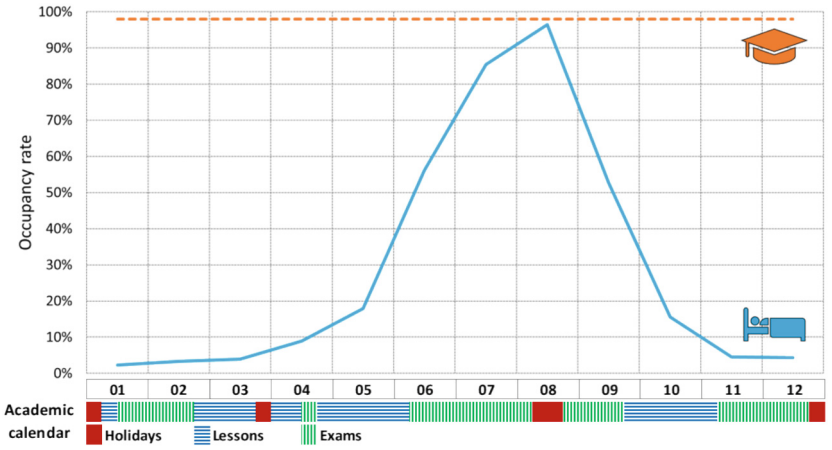

Fig. 4. Student and hotel occupancy rates and organization of academic activities

5.2 Proposed Management Model

For the determination of the profit of the manager it was necessary to reconstruct all the revenues and costs associated with this type of structure. The main form of revenue is linked to the rooms so, downstream of a market analysis, it was planned, for each type of room, the monthly rate assuming that the function is student (differentiated in case of standard and preferential rate) and the daily rate in the hotel hypothesis, variable depending on the seasonality (Table 2).

Table 2. PBSA and hotel rates

Room	PBSA rates (€/month)			Hotel rates (€/day) for season		
	Standard	% discounted	Reduced	Average	Low	High
Single	480	15%	408	70	54	86
Double	600	15%	510	100	77	123
Apartment	750	15%	638	140	108	172

It is assumed that the preferential rate will be less than 15% compared to the standard rate, as provided for by [25].

The turnover related to the canteen, restaurant and bar business has been estimated assuming an average daily consumption and an average amount per meal, both variable by type of consumption and user. The turnover deriving from the conference activity is determined assuming the number of annual events and a revenue associated with the event rental, in line with the reference market.

Through the analysis of the reference literature [26] and of the evaluation best practices [27, 28], the costs associated with the management of beds are estimated both in the

case of the student and in the case of tourist accommodation. To determine the costs associated with conferences, the cost of cleaning per event and the costs of food & beverage related to welcome coffee, coffee break, light lunch and aperitif are identified. Finally, the costs associated with canteen and catering activities are determined as a percentage of the respective revenues. The sustainable rent is determined as a percentage of the total turnover of the structure. The analysis of the profit of the operator, the percentage of the costs on revenues and the percentage of the profit on turnover allows to evaluate the performance of the project and the feasibility of the intervention from the point of view of the manager.

5.3 Model Application

The analysis of the endowment of facilities dedicated to student hospitality shows a gap between the quantity and quality of accommodation on average in Europe and those in Italy, especially in the cities of the center-south. This not only penalizes students, but it also makes our universities less attractive to foreign students, creating the ideal conditions for the proliferation of a huge "grey" market of houses rented exclusively to students, strongly changing the rental market without offering an adequate level of services to students. For these reasons through the National recovery and resilience plan (PNRR) [29] the total available resources are equal to 1,198,000,000.00 euros in order to finance at least 60,000 additional beds by 30 June 2026. The PNRR contribution granted by the Ministry of Universities and Research to the managing entity, as a result of the implementation and availability of each bed in the framework of the selected and financed interventions, is determined in a fixed amount of 19,966.66, and is related to the coverage of part of the rental income for the first three years of management of the facilities. The measures financed under this decree must provide for deadlines compatible, at the latest, with the provision of beds for the assignment by the deadline of 30 June 2026.

In order to accelerate this process, the PNRR foresees an active role for private investors through the co-financing of actions to acquire the availability of beds for university students, by obtaining the right of ownership or establishing a long-term lease or other form of use of the buildings or parts thereof. Expenditure eligible for part-financing shall relate to the purchase of buildings or parts thereof or to rent or other use, under contracts of more than nine years' duration. The buildings must be suitable for the function of university residence and managed directly by the proposers, or, after agreement with the proposers, by both public and private entities. In the case of purchase, the costs incurred for the execution of the works after the purchase are eligible for co-financing, but no redevelopment is allowed.

In coherence with the incentive mechanism activated by the PNRR, two scenarios are hypothesized in the present work: the first, called "Business As Usual" (BAU) provides for the resolution of the previous problem of operational research; the second scenario, called "Project", provides for the identification of the functional mix capable of maximizing the operator's profit while maintaining unchanged the fee defined in the BAU scenario, providing for a financing of 75% of the rent and adding the previously described constraint to ensure the predominance of the student function over the tourist-receptive one.

The application of the algorithm to maximize the profit of the manager highlights - in the case of the BAU scenario - the achievement of the maximum profit in the event that all the rooms are used as a mixed function, i.e. hotel use from 15 June to 15 September and use of student accommodation in the remaining period of the year (Eq. 1):

$$MAX\,(U_{BAU}) \Rightarrow \begin{cases} T_{1,3} = 8 \\ T_{2,3} = 28 \\ T_{3,3} = 4 \end{cases} \tag{1}$$

The application in the case of the project scenario leads to the achievement of the maximum profit in the case of a fair distribution of rooms compared to the 4 functions provided. This means that 25% of the rooms (2 single, 7 double and 1 mini-room) are used for student accommodation at market rate, another 25% for student accommodation at discounted rate, 25% exclusively for tourist accommodation and the last 25% for mixed use, that is in the period of high season for hotel use and the rest of the year for student use (Eq. 2):

$$MAX\left(U_{project}\right) \Rightarrow j = 1,2,3,4 \begin{cases} T_{1,j} = 2 \\ T_{2,j} = 7 \\ T_{3,j} = 1 \end{cases} \tag{2}$$

Analyzing the performances associated to the two different scenarios we can observe that (Table 3): *(i)* the profit of the manager in the two cases is comparable; *(ii)* in the scenario of "Project" there is an increase of the ratio profit/ revenues and *(iii)* there are interesting performance for the ratio revenues/ costs regarding the scenario BAU.

This result not only guarantees in the Project scenario a greater promotion of hospitality for deserving students and deprived of other means but allows a minimization of the risk associated with management guaranteed by the presence of a high differentiation of functions throughout the year. On the other hand, in the Project scenario there is an increase in complexity in the management of the structure and this strongly constrains the performance associated with the management model to the financing guaranteed by the PNRR (equal to 75% of the management fee).

Table 3. Comparison between the main performance indicators

Performance indicator	BAU scenario	Project scenario	Comment
Profit	202,000 €	215,000 €	+6.4%
Profit / Revenues	31%	46%	+48.4%
Revenues / Costs	2.3	2.8	+22.0%

6 Conclusions

In recent years there has been an increase in the attention of investors in the student housing sector thanks to the low risk of investing in this asset class, guaranteed by low arrears and high occupancy, and the presence of incentives allocated through the PNRR.

However, the growth of the costs associated with the management of these facilities and the impossibility of reversing these increases on users, given the need to contain room rates, especially in less attractive cities, has seen the compression of the operator's profit. This has triggered the birth of new business models aimed at maximizing the profits of the manager by opening these facilities to users other than students, both enhancing the spaces such as conference rooms, and promoting a mixed management student-hotel.

Based on these considerations, a management model of these structures, of the student-hotel type, has been proposed in the present paper, in order to determine the maximum profit of the manager to vary the alternative functions. In this way, by applying the principles of operational research, it was possible to compare the results derived from two scenarios, respectively "Business as Usual" and "Project". The comparison and the analysis of the obtained results allowed to show that in both the scenarios the profit of the manager is similar, while the ratio between profit and revenues and revenues and costs is better in the Project scenario. This means that not only in the Project scenario a greater promotion of hospitality for deserving students is guaranteed, but this allowed a minimization of the associated risk with a high differentiation of intended functions.

The future development of the present work consists in the application of a sensitivity analysis [30–33] in order to determine the evolution of the operator's profit as functions change and the application to different case studies. Furthermore, the integration of risk considerations related to the two scenarios and the proposed model could be useful for further research.

Note.
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Impacts of Urban Decay on the Residential Property Market: An Application to the City of Rome (Italy)

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Abstract. Urban decay is a complex phenomenon that encompasses physical deterioration, environmental degradation, and social disintegration that negatively affects the livability, safety, and economic vitality of urban areas, leading to demographic displacements, disinvestments and significant repercussions on housing dynamics. This study aims to develop a regression methodological approach to determine the effects of urban decay factors on the residential real estate market in Rome (Italy). The methodology involves the collection of a set of variables to describe and interpret the effects of urban decay on property values, followed by the application of Weighted Least Squares (WLS) regression to assess the marginal prices of these identified variables. The use of WLS allows to take into account the problem of heteroscedasticity in the evaluation process, ensuring its robustness. The proposed methodology is adaptable to different spatial contexts and provides valuable decision support for stakeholders involved in urban regeneration initiatives aimed at revitalizing decayed areas.

Keywords: Urban decay · property market · property values · Weighted Least Squares regression · regression analysis

1 Introduction

Urban decay represents a significant challenge for many cities; it is a complex, multifactorial process which consists of the deterioration of physical, social and economic aspects of urban spaces [1]. This phenomenon is characterized by a convergence of interrelated factors of different nature [2]. For example, from a physical perspective, decay is manifested through abandoned or poorly maintained buildings, dilapidated roads and/or infrastructure, and the presence of disamenities, such as graffiti, litter, and all the elements that contribute to an inhospitable urban environment [3].

With reference to environmental issues, the presence of degraded or abandoned buildings contributes to the problem of land consumption. These buildings, in fact, no longer

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accomplish the original purpose for which they were designed, are not used efficiently, and occupy parts of the natural soil in urban areas. Moreover, their presence intensifies the heat island effect through the prevalence of impermeable surfaces like asphalt and concrete. Furthermore, these buildings can exacerbate environmental pollution due to their frequent construction with outdated materials and technologies, such as asbestos, which pose significant environmental hazards [4].

In particular, this condition is often associated with negative impacts on various aspects of urban livability and quality of life [5]. The phenomenon of urban decay is closely linked to different choices that the population makes regarding the best place to live: if the neighborhood conditions become less attractive, a change in demographic composition can occur. Some inhabitants can decide to leave the decaying neighborhoods and move to areas with a higher urban quality level, and this can be associated with a replacement of individuals who cannot access to high quality housing and neighborhood infrastructures [6]. Moreover, urban decay is often considered a catalyst for crime and violence spread in the most affected areas. This, in turn, compromises the safety of the inhabitants and encourages their displacement from these areas [7].

From an economic point of view, urban decay can significantly affect real estate investment decisions and, in general, the economic dynamism of each affected area and the entire city. It, in fact, can discourage private investors from the activation of redevelopment interventions in such areas, due to the perceived higher risks associated with them [8]. This generates a boost in the deterioration level and, in particular, also an increase in different types of obsolescence (functional, structural, environmental, etc.) [9].

These aspects do not only negatively affect the level of attractiveness [10]. The decline in the quality of services and the migration flows of residents associated with the deterioration of the urban environment contribute to a variation in housing demand, with a reduction in property values [11]. Regarding the relationship between urban decay and property values, Breger [12], one of the first Authors to study the causes of urban decay, defines it as a "*critical stage in the functional or social depreciation of real property beyond which its existing condition or use is unacceptable to the community*". Property values are defined according to the specific features of the asset and those that characterize the surrounding context, in terms of available services, quality of urban and green spaces, provision of public infrastructure, etc. Therefore, if an urban area is affected by urban decay issues, a negative impact on the real estate market can be observed [4].

Determining the impact of urban decay on property values can be an important support for public and private subjects involved in the planning of urban redevelopment strategies in those areas that are affected by this phenomenon.

In the field of sustainable urban development policies - supported by initiatives such as the New European Bauhaus [13] and the 2030 Agenda [14] - the recovery of existing resources and the reduction of natural soil consumption, as well as the activation of strategies to regenerate degraded and abandoned areas in cities are extremely necessary [15]. In this context, the issues related to urban regeneration initiatives emphasize the need for a comprehensive and inclusive approach involving different stakeholders such as investors, urban planners, policymakers, and community at large [16, 17]. These

stakeholders have often conflicting multidimensional interests, and they should work together in order to address the challenges associated with such initiatives [18]. The analysis of the existing relationships between urban decay and the real estate market plays an essential role, as it provides relevant decision support for stakeholders involved in the investment and urban development initiatives.

2 Aim

The present research is part of the outlined framework. The work's aim concerns the definition of a regressive methodological approach for the determination of the effects of urban decay's factors on the housing market quotations. The aim is pursued through a structured approach that consists of the following phases: (i) identification of the explanatory variables' set; (ii) data collection and correlation analysis; (iii) regression analysis; (iv) results discussion (see Fig. 1).

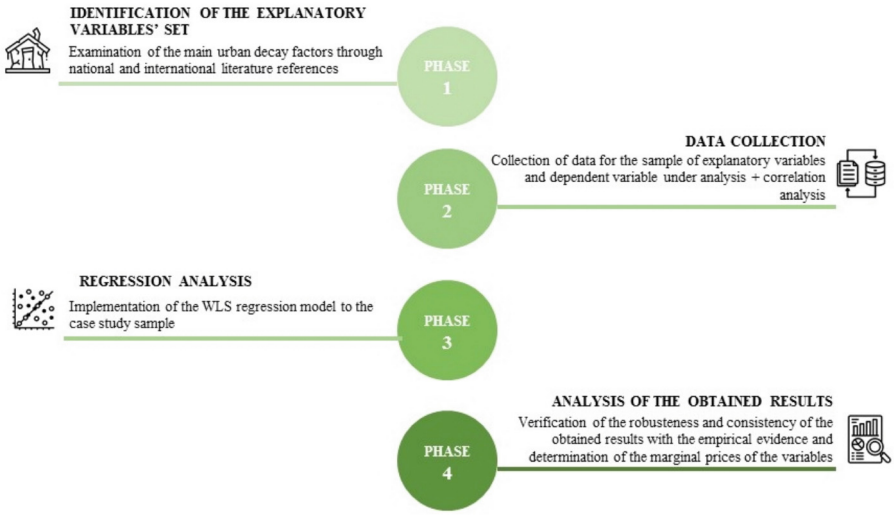

Fig. 1. The phases of the proposed evaluation methodology

The proposed methodological approach is applied to the city of Rome (Italy) with reference to the residential sector. In particular, 117 trade areas identified by the Real Estate Market Observatory (REMO) of the Italian Revenue Agency are considered.

The remainder of the research is structured as follows: Sect. 3 consists of an overview of regression models application for the real estate market analysis; Sect. 4 describes each phase of the proposed methodology; Sect. 5 discusses the obtained results for investigating the coherence with the empirical evidence; Sect. 6 provides for the conclusions of the work and the future developments.

3 Background

In the field of the real estate market study, the formation mechanisms of property prices are widely analyzed through the development and definition of several assessment models.

The Hedonic Price Method (HPM) is an approach widely used in the literature to evaluate the impact of various externalities on property values. In fact, this method makes it possible to determine the effects of the attributes of a property that are not directly measurable [19]. Typically, HPM uses regression models to identify the existing functional relationships between a dependent variable – generally the property price - and one or more independent variables. In this way, the value of the dependent variable can be assessed based on the values of the other ones [20]. In order to implement the HPM, several kinds of regression analysis can be used: parametric, nonparametric, and semi-parametric models [21].

Parametric models provide that the regression curve has a predetermined functional form described by a finite set of parameters represented by the coefficients of the independent variables. Among parametric models, Ordinary Least Square (OLS) is commonly used to identify the optimal line through a set of data points. The goal is to minimize the sum of squares of the residual errors, which are the differences between the observed and estimated values. This process allows to determine the coefficients of the line that best fit the collected data [22]. One of the main assumptions of OLS is the existence of homoscedasticity, where errors have a constant variance. Violation of this assumption, resulting in a variable variance of the errors, leads to the condition of heteroscedasticity [23]. This condition can lead to changes in both the estimated standard errors of the coefficients and the value of the coefficients. With this regard, an alternative parametric model known as Weighted Least Squares (WLS) can be implemented to solve the heteroscedasticity problem of regression analysis. WLS assigns different weights to each observation, proportional to the inverse of the variance. As a result, observations with higher estimated variances receive lower weights and vice versa. In this way, the model accounts for heteroscedasticity in the data during the parameter estimation process [24].

Unlike parametric models, the non-parametric ones do not predefine the form of the regression function that relates the dependent variable with the independent variables. Consequently, such models allow the use of flexible functions that can capture more complex and nonlinear relationships between the observed variables [25]. Non-parametric models are particularly useful when the data are not suitable for applying the parametric ones and when the relationship between the variables is not immediately identifiable. Among these ones, one of the applicable methods for the study of real estate values is Kernel estimation, which allows the value of the dependent variable at a point to be estimated based on nearby observations, giving greater weight to the variables closest to the one of interest in a fixed surround. Another non-parametric model is the Nearest Neighbor method, which differs from Kernel estimation by the presence of a variable size surround.

Semi-parametric models represent a balance by combining the ease of interpretation of results characteristic of parametric models with the flexibility offered by nonparametric models. For example, one of the simplest semi-parametric estimators to compute and

visualize is the Generalized Additive Model (GAM) which is constructed by combining generalized linear models with smooth function of independent variables. [26].

In the outlined regression analysis framework, the parametric approach emerges as the most applied model for real estate research issues. A notable example of its application is evident in the work of Chwiałkowski et al. [27], where the WLS method is used to assess the impact of the proximity of Wielkopolski National Park on real estate values in Mosina (Poland) revealing a positive influence. In another work, the same Authors [28], use both OLS and WLS to examine the effects of urban public transport on residential property prices in Poznan (Poland), reporting a higher accuracy of WLS than OLS. In another study on the city of Poznan, Trojanek et al. [29] investigate the impact of air noise on house prices. In this study, the Authors define an integrated regression model that consists not only of the application of OLS and WLS but also the inclusion of Spatial Autoregressive (SAR) and Spatial Error (SEM) models. The incorporation of SAR and SEM aims to improve the efficiency of the assessment by considering the spatial dependency of variables. In a study aimed at understanding the effects of urban green spaces on residential prices in Warsaw, Trojanek et al. [30] employ a diverse set of models, including OLS, WLS, and the Median Quantum Regression (MQR) model. This methodological comparison is chosen to ensure the robustness and reliability of the results. Some studies, by addressing issues of heteroscedasticity, such as those of Teck Hong [31] and Tse and Love [32], use, in addition to WLS, a heteroscedasticity consistent covariance matrix estimator. This further step is implemented to accurately estimate the coefficients of various attributes on house prices.

4 Methodology

4.1 WLS Regression Model

In order to study the effects of the urban decay factors on the residential real estate market of the city of Rome, a WLS regression model is developed. It is a generalization of OLS and linear regression in which knowledge of the unequal variance of the observations (heteroscedasticity) is computed into the regression. The WLS regression model reduces the heteroscedasticity problems in order to accurately assess the phenomenon to be analyzed. The main difference with OLS is the assumption of having different weights for different observations. In particular, those observations for which a greater error variance is observed correspond to lower weights.

4.2 Phase 1. Identification of the Explanatory Variables ‘Set

The phenomenon of urban decay is extremely relevant in the field of urban planning practices and real estate market analysis. In particular, it can be described as the main consequence that occurs when the balance between all the factors that characterize a specific urban area, in terms of social status, economic conditions, and environmental quality, significantly changes by providing for an in-depth transformation of the context.

The real estate market reflects all the urban transformations, both physical, demographic, and economic, easily explainable by the fact that property price is a function

of intrinsic (property-related) and extrinsic (context-related) features. The study of real estate values, therefore, can be useful for capturing the transformations taking place in the urban context, including those related to the urban decay phenomena. In order to highlight and determine the prices' effects of urban decay-related factors in the city of Rome (Italy), in the present work the dependent variable (Y) is the unit residential quotation (€/m^2) provided by the REMO for the first semester of 2023.

For the identification of the explanatory variables' set, the national and international literature of the field has been examined and, according to the obtained results, the chosen set of explanatory variables is composed of quantitative factors capable of adequately representing the social, economic, and environmental level of the 117 considered REMO areas. In particular, a set of 6 explanatory variables, adequately balanced, and capable of enucleating the main peculiarities of the urban decay phenomenon is identified. It is possible to classify them into two categories: (i) socio-economic and environmental variables and (ii) urban decay variables. The first category represents the main socio-economic and environmental features that characterize the REMO zones context, instead, the second one pertains to the enucleation of the most relevant Urban Decay factors of the zone, according to the specific case study and the literature review carried out. The 6 explanatory variables are following described:

Socio-economic and Environmental Variables

1. Residential Population (P): it consists of the number of individuals living in the i-th REMO zone according to the latest update of the population census provided by ISTAT in 2011;
2. Per-capita income (R): it is defined as the quantity of gross domestic product hypothetically produced, in a certain period of time, by a person of the i-th REMO zone. It is calculated in units of euros for one year and updated in 2021, as provided by the Urbistat Geosoftware;
3. Surface of the urban green park (V): it represents the km^2 of the territorial surface of the green parks for the city of Rome which falls within the perimeter of the i-th REMO zone (source: https://download.geofabrik.de/europe/italy.html)

Urban Decay's Variables

1. Surface of the degraded urban area (A): it represents the km^2 of territorial surface of those census sections for which the Index of Social Disease and the Index of Construction Disease, calculated by the Italian National Statistical Institute (ISTAT) for the purposes of the "Call for the submission of proposals for the preparation of the national plan for the social and cultural redevelopment of degraded urban areas (DPCM 21 October 2015)", is > 1;
2. Index of Social Disease (D): it results from the weighted average of the deviations of the values of the following indicators, referring to the semester preceding that of the survey, from the respective national average values, detected by the ISTAT census: Unemployment rate, Employment rate, Youth concentration rate, Education rate. The formula used for the calculation is the following:

$$D = 0.40 * (DIS - DISNAZ) + 0.30 * (OCCNAZ - OCC) + 0.15 * (GIOV - GIOVNAZ) + 0.15 * (SCOLNAZ - SCOL)$$

Where:

DIS = Unemployment rate; OCC = Occupancy rate; GIOV = Youth concentration rate; SCOL = Education rate; DISNAZ = National Unemployment rate; OCCNAZ = National occupancy rate; GIOVNAZ = National Youth concentration rate; SCOLNAZ = National Education rate

3. Index of Construction disease (De): compares the state of conservation of buildings in the degraded urban area with the national average value according to the following formula:

$$De = [(ERp + ERm)/TotER]/0.168$$

Where: ERp = Residential Buildings in the degraded urban area in a very bad state of conservation; ERm = Residential Buildings in the degraded urban area in a mediocre state of conservation; Tot ER = Total residential buildings in the degraded urban area; The weighting coefficient corresponds to the national percentage of residential buildings with a "very bad" or "mediocre" state of conservation.

As it is possible to see, an attempt has been made to structure a database that is balanced against factors explicitly focused on issues of urban degradation and factors involved in the definition of the phenomenon, from other points of view.

4.3 Phase 2. Data Collection and Correlation Analysis

The WLS regression model is applied to a sample that refers to the sub-municipal territorial subdivision of the city of Rome (Italy) provided by REMO. In particular, 117 are of interest in this research because no data on the presence of an offer for the residential real estate market were found in the other areas, therefore they could not be considered in this analysis.

For each of the considered REMO zones, the collection of data related to the 6 chosen explanatory variables and the dependent one is carried out. The descriptive statistics of the variables are reported in Table 1.

Table 1. Main statistical features of the sample of variables

	Average	Standard deviation	Min	Max	Variance
Y	2,610.68	1,066.48	1,125	1,125	1,137,374.10
P	17,970.78	14,352.58	536	79,837	205,996,493.7
R	20,251.70	7,526.26	8,837	57,571	56,644,578.42
V	0.26	0.52	0	3.51	0.27
A	0.54	1.11	0.001	6.23	1.22
D	7.32	6.04	1.06	40.41	36.46
De	3.23	1.55	1.12	5.95	2.42

Once the dataset has been completed, in order to identify the phenomena of the high correlation of the variables considered which may affect the robustness of the results of

the regression analysis of the subsequent steps of the proposed methodology, the Pearson coefficient is calculated. The correlation matrix obtained is shown in Table 2.

Table 2. Pearson correlation matrix

	Y	*A*	*D*	*De*	*P*	*R*	*V*
Y	1						
A	–0.2745	1					
D	–0.0690	0.0647	1				
De	0.1433	0.0906	0.2875	1			
P	0.0860	–0.1103	–0.0637	–0.0526	1		
R	0.9282	–0.1831	0.0023	0.1815	0.0268	1	
V	0.0982	–0.1436	–0.0492	–0.0127	0.1867	0.04847	1

As can be seen by the correlation results, the variables A and D are the unique ones that have negative signs with reference to the dependent variable Y. Other negative correlation relationships are observed between the variables P with D (–0.0637) and De (–0.0526), R with the variable A (–0.1831) and the variable V with A (–0.1436) and De (–0.0127). The highest level of correlation is found for the explanatory variable of the per-capita income (R) and the dependent variable (Y) of the unit residential quotation - equal to 0.9282 with a positive sign. The latter highlights the significance of the per-capita income in the explanation of the real estate values formation in the considered sample, as also attested by the literature of the field. It appears to be consistent also with the empirical evidence.

The correlation analysis shows a very low degree of interdependence of the set of chosen variables.

4.4 Phase 3. Regression Analysis

The implementation of the WLS regression model to the case study sample shows interesting statistical performance. Its application has generated a model characterized by high statistical efficiency with an R2 equal to 0.986 (corrected determination index equal to 0.986), as reported in Table 3:

Table 3. Results of the regression analysis

Variable	Coefficient	Standard error	T student	P-value
R	7294.91	72.6441	100.420	<0.00001***
V	209.655	46.2954	4.529	0.00002***

(*continued*)

Table 3. (*continued*)

Variable	Coefficient	Standard error	T student	P-value
P	255.888	73.1573	3.498	0.00068***
A	– 434.972	168.347	–2.584	0.01107**
D	–298.193	145.871	–2.044	0.04330**
De	85.3217	53.5852	1.592	0.11417

Note: *** is for $p < 0.01$, ** is for $p < 0.05$

The implemented regression is robust because the model has strong fitness measures, indicating that a suitable set of both socio-economic and environmental variables and urban decay variables has been constructed.

As it is possible to observe from Table 3, all 6 explanatory variables are statistically significant in the regression analysis. In particular, by observing the obtained p-values, it is maximum for the per-capita income variable (R) and the minimum for the index of construction disease (De). The absence of the constant term in the regression equation could be explained by observing the significance of the variable R: it means that R is the most influencing explanatory variable on the residential real estate market of the considered sample, so as to explain almost completely the phenomenon of real estate price formation. It is consistent with the empirical evidence and the reference literature in the field: income level is, in fact, considered a fundamental determinant of real estate housing prices [33, 34]. For the index of construction disease (De), the results may differ from those expected, but it should be noted that the difference, in numerical terms, with the p-value thresholds (0.10) for the eligibility of the variables in the explanation of the phenomenon under examination is minimal (0.01417). The explanatory variable De, therefore, although it is the least significant one among those considered, in absolute terms, still appears relevant in the process of formation of the real estate values of the sample in question.

The F test is always significant. The dispersion graph of the standardized residual shows that the hypothesis of homoscedasticity is not violated. The hypothesis of a normal distribution of errors is also tested. The percentage average between the detected values of the dependent variable (Y) and the estimated ones predicted by the model is about 5%. The multicollinearity coefficients (VIF) are all < 10, as following reported: $R = 5.094$; $V = 1.315$; $P = 2.368$; $A = 1.251$; $D = 2.596$; $De = 5.453$.

4.5 Phase 4. Results Discussion

Among the 6 explanatory variables, for two of them a negative coefficient is detected (Table 4). The surface of the urban degraded area (A) has an inverse functional relationship (–434.972) with the dependent variable (Y). It means that if the territorial extension of it increases, the unit residential quotation decreases. In particular, for each unit increase of the explanatory variable A, specifically equal to 6 km^2, the unit residential quotation respectively decreases by about 435 €/m^2 and vice versa, that is the marginal price of this variable. Similar comments can be made for the variable representing the

Table 4. Coefficients and significance of the variables

Variable	Coefficient	Sign
R	7294.91	***
V	209.655	***
P	255.888	***
A	– 434.972	**
D	–298.193	**
De	85.3217	n.a.

social disease (D): an inverse functional relationship with the unit residential quotation is detected, therefore, if a unit increase - equal to 40 - of the index value occurs in the i-th REMO zone, the dependent variable decreases of about 299 €/m^2 and vice versa, or the obtained marginal price of this explanatory variable (D).

For the explanatory variable that expresses the surface of the urban green parks (V) a positive functional relationship between it and the unit residential quotation (Y) is observed. In particular, if the green surface increases by 4 km^2 – unit growth – the residential quotation also increases by about 210 €/m^2 and vice versa, as the marginal price of the urban green park's surface. Also, for the number of residential population, a positive functional relationship with the housing quotations is found. Specifically, a unit increase – equal to about 80,000 residents – corresponds to a unit growth of the residential quotations equal to 256 €/m^2 and vice versa. For the most significant explanatory variable (R), the obtained positive functional relationship highlights that if the per-capita income varies through, for example, a unit equal to 57,500 €/year, the residential quotations vary too of 7,300 €/m^2.

5 Conclusions

The existence of abandoned or poorly maintained properties, often with overgrowth and disorder diseases of different kinds – from social to economic and environmental - is a complex and important real estate issue [35]. Breger [12] describes urban decay as a critical factor in the functional or social depreciation of a real estate property. For these reasons, the importance of analyzing urban decay's effects on property prices is widely recognized.

The aim of the work has regarded the definition of a regressive methodological approach for the determination of the effects of urban decay factors on the residential real estate market of the city of Rome (Italy). A structured approach has been proposed, articulated as follows: (i) identification of the explanatory variables' set; (ii) data collection and correlation analysis; (iii) application of the WLS regression to the case study; iv) analysis of the obtained results. A balanced set of explanatory variables that are able to express the wide effects on the property values of the urban decay phenomenon has been made. The implementation of the WLS regression has allowed to find interesting

results for the marginal prices of the detected variables. In particular, for the study sample, among the analyzed urban decay factors, the surface of the urban degraded area and the level of the social disease are the most influencing variables on the property values, in negative terms. In particular, a unit decrease of both variables is able to reduce the property quotations by about 367 €/m^2. Instead, with regard to the socio-economic and environmental conditions in the surrounding context of the study sample, the per-capita income has been able to increase the unit quotation of about 7,300 €/m^2, the extension of the urban green park of about 210 €/m^2 and the population residents of about 256 €/m^2. All of these variables affect, through a positive functional relationship, the residential quotations of the study sample of the city of Rome (Italy).

The proposed methodological approach has allowed to highlight in a clear and transparent way the effects of the main urban decay-related factors on the residential real estate market. Heteroscedasticity problems have been considered in order to provide for an efficient and robust regressive approach. The model's applicability to different spatial contexts and housing markets allows it to consider variables of general relevance to urban decay, going beyond the specifics of each case study. This flexibility allows for a comprehensive characterization of the effects of urban decay and their impact on marginal prices in different contexts. It can be useful for the identification of the most critical urban areas for defining adequate strategies that can improve urban livability.

Future insights can regard the examination of a different set of explanatory variables that can be able to take into account other urban decay-related issues, by also comparing the results with the ones that can be obtained through the implementation of other econometric analysis and regression techniques. Among the additional variables to be considered in future developments, elementary indicators derived from the disaggregation of the indices used in this study (D and De) could be included, allowing for more accurate capture of detailed characteristics.

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An Analysis of the Airbnb Market: A Detailed Look at Four Italian Cities

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Abstract. The Sharing Economy, or the economy of sharing, is an economic phenomenon that has rapidly spread in recent years, transforming the ways in which resources and services are accessed and consumed. This phenomenon has had a significant impact on consumption dynamics, redefining the concept of ownership and promoting the idea of temporary and shared access to goods. An emblematic example is represented by Airbnb, a multinational company founded in 2008 and valued at 35 billion dollars. With over 4 million hosts and 800 million guests in more than 220 countries and regions, Airbnb offers communities the opportunity to make the most of their cultural and scenic heritage, attracting a variety of visitors eager for authentic experiences. In this regard, the present study proposes a methodological model capable of empirically analyzing the Airbnb market in four Italian cities, adopting an integrated approach that combines Principal Component Analysis (PCA) and clustering based on the use of the k-means algorithm, to arrive at a deeper understanding of the data. The results emerging from the research highlight a significantly negative correlation between price and distance from the city center, also revealing a negative correlation between reviews and price, as well as between reviews and distance from the city center. Through the analysis of the research results, it aims to make a relevant contribution to academic literature, providing new perspectives and insights for further studies on Airbnb dynamics, as well as on the economic and social implications of resource and service sharing in the context of the Sharing Economy.

Keywords: Airbnb · Real Estate Market · Short-Term Rent

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1 Introduction

In the last decade, the Sharing Economy has gained increasing relevance as a social and economic phenomenon, generating a significant impact on consumption dynamics and shaping the contemporary economic landscape [1]. This innovative economic model, based on the sharing of resources, goods, and services among individuals through digital platforms, has exerted a remarkable influence in various economic sectors. Services such as carpooling with BlaBlaCar, household task management through TaskRabbit, culinary experiences offered by EatWith, pet hospitality with DogVacay, bicycle and sports equipment rental through Spinlister, along with platforms like Uber for private transportation and Airbnb for accommodation, have all contributed to shaping this new mode of sharing and economic collaboration. The Sharing Economy, or the economy of sharing, can be defined as an economic model in which individuals or businesses share access to resources, goods, or services through digital platforms, either for free or for a fee. This approach fosters collaboration among individuals, enabling them to mutually benefit from underutilized resources or offer services directly to peers, often bypassing traditional intermediaries such as companies or organizations [2]. An emblematic example of the sharing economy is represented by Airbnb, one of the leading online accommodation rental platforms worldwide. Three visionary young entrepreneurs, Brian Chesky, Joe Gebbia, and Nathan Blecharczyk, in the vibrant context of San Francisco in 2008, gave life to Airbnb, a company that would revolutionize the way we think about hospitality and travel globally within a few years. The founders of Airbnb had an ambitious goal: to create an authentic travel experience that would allow people to connect with local culture and have unique experiences, going beyond the traditional patterns of the hotel industry. Airbnb offers hosts, who are the owners of the accommodations, the opportunity to make available one or more rooms, an entire apartment, or even just a shared room [3]. The platform's success has been fueled by the growing demand for personalized accommodation solutions from travelers, different from standardized hotel accommodations. The vast differentiation of offerings allows visitors to choose, in line with their tastes, needs, and preferences, from a wide range of options such as designer apartments, rustic countryside houses, or local residences.

Over the years, Airbnb has continued to grow exponentially, expanding globally and establishing itself as a reference point in the home-sharing industry. Just consider that as of 2023, Airbnb had 5 million accommodation listings worldwide, in 191 countries.

The platform has had a significant impact on the global economy, offering new income opportunities to hosts and allowing travelers to discover unique and authentic destinations. Today, Airbnb represents much more than just an online booking platform. It has become a cultural phenomenon and a symbol of global sharing and hospitality. Almost all major urban centers are now affected by the phenomenon, offering advantages for both hosts and guests. For hosts, renting a room or an entire property through Airbnb represents an opportunity to earn extra income by leveraging their real estate resources [4]. For guests, Airbnb offers a flexible and often more affordable alternative to traditional hotels. However, there are also critical aspects of the phenomenon. One of the main disadvantages is the potential unfair competition against traditional accommodation facilities, which must comply with specific regulations and standards regarding safety, taxation, and service quality [5, 6]. Moreover, the Airbnb phenomenon

can lead to an increase in long-term rental prices and gentrification in certain areas, with a negative impact on the social fabric of local communities [7, 8]. This study aims to empirically examine the Airbnb phenomenon in four Italian cities: Rome, Milan, Naples, and Bologna, over the course of a single year, using a dataset consisting of 62.810 property listings. The conducted analysis, along with a review of the growing literature on the sharing economy, contributes to understanding the functioning of the tourist accommodation sector. Specifically, it provides an interpretive framework of the Airbnb market in the four Italian cities under study, using the combined application of Principal Component Analysis (PCA) and K-means clustering. The work is organized as follows. The second section presents a review of case studies from the literature regarding the expansion of Airbnb and its impact on various sectors of society. The third section illustrates the case study, defining the areas under examination, the data, the applied methodology, and a summary of the results. Finally, the fourth section draws the conclusions of the study and outlines possible future developments.

2 Literature Review

The expansion of Airbnb has generated significant implications in the tourism industry and the practice of home sharing, triggering a series of complex dynamics that have permeated various spheres of society, sparking widespread academic interest. Numerous studies have been undertaken to examine the different facets of this phenomenon, analyzing how Airbnb impacts the economy, the real estate market, the environment, the social cohesion of local communities, and the visitor experience. Each of these facets represents a specific perspective that contributes to a deeper understanding of the overall effects of Airbnb on various aspects of society and the economy. Oskam & Boswijk (2016) consider Airbnb as a tool for optimizing real estate resources [9]. This innovative home-sharing model presents itself as a potential source of additional income for property owners. Many owners have found that making their homes available on Airbnb can be a true "gold mine." The platform offers them the opportunity to make the most of their properties by generating income through sharing available spaces. For owners who have a second home or vacant rooms in their residences, Airbnb provides a convenient way to monetize otherwise unused spaces. This represents an advantageous opportunity to generate additional revenue, which can be used to cover property management expenses such as utilities or mortgage payments [10]. In addition to the possibility of generating extra income by allowing property owners to monetize their properties more flexibly, Airbnb gives owners greater control over the management of their assets. They are able to determine rates, choose when to make their homes available, and engage in direct communication with guests. This level of control holds considerable appeal for those who wish to personally oversee their short-term rental activity [11]. This is particularly effective in places where tourism represents a significant source of income. Airbnb offers communities the opportunity to make the most of their cultural and scenic heritage, attracting a variety of visitors seeking authentic experiences. The unique and authentic properties, often offered by local residents, constitute a strength that sets Airbnb apart from traditional models of accommodation [4]. Airbnbs often have more affordable prices compared to hotels and offer a more intimate experience, along with household

amenities that are not available in hospitality establishments. These factors can attract a significant portion of the clientele that traditionally chose hotels [5]. This comparison between hospitality establishments and Airbnb reflects the complexity of a constantly changing market. While Airbnb offers new economic opportunities for property owners, traditional hotels must face the challenge of adapting to an evolving market, seeking to differentiate themselves and offer experiences that meet the changing expectations of modern travelers. According to studies conducted by Zervas, Proserpio, and Byers [6], Airbnb's entry into the Texas market had a negative impact on the hotel industry, revealing that a 1% increase in Airbnb listings resulted in a 0.05% reduction in quarterly hotel revenues. Other authors [12], using a large dataset comprising 28 cities in the United States, have highlighted that a 1% increase in hotel room rates led to a 1.397% increase in the availability of accommodations on Airbnb. This demonstrates the close substitutability relationship between the two markets, even though the services offered by Airbnb differ significantly from those of the hotel industry, targeting distinct customer segments [13]. Scholars describe users of traditional hospitality establishments as a particularly demanding category of consumers with high expectations for the services offered. Tussyadiah (2015), while acknowledging that Airbnb has lower costs compared to traditional hospitality establishments, shows that Airbnb guests are typically highly educated individuals characterized by frequent travel and a propensity for choosing less conventional accommodation solutions [14]. This suggests a user profile that, in addition to being cost-conscious, is motivated by an interest in more authentic and personalized travel experiences. Guttentag et al. (2018) and Adamiak et al. (2019) conducted in-depth investigations into the motivations that drive travelers to prefer Airbnb, highlighting the importance of experience authenticity, value for money, and the opportunity to interact with the local community [4, 11]. These elements have not only shaped travelers' preferences but have also significantly influenced market dynamics, amplifying the change in consumer perspectives regarding traditional accommodations such as hotels. On one hand, the advent of Airbnb has represented a promising source of income for many property owners. However, it has also triggered an increase in rental costs and consequently a reduction in the availability of long-term accommodations [15]. Many property owners prefer short-term rentals, renting out their units on platforms like Airbnb and generating significant profits, rather than opting for traditional long-term leases. This inevitably reduces the supply of long-term accommodations in the market, leading to an increase in remaining rental prices [7]. Furthermore, the opportunity to generate additional profits may drive individuals to invest in real estate and acquire new properties for the short-term rental market. The awareness that investors can generate extra income by converting their properties into Airbnb accommodations often leads them to purchase new properties at a higher price than their actual value. They are willing to invest further in property acquisition, seeing the potential that comes from short-term rentals [16]. An analysis conducted by Lee (2016) examined the influence of Airbnb on the real estate sector, highlighting how Airbnb's expansion can contribute to rental price increases and a reduction in the availability of affordable housing [7]. Similarly, Barron, Kung, and Proserpio (2017) analyzed the impact of Airbnb activities on property values and lease contracts. Their findings revealed that a 10% increase in commercial transactions associated with Airbnb listings resulted in a 0.39% increase in long-term rental prices and a

0.64% increase in housing prices [17]. In France, a study by Ayouba K et al. (2019) in eight cities highlighted that the increasing number of Airbnb listings for tourism purposes exerts upward pressure on the long-term rental market in Lyon, Montpellier, and Paris, with respective percentage increases of 0.3851%, 0.3982%, and 0.5242% [18]. These phenomena, including rental price increases, pressure on the long-term rental market, reduced availability of affordable housing, and property value increases—all attributable to the intensification of Airbnb listings—contribute to distorting the real estate market through two interconnected mechanisms: conversion and gentrification.

Considering the opportunity for property owners to generate additional profits, there is an authentic process of conversion where dwellings that were previously intended for long-term rentals or residential use are now absorbed by the Airbnb market, representing units that are taken away from the residential rental market and primarily transferred to the tourism and hospitality sector [8]. This phenomenon is not limited to peripheral areas of cities but mainly occurs in historical centers and central neighborhoods, which are considered attractive for tourists or those seeking short-term accommodations. The conversion of residential units into Airbnb properties has caused a substantial increase in property values and long-term rental prices, gradually contributing to the so-called urban gentrification. This process is associated with the arrival of new residents with higher purchasing power, who progressively replace low-income groups or pre-existing historical communities. Due to rising prices, low-income residents are forced to move elsewhere, making room for new high-income inhabitants [19]. It is important to emphasize that financial aspects are not the sole determining factors in gentrification, as socio-cultural dynamics can also come into play. While the profits derived from sharing economy operations contribute to revitalizing the local economy, there is also a phenomenon of touristification closely related to gentrification [3]. Many historical centers are literally overwhelmed by tourist flows, causing a series of issues related to the inability of these neighborhoods to cope with such a situation. Research conducted by Jordan & Moore (2018) highlights the intricate relationships between residents and tourists. The significant increase in tourist flows in specific urban areas puts additional pressure on local communities. This phenomenon brings about a change in the demographic composition, with an increase in short-term tourist presence and a decrease in long-term resident population. A massive presence of visitors can compromise the quality of life for local residents, causing disturbances, excessive noise, overcrowding neighborhoods, and creating tensions between residents and visitors [20]. Moreover, the significant increase in visitor flow has a direct impact on the surrounding environment. While the sharing economy in the tourism sector offers a considerable opportunity to promote sustainability through the utilization of underutilized assets and the expansion of services without further constructions or acquisitions, thus reducing the sector's environmental impact, it is equally true that increased travel and the use of short-term accommodations can contribute to increased energy consumption and carbon emissions [21–25]. It is crucial to consider these dynamics in formulating appropriate policies and regulations to manage the impact of Airbnb on local communities. On the other hand, the growth of Airbnb has raised fundamental questions regarding the need for specific regulations concerning its governance. In order to counter the phenomenon of indiscriminate conversion, many countries and urban centers have adopted specific regulations aimed at addressing the

legal and financial aspects associated with the use of Airbnb. According to arguments put forward by Guttentag (2015), Schneiderman (2014), and Streitfeld (2014), a significant amount of short-term rentals operate illicitly in numerous cities, as hosts, those who provide properties on platforms like Airbnb, may not comply with the associated tax obligations [5, 26, 27]. Just a few months ago, it was reported that Airbnb in Italy was fined a massive amount for not paying taxes on nearly 4 billion euros in short-term rentals. In response to this issue, various countries and urban centers have introduced specific regulations to address the legal and tax-related issues associated with Airbnb [28]. Research conducted by Wachsmuth et al. (2018) examined the different regulations introduced to address the legal and tax-related issues associated with Airbnb, analyzing the impacts of these policies on the market and the community, and highlighting the complexity of regulation in a continuously evolving sector like Airbnb [19]. For example, Quattrone et al. (2016) focused their attention on the regulation of Airbnb in London, highlighting the lack of effective rules to adequately manage the phenomenon and proposing innovative policies based on in-depth analysis of spatial and economic patterns of housing supply and demand [1]. A similar approach was followed by Lee (2016), who, through the use of legal and statistical analysis, explored the impact of short-term rentals on the residential rental system in Los Angeles, offering suggestions on how local authorities and policymakers can adequately regulate the phenomenon [7]. The analyses developed on the Airbnb market in four major Italian cities and the obtained results show some peculiar aspects of the short-term rental market that differentiate it from other segments of the real estate market in relation to the specific needs of users.

3 Case Study

3.1 Research Areas

The cities under study, situated within the Italian urban context, are Rome, Milan, Naples, and Bologna. In 2023, Airbnb continued to consolidate its presence in Italy, becoming one of the most widely used accommodation rental platforms in the country. Data for that year shows a significant increase in the availability of accommodations on Airbnb in various Italian cities. In Rome, the number of listings registered on Airbnb exceeded 29.000, representing a notable increase compared to the approximately 12.000 listings in 2017. The Italian capital continues to be one of the preferred destinations for tourists, and Airbnb has contributed to meeting the demand for alternative accommodations. Milan has also experienced considerable growth in the availability of Airbnb listings. In 2023, the number of listings on the platform reached 24.936, representing an increase of about 10.000 listings compared to 2022. The city of Milan, renowned for its vibrant nightlife and its status as a financial center, has attracted an increasing number of tourists and business travelers. Naples and Bologna, albeit to a lesser extent than Rome and Milan, have also seen an increase in the availability of accommodations on Airbnb. Naples witnessed an increase from 7.175 to over 10.000 listings in 2023, while Bologna saw an increase from approximately 3.685 to over 4.700 listings during the same period [29]. These data confirm the important role that Airbnb has assumed in the Italian real estate market, offering a wide range of accommodation options for travelers.

3.2 Data Description

For our research, we used a dataset consisting of 62.810 listings of housing units published on the renowned Airbnb platform during 2020, pertaining to the cities of Rome, Milan, Naples, and Bologna. The data was collected through the Inside Airbnb website (http://insideairbnb.com/), a platform founded by Murray Cox with the aim of analyzing the Airbnb phenomenon and its impact on the real estate market and urban social fabric. The website provides access to raw data concerning property listings on Airbnb, allowing users to examine trends, supply patterns, and prices. By accessing the data, scholars, journalists, activists, and the general public can explore how Airbnb influences the rental market, gentrification, and much more. In order to ensure accurate, homogeneous, and meaningful analysis, some restrictions were applied to the collected data. Specifically, Airbnb listings with more than 4 bedrooms and 6 bathrooms were excluded, as properties of such large sizes could have significantly higher prices compared to the average, making them incomparable to more common accommodations and distorting the analysis results. Subsequently, listings with more than 15 reviews per month were removed, as they were considered extreme values or outliers. These listings potentially represent accommodations subject to aggressive marketing strategies, which may not be representative of the average Airbnb listings. Additionally, listings with prices exceeding 300 euros per night were excluded, as they represent luxury or highly exclusive accommodations. Following these preprocessing steps, the dataset included 23.956 listings for Rome, 15.019 for Milan, 5.792 for Naples, and 3.203 for Bologna.

To empirically examine the Airbnb market in the four Italian cities under study, the analysis focuses on four main variables: price, number of bedrooms, number of reviews per month, and distance from a reference point in the city center. These variables are considered crucial for analyzing the Airbnb market as they have the potential to influence the dynamics of short-term rentals. An exploratory data analysis of the available data is presented in Fig. 1. It should be noted that the number of reviews is a proxy variable for the employment rate.

3.3 Methods

The interpretative framework of the Airbnb market in the four Italian cities under investigation was empirically delineated using a combined approach of Principal Component Analysis (PCA) and cluster analysis based on the k-means algorithm.

Principal Component Analysis

Principal Component Analysis (PCA) is a technique used in the field of multivariate statistics to address complexity and redundancy in data, especially when dealing with datasets that have a considerable number of variables [30, 31]. The primary purpose of this model is to reduce the dimensionality of the dataset while preserving most of the information contained in the original data. Essentially, PCA examines and simplifies the data to understand the structure of the covariance matrix of a group of variables through a reduced set of linear combinations. The model is able to transform a set of correlated variables into a new set of uncorrelated variables, called principal components, which are arranged in such a way that the first component explains the maximum variance in

the data, the second component explains the maximum remaining variance, and so on. This is achieved through a linear transformation of the variables that projects the original variables onto a new Cartesian coordinate system, where the variables are arranged in descending order of variance.

Formally, given n observations of a set of features $X_1, \ldots, X_p$, the first principal component can be defined as the normalized linear combination of the original features as:

$$Z_1 = \phi_{11} X_1 + \cdots + \phi_{p1} X_p \tag{1}$$

where the vector $\phi_1 = (\phi_{11}, \ldots, \phi_{p1})^T$ is referred to as the principal component loading vector, and $\sum_{j=1}^{p} \phi_{j1}^2 = 1$ to ensure not to have an arbitrarily large variance. Hence, given an $n \times p$ dataset $\boldsymbol{X}$, and assuming the features to be centred to have zero mean, PCA search for the linear combination of the values as:

$$Z_{i1} = \phi_{11} X_{i1} + \cdots + \phi_{p1} X_{ip} \tag{2}$$

that has the largest variance under the constraint that $\sum_{j=1}^{p} \phi_{j1}^2 = 1$. The first principal component loading vector therefore results from the optimization:

$$\underset{\phi_{11}, \ldots, X_{ip}}{maximize} \left\{ \frac{1}{n} \sum\nolimits_{i=1}^{n} \left(\sum\nolimits_{j=1}^{p} \phi_{j1} x_{ij} \right)^2 \right\} subject\ to \sum\nolimits_{j=1}^{p} \phi_{j1}^2 = 1 \tag{3}$$

Notice that one can write $\frac{1}{n} \sum_{i=n}^{n} z_{i1}^2$, and that since $\frac{1}{n} \sum_{i=n}^{n} x_{ij} = 0$, the average of $z_{11}, \ldots, z_{n1}$, which are usually called as the scores of the principal component, will also be 0. Therefore, the objective to maximized is equivalent to the sample variance of the n values of z_{i1}. Operationally, the problem is solved via an eigen decomposition or via singular value decomposition [32, 33]. Moreover, principal component analysis (PCA) can reveal relationships among data that were not previously evident, enabling new interpretations. Despite involving minimal loss of initial information, PCA is widely used because it confines such loss within acceptable margins. It is worth noticing that PCA can be also extended for its application to spatio-temporal data [34–36], in which case is often referred at as Empirical Orthogonal Functions Decomposition [37]. In such case data are decomposed into fixed temporal scores and their corresponding spatial loadings [38].

K-Means Clustering

Clustering refers to a set of unsupervised learning techniques aiming at finding subgroups, called cluster, into a dataset. While with PCA the aim is identifying a low dimensional representation of the data explaining a sufficiently large fraction of the data variance, with clustering the aim is determining homogeneous subgroups among the available observations. K-means is a popular clustering algorithm partitioning the dataset into K distinct and non-overlapping clusters [39]. Given a desired number of clusters to be identified into the data, K-means assigns the $i - th$ observation to a cluster C_k, for $k = 1, \ldots, K$, minimizing the within-cluster variation. For a cluster C_k the latter

is defined as the measure $W(C_k)$ of the amount by which the observations within a cluster differ from each other. This implies solving the optimization function:

$$\underset{C_1,\ldots,C_K}{minimize}\left\{\sum_{k=1}^{K} W(C_k)\right\}. \tag{4}$$

Here within cluster variation was defined based on Euclidean distance so that

$$W(C_k) = \frac{1}{|C_k|}\sum_{i,i'\in C_k}\sum_{j=1}^{p}(x_{ij} - X_{i'j})^2 \tag{5}$$

in which $|C_k|$ is the number of observations in the $k - th$ cluster. The solution to the defined optimization problem is algorithmically found as in Algorithm 1 [40] Table 1.

Table 1. K-means clustering.

Algorithm 1
1. Randomly assign to each observation an initial cluster from 1 to $\boldsymbol{K}$.
2. Until the cluster assignment stop changing:
• For each of the $\boldsymbol{K}$ clusters, compute cluster centroid as the vector of the $\boldsymbol{p}$ feature means for all the observations included in the $\boldsymbol{k-th}$ cluster;
• Assign each observation to the cluster whose centroid is closest, based on Euclidean distance.

Notice that Algorithm 1 provides a local optimum and depends on the initial random assignment of observations from step 1. To limit the bias induced by such randomness, the algorithm is generally executed multiple times and only the solution resulting in the minimum value of the objective function is selected as final clusterization. The solution also depends on the number K of clusters to be identified in the data. Multiple approaches can be used to determine the optimal number of clusters for the data at hand [41]. Here the Within-Cluster Sum of Squares (WSS) was used to quantify the compactness of clusters by measuring the sum of squares of distances between each data point and its assigned cluster centroid [42]. By evaluating WSS across different numbers of clusters it is possible to identify the point at which further partitioning of data into clusters does not significantly decrease the within-cluster variance, indicating an appropriate number of clusters for the dataset.



Fig. 1. Exploratory data analysis: Pairwise plots among the considered features, including correlations.

3.4 Results and Discussions

The results of the principal component analysis and subsequent clustering have revealed some interesting correlations among the variables under investigation. It should be noted that the analysis of the data, being limited to the territorial boundaries of the cities under study, is evidently influenced by the geographical extent of the municipal administrations as well as the size of the real estate market. In particular, according to the 2011 ISTAT census, the city of Rome had a total number of dwellings of 1.259.649, Milan 643.053, Naples 361.966, and Bologna 206.689. It is therefore normal that the total number of accommodations on Airbnb is higher for Rome, followed in the same order by Milan, Naples, and finally bologna. However, when measuring the percentage of Airbnb's impact on the total residential property, the percentage varies between 2% and 3% for all cities, with the following values: Milan 3%, Rome 2.4%, Naples 2.1%, Bologna 2%. Regarding the prices of accommodations, it has been observed that Rome is the most expensive city, followed in descending order by Milan, Bologna, and finally Naples. This finding contrasts with the long-term rental market, where Milan is at the forefront, surpassing Bologna by approximately 30% (based on the average value of the

entire municipal territory), followed closely by Rome and then Naples. The demand for accommodation by university students certainly has a significant impact on the long-term rental market in Milan and Bologna. This, however, demonstrates the independence of the two market segments (short-term and long-term rentals). This independence is even more evident when looking at the distribution of values within each city. for example, in the case of the Western Area of Naples (Posillipo), despite higher rental prices in the city for long-term leases, low-priced Airbnb accommodations from cluster 1 are found, indicating a distance from the city center. From the results of the clustering (see Figs. 1, 2, 3 and 4), Bologna, Milan, and Rome show a significantly negative correlation between price and distance from the center. Therefore, the prices of Airbnb listings follow the normal trend of the residential real estate market, where urban rent decreases from the center towards the outskirts. Location is also a determining factor for Airbnb users in their choice of accommodation. Accommodations located further from the center require visitors (for tourism or work) to spend more time and effort to reach the main attractions, points of interest, or business areas of the cities. This correlation is reversed for the city of Naples. This different trend can likely be justified by considering that Naples is in a territorial context with numerous tourist attractions outside the historic center and administrative boundaries of the city. Think of the Sorrento Coast, Pompeii, Mount Vesuvius, and the Islands (Ischia and Capri). Therefore, the choice of accommodation serves as a logistical base for visiting the city as well as other destinations. This is clearly evident when observing the map (see Fig. 4), where cluster 1 "low prices, far from the center" concentrates in the Western area, which has the lowest accessibility both to the city center and other tourist destinations. The same rationale explains why Naples has the greatest distance of Airbnb accommodations from the Center, Followed by Rome, Milan, and Bologna. This finding is also justified by the different spatial distribution of the cities. Bologna and Milan are monocentric cities, with a well-defined historic center as the main focal point. On the other hand, Rome, especially, but to some extent Naples as well, can be considered polycentric cities with multiple areas of interest and therefore a greater spatial dispersion of Airbnb listings. The analyses also show a negative correlation between reviews and price, as well as between reviews and distance from the center. This implies that cheaper accommodations located in less central areas tend to have a higher number of reviews. This corresponds to a higher occupancy rate for peripheral accommodations, which are often chosen for economic reasons. This is in line with the results of other studies that have already highlighted the particularity of the typical Airbnb guest, who is usually cost-conscious, motivated by an interest in personalized and authentic travel experiences, and inclined to opt for unconventional accommodation solutions.

In Fig. 2, the first component explains 35% of the data variability, while the second explains 28%. The first component discriminates based on price and number of rooms, while the second discriminates based on distances and reviews.

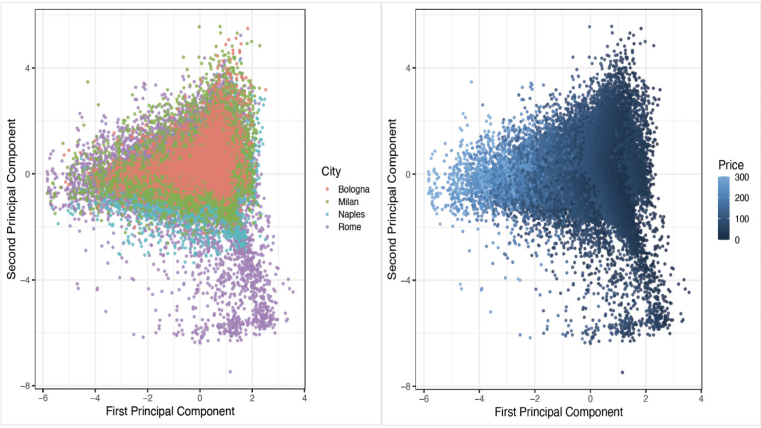

Fig. 2. PCA: Data are plotted in a two-dimensional projection based on the values of the two first principal components. Each point corresponds to a single Airbnb location. Points are colored based on the city the Airbnb belongs (left) and based on price (right).

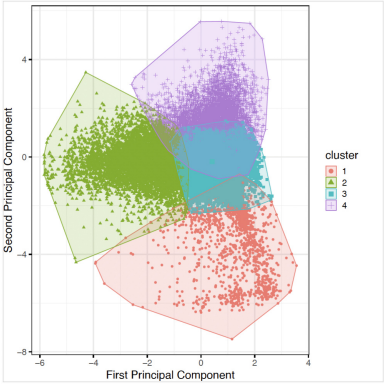

Fig. 3. PCA: K-means clusters: Results of K-means are visualized in the two-dimensional representation of the feature space obtained using the two first principal components derived from PCA. Cluster 1: Low prices, far from the center; Cluster 2: Medium-high prices, not far distances, mostly 2 rooms; Cluster 3: Low prices, average distances, 1 room, few reviews; Cluster 4: Low prices, short distances, 1 room, many reviews.

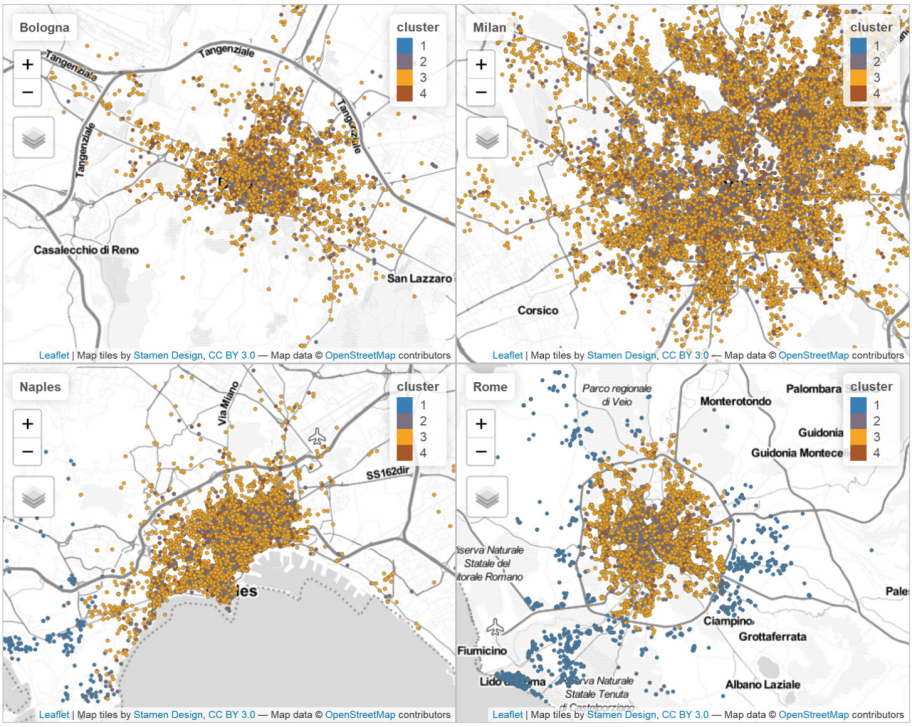

Fig. 4. Spatial distribution of clustered Airbnb listings in the metropolitan areas under study.

4 Conclusions

Airbnb has revolutionized the tourism accommodation sector and the way people approach travel. Firstly, it introduced a new form of lodging that goes beyond traditional hotels and bed and breakfasts. People can now choose to stay in private homes, apartments, or rooms within residences, offering a wide range of accommodation options to fit the needs and preferences of travelers. This has led to the spread of the sharing economy concept, where individuals can make their own properties or unused living spaces available to earn extra income. Additionally, Airbnb has promoted a more authentic and intimate experience for travelers. Choosing to stay in residential neighborhoods rather than tourist areas allows travelers to immerse themselves in the local culture and interact with residents, providing a more authentic and meaningful experience. Flexibility and personalization are other key aspects of Airbnb. People can select accommodations that meet their specific needs in terms of location, size, comfort, and budget, offering greater freedom of choice compared to traditional hotels. This shift in the accommodation landscape has had a significant impact on the traditional hotel industry. Hotels have had to adapt and improve their services and marketing strategies to remain competitive in an increasingly diverse market. However, in addition to its advantages, Airbnb has also raised concerns about its effects on local communities. Increased long-term rental prices and mass tourism in residential neighborhoods have become significant issues in many

cities, prompting greater attention to short-term accommodation regulation policies. By combining Principal Component Analysis (PCA) and clustering analysis using the k-means algorithm, this research aims to empirically examine the Airbnb phenomenon in four Italian cities. The focus is on four key variables: price, number of bedrooms, number of reviews per month, and distance from a landmark in the city center. To achieve this, a dataset consisting of 62.810 listings of properties used as accommodations in the four cities under investigation - Rome, Milan, Naples, and Bologna - over the course of a single year was examined. The results suggest a significantly negative correlation between price and distance, except for the city of Naples. This indicates that while in cities like Rome, Milan, and Bologna, prices tend to decrease as the distance from the center increases, Naples, renowned for its natural beauty, breathtaking coastlines, historic neighborhoods, and numerous cultural and artistic attractions scattered throughout the entire metropolitan area, being a polycentric city, has numerous tourist attractions outside the historic center and administrative boundaries of the city. Therefore, the variety of points of interest outside the historic center can influence the demand and perceived value of Airbnb accommodations, keeping prices relatively stable even in peripheral areas. This is why Airbnb listings in the city of Naples have a higher average distance from the historic center compared to the other cities under study. The results also highlight a negative correlation between reviews and price, as well as between reviews and distance from the center. The negative correlation between reviews and price, as well as between reviews and distance, suggests that cheaper Airbnbs and those located slightly further from the center tend to be more popular and utilized by guests. This could indicate that travelers are willing to sacrifice the convenience of a central location to save money or have a greater choice of accommodations with more reviews, which are considered more reliable. Furthermore, the results revealed that the Airbnb supply in the cities under study is primarily concentrated on accommodations with 1 or 2 bedrooms, which could reflect the prevalent demand for smaller accommodations suitable for couples or solo travelers, rather than larger groups. Finally, the comparable prices among the cities indicate that there is a certain uniformity in Airbnb costs between Rome, Milan, Bologna, and Naples, although Naples shows slightly lower average prices compared to the other cities. Although our study has enriched the emerging literature on home-sharing by offering significant theoretical contributions and improving academic understanding of the sharing economy and the dynamics of home-sharing activities, a limitation should be noted. The methodology adopted is not dynamic, as it is based solely on cross-sectional data collected in a single time period. This approach may not fully capture the variations and evolutions over time in home-sharing practices and their socioeconomic implications. Therefore, future methodological approaches could benefit from an analysis that captures the long-term dynamics and trends of home-sharing activities, as well as exploring how real estate markets, including informal ones, are changing due to the presence of Airbnb.

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 Rational Method for the Quick Assessment of the Areas' Weights Applied to the Italian Context

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Abstract. When referring to NRRP treatments for brownfield site rehabilitation and regeneration, location's weights and measures are crucial factors. Public administration and private subjects can greatly benefit from the use of rapid estimating techniques that consider the location of the intervention through coefficients connected with the area incidence of the region under consideration when designing "win-win" project solutions. It becomes necessary to have valuation tools that allow for an assessment of the eminently building areas while also taking into account their location in order to provide assistance for resource allocation.

The core-objective of this work is to identify an innovative method for assessing the weight of positional return that allows public and private entities to be aware of the presence of a trade area in the considered territory. The method consists on defining the positional performance through the determination of a coefficient that takes into account the incidence of the localization.

The area-wide impact factor estimation method has been implemented for all 104 Italian provinces. The results are empirically collected and spatially translated using appropriate cartography with the distribution of the incidence factor for each trade area of the considered city. In the conclusions, the practical implications and benefits of the proposed evaluation method are clarified.

Keywords: Urban rent · real estate assessment · rational model · location

1 Introduction

The National Recovery and Resilience Plan (NRRP), established by Italy to administer European funding for recovery and resurgence, operates across the country through a number of urban redevelopment and regeneration projects [1]. This instrument heavily focuses on the suburbs, functioning through Integrated Urban Plans (PUI) and supporting the National Innovative Programme for Housing Quality (PINQuA) [2–4]. The first strategy aims to mainly improve the suburbs of Metropolitan Cities, whereas the second aims to build new public housing and redevelop degraded areas across the country, implementing a new management of social housing with the goal of ensuring urban social welfare.

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In order to have assistance for resource allocation, evaluation methods that provide a trustworthy assessment of building areas that also takes into consideration the influence of their location on value are required. Determining the location's weight and estimating the area are both highly relevant in NRRP interventions for the rehabilitation and regeneration of brownfield sites. In this regard, public administration and private subjects can greatly benefit from the use of rapid estimation procedures, which consider the location of the intervention through coefficients correlated to the area incidence of the considered plot, when defining «win-win» project solutions.

2 Aims

The inability of applying direct processes for estimating building areas owing to a lack of purchasing and selling prices in similar locations prompted the development of a new tool to address this issue. The approach consists in determining a coefficient that, starting from the trade area quotes, takes into consideration the area's location and hence the extrinsic characteristics that join the assets inside it. It is a tool that allows to determine not only the market worth of a region, but also its weight within the territory under consideration.

Because it is difficult to identify a potentially active market and carry out a direct (synthetic-comparative) approach, the transformation value is mostly used to estimate building areas. The suggested procedure overcomes the limitation of a lack of comparison samples by integrating with existing approaches, resulting in an accurate and quick estimate that considers location weight.

Integrating with the estimation by transformation value not only supports a faster valuation, but also takes into consideration all of the elements that describe the area in which the place is situated. Building types, geographical features, the existence of urban services and infrastructure, and the socio-economic backdrop are all examples of extrinsic qualities.

This process aims to be supplementary rather than a replacement for techniques like a Discounted Cash Flow Analysis (DCFA), as it is still required to be performed and is therefore an auditing instrument. It was developed to remove the difficulties associated with estimating building areas in situations where there are no purchase and sale prices for comparable areas. Consequently, an estimate of the area's value may be obtained fast by using this coefficient.

The identification of these incidence determinants is helpful not just for the urban regeneration and redevelopment actions envisaged by the NRRP, but also in other settings. It is a useful tool for both public and private actors: it may assist private actors in determining the conveniences of an activity, as well as offering an assessment of the weight of the buildable area on the revenues. In the case of public-private partnerships, it enables public entities to grasp the true convenience of an operation, allowing them to make appropriate requests to the private entities carrying out interventions.

Its application is also beneficial for valuation companies, who frequently do valuations using indirect methods. For example, in the case of the implementation of the DCFA, the use of an area incidence factor verifies the valuation performed by indirect procedures, taking into account the uncertainty that can be found in the use of a DCFA

due to several ordinary assumptions, such as the determination of the development phase, development indices, and discount rate. As a result, the approach in question serves as a check tool that integrates with the current methods.

As a result, the technique in question gains significant relevance in the technical and economic feasibility project (TFPE) after the revisions provided by the Italian D.L. 36/2023 on design levels [5]. The suggested approach has received more credibility when the second level of planning (former final project) was shelved. This is because the D.L. 36/2023 mandates a better connection between the executive project and the technical-economic feasibility project. The direct communication between the first and second levels of planning, which shifts from three to two levels, calls for perspective change-set. Less randomness is possible when using the suggested strategy in the TEFP since localization effects and market specificity are taken into consideration when choosing event elements. Because the goal of public administrations is to keep technical expenditures to a minimum, utilising this know-how would significantly cut them. In fact, the proposed method may be used at the preliminary level before performing an advanced analysis such as a DCFA, resulting in a rapid, reliable, and cost-effective estimate. The developed method therefore allows for an understanding of the cost-effectiveness of a project, when it is still in the TFPE phase, before performing an advanced assessment in the executive project, cutting technical expenditures and time while also working as a dependable, integrative, and controlling tool.

The proposed method, in light of the ideas just outlined, provides for a surprisingly useful instrument for identifying the region and assessing the suitability of the intervention. It is highly important in urban reconstruction and regeneration since the areas are not necessarily abandoned, but they may contain industrial warehouses, obsolete structures, or require clean up. As a result, determining the worth of the unoccupied land would support to define the intervention's appropriateness.

Deconstructing the convention of processes is actually crucial in the suburbs, especially in the harder-to-locate places. Urban regeneration initiatives are not always convenient for private individuals because of market values that are comparable to construction costs. There are additional costs associated with purchasing the area, possibly reclaiming it, and putting community interventions into place, which run the risk of rendering the project unprofitable [6–8].

Therefore, it is suggested as a simple way for private citizens and governmental administrations to manage and comprehend the benefits of both empty spaces and buildings, as well as places that need to be reclaimed or developed.

The research is articulated as follows. In Sect. 3 the method implemented is explained. In Sect. 4, the method is applied to the trade areas ("microzones") of the 104 Italian provinces, in order to define an abacus of the value coefficients and to elaborate appropriate thematic maps. Finally, in Sect. 5 the main conclusions are drawn.

3 Method

The purpose of the method developed is to measure the income in terms of the incidence of the value of built-up land, by identifying a coefficient called the INCidence income factor (INC_j). Its determination takes from Guerrieri's proposal [9] that assumes the

following configuration:

$$INC_j = \frac{(Quot_j - Quot_{min})}{Quot_j}$$

where $Quot_j$ and $Quot_{min}$ refer respectively to the quotation of the relevant trade area ("microzone") and the minimum market quotation. The quotes used to calculate the coefficient in question are based on the residential market quotations for the microzones as published on the website of the Italian Revenue Agency [10]. The Italian real estate agents consider a geographical segmentation of the market in microzones, defined according to the Presidential Decree 138/1998 and ensuing the Regulation issued by the Economy and Finance Ministry. A microzone is described as «a portion of the municipal territory […] that is homogeneous in terms of location, urban-style, historical-environmental, socioeconomic characteristics, as well as the endowment of urban services and infrastructures». For the Italian regulation, the "microzone" is a part of the urban area that must be urbanistically homogeneous and, at the same time, must constitute a homogeneous real estate market segment. A microzone is an area of the real estate market in which exogenous factors (accessibility, presence of services, building characteristics, green areas, pedestrian zones, etc.) contribute to the formation of real estate prices in a uniform manner: a microzone includes properties that differ only by intrinsic characters, which are specific to the individual property. In each microzone, the real estate units are uniform in terms of typological characteristics, age of construction, and prevailing use; it identifies homogeneous territorial market areas in terms of income and values, and in particular in terms of the extrinsic characteristics of the real estate units' incidence on these entities [11].

By identifying the marginal region in the area under consideration and adding an absolute annuity to which an annuity of zero is given, this formula may be used to convey a minimal quotation ($Quot_{min}$). In contrast, the other areas have a different rent from the marginal area because of their location-related production capability. The area incidence factor may be calculated by dividing the differential rent, which is determined by the difference between the quotation of a j-*th* area and the marginal region, by the quotation of the reference area.

The location is already taken into account in the property market quotations for the microzones, therefore identifying a coefficient quantifying the area incidence allows for the provision of a numerical number representing its weight.

4 Application of the Proposed Method in the Italian Context

Based on the method illustrated above, the incidence factor for the microzones of all 104 Italian provinces has been calculated.

The study focused on residential data of the main Italian cities, divided in microzones B (central), C (semicentral), and D (peripheral) with the exception of L'Aquila, where - after the earthquake event in 2009 - the results for several types in the commune's centre areas remain unknown. As a result, it was decided to exclude it from the analysis because the areas where the evaluations are being carried out represent more than half of the population, and so would not be representative of the city.

The corresponding market prices were established by a factual search of data from property market quotations released by the Italian Revenue Agency on October 15, 2023, in comparison to the first semester of that year. The market values taken into account refer to conventional conservative residential areas; if these characteristics were not present, they were assumed to be existent in the area. For example, in Milan's microzone C13 - CITY LIFE, only market values for civil housing with a high level of maintenance conditions were present, whereas in Savona, only market values for affordable houses with a normal level of maintenance conditions were present. Because the goal of the study is to assess the area's incidence, the values of the finished work must be assumed in the various zones.

The determined area incidence factor for all Italian provinces has been displayed on a map using the QGis programme, with the objective of representing how they spread all over the national territory. The province of Piacenza is depicted in Figs. 1 and 2, which serve as an example of the outputs of the analysis and illustrate the structure of the data acquired in an empirical and graphic form (the microzone characterized by $Quot_{min}$ is highlighted in yellow).

It is possible to observe that, in the majority of provinces, the central zones are characterized by a higher incidence factor, as theorized by classic economists who considered the centre as a location in which there are the most services, activities, employment, and urban transportation, i.e. the location in which the functions are located. One example is the province of Piacenza, where the area with the lowest incidence is in the outskirts and it increases as it gets closer to the historical centre, which has the highest incidence. This slow progression may be seen primarily in the northern Italian provinces, with the exception of Reggio Calabria and several central provinces.

However, not all provinces have a progressive move towards the centre; in fact, there are various situations, such as in Cosenza, where there is a significant difference between the peripheral and central zones, or provinces that have the highest percentages in both semi-central and peripheral zones, such as Terni and Rieti. From the preceding example, it is possible to discover the opposite of what was previously said; in fact, the province of Frosinone has the lowest incidence in the centre and the highest in the periphery, with a percentage of around 56% (see Figs. 3 and Fig. 4).

zone code	area	microzone	market value [€/m²]			INC factor
			min	max	average	
B1	central	CENTRO STORICO ENTRO LE MURA FARNESIANE	1200	1700	1450	37%
C1	semicentral	B.RA MILANO, VIALE S. AMBROGIO, P.LE ROMA, VIA COLOMBO, VIA BEATI	960	1300	1130	19%
C2	semicentral	STRADA RAFFALDA, VIA XXIV MAGGIO, VIA IV NOVEMBRE, VIA CAMPI	1000	1500	1250	26%
D1	**peripheral**	**ZONA CAPITOLO, ZONA CAORSANA, LE MOSE, GIARONA**	**740**	**1100**	**920**	**0%**
D2	peripheral	SAN LAZZARO, ZONA PEEP, ZONA FARNESIANA OLTRE VIA BEATI E CORSO EUROPA	800	1200	1000	8%
D3	peripheral	ZONA STADIO, ZONA 2000, ZONA GALLEANA, ZONA BELVEDERE E BESURICA	970	1300	1135	19%
D4	peripheral	VEGGIOLETTA, SANT`ANTONIO, BORGOTREBBIA	770	1150	960	4%

Fig. 1. Compute the Piacenza area incidence.

As previously stated, while there is a progressive northerly trend towards closer proximity to the central zone, there are more varied and diversified situations in the south and the centre of Italy; it is more common to come across situations similar to those previously mentioned in Terni and Rieti, where the incidence is distributed in an irregular and discontinuous manner. The two announced provinces can be supplemented

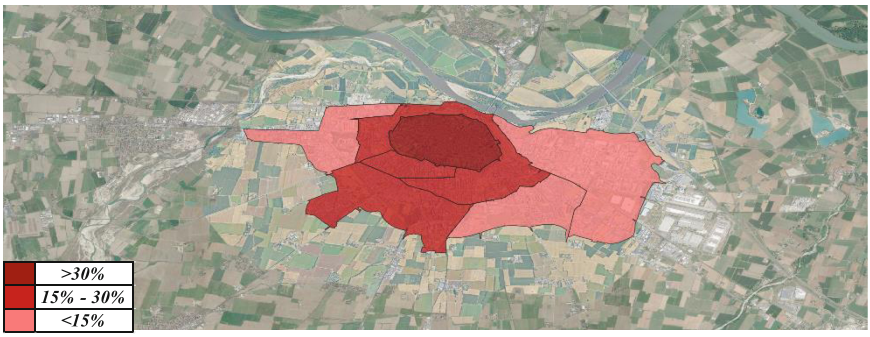

Fig. 2. Area incidence map based on Piacenza's microzones.

zone code	area	microzone	market value [€/m²]			INC factor
			min	max	average	
B1	**central**	**P.V.VENETO,V.G.MATEOTTI,C.REPUBBLICA,L.TURRIZIANI,L.S.ANTONIO**	**670**	**830**	**750**	**0%**
B2	central	P.M.FANI,V.MARITTIMA,V.MAZZINI,V.MORO,P.DE MATTHAEIS,V.MARIA	810	2500	1655	55%
B3	central	V.MARITTIMA (FANI), V.CIAMARRA, V.FIRENZE, V.BRIGHINDI, V.A.LATINA	700	940	820	9%
C1	semicentral	V.LA BOTTE,INCR.SS214,INCR.SS155,INCR.SS6,V.CAVONI,V. FABI	840	960	900	17%
C2	semicentral	SS 214, V.MARIA,V.P.FONTANA,MASTRUCCIA,CIMITERO,ORTO FRUTTICOLO	740	940	840	11%
C3	semicentral	CASALENO,LA TORRE,CERRETO,C.COTTORINO,LA BOTTE,C.DEL VESCOVO	790	990	890	16%
D1	peripheral	V.VALLE,CONTESSA,PIGNATELLE,CERRETO,VETICHE,COLLEMARTE, MANIANO	690	890	790	5%
D2	peripheral	CASA CIRCONDARIALE,MOLA D ATRI,SODINE, FONTANA DEL CERRO	690	890	790	5%
D3	peripheral	VIA CASILINA SUD, VIA F. CORINA, VARIANTE CASILINA	1400	2000	1700	56%

Fig. 3. Calculation of Frosinone area incidence.

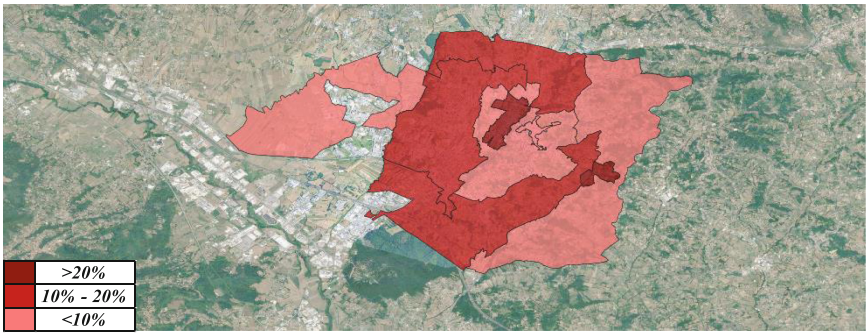

Fig. 4. Map of area incidence in relation to Frosinone's microzones.

by Benevento and Enna, where, in addition to having an erratic distribution of the incidence factor, it is possible to determine the maximum and the minimum percentages in the central zones or the province of Cagliari, which shows the maximum and the minimum percentages in the peripheral zones. The geographical value distribution and empirical findings for the Cagliari case are followed at this point in Figs. 5 and 6.

An additional tendency that has been observed concerns the coastal provinces, that report higher incidence rates in uniformly positioned areas near the sea (like in the cases of Siracusa, Rimini, Pescara, Catanzaro, and Messina).

Undoubtedly, the characteristic shared by all Italian metropolitan cities is the location of the area with greater and lesser influence inside their own territory. Where the former

is mainly located in central areas, the latter is always located in the suburbs with the exception of Palermo.

zone code	area	microzone	market value [€/m²]			INC factor
			min	max	average	
B1	central	MARINA - STAMPACE	1900	2400	2150	37%
B2	central	SAN BENEDETTO - TRIBUNALE - VIA SONNINO	1800	2300	2050	34%
B3	central	VILLANOVA	1600	2300	1950	31%
B4	central	CASTELLO	1500	2200	1850	27%
C2	semicentral	LA VEGA - FONSARDA	1700	2200	1950	31%
C3	semicentral	VIA POLA - VIALE MERELLO - BUONCAMINO	1700	2300	2000	33%
C4	semicentral	MONTE URPINU - BONARIA	2000	2700	2350	43%
C5	semicentral	GENNERUXI - VIA CASTIGLION	2000	2500	2250	40%
D2	peripheral	SANT`AVENDRACE - SAN MICHELE	1500	2100	1800	25%
D3	peripheral	AMSICORA - MONTE MIXI	1900	2400	2150	37%
D4	peripheral	QUARTIERE DEL SOLE - LA PALMA	2000	2700	2350	43%
D9	peripheral	MULINU BECCIU - FANGARIO - BROTZU	1300	1800	1550	13%
D10	peripheral	IS MIRRIONIS - MONTE CLARO	1500	2100	1800	25%
D11	peripheral	PIRRI NORD (BARRACCA MANNA - IS ARGIOLAS - S. TERESA)	1500	2000	1750	23%
D12	peripheral	PIRRI CENTRO - MONREALE - SANTA MARIA CHIARA	1650	2000	1825	26%
D13	peripheral	/PIRRI OVEST (IS BINGIAS - VIA VESALIO)	1700	2200	1950	31%
D14	**peripheral**	**LA PLAYA - VIA SAN PAOLO**	**1200**	**1500**	**1350**	**0%**
D15	peripheral	SAN BARTOLOMEO - SANT`ELIA - CALAMOSCA	1600	2000	1800	25%
D16	peripheral	POETTO	2200	3100	2650	49%

Fig. 5. Compute the Cagliari area incidence.

The majority of the provinces with extremely high incidence factors belong to those specific circumstances where the market quotations for residential properties in a typical maintenance condition were absent. The province's maximum incidence factor can reach 79% due to places like Genoa, which have many areas with values referring to affordable civil dwellings in a normal state of preservation. This increases the difference between the $Quot_{min}$ and $Quot_j$, i.e. the minimum and the reference market quotations.

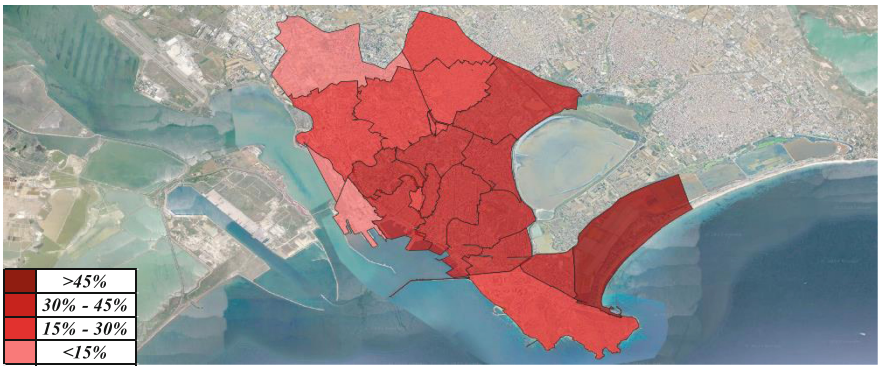

Fig. 6. Map of area incidence based on Cagliari's microzones.

Thereafter, a national map has been created, on which the average incidence rate for each Italian province has been represented (Fig. 7).

As the above-reproduced map illustrates, the national incidence rate is almost equal to 22% and it is distributed rather evenly over the whole territory. The provinces where the incidence is higher, like Taranto, with a median of around 58%, and where it is lower, like Vercelli, with a median of roughly 3%, have been identified.

provinces	INC factor
AGRIGENTO	34%
ALESSANDRIA	6%
ANCONA	18%
AOSTA	16%
AREZZO	18%
ASCOLI PICENO	22%
ASTI	40%
AVELLINO	9%
BARI	31%
BELLUNO	9%
BENEVENTO	8%
BERGAMO	27%
BIELLA	12%
BOLOGNA	20%
BOLZANO	21%
BRESCIA	26%
BRINDISI	21%
CAGLIARI	30%
CALTANISSETTA	57%
CAMPOBASSO	18%
CASERTA	17%
CATANIA	33%
CATANZARO	43%
CHIETI	9%
COMO	27%
COSENZA	29%

provinces	INC factor
CREMONA	6%
CROTONE	10%
CUNEO	16%
ENNA	25%
FERMO	9%
FERRARA	24%
FIRENZE	28%
FOGGIA	18%
FORLI'	10%
FROSINONE	19%
GENOVA	52%
GORIZIA	10%
GROSSETO	12%
IMPERIA	23%
ISERNIA	13%
LASPEZIA	15%
LATINA	20%
LECCE	28%
LECCO	10%
LIVORNO	15%
LODI	6%
LUCCA	23%
MACERATA	17%
MANTOVA	36%
MASSA CARRARA	13%
MATERA	22%

provinces	INC factor
MESSINA	21%
MILANO	42%
MODENA	14%
MONZA	19%
NAPOLI	37%
NOVARA	19%
NUORO	16%
ORISTANO	10%
PADOVA	27%
PALERMO	36%
PARMA	20%
PAVIA	20%
PERUGIA	30%
PESARO	19%
PESCARA	32%
PIACENZA	16%
PISA	24%
PISTOIA	6%
PORDENONE	18%
POTENZA	20%
PRATO	16%
RAGUSA	12%
RAVENNA	34%
REGGIO CALABRIA	27%
REGGIO EMILIA	23%
RIETI	13%

provinces	INC factor
RIMINI	17%
ROMA	33%
ROVIGO	7%
SALERNO	27%
SASSARI	25%
SAVONA	32%
SIENA	31%
SIRACUSA	43%
SONDRIO	11%
TARANTO	58%
TERAMO	18%
TERNI	14%
TORINO	43%
TRANI	8%
TRAPANI	9%
TRENTO	23%
TREVISO	23%
TRIESTE	16%
UDINE	31%
VARESE	27%
VENEZIA	15%
VERBANIA	22%
VERCELLI	3%
VERONA	27%
VIBO VALENTIA	21%
VICENZA	25%
VITERBO	17%

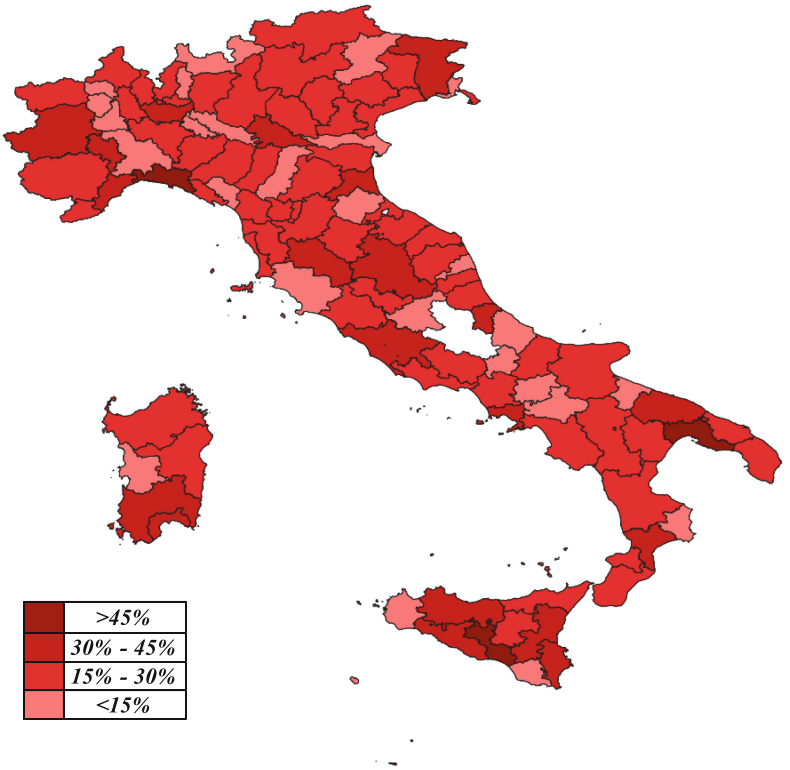

Fig. 7. Mapping of the average area incidence factors for the Italian provinces.

regions	INC factor
ABRUZZO	20%
BASILICATA	21%
CALABRIA	26%
CAMPANIA	20%
EMILIA ROMAGNA	20%
FRIULI VENEZIA GIULIA	15%
LAZIO	17%
LIGURIA	30%
LOMBARDIA	20%
MARCHE	19%

regions	INC factor
MOLISE	11%
PIEMONTE	18%
PUGLIA	26%
SARDEGNA	16%
SICILIA	27%
TOSCANA	17%
TRENTINO ALTO ADIGE	22%
UMBRIA	22%
VAL D'AOSTA	16%
VENETO	19%

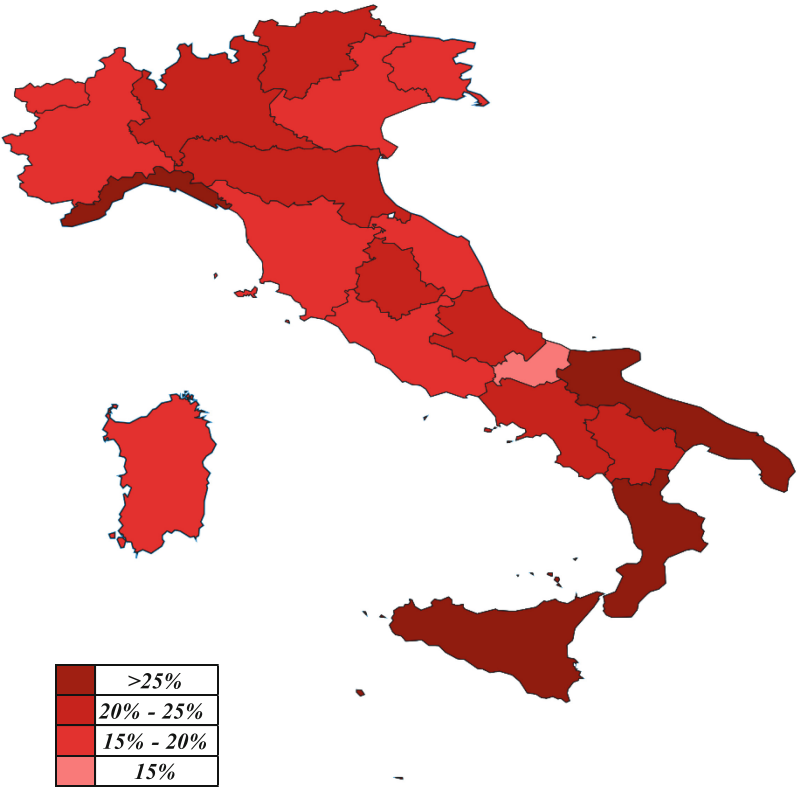

Fig. 8. Mapping of the average area incidence factors for the Italian regions.

The majority of cities have an incidence rate that, on average, ranges between 15% and 30%. However, some provinces, like those in Genova, Taranto, and Caltanissetta, have incidence rates that are noticeably higher than the average value, due to the absence of normalcy in the percentage of civil-dwelling units as previously stated.

Following that, a national map has been elaborated, in which the average incidence per area for each region has been displayed (Fig. 8).

The average area incidence throughout the regions is 20%; the Liguria region is characterized by the greatest occurrence at 30%, whereas the Molise region reports the lowest prevalence at 11%.

Southern Italy has the largest area incidence, as the chart in Fig. 8 already makes clear, with three regions over 25%: Apulia (26%), Sicily (27%), and Calabria (26%). Only Liguria surpasses the 25% threshold in the North, with 27% being the area with the highest rate, according to the Centre. The average proportions for the south, centre, and north of Italy are respectively equal to 24%, 20%, and 21%, based on the incidence factor averaged over the areas of the several zones. After careful analysis, it has been possible to conclude that this trend is due to the fact that there is a greater difference in the population densities of different zones in the southern.

5 Conclusions

The objective of the work has been to provide an innovative tool that is able to consider the weight of the position rent in the overall value of an urban transformation interior. Specifically, the method in question allows stakeholders (public and private ones) to be aware of the incidences of the microzones, both locally (within the province) and nationally (by region or macroarea).

The main results of this work have been: *i*) a detailed abacus, which makes it possible, for each microzone of each Italian province, to quickly identify the area incidence factor; *ii*) a geo-referencing of the outputs on each Italian province and on the entire national territory, in order to support public and private operators, by means of a graphic interface of easy consultation that visually translates the area incidence factors through a rational and objective method in the investment decisions on the territory. These coefficients are therefore fundamental in identifying the effective incidence of the areas in the transformation/re-qualification/regeneration projects of the territory, making it possible to arrive at a reliable judgement of convenience on the real estate initiatives considered. In synthesis, the main advantages of the method are:

i. the quick assessment of a "first" market value of buildable areas, depending on their location;
ii. a rational evaluation of the incidences of location rent, in order to provide for value-for-money judgements on urban regeneration and redevelopment projects that are less affected by uncertainty;
iii. a valid tool for the integration and control of indirect procedures (income approach methods), in particular of a Discounted Cash Flow Analysis, as the most applied technique for the assessment of the market values of buildable areas [11].

The proposed method constitutes a tool that makes it possible to check, in an integrated manner, the valuations that are performed for buildable areas and also to understand and quantify the convenience of an investment on the territory. In the light of the NRRP (National Recovery and Resilience Plan), the outputs of these types of methods are useful in order to adequately support the evaluation of the conveniences of urban

regeneration and redevelopment interventions. Furthermore, the area incidence factors determined by the developed method also represents a useful reference in the case in which the cost approach is applied, in order to objectively assess the weight of the area on the market value of a building.

The method has further uses for local public entities, such as municipalities, which have to annually estimate the values of building areas for the calculation of property tax. Having a coefficient at their disposal to quickly assess the market values of the building plots will make it easier for public authorities to identify them, as well as for citizens to understand how much they have to pay. The usefulness of the proposed method can be also seen in the process of determining the values of the superficiary rights in social housing initiatives [12, 13].

The procedure adopted makes a significant contribution and suggests several directions for future research, such as the application of this tool as a comparison check of a Discounted Cash Flow Analysis on multiple case studies, in order to test and ascertain the validity of the method. Future developments, moreover, could concern the implementation of the developed method to other intended uses (commercial, productive, tertiary), possibly also in a combined manner, where, in most cases, large urban redevelopment projects foresee a mixture of functions. Finally, another research perspective concerns the temporal analysis of the area incidence factor of each microzone of the considered cities, in order to reconstruct the evolution of the differentiated location rent throughout the national territory [14, 15].

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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Assessing the Value of Cultural Landscapes Through the Integration of Biophysical-Economic Valuation, Risk Assessment and Cost-Benefit Analysis

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Abstract. This contribution is a part of an ongoing research work that aims to increase the resilience of cultural landscapes through the development of an integrated method, to safeguard, valorise, and manage cultural landscapes, with benefits on the mobilization of resources, on the participatory process, on the co-design of solutions. The paper aims to explore how ecosystem services and economic valuation can integrate risk assessment of cultural landscape. Two literature reviews are made on the state of the art of Ecosystem Services Approach and Cost-Benefit Analysis to assess the biophysical-economic value of cultural landscapes, mostly in relation with the climate-related hazards and socio-demographic vulnerabilities. The main findings are considered to develop an integrated assessment method, where Ecosystem Services framework will be adapted and integrated within the Risk Assessment, while interacting with the Cost-Benefit Analysis to estimate benefits from measures of conservation and restoration and also costs of adaptation and avoided damage cost. This research work can aid environmental engineers and urban planners to integrate biophysical and economic valuations with landscape conservation and disaster risk reduction. The method can also be addressed to public bodies to better understand the complexity of cultural landscape value and to be informed on potential implications for damages or losses caused by natural hazards.

Keywords: Ecosystem Services Approach · Cost-Benefit Analysis · Risk Assessment · Cultural landscape

1 Introduction

In a context of climate and societal increasing challenges, taking planning decisions is becoming more and more demanding, concurrently with the complexity of decision-making process and the fragility of urban and territorial systems. This is even truer at landscape level, where diverse government levels and planning competencies intersect and overlap, making the decision-making process even more scattered and fragmented.

The European Landscape Convention (ELC 2000) defines the entire landscape as the result of the combination of human and environmental rules. Cultural landscapes (CL),

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which are dealt with this contribution, are famous for representing this union (Pannel 2006), where culture acts as the agent, whereas nature acts as the instrument (Sauer 1925). UNESCO WHC Convention (1992) defined CL, on the one hand, as a site where specific land use techniques contribute to preserve and valorise its biological diversity, and on the other hand, a site as reflection of traditions, beliefs and art of communities connected with nature. CL is labelled as extraordinary when the relationships with the environment and humankind are recognizable and unique (Cassatella and Peano 2010). Its Outstanding Universal Value (OUV) belongs to all communities of the world so that must be preserved for both present and next generations. The non-extraordinary CL have similar characteristics but not enough to be included in humanity's heritage.

Regardless of this classification, all CL express a complex value (i.e. aesthetic, social, cultural, and economic) shaped by local communities for centuries. Compared to the individual cultural good or environmental asset, they encompass the system in which they occur, the relationships with local communities, and the environment. The values they convey continuously evolve over time and mark the intangible sphere of cultural heritage (Wijesuriya et al. 2013). To better explain the complex relations between humans, societal and cultural components with the ecological and environmental dynamics in a CL, we will refer here to the framework of Socio-Ecological Systems (SES) that are defined as complex systems that result from social and ecological forces and factors (Peng et al. 2023).

With rising concerns about climate change impacts, the need for preserving, valorising, and managing CL's value by contrasting natural hazards (e.g. coastal erosion, floods, or fires) and human-induced hazards (e.g. land use change, conflicts, vandalism, tourism pressure, or community abandonment) and by adapting to climate change has become a priority goal (Mitchell et al. 2015).

The concepts of resilience and Ecosystem Services (ES) are relevant pillars to achieve this goal.

Resilience as the capability of a SES to respond, adapt and transform itself across different time and spatial levels (Holling 1996, Gunderson and Holling 2001) has only recently being taken into account for CL's and territorial issues (Brunetta et al. 2019; Assumma et al. 2021; Coscia and Voghera 2023; Aimar 2024). Incorporating resilience "as outcome and as process" (Cutter 2016) within assessment framework can improve the knowledge on resilience in suburban and rural areas, thus increasing the preparedness of Decision Makers (DMs) to damages or losses to the value's components (i.e. cultural, economic, and social).

The Ecosystem Services (ESs) framework and the biophysical-economic valuation are approaches that have triggered relevant results over time in the field of environmental and social sciences for assessing environmental systems. More recently, they have also been employed to support urban and territorial planning issues for example within strategic environmental assessment procedures (Salata et al. 2017; Assumma et al. 2022, Quagliolo et al. 2023).

Integrated assessment frameworks for decision-aiding are needed, on the one hand, to understand and evaluate CL's value, its vulnerabilities, and on the other hand to favour a strengthening of CL's coping capacity through policies and measures. Moreover,

these frameworks must consider more and more the potential effect of instabilities in rescheduling time and financial flows of these interventions.

Public bodies need integrated assessment tools that are intuitive to employ, flexible, and replicable at various phases of the assessment and planning processes, as well as to monitor medium- and long-term impact of measures. Indeed, understanding the potential impacts of climate change over CL and their ES, together with the changing values of those ES in the future, may support the development of preventive actions and the proper definition of Cost-Benefit Analysis (CBA) would allow them to properly plan the actions throughout the time. Private sector is increasingly responsible for integrating environmental and climate change issues together financial affordability into their transformation projects. In fact, the investment on green bonds (e.g. IT BTP Greens, Green Climate Fund, Green transition fund, ESG funds) allow them to raise their capital (UNFCCC 2010; CDP Venture Capital 2022). Since these policies are gradually being defined, European Commission is progressively stimulating both private and public sectors to work together on financing adaptation (EC 2021). These assumptions could also have positive implications in a wider context of CLs enhancement.

In light of this context, it is possible to state that assessment techniques and tools to understand climate hazards and their potential impact over CL and ES naturally evolves to assist DMs and stakeholders according to desiderata and rules (Moroni and Lami 2020; Moroni 2020) and can combine results into interdisciplinary or transdisciplinary outcomes.

In this light, the main aim of this paper to explore the possibility of developing an integrated framework for the assessment of biophysical and economic valuation of cultural landscapes under climate related risk. To do this, this paper develops a literature to design the methodological proposal. On the one hand, the biophysical and cultural assessment of Ecosystem Services and its relations with Risk Assessment models are explored to understand and evaluate their matureness consideration into CL resilience assessment. On the other hand, the CBA integrates both InVEST modelling's and Risk assessment's models by considering costs and environmental and social benefits of a measure (t_1) and the state of the art (t_0), to preserve and increase CL's value and its resilience.

The contribution is subdivided into four sections: Sect. 2 describes the methodology; Sect. 3 presents two literature reviews, the first on Ecosystem Services with Risk Assessment and the second on CBA; Sect. 4 clarifies how the integrated assessment methodology is intended to be developed.

2 Methodology

Two parallel literature reviews are developed to explore what has been done so far for the biophysical and economic assessment of cultural landscapes and in relation to risk assessment, with the purpose of selecting those aspects of the two methodologies that may be particularly effective in responding to a specific assessment problem, namely that of linking biophysical and economic aspects within the assessment of CL's value and its resilience. This will allow us to identify interlinkages for the methodological proposal in the discussion phase.

Both literature analyses were developed by accessing the Scopus database in the reference period 2001–2024 and by considering results mainly in English.

2.1 Literature Review on Ecosystem Services Approach with Risk Assessment

The review started looking for the keywords search in Scopus, departing from 2001, the year when the Millennium Ecosystem Assessment was published, to the beginning of 2024. The initial search included: "Ecosystem Services" AND "Risk Assessment" and Cultural Landscape". This first search reported just 5 results; thus, the search was reformulated using only Ecosystem Services" AND "Risk Assessment".

The literature search gave back 56 results that included scientific papers and one chapter book that was excluded from the first screening process since no abstract nor the full text was available. The remaining 55 papers were screened through the reading of the abstracts. Three of them were excluded because abstracts were not available in English, and relevant papers to be read in full were selected according with the main objectives of this work: papers needed to address the integration of Ecosystem Services into cultural landscape climate-related risk assessment. Most of the papers excluded (N28) were considering the integration of ecosystem services as possible indicators into ecological/chemical risk assessment, while an important number of papers was looking at ES integration into non-climate-related risk assessment (N19). In this case most of the papers looked at past, present and potential future land use change as the main hazard into ES assessment and considered urban areas as their referenced case studies.

The remaining articles (N5) were read in full, and they were analysed looking at the following: climate-related hazard considered (according to the latest IPCC report); location of the case study, if any and methods and tools used for the assessment.

2.2 Economic Evaluation for Resilient Cultural Landscapes

The assessment of CL's economic value considers those techniques belonging to the branch of economic evaluation of public goods. The Total Economic Value (TEV) is a paradigm widely recognised by economist today for estimating the economic value of environmental goods and services such as of cultural heritage and landscape (Pearce and Turner 1991; Adamowicz et al. 1994; Pascual et al. 2010; van der Heide and Heijman 2013; Tagliafierro et al. 2016).

CL are pure public goods that produce externalities, since they can provide multiple benefits to local communities (e.g. psycho-physical well-being, or sense of identity and of belonging, among others) even if this means being exposed to potential damages and land degradation. CL's economic value cannot be dominated by market rules as for private goods. Indeed, the co-presence of non-competitivity and non-excludability from market implies the construction of a hypothetical market in which CL' economic value can be estimated. TEV summarizes the following types of use: (i) Direct use value which is derived from the tangible use of primary resources and/or the services they can produce. This value in turn can be distinguished into primary use (e.g. getting wood from a forest) and secondary use (e.g. using water from a spring near a house property); (ii) Indirect use, which refers to the future and potential use of the good and/or service. This value is further classified into optional use value (e.g. benefits from wildlife and

habitats), bequest value (e.g. local heritage value, or sites in danger), and existence value (e.g. protected areas and animal and plant species).

TEV of cultural landscape can be assessed by employing economic evaluation methods, which can be classified into two groups (Pearce and Turner 1991).

Non-monetary methods employ sets of indicators to calculate cultural heritage and landscape's value at the state of the art or at potential state (t_0 - t_1) by aggregating its multidimensional components (e.g. cultural, economic, or social) and sub-components (e.g. cultural indicators, economic indicators, and so on) into a composite and synthetic index [0, 1]. Composite index valuation can aggregate both qualitative and quantitative data obtained for example from statistical and geo-catalog sources, or surveys (Jesinghaus 2000; van der Heide and Heijman 2013; Tagliafierro et al. 2016). It may be supported for example by Multicriteria Decision Analysis/Making (MCDA/M) to organize the decision problem into simpler elements or to explore interdependencies between the same elements, with the purpose of ranking, sorting, choosing, or describing alternative scenarios. These techniques are retained suitable to integrate dynamic Problem Structuring Methods (PSM) since it can encourage an iterative process between value focused thinking and alternative focused thinking (Corner et al. 2001; Ehrgott et al. 2010). In relation to cultural landscape, this integration could ascertain the relevance of indicators through the involvement of multidisciplinary panels of specialists and with the opportunity to favour the participation of local actors and stakeholders.

Monetary methods can estimate the economic-financial value generated by cultural heritage or landscape, as well as the cost for its preservation, damages, or loss (Price 2013). CL's economic value can be estimated on stated preferences of local communities/tourists through the Willingness to Pay (WTP) to use a CL, or the Willingness to Accept (WTA) a compensation due to CL value's damages/losses. Conjoint Valuation Method (CVM) can estimate WTP using sets of attributes (e.g. olive groves extent, transport accessibility, panoramic view, landscape eyesores, or cost, among others). The revealed preferences can consider the Hedonic Pricing Method (HPM) to explore the effects CL's attributes on the pricing of real estate properties. The Travel Costs Method (TCM) can capture the costs incurred by tourists to use that cultural asset or landscape (La Riccia 2023). However, the application of one of these techniques cannot solely determine the economic-social affordability of a transformation in a cultural landscape. It is necessary to integrate CL's value as WTP/WTA within a Cost-Benefit Analysis (CBA) thus completing the economic evaluation framework.

When the assessment of CL's value is required due to a transformation with DMs' recommendation to adapt to climate-change and specific risks, natural and/or anthropic, or even to a black swan, the integration of biophysical and economic outputs in relation to the function of the risk, becomes of crucial relevance such as for public bodies, in the design and planning of winning measures, or for academics and freelances an opportunity to operationalise interdisciplinary and transdisciplinary approaches to CL's resilience (Fig. 1).

2.2.1 Literature Review on Cost-Benefit Analysis for Cultural Landscapes

To explore the role played by economic valuation in determining CL's value, an investigation on Scopus'database was performed on the most suitable valuation approaches for

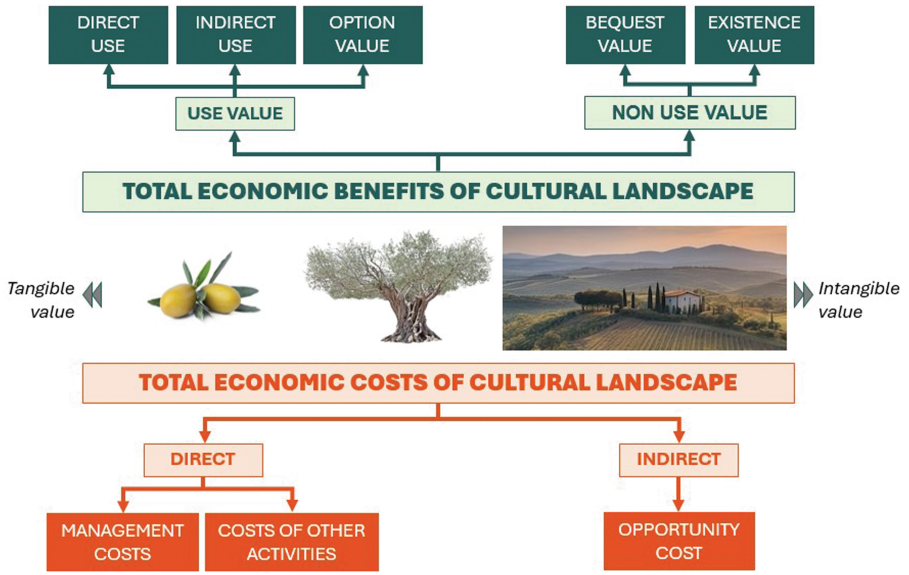

Fig. 1. TEV paradigm between CL's costs and benefits (Adapted from Baig et al. 2007)

decision-aiding and regarding conservation, valorisation, and management procedures in risk and climate change scenarios.

After analysing each query result, the findings were sorted according to consistency classes (i.e. low, medium, and good) following the paper's goal. (i) Low consistency refers to those studies that identify measures without providing the way or the assessment methods that helped the authors to identify them; (ii) Medium consistency refers to reviews or studies that employ assessment methods (not economic); (iii) Good consistency means that reviews or studies consider economic valuation techniques.

The first query considered the keywords "cultural landscape" and "economic value" to investigate the role of economic evaluation with respect to environmental or social assessments, thus giving back 39 results.

Subsequently, the query included the keyword "risk". This returned only three results, only one of which has a medium consistency (Bernués et al. 2014), since it employed a Choice Experiment model (CE) to estimate the WTP to preserve ESs from fire risk in mountain agrosystems, where CL is considered as one of the evaluation model's attributes.

The keyword "risk" was then substituted with "resilience" obtaining 11 results, of which five with a medium consistency. The query's term "economic value" was substituted by "cost-benefit" considering the main goal of employing CBA as part of the methodological proposal. This produced ten results of which three with a medium consistency and four with a good consistency.

A subsequent query considered the integration potential with "cultural landscape" AND "cost-benefit analysis" AND "ecosystem services", thus giving back five results of which two with a good consistency and one mediumly consistent. The searching was concluded with a last query "cultural landscape" AND "cost-benefit analysis" AND

"ecosystem services" AND "risk" which gave back no results. However, no duplicates were found. The results are discussed in detail in Sect. 3.

3 Discussion of the Results

From a research perspective, this analysis assisted the authors in determining the way in which economic valuation, biophysical valuation, and risk assessment can be methodologically and operationally integrated. This will enable the authors to develop an integrated assessment framework that will take into account various types of CLs and be replicated on a European scale. The following subsections discuss the findings of the two literature reviews.

3.1 The Literature Review on Ecosystem Services and Risk Assessment

As detailed in the methodological section, five papers were reviewed having a in depth analysis of the climate related hazard they considered, the method and tools used for the risk assessment analysis and the location of the case studies.

Among the identified relevant articles, four of them considered a multi-hazard evaluation, looking simultaneously at hydrometeorological hazard, temperature and drought and, in some cases, non-climate related hazard as land use change. One paper (Vigna et al. 2024) looked explicitly at the integration of Cultural Ecosystem Services (CES) into wildfire risk assessment.

The case studies covered river deltas (Peng et al. 2023 and 2024) in China, coastal habitats (Barausse et al. 2022) in the North of Italy and in the Atlantic coastal region (Caro et al. 2020), eight small municipalities in the Alpine landscape (Vigna et al. 2024).

Going deeper into the contributions, Peng et al. 2023, performed a systematic literature review of ES integration into risk assessment considering a multi-hazards perspective over coastal deltas as SES. The literature review is comprehensive for coastal deltas assessment, but there are no references to other types of landscape. Nevertheless, this work led (Peng et al. 2024) to propose a systematic and operation integration of ES into risk assessment frameworks for river deltas. Indeed, according to the authors, despite adopting a social-ecological and multi-hazard perspective, previous risk assessments failed to achieve balanced consideration of both social and ecological sub-systems.

The adapted framework proposed and further tested in the case of the Pearl River and Yangtze Delta in China integrates various risk components (Risk = Hazard × Exposure × Vulnerability) from the spatial perspective of the SES and it was applied to four main types of hazard: namely hydrological, meteorological, climatological and mixed (salinity). Peng et al. (2024) used a spatial approach through GIS and a series of indicators that responded to the different risk categories, further weighting them and proposing a composite and risk index. ESs specifically have been integrated within the vulnerability assessment, considering provisioning, cultural, and regulating services as modular independent indicators.

The paper from (Barausse et al. 2022) proposed a novel methodological approach to perform climate risk assessment in Natura 2000 sites integrating the standard of ISO 14090 in combination with the theoretical framework of ecosystem services assessment

and local stakeholder participation. The approach is interesting and mainly looked at the identification of climate-related issues for local protected habitats. Even though the idea of integrating an ISO standard with ES results promising, the implementation of such approach should be tested beyond Natura 2000 sites, further integrating cultural aspects into the evaluation. In this contribution the biophysical evaluation was mainly performed using qualitative impact chain analysis.

Caro et al. (2020) looked at the vulnerability of coastal ecosystems with specific regard to sea level change and organic enrichment of water. To establish a relationship between potential final risk and ecosystem service supply, Caro et al. (2020) proposed to consider ecosystem services' abundance as a resilience descriptor further integrating them into the habitat risk assessment (HRA) model from the InVEST tool. Similarly to Peng et al. (2024), the authors assigning different weights to provisioning, regulation, and cultural services.

Moving deeper into CES, Vigna et al. (2024) argue that conventional assessments of wildfire risks often overlook the potential loss of ecosystem services, particularly cultural ones (CES). This study presents a methodology for integrating CES into wildfire risk assessment, combining expert CES participatory mapping with standard procedures based on fire hazard and vulnerability modelling (Vigna et al. 2024).

As well as in other discussed contributions, the ES information was integrated into the vulnerability assessment contributing to develop five classes of vulnerability (i.e. very low, low, medium, high, and very high vulnerability).

3.2 The Literature Review on Economic Evaluation Methods

The papers were examined in full and from the perspective of consistency with respect to the authors' goal, and this has implied a further reduction of the results. Using the term "cultural landscape" instead of "landscape" in our searching has limited the scope of the literature search. The most common references are to mountainous, agro-forestry, wetland landscapes, agropastoral drylands, peatland and moorland. A considerable number of studies aimed to gather solutions to contrast at specific risks (e.g. wildfire, see Moore 2019) and provided a framework that can be potentially addressed to less developed countries. Most of CLs dealt with these studies is limited to some CL's types, they do not consider a multi-hazard perspective or rather the concurrence of multiple extreme events (i.e. black swan). Moreover, these studies propose the employability of approaches and related solutions to preserve and manage extraordinary landscapes rather than ordinary. Their distribution is unbalanced between the countries of the Great North, represented mainly by USA and UK, and the countries of the Great South that collect the highest number of studies.

The results of the first query showed an asymmetrical distribution ("cultural landscape" AND "economic value"), which attempted to explore the scientific focus on economic value in comparison to the other value's dimensions of cultural landscape (39 results versus 48 and 269 findings, respectively). The number of results can also be attributed to the fact that, with respect to the research on the other two dimensions started in the mid-80s (i.e. environmental and social), CL's economic value only begun to be investigated in the mid-90s.

Mangels et al. (2017) identified relevant effects of land use on species richness and diversity by calculating a Land Use Intensity index (LUI) and using both ANOVA and ANCOVA to explore the relationships between land-use niche and species traits.

Reang et al. (2022) dealt with agrosystems and evaluated biodiversity and aesthetic values of landscapes and the economic value for farmers through indices.

Moore et al. (2019) defined an integrated fire management framework and recognised that damage and loss assessment (e.g. suppression costs and opportunity costs) could have implications for wildland fire prioritization and investment. These results demonstrated this type of approach is still limited and lacks of a comprehensive approach to integrated assessment.

The query that included "cost-benefit" keyword and that produced ten results of which three with a medium consistency and four with a good consistency are discussed below, respectively.

Wersebeckmann et al. (2022) tackled the issue of revegetation of vineyard terrace embankments to reduce erosion risk and satisfy biodiversity conservation demand at the best cost-benefit ratio for winegrowers.

Karanth and Nepal (2012) compared the results on a survey and interviews led in India and in Nepal on the communities' perception of benefits generated by protected areas and on their potential loss.

Wolsko and Marino (2016) discussed that the current uses of CBA and disaster-climate-change studies cannot sufficiently provide sets of solutions without considering the issue of long-term psychological well-being and cultural integrity of communities who survived to "habitual" disasters or be forced to migrate/abandon their places.

Enengel et al. (2011) focused on transactional costs of decision-making and on costs of implementation. They developed an integrated analytical framework to obtain individual efforts (i.e. time and money), benefits, and risks of participants in landscape co-management processes.

Newton et al. (2012) developed a multi-phase approach which consisted of (i) the economic valuation of ESs' for a set of restoration scenarios; (ii) the assessment of costs for restoration of each habitat type (i.e. cost of habitat establishment, annual maintenance costs, marginal cost); estimation of net benefits as Marginal changes in the Value of Benefits (MVB) and Marginal changes in the Value of Costs (MVC) by subtracting the total value of each benefit of each scenario from the total value of each benefit of each restoration scenarios; (iv) CBA to calculate Cost-Benefit Ratio (CBR) for two costs options; (v) assumption of the discount rate; (vi) assessment of biodiversity value; (vii) Multicriteria Spatial Decision Support System (MC-SDSS) to rank the restoration scenarios by considering both market and non-market values.

Rickards and Howden (2012) conceptualised the characteristics of transformational adaptation to climate-change in agriculture sector at the farm and regional scales and focused on five types of costs: (i) transaction costs, (ii) opportunity costs, (iii) cost of relevance to CC adaptation, (iv) cost of incomplete adaptation and (v) cost-efficiency. Mueller et al. (2019) employed Choice Experiment (CE) to assess the value of groundwater recharge for watershed restoration in semi-arid landscapes and then estimated WTP through a Bayesian mixed Logit model. This model allowed to estimate the monetary value of environmental benefits once being imported within CBA.

Nuno and Morales (2020) used a mixed model founded on Linear Mixed Model (LMM) and CBA by taking into account the potential ecosystem service trade-offs resulting from the implementation of agri-environmental measures.

Dorresteijn et al. (2017) recognised the ability of CL to provide cultural ESs to poor local communities by developing a survey on the potential services-disservices on specific ESs. They used a linear model that included location and socio-economic characteristics of local communities, each one associated to one of the following profiles: "high costs/low benefits", "low benefits/low costs", and "high benefits, high costs". That study demonstrated that services and disservices must be disaggregated for a more sustainable management of CL rather than spreading costs and benefits homogeneously to local community.

Davies et al. (2016) investigated the relationships and trade-offs in peatland fire management through the estimation of costs and benefits from the managed fire.

4 Conclusions

The strengths and limits founded in these studies will lead to the design of the integrated assessment framework. As shown in the figure below, this proposal can support both the assessment and planning processes along the ex-ante, in-itinere, and ex-post phases.

A preliminary phase will set the context through the development of sectorial analyses, from the recognition of ecosystem services and disservices to the characterisation of individual risk components, until to the exploration of communities' perception on CL's value and on its potential enhancement or compromission. This phase will be employed in relation to individual hazards and/or to multi-hazards. The choice could influence the complexity of the remaining structure of the integrated assessment framework.

The core phase aims to compare the suitability of sets of alternative options between CL's present conditions (e.g. BAU-Business as Usual scenario) and other potential states. Concerning the integration of ES biophysical values into climate risk assessment of cultural landscape, few publications proposed an operational framework to navigate this complex field. Most of them proposed to integrated ES evaluation into the vulnerability risk components, using, in most of the cases, either qualitative or quantitative weighted systems. GIS, INVEST and similar biophysical and spatial approaches have been used, acknowledging the fact that maps may be considered a powerful instrument to support DMs in this field. Multi-hazards approach is starting to raise, allowing for the evaluation of ES multiple benefits simultaneously. Despite the potential support of ES into climate adaptation and enhanced resilience, the review around this topic still highlights the need for further research.

This is needed to support DMs and planners in better shaping future responses (Vignoli et al. 2021) The ESs outputs will be imported within the risk assessment to act positively on a potential risk reduction. Indeed, the modification of biophysical ecosystem services expressed in monetary units can be better taken into account within risk assessment. Parallelly, CBA will evaluate the socio-economic and environmental affordability of the sets of scenarios by calculating the main economic-financial indices (i.e. NPV, IRR and CBR) and then concluding with a "What-if scenario" analysis on the risk of investment. The CBA outputs will integrate the benefits produced by ESs to refine

eventually the measures considered in the ongoing evaluation and planning phases. Both biophysical and economic-financial outputs will be matched within a matrixial environment to evaluate causes and potential environmental, economic, and social implications. Subsequently, it will be possible to determine the risk acceptability of each transformation scenario. For example, alternative options could refer to transformation scenarios of expansion of given interventions and to their effects on ES and on CL (Caprioli et al. 2021; Assumma et al. 2022; Quagliolo et al. 2022), as well as mitigation actions and/or compensation models for land take reduction (Anelli and Tajani 2022).The scenario retained as the most suitable in biophysical, economic-financial and risk terms can be communicated to actors and stakeholders actively involved into the process and thus moving on risk management and/or overcoming (Torrieri and Rossitti 2020).

A last phase will complete the integrated assessment framework once the measure under evaluation will be implemented effectively. In this sense, a set of Key Performance Indicators (KPI) that derives from the previous analyses and from the relevant literature will monitor the achievement of the objectives, to verify the control of standards and to check the effective implementation of the considered policies. This phase, as it happens in real procedures of strategic environmental impact assessment will be performed periodically and beyond the implementation of the project (Fig. 2).

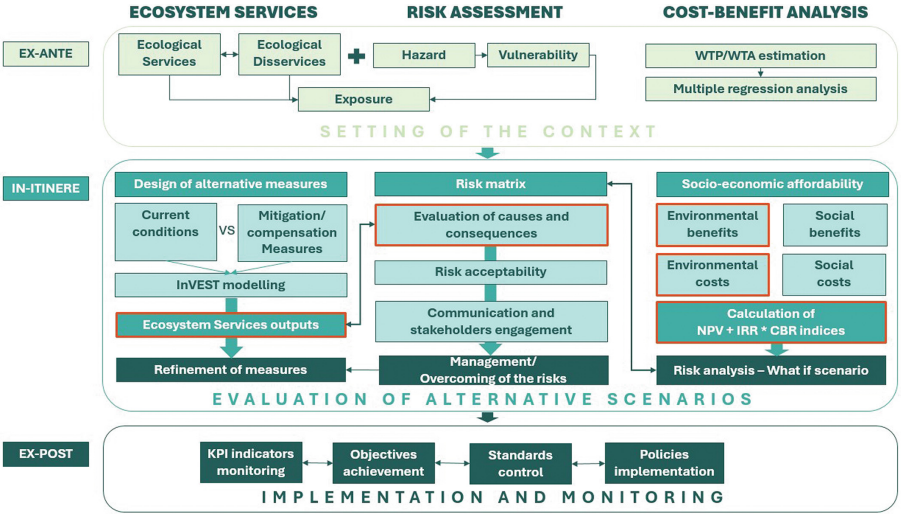

Fig. 2. Design of the preliminary integrated assessment framework

From a research point of view, this analysis supported the authors in determining economic valuation, biophysical valuation, and risk assessment can methodologically and operationally be integrated. This has enabled the authors to define a preliminary integrated framework that can consider the diversity of coastal cultural landscapes and be replicable on a European level.

Both the literature reviews aimed to bridge the current demand of public bodies, urban planners, architects, and engineers' freelancers to employ evaluation techniques and tools capable to provide dynamic results, by considering sets of alternative options, economic feasibility for competitive and buildable projects, while being evaluation techniques accessible to a broad spectrum of users, without renouncing their complexity. These findings will be included in a project's strategy with the purpose of strengthening the interlinkages between the disciplinary areas and thus favouring the preservation, enhancement, and management of the value of cultural landscapes under risk and uncertainty.

Many methodological difficulties are counted today in estimating the costs of adaptation, but the recognition of uncertainty is the most significant requirement to build robust and winning strategies, rather than conceiving it as an excuse for inaction (Watkiss et al. 2010).

A limitation detected at this step may be transformed as an opportunity for the future, that is the need for deepening the knowledge on recent transformation projects, or definite adaptation measures within the project's case studies and gathering data helpful to estimate the Net Present Value (NPV), the Cost-Benefit Ratio (CBR) and the Internal Rate of Return (IRR) through the comparison between the state of the art and sets of alternative transformation scenarios.

A survey will be conducted in a real case study to investigate CL's value perception, by estimating the Willingness to Pay (WTA) for CL enhancement and management and the Willingness to Accept (WTA) for damages caused by natural hazards or human-induced risks on CL. The employment of the Conjoint Valuation Method (CVM), or the Hedonic Price Method (HPM) will be fundamental for the WTP/WTA estimation and their integration within the CBA Analysis.

The next steps of this work are here provided. First, the authors will integrate Ecosystem Service Approach (ESA) with Risk Assessment (RA) and Cost-Benefit Analysis (CBA) by proving its feasibility in a real case study. This objective aims to test the methodologies in different coastal cultural landscapes. The comparison of results will give us the opportunity to consolidate this methodological integration for being replicated for both ordinary and extraordinary cultural landscapes. The methodological framework's usability will be investigated also in relation to the potential interlinkages with other disciplines such as history and conservation of cultural heritage and landscape, hydrogeology, sustainable planning and architecture and building production. The achievement of the mentioned steps will favor the potential consolidation of the integrated assessment framework within a multi-level interoperable platform.

Disclosure of Interests. None.

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A Systematic Analysis of the Scientific Literature on the Relationships Between Urban Redevelopment Initiatives and Property Market Dynamics

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Abstract. The present research concerns the relevant and current issue of the urban regeneration. In particular, a systematic literature review on fifty contributions focused on the investigation of the relationships between the definition of urban redevelopment initiatives and the property market dynamics is carried out. The mentioned relationship is analyzed by taking into account both (i) the effects that the interventions on the territory determine on the real estate mechanisms, in terms of variation in the real estate values and dynamism of the supply and demand and (ii) the modalities in which the market trends (volume of transactions, prices, rents, average sales times, supply and demand) influence the urban transformation processes. The study is part of a wider research line and intends to provide an intermediate step of the analysis of the consistent relevant literature focused on the double perspective in which the link between the projects on the territories and the property market dynamics can be dealt with.

Keywords: redevelopment projects · sustainable development goals · property prices · real estate market

1 Introduction

Within the cities governance processes, the urban regeneration policies constitute an important strategy aimed at the transformation and development of the territories. In general terms, starting from the needs of the community, the operations of the real estate enhancement and renovation of public spaces determine positive effects in attracting new activities and investments and generate benefits in terms of urban quality improvement.

The implications of the urban transformation on the real estate market are closely linked to the activation of an integrated economic layout capable of promoting the launch of actions related to sectors that are different than the construction one (mobility, infrastructures, public services, tertiary sector, production) [1] in a more holistic vision of the city system and its components.

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In this sense, if appropriately oriented and carried out, the urban redevelopment initiatives allow the definition of effective and participatory relationships among politics - the main place for decisions -, and urban, territorial and landscape planning, aimed at the successful relaunch of the territory in the perspective of the three sustainability (environmental, social and economic) pillars [2–4].

Therefore, any strategic action that involves the local communities cannot be correctly developed if the effects that the project could determine in the various fields are not *a priori* analysed. Among the affected economic sectors, the real estate sector assumes a fundamental role as it is a proxy variable of the appreciation of potential buyers and investors for the existing building stock near to the urban pole (building or public space) to be redeveloped. Similarly, with reference to the time before the redevelopment, the presence of degraded/derelict areas within a city has negative effects on the real estate market, decreasing (i) the demand for neighbouring properties both for leasing and purchase and, consequently, (ii) the market values.

In the mentioned framework, the presence of abandoned areas or disused properties makes it necessary for actions (even in a sufficiently short time) by the local authorities aimed at preventing that the negative effects due these existence can be reflected in the medium-long term for the community and that the real estate market could be significantly affected in terms of a collapse in the number of transactions and real estate prices. In theoretical terms, the urban regeneration interventions allow to renewal the image of the portion of the city undergoing transformation [5], by reducing the number of empty and underused real estate units which, in turn, potentially generate negative impacts on the property asset value related to the main risks associated to the progressive degradation of the considered the area.

The presence of abandoned properties and/or areas is, in fact, strictly associated with the phenomena of urban decay and criminality and the real estate/urban redevelopment projects favour the short-term growth of jobs connected to the urban recovery project which normally require a wide set of diversified skills and the inclusion of new workforces in the economic activities to be introduced [6]. In the real estate market, the trend of selling and rental prices is significantly influenced by the specificities of the urban area in which the property is located and the possible existence of close disamenities has negative impacts on the market demand for the area which, as mentioned, is reflected in the market values. The lower rents or prices that characterize the properties located in the proximity to the damaged territories (for which urge and relevant rehabilitation projects are needed) represent a direct economic cost borne by some communities which could be avoided through targeted intervention policies of governments or local entities.

It should be highlighted that, beyond the collective and potential investor's interest in intervening on urban territories with specific and effective recovery initiatives, a direct economic advantage for all properties owners in the neighbouring areas in supporting redevelopment initiatives is attested. This benefit firstly translates into an increase in their market values [7, 8]. Among the economic effects of the degraded and abandoned areas presence, those related to the (longer or shorter) time period required for the property lease or sale should be included: these could be different compared to other areas of the city and, consequently, could lead not only to losses linked to the lower unit rent and

price, but also to a higher risk due to the lack of attractiveness of the area which causes more extended negotiation times and, very often, subsequent asking prices decrease.

The existing relationship between the implementation of initiatives aimed at recovering underused assets and/or degraded sites and the realization of the opportunities connected to such operations, in terms of increasing urban prosperity and quality of life, is part of a more complex process in which the advantages for all interested parties (public entities, private investors, local communities, etc.) are numerous. The outcomes of effective territorial transformation strategies translate, first of all, into preventing the trigger or continuation of urban tissue deterioration, by improving the physical, economic and social infrastructures, generating new jobs, increasing the market value of near properties (especially residential and commercial).

2 Aim

In recent decades, the relevance assumed by the urban planning based on the programming of targeted interventions to be implemented in the territory is increasingly central.

Urban redevelopment inevitably determines a redefinition of the market values of the properties located in the area in which the transformation initiative is carried out. The benefits deriving from the realization of urban development projects, in fact, do not "only" concern the increase of the life quality of the citizens, but also the properties enhancement in the redeveloped territory. In this sense, the regeneration determines a significant economic impact on the surrounding building tissue and on the new area potentialities and, in light of the possible territorial changes that can be triggered through the planned redevelopment projects, the projection of the future market unitary prices aims of analyzing the effects on the existing assets values.

The urban policies that guide the existing city transformation and the evaluation tools are essential for a valid *ex ante* analysis of the likely impacts that the redevelopment could have on the dynamics of the reference real estate market.

Therefore, among the different strategies for renovating the public and private property stocks, the examination of the local market trends (existing demand and current and forecast supply) constitutes a fundamental phase to support the choice processes.

In the outlined context, the present research intends to provide a systematic literature review on fifty academic contributions focused on the investigation of the relationships between the definition of urban redevelopment initiatives and the property market dynamics. The literature on the topic is particularly widespread and these fifty contributions represent a first selection of all the existing studies: for this reason, they do not intend to constitute an exhaustive framework on the topic, but a first analysis of what has already been carried out. In particular, in the work this relationship is studied taking into account both (i) the effects that the initiatives on the territory determine on the real estate mechanisms, in terms of variation in the real estate values and dynamism of the supply and the demand and (ii) the modalities in which the market trends (volume of transactions, prices, rents, average sales times, supply and demand) influence the urban transformation processes.

In Fig. 1 the two main perspectives explained in the relationship between the market and the urban redevelopment are shown and the double linkage that is established

between them in terms of cause and effect is highlighted by the double direction of the introduced arrow.

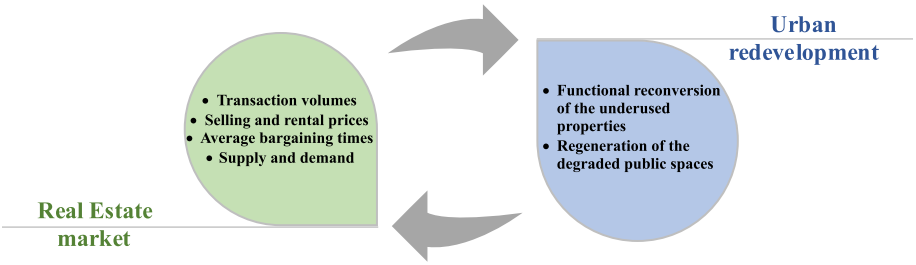

Fig. 1. The double relationship between the urban regeneration initiatives and the property market dynamics

The existing reference literature is mainly focalized on the first aspect described (analysis of the impacts deriving from the implementation of urban interventions on the real estate market) and aims to provide a valid support for decision-making processes, since the increase in the property asset values is included among the benefits associated with the development of such initiatives. In this sense, different Authors have carried out e*x ante* and *ex post* evaluations on the possible (in the situation of a preliminary assessment with the intervention that is not yet implemented) or already obtained (in the situation of an *ex post* evaluation with the intervention that is concluded) implications that the urban renewal project generates on the local real estate market [9–13]. With reference to different geographical contexts and time periods, the main purpose of the scientific contributions belonging to this research line concerns the definition of evaluation models capable of examining the market effects connected to the execution of real estate and/or urban enhancement initiatives in order to address the local government policies. In general terms, it is known that an urban transformation strategy (appropriately developed starting from the analysis of the framework of the community needs and following the verification of the financial and economic feasibility of the project) produces an increase in the urban quality of the area in which the project is implemented and, thus, a positive variation in the property values. The direct relationship that associates the raising of the quality conditions of the place, consequent to any redevelopment project on an urban scale, and the increase in the values of the property stock represents a crucial and widely studied in the literature issue.

The same relationship between the urban redevelopment and the dynamics of the real estate market in the opposite direction (aimed, therefore, at verifying how the specificities of the market affect the transformation operations to be carried out in the territory) is explored in targeted studies of the reference literature [14–16].

In particular, starting from the examination of the market trends (analysis of the supply and demand and the average market values), the decision-making processes related to the urban redevelopment can be guided by the local market mechanisms. In this sense, in the present review a set of papers that intend to evaluate whether and to what extent the market dynamics orient the urban planning choices are explained and

studied. From this perspective, the analyzes focused on the examination of the linkage between the market trends and the local renovation initiatives to be carried out, are part of the broader context of the scientific researches aimed at providing effective tools to support the public administrations and the potential investors towards aware and profitable choices. In fact, the identification of the aforementioned relationship should be included among the operations for the *ex ante* evaluation of the sustainability of the interventions in order to validate or refute the investment choices. It should also be pointed out that from the first phases of defining the project solution, the analysis of the current and forecast market supply and demand constitutes a fundamental step for the continuation of the subsequent levels of planning and of the following intervention realization. This demonstrates the importance assumed by the examination of the existing market conditions in the urban area in which the project is located and, from a broader perspective, of the city in order to (i) select the intended uses that are most suitable to the current needs and requests of the local community, (ii) possibly, move the area in which to operate to other ones in which the market dynamics are more adequate to the set purposes.

Therefore, the goal of present research regards the (not exhaustive) recognition of the literature focused on the illustrated topic, by distinguishing the studies that analyze the explicit relationship in one perspective (effects of redevelopment on the dynamics of the real estate market) and those that delve into the same issue but in the opposite sense (impacts of the real estate mechanisms on the redevelopment choices), with different purposes and practical implications. From the first screening of the researches on the topic, its relevance has clearly emerged and it will be further explored through the increase of the set of papers.

To successfully achieve the fixed literature review's targets (that in the current form constitutes an intermediate step of an in progress research aimed at providing a comprehensive and wider framework of the scientific contributions on the topic), this work is articulated as follows. In the third section the method carried out for identifying the papers to be included in the collection is briefly illustrated. In the fourth section the analysis of the records included in the review is developed in order to summarize the most relevant outputs and to highlight the main focuses. In the fifth section, the conclusions of the work are discussed.

3 The Methodology Adopted for the Literature Review Development

To effectively carry out the systematic analysis of scientific literature papers on the already introduced topic, the first phase of the implemented methodology concerns the definition of targeted keywords and combinations of them, to be included in the main databases for the selection of records consistent with the focus. In particular, the identification and selection of contributions has been carried out on the Scopus, Web of Science and Google Scholar databases by entering the following keywords: (i) urban requalification, (ii) urban transformation projects, (iii) interventions on territory, (iv) real estate market, (v) properties prices, (vi) rental prices, (vii) residential market dynamics, (viii) real estate trends, (ix) relationships between market and redevelopment.

Starting from the obtained multiple records, the detection of the most adequate ones has been performed, by taking into account the consistence with the objectives of the present analysis, the availability of the open access text and the language of the selected contributions, thus excluding those whose topic is not consistent with the aspects strictly connected to the explored focus, and those not available and written in a language other than English. From the selection carried out according to the chosen exclusion criteria, fifty papers have been definitively collected and subsequently analysed, in order to investigate the issues analyzed by each work, to identify the goal, to highlight any points of contact and differences in terms of obtained outputs.

The methodology used for the collection of scientific contributions has allowed to provide a (non-exhaustive) framework of fifty papers focused on the analysis of the existing relationships between urban redevelopment and the dynamics of the property market, in terms of (i) effects generated by the implementation of intervention on market mechanisms or, vice versa, (ii) influence determined by the local market trends on the urban planning choices.

It should be highlighted once again that the present work is part of a wider research (currently *in itinere*) that intends to examine the topic in a more detailed way: in this sense, this study represents an intermediate step of a broader analysis.

With reference to the set goals, in Table 1 an overview of the fifty papers collected in the present review is provided: according to the chronological order of the references, the year of publication and the geographical context of analysis (if expressly declared) of each record are included in the second and third columns, and the studied relationship (among the two previously explained) based on the goal of each research is reported in the fourth column.

Table 1. Analysis of the selected records

No.	Year of publication	Context of analysis	Analyzed perspective
[17]	1992	USA	Real Estate market -> Urban redevelopment
[18]	1994	Newcastle upon Tyne, England	Urban redevelopment -> Real Estate market
[19]	1999	Pacific Rim Cities	Real Estate market -> Urban redevelopment
[20]	2001	Undefined	Real Estate market -> Urban redevelopment
[21]	2002	China	Urban redevelopment -> Real Estate market
[22]	2002	China	Real Estate market -> Urban redevelopment
[23]	2003	Singapore	Urban redevelopment -> Real Estate market

(*continued*)

Table 1. (*continued*)

No.	Year of publication	Context of analysis	Analyzed perspective
[24]	2003	Beijing, China	Real Estate market -> Urban redevelopment
[25]	2005	Hong Kong, China	Real Estate market -> Urban redevelopment
[26]	2005	Athens, Greece - Bratislava, Slovakia - Brussels, Belgium - Helsinki, Finland - Lyon, France - Madrid, Spain - Manchester, England - Newcastle upon Tyne, England - Stuttgart, Germany - Valencia, Spain - Vienna, Austria and Zurich, Switzerland	Urban redevelopment -> Real Estate market
[27]	2009	Milwaukee, Wisconsin - USA e Minneapolis, Minnesota - USA	Urban redevelopment -> Real Estate market
[28]	2011	Norway	Real Estate market -> Urban redevelopment
[29]	2011	Undefined	Urban redevelopment -> Real Estate market
[30]	2011	Hong Kong, China	Urban redevelopment -> Real Estate market
[31]	2013	China	Real Estate market -> Urban redevelopment
[32]	2013	Undefined	Real Estate market -> Urban redevelopment
[33]	2014	Reggio Calabria, Italy	Real Estate market -> Urban redevelopment
[34]	2015	Italy	Real Estate market -> Urban redevelopment
[35]	2015	Italy	Real Estate market -> Urban redevelopment
[36]	2016	Milan, Italy	Real Estate market -> Urban redevelopment
[37]	2016	Kalisz, Poland	Urban redevelopment -> Real Estate market
[38]	2016	Undefined	Real Estate market -> Urban redevelopment
[39]	2017	Taipei, Taiwan	Urban redevelopment -> Real Estate market

(*continued*)

Table 1. (*continued*)

No.	Year of publication	Context of analysis	Analyzed perspective
[40]	2017	Oslo, Norway	Urban redevelopment -> Real Estate market
[41]	2017	Krakow, Poland	Real Estate market -> Urban redevelopment
[42]	2017	Shenzhen, China	Urban redevelopment -> Real Estate market
[43]	2017	Konya, Turkey	Real Estate market -> Urban redevelopment
[44]	2018	Sydney, Australia	Real Estate market -> Urban redevelopment
[45]	2018	Hong Kong, China	Urban redevelopment -> Real Estate market
[46]	2018	Milan, Italy	Real Estate market -> Urban redevelopment
[47]	2018	North of Italy	Real Estate market -> Urban redevelopment
[48]	2019	Naples, Italy	Real Estate market -> Urban redevelopment
[49]	2019	Tehran, Iran	Real Estate market -> Urban redevelopment
[50]	2020	Osun, Nigeria	Urban redevelopment -> Real Estate market
[51]	2020	Milan, Turin, Padua, Novara, Udine (Italy)	Real Estate market -> Urban redevelopment
[52]	2020	Naples, Italy	Real Estate market -> Urban redevelopment
[53]	2020	China	Real Estate market -> Urban redevelopment
[54]	2020	Reggio Calabria, Italy	Real Estate market -> Urban redevelopment
[55]	2020	Bari, Italy	Urban redevelopment -> Real Estate market
[56]	2020	Copenhagen, Denmark and Hamburg, Germany	Urban redevelopment -> Real Estate market
[57]	2020	Porto, Portugal and Brescia, Italy	Urban redevelopment -> Real Estate market

(*continued*)

Table 1. (*continued*)

No.	Year of publication	Context of analysis	Analyzed perspective
[58]	2020	Trento, Italy	Real Estate market -> Urban redevelopment
[59]	2021	Poznań, Poland	Urban redevelopment -> Real Estate market
[60]	2021	Singapore	Urban redevelopment -> Real Estate market
[61]	2022	England	Real Estate market -> Urban redevelopment
[62]	2022	Buenos Aires, Argentina	Real Estate market -> Urban redevelopment
[63]	2022	China	Real Estate market -> Urban redevelopment
[64]	2023	Connecticut, USA	Real Estate market -> Urban redevelopment
[65]	2024	Hong Kong, China	Urban redevelopment -> Real Estate market
[66]	2024	Delhi, India	Urban redevelopment -> Real Estate market

4 Results of the Records Analysis

The effects that the urban regeneration can generate on the property market are multiple and can translate into positive or negative results. The redevelopment of degraded or abandoned urban tissues or buildings through targeted interventions can – *inter alia* – determine significant changes in the selling or rental prices of the properties located in the surrounding areas, with the consequent variations in the market demand and supply.

In this regard, the scientific literature is full of relevant contributions that aim to demonstrate and examine the existing relationship between the urban redevelopment and the real estate market dynamics. By analysing this relationship, the publications are focused on several aspects of the overall topic, also based on the different case studies for which the mentioned link is studied.

For example, Healey in 1994 [18] has investigated the impact of the public policy on the real estate development in an old industrial urban area of Tyne and Wear (in the North East of England) and the connected effects on the main trends of the specific sector. Furthermore, the Author has underlined the importance of understanding a priori the specificities of the local real estate development for the effective design and the evaluation of public governance strategies aimed at its strengthening and improving.

The implications of the urban redevelopment implemented with both public and private funds on the residential market segments in [27] have been dealt with by De Sousa et al. and by Ki and Jayantha [29], with the purpose to assess the variations on housing prices after the examined interventions.

Through the application of mathematical models and the use of technological tools such as Geographic Information Systems (GIS), Tiboni et al. [57] have defined a methodology for analyzing the effects of urban regeneration in historic centres, able to provide a useful tool for public subjects as promoters of redevelopment initiatives.

Similarly, Jayantha and Yung [45] have explored the consequences derived from the enhancement of historic buildings on the values of commercial properties located in the immediate proximity of the renovated sites.

The use of the Quantile Regression technique has allowed to assess the direction and strength of the impact of the urban renewal processes on the housing market mechanisms in terms of prices changes in the secondary residential market in downtown of Poznań (Poland), in order to analyse the redistribution of the implications on the specific market [59].

According to Gospodini [26], however, the discussion also concerns the potential of the urban transport infrastructures (such as subways, regional railways and tram) realization, that can indirectly act as a catalyst for the regeneration of degraded areas. The focus is, then, more recently reiterated in the research carried out by Agnihotri and Paul [66], in which the relationship between metropolitan rail connectivity and housing prices in Dehli has been studied. A direct spatiotemporal influence on the residential values in the surrounding areas has been found, by assessing the average annual price shift for apartments around metro stations from 2010 to 2019.

By analyzing the specific case of Singapore, Dell'Anna et al. [60] have identified the close correlation between the urban infrastructural development and the real estate market.

The economic policies of the local public administrations have often affected the planning of the redevelopment interventions. Bruns-Berentelg et al. [56] have dealt with the regeneration processes implemented since the 1990s in the cities of Copenhagen (Denmark) and Hamburg (Germany). While the objective of the Danish administration pursued in the redevelopment of its Ørestad and port districts was to finance a mass transport system at city level and, therefore, to improve competitiveness through the development of infrastructure, that of the German town is was to use the redevelopment of HafenCity's waterfront to increase competitiveness through port modernization.

In addition, Yau [30] has explained how the urban redevelopment may be responsible for the gentrification of neighbourhoods due to the resulting increase in property prices and rents near redeveloped sites. The same topic has been then explored in depth by Liu et al. [42] through the exam of the causes and consequences of redevelopment-induced indirect displacement. The Authors have investigated the chain effects of price-shadowing in Shenzhen (China), by concluding that the urban regeneration exhibits strong impacts on adjacent housing prices by creating property hotspots and bringing about changes in the market mechanisms.

By reversing the perspective and analyzing the role of the real estate market in the definition of urban regeneration policies, the literature traces a clear common thread. The exam of the current real estate dynamics is certainly useful for supporting decision makers in developing effective urban regeneration plans and projects, and thus orienting their choices. This topic is widely developed in [52] with the aim of analyzing the real estate mechanisms of the city of Naples (Italy) through the integration of a Multi-Criteria Decision Analysis method (MCDA) and the GIS.

The evaluation of real estate assets value currently represents one of the crucial aspect for the territorial marketing strategies definition, with a view to developing high-performance and competitive cities. In this framework, an integrated assessment model capable of mapping out and encapsulating the multidimensional set of factors that shape the attractiveness of alternative real estate transactions has been proposed by Del Giudice et al. [48].

The study of the real estate market data, to understand the differentiation of housing prices and orient the urban space transformation initiatives, is a key issue of the discussion of Wu [22] carried out for the Chinese city of Shanghai.

The implementation of the multi-criteria analysis methodologies has proven to be particularly useful in the processes of urban regeneration and local development. In fact, Calabró and Della Spina [38] have concluded that these assessment tools are highly strategic, especially if adopted before the planning or feasibility verification phases, by playing a monitoring and management role of the projects to be carried on the territories.

With reference to the UK commercial property markets, the benefit in the use of system dynamics modelling to understand the market mechanisms and their long-term behaviour has been pointed out in [61]: the approach concerns non-linear model of the complex relationships and behavioural factors that are difficult to include in existing econometric models, among which the potential impact of the redevelopment on the supply of new properties and rental growth and the response times of various parts of the market development process to the market signals. Within the illustrated question, the study carried out by Omidipoor et al. [49] has explained how the active involvement of owners, investors and administrations is able to increase the success of the urban redevelopment. In order to promote the participatory processes, a spatial decision support system based on GIS tool for the owner-investor partnership in the renovation of the urban blighted areas has been developed. Similarly, Lombardi and Ferretti [34] have claimed that the current decision-making processes are based on evaluation systems that are not able to address the problem as they do not take into account the complete involvement of the interested actors. Therefore, the Authors have presented an innovative generation of evaluation systems to orient the decision-making mechanisms in the urban planning and regeneration, in order to empower planners and decision makers to better understand the interaction between city design, social preferences, economic issues and policy incentives.

Then, Bottero et al. [47] have developed an evaluation model to support the choice process related to the interventions of urban regeneration. In particular, in the study an original multi-criteria approach that combines SWOT Analysis, Stakeholder Analysis and PROMETHEE method for the assessment of alternative regeneration strategies of an urban area in Northern Italy has been proposed.

5 Conclusions

In the present paper the relationship (in both perspectives) between i) the effects that territorial regeneration interventions could determine on the real estate dynamics, in terms of changes in property values and dynamism of supply and demand and ii) the modalities in which the market trends (volume of transactions, selling prices, rents, average sales times, supply and demand) can influence the urban transformation processes, has been examined.

The analysis of the scientific literature on the topic (fifty relevant paper) has allowed to highlight the general significant positive effects of a redevelopment project on the surrounding real estate market mechanisms. Furthermore, the study has pointed out how the various factors (sales and rents time, market trends, size of the area to be redeveloped, etc.) can affect the implementation of an urban project and the previous decision making processes. In this sense, the territorial renewal initiatives – if effectively carried out in consistence with the current needs of the community and the reference regulatory provisions - increase the attractiveness of the local real estate market. Therefore, an intimate connection between the transformation of urban space and the increase of the property market values is established: the renovation project, in fact, will promote the market desirability, by generating the rental and selling prices growth related to the properties located in the same urban context. This output is ordinarily found in the academic contributions aimed at assessing the impact of these urban strategies on the value of the existing (residential, commercial, offices, etc.) property assets carried out in different international geographical contexts.

However, despite being potentially positive due to their ability to meet the communities demand and to provide new and necessary infrastructures and collective services to replace the lacking or inefficient ones, the urban redevelopment investments have a high implicit risk. In fact, the cogency to support the public administrations in the choice processes (in the situations in which different proposals are developed or limited financial resources can be used) has emerged. In this sense, the evaluation discipline should orient the decision mechanisms related to the implementation of valid urban initiatives toward those able to generate a series of positive consequences for the economy and local well-being. Furthermore, the assessment of the effects of the regeneration operations on the property market dynamics represents a useful tool capable of addressing the projects to be carried out on the territory. The evaluation models – defined for the verification of the feasibility of the projects and their selection among different alternatives – should be combined in multi-criteria analyses for the effective process control.

In addition, the systematic exam of the scientific literature concerning the relationships between the property market trends and the urban interventions planning has highlighted how the (current and forecast) market supply and demand can influence the identification of the initiatives to be performed on the territories. The integration of the investigation of the real estate market specificities with the use of the GIS tool can provide a valid indication for obtaining an initial ‘snapshot’ of the areas to be renovated and for planning future urban regeneration scenarios. In the outlined framework, the real estate dynamics that characterize a specific urban context and the communities’ needs overview represent helpful references for guiding urban planning strategies.

In this sense, this review does not aim to identify and systematize the contents of all the relevant papers, but it limits itself to providing an approach to the analysis of the studied relationship. This goal has been pursued through the study of the consistent relevant literature on the analysis of the double perspective in which the relationship between the investments on the territories and the property market dynamics can be identified and interpreted.

The practical implications of the study carried out in this paper and in progress for further developments, firstly, regard the development of a framework of significant studies on the issue that, with reference to different geographical contexts and purposes, intend to focalize on multiple aspects related to the broad question. Currently, the urge to define suitable polices for the sustainable development of the cities is strictly connected to (i) the scarce public financial availability, (ii) the consequent involvement of private investors (who take part to the initiatives in the only profitable situations), (iii) the need to improve the quality of the degraded and/or abandoned urban areas, (iv) the fixed goals for the creation of more living and safe cities. The likely effects that an urban regeneration initiative could determine on the property market mechanisms (in terms of future forecast demand and supply, real estate prices, selling time, etc.) constitute an important question to be assessed in the wider framework of the benefits deriving from these interventions implementation, as they are mainly indicative of the market appreciation of the specific urban area and, thus, of the value of the property (residential, commercial, offices) assets. On the other hand, the analysis of the current and forecast market trends is fundamental to address the urban planning and design decisions, as the market dynamics (in terms of appreciation and preference by the community, prices, number of transactions, etc.) constitute a proxy variable of the urban quality level of the specific area. The choices of the potential users and investors of living or investing in a specific territory allow the decision makers to understand its potentialities and to identify the areas on which a higher interest by them could be attested. However, this should not determine an unbalanced development of the cities, but should help the planning of the interventions to be carried out according to the given priorities, that are associated to the current property market mechanisms (interest shown by potential investors, demand and supply dynamism, etc.).

Note: The current study has been developed within the current research "Resilience and sustainability of urban regeneration initiatives. Methods for assessing the effectiveness of investments on the built environment", Call for Research Projects 2022, Sapienza University of Rome.

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Exploring the Privacy Horizons: A Survey on HCI & HRI

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Abstract. With the constant evolution of technology and the rise of Human-Computer Interaction (HCI) and Human-Robot Interaction (HRI), Human-Technology Interaction (HTI) is becoming more important in everyday life, covering several routines closely linked to technology. In this survey, we aim to examine the important domain of user privacy in the contexts of HCI and HRI. Additionally, we analyze privacy issues, ranging from data collection to ethical and legal implications. Through a detailed analysis, we also highlight challenges and strategies for designing interactive systems that prioritize end-user privacy. This survey aims to provide a clear and comprehensive overview of the challenges and opportunities of integrating privacy into interactive systems. Finally, we will present the different strategies and techniques to be used, such as encryption and anonymization, to improve the level of privacy protection.

Keywords: Human-Computer Interaction · HCI · Human-Robot Interaction · HRI · Human-Technology Interaction · HTI · User Privacy · Ethics · Artificial Intelligence

1 Introduction

With the constant evolution of technology and the rise of Human-Computer Interaction (HCI) and Human-Robot Interaction (HRI), Human-Technology Interaction (HTI) is gaining more and more importance in everyday life, covering several routines closely linked to technology [19]. With the advent of new interactive and always-connected devices, innovative means of interaction between humans and technology have opened up, such as voice assistants, smart home devices, self-driving vehicles, and more. However, these devices have also raised new questions, concerns, and issues regarding the protection of personal data and user privacy [26]. According to the literature, data-driven technologies such as Big Data, Machine Learning, Cloud computing, and the Internet of Things can provide relevant benefits not only for improving production performance but also improve the working environment of humans. However, since these technologies

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require the acquisition, communication, storage, and processing of personalized and potentially sensitive data of human workers, privacy concerns are becoming more relevant [8]. In the context of HCI, for instance, particular attention is paid to the widespread routine of unconscious data collection, which violates users' privacy, autonomy, and self-determination. These problems are exposed in many recent studies, where users are not informed or are unaware that data is being collected without their consent [18]. In addition, high-tech sectors, such as the automotive industry, are adopting new criteria for evaluating cybersecurity related to human-technology interaction; this represents a growing awareness of the importance of security and privacy considerations in the domain of human-robot interaction.

We aim to examine how these considerations apply to HCI and HRI in general by setting out the issues and strategies to minimize privacy risks. In this context, this survey undertakes an in-depth analysis of the complex world of privacy from various perspectives, considering the challenges posed by technological evolution, innovative design strategies, and the related methodologies required to preserve end-user privacy.

2 Methods

In this section, we analyze the proposed methodology that led to the drafting of this survey. It is necessary to use a suitable search methodology to investigate and analyze a research problem and explain which design strategies and techniques can be used to protect the privacy of end-users in HCIs and HRIs.

2.1 Keywords, Databases, and Search Strategy

The first step was to select the relevant keywords and scientific databases to extract information regarding our objectives. For this phase, we selected keywords such as "privacy", "HCI", "Human-Computer Interaction", "Human-Robot Interaction", "HRI","Human-Technology Interaction", and "HTI" with the Boolean operators "AND" and "OR" where necessary. Google Scholar, ACM Digital Library, Semantic Scholar, and IEEE Xplore were used as the academic databases for searching the documents.

2.2 Data Extraction

For this research, we used the most recent and relevant documents concerning our objectives. After the extraction of articles, a further check was performed by an initial scanning of the title and abstract of the papers. This was done to analyze the relevance of the paper to the problem and to check whether it was a potential candidate for further investigation. Subsequently, the full texts of selected articles in the previous phase were thoroughly read and the final articles were selected. As a final step, we extracted relevant information related to our objectives. In particular, each selected paper was annotated, by noting the

bibliographical data and its salient points (proposal/device), results, limitations, future work, and privacy considerations. The key documents for drafting this paper were original journal articles and conference papers. Some review papers were chosen for their useful basic concepts of privacy for end users.

3 Privacy: A Preliminary Analysis

The term privacy is a complex and multidimensional concept that plays a fundamental role in today's society. It influences various aspects of our daily lives, from the personal to the social and economic spheres. When we mention privacy, we refer to the ability of individuals to control access to their personal information and data while minimizing interference from unauthorized third parties. As privacy is a very complex concept, we can categorize it into different groups:

1. **Physical Privacy**: Physical privacy refers to the right of individuals to maintain control and privacy over their bodies, personal spaces, and physical personal information by restricting access to outsiders. This type of privacy encompasses both the home and work environment and includes the integrity of the body, preserving physical safety, and preventing unintended actions such as unauthorized photographs. Finally, there is the issue of freedom of movement which concerns the ability to move without being constantly monitored in both the physical and digital worlds [16].
2. **Data Privacy**: Data privacy concerns all digital interactions that people may have during their daily lives [31]. This type of privacy can in turn be divided into different spheres:
   - **Personal privacy** concerns with the protection of individual's identifying information such as name, address, and any information that organizations or services may collect [9];
   - **Financial privacy** deals with the sharing and protection of sensitive information related to personal finances such as banking transactions and investments while maintaining the integrity of financial transactions [6];
   - **Health privacy** refers to maintaining patients' sensitive medical data such as patient's name, date of birth, address, photos, ID card number, telephone number, and medical record number. This should be done while preserving privacy and data availability by anonymization and de-identification techniques. This type of privacy can also be referred to as personal privacy of patients [27]; The Health Insurance Portability and Accountability Act (HIPAA) act for privacy safeguards Protected Health Information (PHI) or identifiable health information of the individuals [7].
3. **Communications Privacy**: As technology continues to evolve, communications privacy plays a more fundamental role. It covers different communication aspects, from the protection of interpersonal communications that can take place via messages, and calls, to the confidentiality of digital interactions on social media. This important aspect concerns communications in the work environment, as business emails and conversations with colleagues should be private and secure [25].

4. **Information privacy**: Information privacy concerns the control over the disclosure of personal information such as the protection of an individual's beliefs and opinions, preventing them from being misused. Information privacy therefore relates to the right of individuals to determine the method, time, and scope of information to be disclosed to others [35]. Another aspect is creative expression, in that a person's artistic and creative works must be preserved.

It is important to emphasize that the different categories of privacy are not clearly distinguished and often interact with each other. Moreover, technological developments continue to redefine these notions, raising new challenges and doubts about privacy management.

4 Privacy Issues in HCI and HRI

The evolution of Human-Technology Interaction has generated a fusion of digital interfaces and interactive robots and created a new ecosystem rich in opportunities. However, there are challenges and issues regarding user privacy. As indicated in the literature, Privacy is a complex and multifaceted issue that has been studied in a variety of fields, including law, sociology, psychology, and computer science. In the context of HCI and HRI, privacy concerns arise when users interact with systems that collect, use, and share personal information [24]. In this section, we will explore how and what privacy implications for the user are generated by the intersection of interfaces and robots in different contexts and situations.

4.1 Privacy Issues in Voice Assistants and Connected Devices

Voice assistants and connected devices have become increasingly popular in recent years, which has taken human-technology interaction to very advanced levels. As HTI has evolved, new privacy issues have emerged, and "there are also several concerns including deception, infantilization, and privacy" [17]. One of the main problems with these devices is the collection and storage of users' sensitive data. Voice assistants such as Alexa and Google Assistant are designed to recognize and interpret voice commands, but this requires recording and analyzing the conversations users have with them. Furthermore, "the ontological categorization of voice assistants is nuanced with a particular categorization of Alexa as "object like" or "human-like" triggered in relation to the nature of the interaction (e.g., responsiveness) and the user's desire for social connection or companionship" [17]. However, this type of technology raises privacy concerns regarding the private conversations of individuals, as there could be the possibility of unauthorized access and listening to the devices, resulting in the disclosure of captured information. It is also possible for personal information to be inadvertently disclosed through secondary channels as a consequence of what you are doing; such secondary channels can be either connected devices or

voice assistants [22]. Another concern relates to data sharing by organizations that claim to use collected data to improve the user experience. However, there are doubts about the amount and nature of the sharing of collected data, and according to the literature, "personal data is the price people pay for access" [17] the benefits of these technological devices. However, other fundamental questions arise about transparency and user consent regarding how their data is used and shared. Tackling these issues requires a rigorous approach to privacy protection. In this respect, companies should ensure that collected data is encrypted during transmission and storage, thus reducing the risk of unauthorized access.

4.2 Privacy and Security Issues in Drone Use

Another technology that has become very popular in recent years is the use of drones in a wide range of fields, from the exploration of inaccessible territories to industry and recreational use.

However, their ability to collect data and fly over sensitive spaces has raised concerns about the protection of individual and collective privacy. As previous studies have shown, drones can violate users' privacy through unwanted intrusions into private spaces and observing these places [5]. The ability of drones to fly at low altitudes and the ability to record video and take photos could violate people's privacy in their homes or private spaces, triggering additional issues "such as fear of damage or injury and unwillingness to disclose personal information under drone surveillance" [5]. Another issue related to drones is that they may be equipped with technologies and sensors that can collect detailed information about the surrounding environment; this includes geographical, visual, and even biometric data. The collection and analysis of this data by third parties raise questions about data ownership and unwitting profiling of individuals. Furthermore, the transmissions used to control the drones and receive the collected data trigger another concern: the security of the transferred data. Such transmissions can be vulnerable to unauthorized access or cyber-attacks, compromising the confidentiality of the data collected and the privacy of the people involved. It is therefore important that drone users, both at the individual and organizational levels, address these concerns by implementing measures to ensure that people's privacy is respected; this includes regulating the use and encryption of data collected by drones.

4.3 Privacy Considerations and Issues About Social Robots in Public and Private Environments

"More affordable social robots are being commercially released and to implement viable applications of HRI, a combination of HCI, and user experience methodologies could play a pivotal role in assessing new scenarios and evaluating new investigations" [13]. This type of technology has considerable potential to improve people's daily lives. However, it collects sensitive information in new and different ways such as smartphones. The mobility and autonomy of these devices can threaten the privacy of end-users in unique and as yet unexplored

ways [15]. However, the constant exchange of information between people and robots and the increasing interconnectivity of these devices give rise to "scalability problems that make traditional security countermeasures inapplicable". Security flaws can cause damage to vehicles, financial losses, disclosure of sensitive personal data, and traffic accidents introducing additional privacy concerns for users [3]. In HRI, privacy concerns can arise when robots collect personal information about users, such as their location, activities, and preferences. Robots may also capture images and videos of users and their surroundings, raising concerns about surveillance and data security [24]. Social robots are designed to interact and assist people and they offer various applications in both public and private contexts.

In public settings, such as shopping malls, museums, entertainment venues, or healthcare, these robots can be designed to facilitate the public experience or simplify some work, while collecting a wide range of information. However, it is pointed out in the literature that the collection of biometric data, e.g. in healthcare, by robots may cause a violation of users' privacy, as this data is considered personal and confidential. In particular, it is emphasized that the collection of biometric and sensitive data requires the use of numerous sensors. The use of multiple sensors can be considered invasive and pose a threat to users' privacy. Furthermore, the collection of sensitive data by robots is inevitable during the entire human-robot interaction process, which makes the protection of privacy even more important for the effective use of this technology [32].

An experiment from the literature examines people's behavior towards a robot that exploits data collected from customers during interactions. Specifically, the aim of the experiment concerns the ability of robots to interpret privacy expectations in ambiguous social contexts, such as bars or spaces that could be considered both public and private spaces [10]. In private contexts, on the other hand, robots may collect and use users' personal information, such as conversations, consumption habits, and movements within the house. This may pose risks to users' privacy, such as unauthorized disclosure of personal information or non-consensual surveillance [35]. The use of these devices and the privacy issues associated with them will not be discussed in detail below as they have already been examined in Sect. 3. Social robots are also increasingly being made with anthropomorphic forms and, as a result, the use of voices and faces may be more familiar to the user. However, "an important factor to consider is that an anthropomorphic form may mislead or distort users' understanding of the robot's recording capabilities" [14].

4.4 Privacy Considerations about the Use of Apps

With the arrival of the digital era, a wide range of apps have also been introduced that are used in daily activities, giving people instant access to information, services, and entertainment. This has also led to an abuse of data collection by these apps and caused several privacy issues in this area as well. In this section, we will analyze the factors that tend to influence users on whether or not they want to continue using privacy-invasive apps and that could lead to emotional

distress. Nowadays, apps collect various information about users, from browsing preferences to geographical information. Even though they collect more and more data and information that is misused, users tend to continue to use these apps; this is due to factors such as convenience, ease of use, and attraction of these innovative features. As indicated in the literature, "the privacy paradox suggests that people may express concerns about privacy but continue to use privacy-invasive apps" [23]. This highlights how intrusiveness in the collection of personal information by apps can generate feelings of distrust in the digital environment. Despite this concept, the integration of these apps into everyday life tends to minimize emotional distress if they are needed for gaining practical benefits. The data collected by these apps, however, can be exploited to manipulate users' choices and behaviors. Therefore, there is a need for greater awareness among users about the risks of using these apps.

4.5 Privacy Considerations - Ethical and Legal Implications

The increasingly intense interaction between humans and technology entails several complex ethical and legal implications. Therefore, the European Union's General Data Protection Regulation (GDPR) and the California Consumer Privacy Act (CCPA) in the United States are crucial in drafting regulations and practices related to these interactions. The GDPR is a European Union regulation that was enacted to strengthen data protection laws within the EU, giving people more control over the information being collected, processed, and stored by organizations. The CCPA is a privacy law in the United States and was drafted based in part on the GDPR; its purpose is equivalent to the GDPR with some differences in provisions. According to the literature, "Privacy is a fundamental human right that is protected by law in many countries. However, the design of ubiquitous computing systems often fails to take into account the privacy needs and expectations of users, leading to a range of privacy violations and negative user experiences." "Privacy concerns in HCI and HRI can be categorized into several dimensions, including data collection, data use, data sharing, and user control" [24].

From an ethical point of view, human-technology interaction raises important questions about privacy and the protection of personal data. In fact, the collection, processing, and storage of sensitive data often take place in a non-transparent or unclear manner; this can make users feel 'violated'. The GDPR stipulates that to collect and process data, informed user consent must be obtained and should ensure that the data collected is only used for legitimate and specific purposes. The GDPR has several provisions, including the 'Right to Data Portability', which is the right that people have to move their data from one system to another and it is important when a user wants to switch from one device to another. From a legal perspective, however, the CCPA in the US and its GDPR analog in the EU emphasize transparency, accountability, and individual control over personal data [11]. The CCPA also has several provisions, including the 'Right to Know', meaning individuals have the right to know what data is being collected and shared with companies, allowing them to have active

control over their privacy. This is a key point in human-technology interaction as data collection can influence personal decisions such as consumer or financial choices [21]. Technological evolution leads to some crucial questions:

- How can technological evolution be balanced with users' privacy protection?
- How can it be ensured that interactions between humans and technology respect people's rights?

In the next sections, we will investigate which design strategies and techniques attempt to answer these questions and discuss the approaches that seek to enable the preservation of individuals' privacy in the various contexts of human-technology interaction.

5 Techniques and Design Strategies for Privacy Preservation

The evolution of privacy-oriented design strategies has resulted in many techniques that preserve the confidentiality of data collected by systems and bring about a balance between the functionality of systems and respect for privacy. These strategies can address different privacy concerns and help define a more secure and trustworthy digital ecosystem. There are several strategies to preserve privacy in HCI and HRI contexts. These strategies can be considered as design guidelines for interactive systems [30]. Different strategies for privacy preservation are outlined below:

- **Data anonymization:** This strategy is the 'irreversible' and 'permanent' de-identification operation aimed at turning personal data into anonymous data before it is processed or shared. Anonymizing personal data means being able to make use of that information without obligations and responsibilities imposed by data protection regulations. Therefore, through the anonymization process, the risk of recognizing a user will be decreased [20,29].
- **Minimization of data collection:** This strategy involves collecting only the information that is strictly necessary for the proper operation of the system or application. Thus, it can reduce the exposure of personal data.
- **Pseudonymization:** This strategy, on the other hand, is the 'reversible' de-identification operation that can reduce the 'privacy risk'. This strategy replaces personal information with pseudonyms or unique identifiers, making direct association between data and individuals more difficult. The pseudonymized data can be attributed to a specific subject only by providing separately kept additional information [20]
- **Access Control:** With this strategy, suitable controls are implemented to determine who has access to the data and to what extent. This ensures that only people with the right authorizations can access the collected data [1].
- **End-to-end encryption:** This strategy guarantees, through encryption, the confidentiality of information by allowing access only to authorized people. Anyone who does not have the matching private key when transmitting and storing data will not be able to read it. This can prevent unauthorized third parties from accessing or compromising the collected data [2].

- **User consent management:** This strategy involves requesting explicit consent from users to be able to collect, process, or share data that is collected. It also allows the withdrawal of consent at any time the user wishes [12].
- **Privacy by Design:** This strategy aims to ensure a proper level of privacy and protection of personal data from the design phase of any system, service, product, or process as well as during their life cycle. This means that a proper level of data protection is ensured in all activities that involve the handling and processing of data within an organization [4].
- **Data retention limitation:** With this strategy, a specific period is defined for the retention of collected data. At the end of this period, the data will be automatically deleted or anonymized which can reduce the risk of retaining sensitive information for a long and unnecessary time.
- **Transparency and communication:** This strategy involves communicating clearly and explicitly to users about the application of collected data, thus building a base of trust and awareness [33].

Of the strategies and practices mentioned above, some of the most common methods for data protection and privacy protection are: data anonymization, encryption, and privacy by design. In the following we will examine these strategies and discuss why they are important and why they should be used in the design of interactive systems.

5.1 Data Anonymization

This strategy represents one of the first strategies adopted and is divided into four different techniques: masking, randomization, generalization, and layered anonymization.

- **Masking** removes all data that can directly identify the user (e.g. name and address), thus acting on the level of detail without altering the original data.
- **Randomization** alters the original data by separating the user from it and making it less accurate. As the altered data is no longer accurate, it makes it impossible to relate it to a specific individual [36].
- **The generalization of data** involves replacing more specific data entries with broader ones to prevent individual identification. This method is generally used in k-anonymity infrastructures and maintains data usefulness for analysis while preserving privacy [28].
- **Stratified anonymization** is also called re-anonymization. It focuses on anonymizing data already anonymized in a previous phase.

The choice of method to be used depends on the organization's needs; therefore, it must be done by carefully evaluating the database and the objectives to be achieved.

5.2 Encryption

Encryption, on the other hand, is the basis of data protection and is the most important way of ensuring that information cannot be stolen and read by unauthorized third parties. It is essential that a cryptographic algorithm offers:

- **authentication:** the process of attesting to the identity of each participant in a communication;
- **secrecy:** ensuring that no one can read a message, except the legitimate recipient;
- **integrity:** ensuring that no unauthorized alterations are allowed on a transmission, i.e. a message being sent to a recipient must not be altered before delivery;
- **non-repudiation:** providing the certainty that the sender of a message cannot deny having sent it.

Encryption, therefore, serves both to protect transmitted data from being altered or stolen by attackers and to authenticate a user. In encryption, there is a conversion of data from a readable format into an encrypted format that can only be read or processed after it has been decrypted. Only the authorized user can decrypt the data and access the information in its original format. There are plenty of methods to encrypt and decrypt data, but the key to success does not lie in the algorithm. The most important thing is to keep the encryption key (password) secret, or rather to make sure that only authorized persons know it.

5.3 Privacy by Design

Finally, the implementation of the 'Privacy by Design' concept is essential in the design of systems, applications, and technologies involving sensitive data. Indeed, according to the literature, "Design can play a critical role in addressing privacy challenges by incorporating privacy into the design of technologies and systems" [34]. The Privacy by Design approach implies the integration of privacy protection from the earliest stages of a system's development, ensuring:

- **Initial Respect for Privacy:** Privacy by design ensures that data protection is an integral part of the design, reducing risks and breaches.
- **Risk Prevention:** vulnerabilities are identified and addressed from the outset, minimizing security threats and intrusions.
- **User Confidence:** Demonstrates a strong commitment to privacy, increasing user confidence in the secure use of services.
- **Simplified Compliance:** Privacy by design simplifies compliance with privacy laws, thereby reducing legal risks.
- **Reduced Costs:** Providing reduced costs for privacy issues to be handled from the outset for future expenses associated with handling breaches or retroactive changes.

The combined use of these strategies thus makes it possible to minimize privacy risks due to HCI and HRI, but this is not always applicable in all contexts since technological evolution constantly proposes new privacy challenges. The different strategies listed above can also be considered as guidelines to be followed when implementing an interactive system that allows users' privacy to be preserved.

6 Conclusion

The analysis carried out on privacy considerations and issues in HCI and HRI contexts highlights the importance of carefully addressing emerging challenges related to the protection of user data. The constant integration of technology into everyday life has made it imperative to understand the risks and benefits inherent to privacy in human-technology interactions. In an increasingly connected technological world, ethical and legal dilemmas arise and there is a need to balance technological innovations with respect for people's rights by ensuring the protection of their data. Consequently, privacy considerations should start from the initial stages of designing a system, using as many data protection strategies as possible, including the "privacy by design" approach, to minimize the risk of breaches. User-centered system design thus becomes crucial, with a focus on creating innovative and satisfying experiences while respecting the users' privacy preferences. Users' awareness of privacy and the risks associated with HCI and HRI interactions is crucial. Educational campaigns that can help inform individuals about security practices, personal data management, and possible threats should be conducted to achieve greater empowerment. Furthermore, privacy regulations, such as GDPR and CCPA, indicate the increasing focus on the protection of personal data. Consequently, organizations should comply with these regulations while facing new challenges due to technological evolution. Legal compliance is indeed crucial, but it should be complemented by an ethical approach that goes beyond the legal obligation to ensure comprehensive privacy protection. In conclusion, facing new challenges due to technological evolution requires interdisciplinary collaboration and ongoing commitment to create interactive systems that respect the rights of individuals.

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A Tool to Support Automation of Risk Assessment

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Abstract. In the context of risk analysis and assessment, the constant evolution and growth of organizations has led to an increase in the amount of information to be analyzed: a case is provided by the data processing registry, mandatory according to the GDPR. Quality and cost of risk analysis and assessment may be improved by using tools to automate certain steps. In this paper we propose an approach and a support tool for software-aided risk assessment integrated with the state-of-the-art privacy impact assessment (PIA) tool, to define how certain steps in the compilation of a DPIA (Data Protection Impact Assessment) can be automated. The resulting tool chain has been successfully applied to a case dealing with job placement data in a university.

Keywords: Privacy · GDPR · Compliance · DPIA · PIA Tool · Record of Processing Activities · Risk Analysis · Risk Assessment · Information systems

1 Introduction

As organizations have continued to grow and become more complex, there has also been a significant increase in the amount of information they have to examine; consequently, it becomes essential to carry out risk analysis and assessment procedures on an ongoing and recurring basis. In a number of business settings, therefore, the fact that risk assessments and analyses are carried out manually rises as a major issue. The increasing complexity and volume of data has led to a search for new approaches aimed at enhancing the efficiency and accuracy of such assessments [9]. This paper proposes to address this issue by means of a tool capable of automating specific steps in the process of risk analysis and assessment, focusing on data management in the context of the Record of Processing Activities[1], with particular attention to the University Job Placement

[1] According to art. 30 of GDPR.

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section, thus inherently going to transform a process-based data structure into an asset-based one.

The chosen approach involved an in-depth study of a risk analysis and assessment tool widely used in business contexts: the Privacy Impact Assessment (PIA) tool, developed by the Privacy Authority of France. The main aim of this paper is to propose a toolchain in order to automatize some steps in the redaction of a DPIA (Data Protection Impact Assessment) carried out through the PIA tool. We analyzed the existing theoretical and practical basis for risk analysis and assessment and the role of risk analysis and assessment in cybersecurity, checking the different approaches to risk assessment and the importance of continuous management. A focused overview of GDPR, the Data Processing Registry and DPIA is provided in this paper, focusing particularly on the university environment and the Job Placement section to allow a correct connotation of the PIA tool with respect to the case study, with a detailed analysis of their functionality and role in conducting the Data Protection Impact Assessment, in order to show the reader the main issues in the design and development of our approach and of the related toolchain.

With respect to standard procedures, the implementation of the tool designed to automate the compilation of a DPIA provided promising results, reducing compilation time and improving accuracy through the reduction of human errors.

This paper is organized as follows: Sect. 2 introduces the main points about risk analysis and assessment, Sect. 3 resumes the relevant aspects of the GDPR, Sect. 4 presents the DPIA methodology, Sect. 5 discusses the PIA tool and its role in the toolchain, Sect. 6 describes the design process, conclusions close the paper.

2 Risk Analysis and Assessment

Risk analysis and assessment in the context of cybersecurity are key processes for identifying, understanding, and mitigating threats to the security of data and information systems. One of the best ways to address cybersecurity issues is to take a risk-based approach. When it comes to real-world implementation, information security risk management is a challenging process because risk factors can constantly change and evolve. Information security risk assessment (ISRA) is an important part of an information security management system (ISMS) and allows an organization to identify potential threats and decide what prevention or mitigation measures to adopt [11]. Risk management is an ongoing, recurring process that all organizations should do. Organizations that do not conduct risk assessment properly and regularly can suffer serious damage and consequences such as loss of reputation, legal problems, or financial impact.

Several ISRA approaches have been developed over the years, Some of approaches have been conducted using well-known risk assessment methodologies such as the Failure Mode and Effects Analysis (FMEA) [12], while other approaches are founded on methodologies particularly suited for the ICT field, such as NIST SP 800-30 [10] for further information, a comprehensive literature

review about privacy risk assessment methodologies may be found in [14]. However, the problem with many of these methodologies is that they focus primarily on general principles and guidelines, leaving users without adequate implementation details. The goal of risk assessment is to identify all possible risks to resources and accurately assess them to adequately mitigate them. Therefore, the vulnerabilities of each valuable resource (i.e., assets, services, business processes) and the threats that could exploit them are to be identified, and then the relationship between vulnerability and threat is defined as risk. Existing current approaches to risk assessment and information security are classified according to three criteria [8]:

- **Quantitative:** This type of approach involves the use of numerical data and statistics to assess risks. Typically, historical and probabilistic data are used to calculate the probability of a damaging event and its consequences in terms of financial loss, property damage, damage to reputation, etc. Quantitative approaches often involve the use of mathematical models, simulations, and statistical analysis to estimate risks very precisely. The inputs and outputs of quantitative risk assessment can be classified into two categories: monetary and non-monetary. As for monetary assessment, a monetary value is assigned to each asset, vulnerability, threat, and safeguard implementation. In contrast, non-monetary assessment produces a non-monetary number. Quantitative valuation is also known as "expected value analysis."
- **Qualitative:** This type of approach, unlike the quantitative approach, is based on subjective assessments expressed in qualitative terms. Rating scales or matrices are often used to score risks based on factors such as likelihood and impact. Experts in the field assess risks more descriptively, without precise numerical calculations. This approach is useful when quantitative data are lacking or when a much faster and more general assessment of risks is desired. The inputs and outputs of qualitative risk assessment can be classified into two categories: range and linguistic variables for inputs, and range and range (or rank) variables for outputs. In the range variable category, which applies to both input and output, the qualitative assessment evaluates risks in a qualitative risk matrix, which includes a measure of vulnerability and a measure of threat probability, each of which is expressed on a scale of three to five levels (e.g., low, medium, and high). In the category of linguistic variables, expert opinion is used to weight criteria and evaluate alternatives. The concept of linguistic variable is very useful in dealing with situations that are not well defined.
- **Hybrid (Semi-quantitative):** This approach combines both quantitative and qualitative approach methods. Quantitative data are used when available, but supplemented with qualitative assessments when data are scarce or uncertain. For example, you can use a numerical scale to express the probability of an event, but rely on expert assessments to estimate the impact [4]. This approach offers a trade-off between the accuracy of numerical data and the flexibility of qualitative assessments.

2.1 Information Security Risk Management

Information security concerns the protection of information of value to an organization from possible exposure, manipulation, or unwanted destruction. The ultimate goal of an information security program based on risk management is to maximize the organization results (products or services) while minimizing what are the unforeseen negative effects from potential risks. It is critical that risks are managed in such a way that instills confidence in all parties involved and ensures an adequate level of security for the information systems that support the day-to-day activities of organizations [1]. Through proper risk management, a balance between potential and acceptable risks can be achieved. Nowadays, there are different types of frameworks for managing information security risks. Each framework is created to meet specific needs and, as a result, has different objectives and steps. A general information security risk management framework includes four main processes, namely risk definition, risk assessment, risk response and risk monitoring [10]:

1. **Risk definition:** this is the initial stage in which potential information security hazards are to be identified and clearly defined. This includes identifying possible security threats, vulnerabilities in systems, or sensitive data that could be compromised. The goal is to understand what are the risky problems or situations that could jeopardize information security.
2. **Risk assessment:** once all potential hazards have been defined, the next step is to assess them. At this stage, an attempt is made to determine the probability and impact of each identified risk. The likelihood goes to measure how likely it is that a particular hazard may occur, while the impact goes to measure the consequences or damage that may result from the occurrence of the hazard. This assessment allows one to go in and determine which risks are the most critical and require the most attention. There are four ways to address a given risk:
   - **Accept**: The organization understands the risk and its consequences and consciously decides to accept it;
   - **Prevent**: The activity that exposes the organization to one or more risks is avoided altogether;
   - **Transfer**: All or part of the responsibilities and burdens associated with a particular activity and its associated risk are transferred to another party;
   - **Mitigate**: The risk and its consequences are controlled and limited in some way by reducing the risk to a level below that accepted by the organization.

   Usually, an organization risk management involves a combination of these ways: some risks are avoided, some are transferred, some are mitigated, and the others are accepted. As part of the risk assessment process and based on the organization policies, objectives and stakeholder interests, the level of risk acceptance (criteria) must be defined.
3. **Response to risks:** after assessing potential hazards, strategies must be identified and developed to address them. This may include implementing

security measures to mitigate or reduce risks. Risk management aims to control or mitigate possible threats to information security. Information security risks that exceed the level of risk acceptance must be addressed in one of the other ways of risk response, namely by avoiding, transferring, or mitigating the risk (mitigation).

4. **Risk monitoring**: the risk monitoring process is an ongoing process and includes constant oversight of identified hazards and implemented security measures. This ensures that preventive actions are effective in the long run and that new potential hazards are detected in a timely manner. In addition, risk monitoring allows changes to be made to risk management strategies as threats and conditions evolve.

One of the most important aspects of the risk assessment process is the perspective on which it is conducted. Three different perspectives can be considered [11]:

- **Asset-driven**: in this type of perspective, threats and vulnerabilities of each asset are identified and risk scenarios are formed. In a medium to large organization, the number of information assets is considerable. These assets represent valuable resources within the organization. Each information asset is associated with a variable number of risk scenarios, i.e., potential situations in which these assets could be compromised or damaged. The result of this multiplicity of assets and risk scenarios is the creation of large lists of risk scenarios that require careful analysis and constant maintenance. This is the main disadvantage of this perspective, which makes the risk assessment process a tedious and error-prone task. The main advantage, on the other hand, is that they are easier to understand, and given their widespread use, most of the tools available on the market are designed based on this perspective.
- **Service-driven (service-oriented)**: in this type of perspective, all important services in the organization are identified, and risks are identified and assessed according to their impact on them. Unlike asset-driven approaches, this perspective identifies threats and vulnerabilities for each service and not for individual assets. Because the number of services in an organization is significantly less than the number of assets, a service-driven approach is easier to manage.
- **Business-driven**: this type of perspective is based on the goals and processes that support an organization. Values are assigned to business processes linked to business objectives because these processes are more understandable and easily estimated than information assets. This perspective makes it possible to have a risk assessment that is much easier to explain to top management and thus acquire the necessary support.

In addition, risk measurement is the step in which the level of risk associated with a given scenario is quantified. This process is essential for determining whether existing security measures are adequate or whether additional mitigation actions are needed. Two types of risk measurement can be distinguished:

- **Unpropagated**: the risk of a single event or scenario is considered without regard to possible consequences or impacts on other events, processes or assets within the organization. In essence, risk is assessed in isolation, and this is useful in understanding the risk associated with a specific threat or vulnerability.
- **Propagated**: considers not only the initial risk, but also how this risk might propagate through the organization. It focuses on the possible chains of events and related impacts that could occur as a result of the initial risk. This type of measurement is much more complex and takes into account the interconnections between various business processes, systems, and activities. This type of measurement is more comprehensive and better reflects how threats can have knock-on effects within the organization. However, this type of approach requires more analysis and understanding of business dynamics, whereas unpropagated risk measurement provides a more focused view of specific risks.

The choice between these two types of measurements depends on the complexity of the organization and the objectives of the risk assessment. In many cases, it is advisable to consider both measurements to obtain a complete risk assessment.

3 GDPR and Record of Processing Activities

GDPR is a European Union regulation on the processing of personal data and privacy, aimed to strengthen the protection of personal data of European citizens and residents, both within and outside the borders of the European Union. This Regulation was drafted with the aim of protecting the fundamental rights and freedoms of individuals, particularly the right to protection of personal data. According to the European Commission, personal data are all the information inherent to an individual and therefore can cover any type of data such as names, addresses, bank data, health data, and more. However, the GDPR regulates only data related to individuals (including data in the professional or associational sphere), excluding data related to entities with legal personality such as public bodies, associations, etc. The types of data defined by the GDPR are divided into:

- **Personal data**: is information about an identified or identifiable natural person;
- **Genetic data**: are the data related to the genetic characteristics of an individual and provide unique information about the physiology or health of the natural person;
- **Biometric data**: are the data related to the physical, physiological or behavioral characteristics of an individual and which enable or confirm their unique identification (facial image, fingerprints, etc.);
- **Health-related data**: are data related to a person's physical or mental health.

One of the cornerstones of the GDPR is the Record of Processing Activities (RPA), which represents an electronic document with the aim to collect in a systematic way all operations conducted within an organization to process collected data. The importance of the RPA cannot be underestimated, as the GDPR explicitly requires organizations to have one. Every row of the RPA is structured in several fields:

- **Details about the organization**: Name and contact details regarding the person in charge of data processing and of the data protection officer.
- **Purpose of data processing**: Describes the purposes for which the data collected are processed. An example would be corporate personnel management;
- **Categories of personal data**: Defines all categories of data collected e.g. name, contact details, financial data, health data etc.
- **Data recipients**: represents a list of people to whom data may be disclosed or transferred such as service providers.
- **Retention periods**: Indicates the length of time the information will be retained before it is securely stored or deleted. This may vary depending on the purpose of the processing or the type of data collected
- **Security measures**: indicates what technical and organizational measures the organization has taken to protect data, this could include the use of encryption, backup procedures, etc.
- **Breach log**: documents data breaches, actions taken to resolve, and notifications to data protection supervisory authorities.

The Record of Processing Activities must be complete, accurate and constantly updated, and it needs to be easily accessible to data protection authority and people involved in the data processing process within the organization. The information contained in RPA have to be considered of paramount importance, and could form the basis for a risk assessment procedure [3].

3.1 The Entities Involved in the Processing

The GDPR also defines who is involved in processing on different bases:

- Based on the purposes for which the data are collected:
  - **Data Controller**: is the person or organization that collects personal data and decides why and how such data will be processed;
  - **Joint Controller**: is the person or organization that shares the same data processing purposes with another Co-Processor and together they decide how the data will be processed;
  - **Data Processor**: is the person or organization that processes personal data on behalf of the Controller and this is done on the basis of a contract or legal agreement between the Controller and the Processor;
  - **Recipient**: is the person or organization that receives personal data from the Controller and processes it according to the instructions received. In some cases, the Recipient may itself become a Controller for the data received if it processes it for its own purposes;

  - **Authorized Person**: is an individual who has received precise instructions from the Controller to carry out specific data processing activities;
  - **Data Subject**: is the natural person to whom the personal data collected and processed refer. A Data Subject provides his/her data to a Data Controller for purposes specified in the Privacy Policy. The Data Subject also has the right to have control over his/her personal data and to exercise his/her rights under the Data Protection Act;
- Based on the characteristics of the Owner/Director and the types and amount of data processed:
  - **The Data Protection Officer (DPO)** is a legal figure responsible for overseeing all aspects of GDPR implementation on behalf of the Data Controller or Processor. This figure is mandatory for public administrations and ensures compliance with data protection laws by helping to ensure that the rights of data owners are respected.
- Based on the territorial scope:
  - the Representative in the Union of the Data Controller/Responsible Person who is based in a third state is the legal or natural person who on behalf of the Data Controller/Responsible Person acts as a point of contact for data subjects and the Union Supervisory Authorities. This does not absolve the Owner or Manager from overall responsibility for data processing;
  - the Supervisory Authority is a public legal entity established by each member state to oversee implementation and compliance with the GDPR within its territory. It plays a key role in ensuring compliance with data protection laws;
  - the European Data Protection Board is a legal entity at the European level tasked with coordinating the work of the various Supervisory Authorities and supporting the European Commission in promoting and implementing the GDPR. It helps ensure consistency and uniformity in the application of data protection regulations throughout the EU.

The definition and distribution of roles and responsibilities is important in order to develop appropriate security measures for the compliance to GDPR. In addition, to prevent, avoid and minimize risks, the GDPR has introduced a methodological approach called risk-based i.e., a risk-oriented approach. This approach is strictly based on protecting user data and assessing the actual risk for each organization. Risk assessment thus becomes crucial in the context described by the Regulation. The GDPR, in fact, requires the Data Controller and the Data Processor to put in place the necessary technical and organizational measures to ensure a level of security appropriate to the risk, based on its assessment. Hence they must take into account: i) the state of the art of security measures/technologies; ii) the related costs of implementation; iii) the nature, scope, context of data; iv) the purposes and risks of processing.

3.2 Institutional Purposes of the University

In Italy, universities are considered legal entities with public legal capacity and pursuing purposes of general interest. They operate under the jurisdiction of

administrative law and have public authority; therefore, they are considered part of the public administration under Italian law. According to the Constitution, universities enjoy educational, scientific, organizational, financial and accounting autonomy, and this autonomy is regulated by their statutes, internal regulations and relevant legislative regulations. The main purposes of data processing that universities carry out are teaching and research. As for teaching, the main activities related to it include, for example, ensuring the right to study, guidance, curricular courses, tutoring, etc. As for research, on the other hand, universities are involved in national and international research projects and the publication of scientific articles. In recent years, however, the so-called "Third Mission" of the university has emerged as an additional institutional purpose. This mission is also concerned with the dissemination of knowledge and technologies outside the institution itself and includes areas such as:

- technology transfer (patents, third-party services, spin-offs);
- lifelong education (training on the working-age population, organization of conferences, conventions, etc.);
- social engagement (job placement, startup assistance, etc.). o social engagement (job placement, startup assistance, etc.).

4 DPIA: Data Protection Impact Assessment

A data protection impact assessment or DPIA (Data Protection Impact Assessment) is a particular procedure designed to identify, assess and manage the risks associated with a specific type of processing. A data protection impact assessment is required in situations where processing may pose a high risk to the rights and freedoms of individuals. This assessment is mandatory in at least three specific circumstances:

- An accurate and comprehensive analysis of the personal aspects of a person, including profiling;
- The processing of sensitive data on a large scale;
- The systematic and large-scale monitoring of public spaces.

Impact assessment is a process that must be conducted prior to the initiation of processing and should be conceived as a dynamic process, rather than seen as an isolated activity. As mentioned in the previous Section, the GDPR adopts a risk-based approach, which implies that the data controller must manage all potential risks associated with the personal data it processes. This requires the identification, analysis, estimation and mitigation of risks through the implementation of specific security measures [13].

4.1 Why Conduct a DPIA?

A Data Protection Impact Assessment (DPIA) can be conducted for any advanced or innovative procedure related to the processing of personal data.

In some cases, it may be mandatory to conduct a DPIA in accordance with applicable legal regulations. Indeed, personal information can be valuable to the organization that processes it, but it is important to recognize that the processing of such information carries significant liability because of the potential risks to the privacy of the individuals involved. Personal information, however, also has important meaning for those to whom it belongs. Indeed, this data can serve administrative, commercial, or even help build one's image. However, it is critical to recognize that security breaches in data protection can result in negative consequences, causing physical, material and moral harm. Given the often high stakes and evolving systems and threats, risk management allows you to determine what controls are needed to be in place. It also allows for methodical study of the processing of personal data, prioritizing risks and treating them proportionately to optimize costs and make decisions based on the most objective information possible [7].

4.2 How to Conduct a DPIA

In order to conduct a successful Privacy Impact Assessment (DPIA), the following steps must be followed [2] (Fig. 1):

1. **Activity planning:** Creation of a working group, definition of general and detailed objectives, planning of activities, including tasks, time and resources;
2. **Information Gathering:** Acquisition of all necessary information and data through interviews, document collection, and consultation with the offices and departments involved;
3. **Data analysis and description of processing:** Conduct an analysis of the data collected to identify and describe the purposes, categories of data subjects, data involved, and legal basis for processing;
4. **Data Flow**; Use of graphical descriptions (diagrams) of data flow for better assessment of critical processing profiles;
5. **Identification and risk assessment:** Identification of critical issues in terms of risks to the rights and freedoms of data subjects. Assessment of necessary measures to eliminate or reduce these risks in accordance with the principles of the *GDPR*;
6. **Review of assessments made**. Possible review of the analysis and assessments by those involved.
7. **Implementation of mitigation measures:** Implementation of the identified mitigation measures designed to manage and reduce the risks revealed during the analysis and assessment.

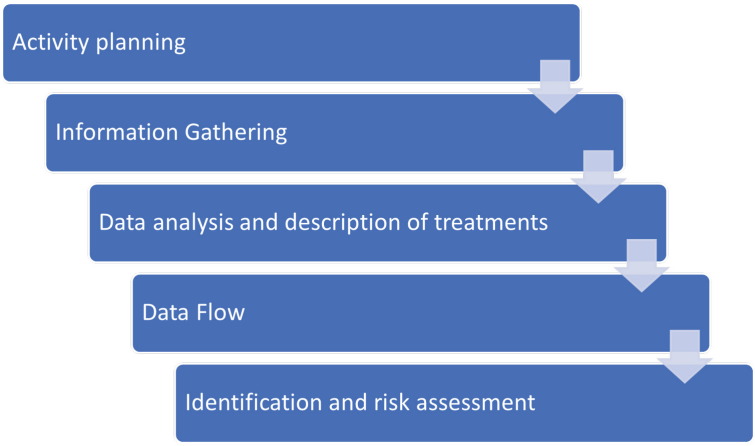

Fig. 1. Steps for conducting a DPIA

5 PIA Tool (Privacy Impact Assessment)

When conducting a DPIA, all steps performed must be documented in detail and accurately by the data controller. The final report will be sufficient evidence, if necessary, of compliance with applicable regulations, in line with the principle of accountability/accountability. The final DPIA document will be signed by the data controller. One of the most relevant tools used for redact a DPIA is the PIA tool, developed by French Data Processing Authority (CNIL) and available for download in CNIL site[2]. This tool allows you to have a preset structure in which to enter the different information for each stage of the DPIA. In fact, the tool is divided into sections, where for each section there are a series of questions to be filled in order to proceed with the various steps to conduct a DPIA [6]. At the end of the process of filling in the information, a document can be extracted that must contain at least the following parts:

1. Introduction: This section provides an overview of the personal data processing analyzed, introducing the key concepts and objectives of Privacy Impact Assessment (DPIA);
2. Body of the DPIA:
   (a) Scope Description: This section goes on to specify the scope and limits of personal data processing, providing a clear understanding of the activities involved.
   (b) List of legal controls: this section specifies and explains the legal controls that guide the processing of personal data, ensuring regulatory compliance.

[2] https://www.cnil.fr/en/open-source-pia-software-helps-carry-out-data-protection-impact-assessment.

(c) List of risk treatment controls: The various controls implemented to mitigate risks associated with the processing of personal data are identified and described, emphasizing the focus on security and privacy protection.
(d) Risk map: A visual representation is used to illustrate the risks associated with the processing of personal data.

3. Conclusion: This section provides a justification for the validity of the DPIA, going on to highlight the findings and decisions made during the assessment process.
4. Appendices:
   (a) Detailed description of the scope: this section further describes the details of the scope of personal data processing.
   (b) Detailed presentation of controls: this section sets out in much more detail what controls are implemented, with an explanation of their functions and purposes.
   (c) Detailed description of risks: this section provides an in-depth view of the identified risks, including potential consequences and strategies to mitigate them.
   (d) Action plan: this section goes into specific actions to be taken to manage the risks and improve the security of personal data processing over time.

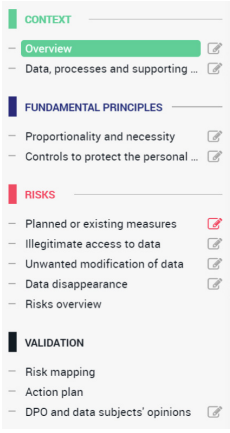

Fig. 2. Sections of the PIA tool

6 The Proposed Solution

The design of the proposed tool has been carried on by applying a process consisting of the phases which follow.

6.1 Collection of Information for DPIA Automation

The first step in this work was to analyze the information provided by the PIA tool. Starting with the graphical interface of the tool, it was seen that it is divided into several sections, each of which provides a series of questions. For each question, one should indicate an answer inherent to the type of analysis to be conducted. Once you have completed entering the information, the tool allows you to produce a final PDF document for conducting the DPIA [5]. In addition, the tool also allows the DPIA to be exported to a JSON file, which will be the focus of this work. In fact, the basic idea was to go and reuse this JSON file to make a tool to automatically compile the DPIA and then import this already compiled file to the PIA tool. In order to do this, the first thing done was to create an empty DPIA and export its JSON file, and then we went on to analyze this file. As shown in Fig. 2, the file will contain a set of information related to the DPIA (such as name, creation date, Author, etc.) and a set of parameters related to the DPIA.


```
"pia": {
    "status": 0,
    "is_example": 0,
    "is_archive": 0,
    "created_at": "2023-11-15T08:30:38.673Z",
    "name": "DPIA Saporito Antonio",
    "category": null,
    "author_name": "Saporito Antonio",
    "evaluator_name": "Mastroianni Michele",
    "validator_name": "Palmieri Francesco",
    "updated_at": "2024-01-16T08:45:56.204Z",
    "structure_id": "",
    "id": 19,
    "progress": 22.5
},
"answers": [···
],
"measures": [···
],
"evaluations": [···
],
"comments": []
```


Fig. 3. JSON file of an empty DPIA

In the context of analyzing this JSON file, we focused on the following fields:

- the answers field, which will contain all the information related to the questions proposed by the tool, with their answers;
- the measures field: which will contain all the information related to the existing measures regarding the DPIA to be conducted.

As shown in Fig. 2, the fields listed above, turn out to be empty due to the fact that an empty DPIA was exported, consequently the next step was to look

for a way to be able to identify the various questions that the PIA tool makes available and have them included in the JSON file. This was done by using hexadecimal codes to be inserted into the text boxes for the answer fields of the various questions, so that they would show up in the JSON file and consequently then be able to locate them.

Specifically, the idea was then to take advantage of a hexadecimal code structure to identify the questions and their fields to be filled in on the JSON file, as shown in Fig. 3. Since the tool is structured in sections (or Divisions), where each section contains a set of questions whose answers are to be entered, for the hexadecimal code structure it was thought to make a code divided into two parts and composed of:

- question section: the first two characters of the hexadecimal code, for example D1 as shown in Fig. 3, represents the first section. The D character was chosen to identify the section or Division in which the question is located;
- question number: the last two characters of the hexadecimal code, for example as shown in Fig. 3, R1 represents the first question contained in the section. The R character was chosen to identify the Response field to be filled in.

At this point, after the hexadecimal codes for all the fields requested by the tool were entered, the JSON file was exported and it contains all the fields requested by the tool with the corresponding hexadecimal code entered manually. For the measures field, however, hexadecimal code could not be entered because there are no associated forms with text boxes to fill in. Therefore, in order to automate this part as well, the JSON file containing at least one manually entered measure was parsed, so that the necessary parameters could be identified in the code to proceed with the automatic entry of measures. Once all the necessary fields were identified in order to be able to automate the process of compiling the DPIA, thought was given to how to provide the JSON file with the necessary information for compilation. Regarding the answers field and thus the entry of answers for each question, the basic idea was to make a CSV file structured that will be filled in with the relevant answers to be transferred to the JSON file (Fig. 4).

The Record of Processing Activities related to a particular data processing activity (in this case, Job Placement) and the Chat-GPT artificial intelligence tool was used in part to compile the answers for each question.

6.2 Python Code for DPIA Automation

At this point, once the CSV file was structured, thought was given to how to transfer the information, contained in it, to the JSON file of the PIA tool. To do this, a source code written in Python was developed through the Google Colaboratory development environment. As a first step, it was planned to make a code that takes as input the JSON file provided by the PIA tool and compiled with the entered hexadecimal codes. The following is a step-by-step description of the code:

id_question	question	text
D1R1	What is the processing under consideration?	text of the answer
D1R2	What are the responsibilities linked to the processing?	text of the answer
D1R3	Are there standards applicable to the processing?	text of the answer
D2R1	What are the data processed?	text of the answer
D2R2	How does the life cycle of data and processes work?	text of the answer
D2R3	What are the data supporting assets?	text of the answer

Fig. 4. CSV file containing the tool questions with the respective codes

- Definition of a function that checks if the file extension is of type JSON, if not, it prints an error message;
- JSON file upload request;
- Checking the file extension: If it does not have the correct extension, prompts the user to upload the file again;
- Extraction of JSON content;
- Loading the contents of the JSON file into a variable called date;
- Initialization of an empty list that will be used later to save responses to be updated;
- Printing an upload confirmation message.

At this point, a second code snippet was developed, very similar to the previous one, but it goes to take as input the CSV file containing the information to be passed to the JSON file. Once the CSV file has been uploaded, the information present in it will be extracted and made suitable for later use. After having loaded both the JSON file and the CSV file and having read the information present in the latter, the next step was to develop a code snippet that allows you to transfer the information extracted from the CSV file and insert it into the JSON file in the appropriate fields.

Below is a step-by-step description of the code:

- Check the presence of the 'answers' response field in the JSON file: if the field is present, the code proceeds to modify the responses in the JSON;
- Iterate through the responses present in the JSON file and the lists containing the information extracted from the CSV file;
- Print question and answer information;
- Modify the answers by adding specific information: concatenate the answers taken from the CSV file to the original text, in this case the question identifiers;
- Provides feedback in case the number of lines in the CSV is insufficient to match all the responses in the JSON;
- Print a message if the 'replies' field is not present in the JSON.

Once the process of transferring information from the CSV file to the fields in the answers field was finished, the next step was to automate the process of inserting existing measures for the measures field. To do this, an additional code snippet was created, below is a step-by-step description of the code:

- While Loop: this cycle repeats infinitely until it is explicitly interrupted by the user, it allows you to continue inserting measures;
- Retrieving the PIA ID, if it is not present, the null value is assigned;
- Check the presence of the 'measures' field. If present, the user is asked to provide the title and content of a new measure;
- Creation of a New Measurement Record;
- Adding the "Measure" to JSON file;
- Confirmation message of the addition of the new measure;
- Control of the Continuation of the While loop: The user is asked if he wishes to insert another measure, if the answer is negative, the program ends, otherwise we proceed with inserting another measure.

The last code snippet involves filling in two more sections of the DPIA by going for the IDs (identified in the JSON file) related to the subsequent questions. To do this, an additional CSV file was made that contains the question ids related to the sections to be filled in and the related question. For each value in the column called "id_reference_to," it looks to see if an object with the same value exists within the "answers" field in the JSON file. If the object exists, it displays information about the object (question id, question, list of answers) and asks the user if he or she wants to add or edit a list associated with that object. If the answer is "y," the user can add new items to the list, which is then updated in the JSON file. If the object does not exist, the snippet provides for the creation of a new object, including the insertion of items into the response list associated with that object. The new object is then added to the JSON file. Once the compilation of the DPIA has been completed, it is necessary to be able to save the new JSON file which will then be the file to be imported into the PIA tool in order to complete the compilation of the fields where human intervention is necessarily required. To be able to save the new JSON file, a specific code snippet was created.

The proposed toolchain has been tested using real data of the job placement administrative process of the University of Campania Luigi Vanvitelli already used in other works [3], and the detailed results, the map of codes and the related CSV are available on request from the authors.

7 Conclusion

In conclusion, in this research work, has been developed a tool to (partially) automate the process of Risk Analysis and Assessment in university processes, in this case the Processing of Personal Data for Job Placement purposes has been assessed. Automating those processes offers several benefits to organizations, including:

- **Efficiency and Speed:** Automation allows for faster and more efficient analysis and risk assessment than manual methods. Repetitive and detailed tasks can be handled faster, enabling timely decision making.

- **Reduction of Human Errors:** Human errors are inevitable, but they can be reduced through automation. Eliminating or minimizing human errors in the analysis and risk assessment stages contributes to greater accuracy and reliability of information.
- **Managing Large Quantities of Data:** Many organizations must manage huge amounts of risk-related data. Automation facilitates the analysis of large datasets, enabling the detection of patterns and trends that are difficult to detect manually.
- **Resource Savings:** Automation allows human resources to focus on more complex, value-added tasks, reducing the workload associated with more repetitive tasks.

As far as future developments are concerned, regarding the automation process carried out for the PIA tool, one could think of going for an additional CSV file regarding the existing measures, so as to create a kind of Dataset containing all possible mitigation measures and let the user dynamically choose which measures to add to the DPIA without having to manually enter text.

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Preventing Data Tampering in Smart Grids: A Blockchain-Based Digital Twin Framework

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Abstract. As modern power systems evolve in complexity and dynamism, there arises a pressing need for innovative methodologies to streamline their management and optimization. Decentralization strategies, enabled by edge computing and Digital Twins (DTs), offer promising remedies to these issues by facilitating real-time interaction with physical systems and integrating data for advanced analytics, including predictive forecasting. While Smart Grids have emerged as efficient solutions for enhancing system performance and reducing costs, certain challenges persist. This paper proposes a novel blockchain-based system designed to counter data poisoning within the domain of energy forecasting in smart grids. Our framework not only ensures the integrity of data but also fortifies defenses against attacks aimed at disrupting data-driven applications. Validation in a practical energy forecasting scenario demonstrates the reliability and efficacy of our approach. Results demonstrate the feasibility of the approach while providing positive insights about the detection of attacks.

Keywords: Smart Grid · Digital Twin · Internet of Things

1 Introduction

The advancement in technologies in the last few years enhanced the quality of industrial processes by reducing costs and increasing efficiency. Supervisory Control And Data Acquisition (SCADA) systems are nowadays widely used in industrial applications in order to control wide systems and take actions when necessary or to prevent possible issues related to machines. Federations of devices are typically used in order to sense an environment or take action. These intelligent networks take the name of smart grid; and are usually composed of tons of Internet of Things (IoT) devices exchanging data used in a multitude of applications ranging from smart predictions to disaster prevention. A particular industrial context, where the IoT sensors are saving money and enhancing quality is composed of an electricity network. Traditional approaches in this field are composed of a

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central hub that interconnects all the infrastructures. It is common to have different macro-area served by a central hub, and those macro-area cover thousands of users. Such an approach is poorly scalable and currently smart grid faces various challenges related to communication, interoperability and security, usually caused by the underlying technologies [7]. These systems usually leverage old systems and it is difficult to re-use or control data produced in this environment from external access. Decentralization aims to solve these challenges by moving the computation away from centralized systems and by providing a mean for interacting with physical and legacy systems. In particular, through edge computing, it is possible to process produced data in order to minimize data exchanged and make such data more interoperable with external systems. Despite the advantages introduced by decentralization in preventing congestion and improving the reliability of the system, it is hard to control a Cyber-Physical System (CPS) in an efficient and real-time way. To overcome these limitations it is possible to leverage Digital Twins (DTs) technology, which is able to provide a digital copy of physical systems in order to control their behavior and to obtain real-time data. These data are widely used in Machine Learning (ML) applications, to implement prediction or forecasting [8]. Deploying Thin Edge Nodes across various locations within the Smart Grid facilitates bidirectional synchronization between digital twins and physical systems. Moreover, it enables the integration of AI applications for automated decision-making, thereby alleviating operational burdens on grid operators. When combining this technology with energy efficiency context, it is possible to unlock the real potential of these algorithms. Currently, DTs are used in the energy sector to control three different phases: production, storage, and consumption [6], highlighting the importance of data produced, and the need for having a system able to certificate authenticity in the entire data flow. As depicted in Fig. 1, estimation of the energy consumed within a period could be used to buy the right quantity of energy to sell to the customers. Considering the case of wrong data acquisition this can lead to problems related to this estimation, such as overprovisioning or underprovisioning.

These have an automatic impact on the price of the energy required to meet the unforeseen rise in demand. Given the common architectures that the smart grid has adopted, if unsecured communication is used or physical access to the smart meter is too weak, attackers may purposefully alter the data that this device acquires or alter it while it is being transmitted. This research focuses on a specific type of smart grid architecture that uses a federated approach to estimate energy provisioning and detect anomalies in collected data. A typical attack scenario, caused by a malicious node, will be described in the manuscript. Relevance of these attacks can lead to an overall deterioration of the model. To effectively prevent these attacks we present a novel system leveraging blockchain technology. Our framework not only addresses the critical issue of data modification but also provides a mechanism to prevent attacks aimed at disrupting data-driven applications. Through validation in a real-world energy forecasting use case, we demonstrate the efficacy and reliability of our approach.

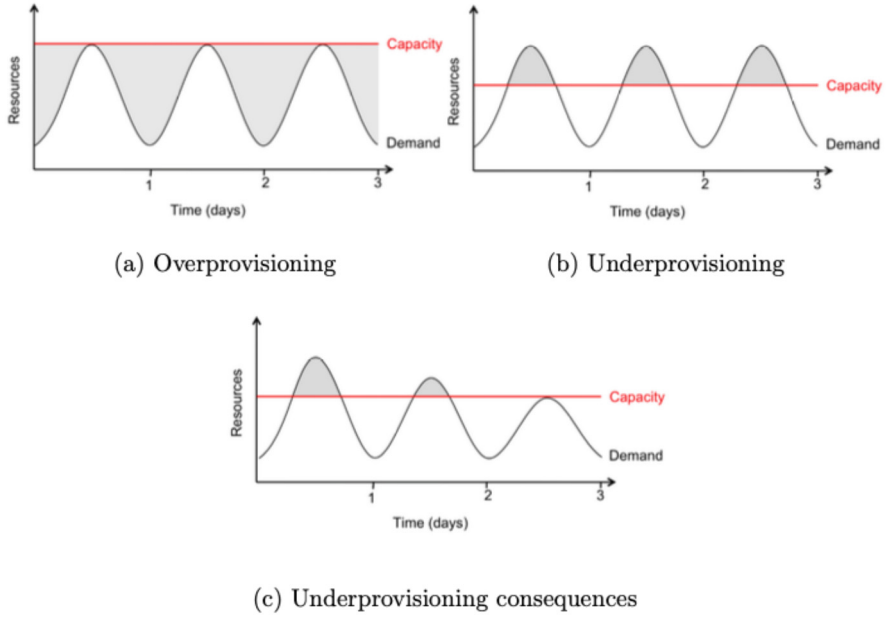

Fig. 1. Energy consumption prediction

The manuscript is structured into five sections. In the second section, we discuss the current research in the field of DTs to enhance the performance of smart grids. In the third section, we discuss of the proposed system, able to prevent attacks related to data poisoning and data modification. In the fourth section we demonstrate the efficacy of the proposed method by discussing results. We conclude the manuscript with the future works and limitations of the proposed approach.

2 State of the Art

In recent years, the increased performance of IoT Nodes, as well as edge devices, paved the way for more advanced applications within the CPS context. Anyway, this particular field introduces multiple challenges that must be take into account when designing a solution. Table 1 describes the most relevant challenges according to a recent review in the field [15]. CPS is usually associated with the DTs concept due to the characteristics of these elements to reproduce the current status of the physical counterpart. Multiple applications have been discussed in the literature, such as predictive [4,11] or prognostics [3] maintenance. An interesting application has been also presented within the automotive field, where a solution able to predict brake pad malfunctions has been presented in [10]. The improvements introduced by this technology are not limited to the economical aspect, but can easily be found also within the medical one [9]. The usage of

Machine Learning (ML) algorithms in combination with DTs can easily speed up almost every process [14], by reducing costs and preventing possible threats to humans.

Anyway, not all the properties can be satisfied by traditional DTs if considering the landscape of attacks which is possible to perform targeting an IoT device and the overall flow of communication between edge devices and servers [1]. A challenge in the development and design of CPS is represented by the significant differences among the various engineering disciplines involved, such as software and mechanical engineering. In fact, they require a highly skilled workforce, encouraging multidisciplinary collaborations between universities and industry. Some solutions, such as [2] proposed the usage of blockchain as a valuable technology to prevent data modification or to prevent unauthorized access to the system, anyway most of the works described do not cover all the challenges currently existing in a CPS. Our work aims at solving all these challenges by providing a strong framework able to prevent data tampering while ensuring the data heterogeneity and real-time data from sensors.

Table 1. Properties of a strong Cyber-Physical Systems (CPS)

Property	Description
Data heterogeneity	Systems must be able to support a large number of different applications and devices. Digital devices use different communication protocols such as Bluetooth, Zigbee, RF, and infrared
Reliability	Reliability and security are fundamental requirements due to how actuators influence the environment. Any failure of CPS components can lead to system degradation, resulting in serious harm to people and things
Data management	It is necessary to store and analyze big data from various connected devices, process them, and display the results in real-time
Privacy	Since CPS manage large amounts of data, including sensitive information such as health, gender, religion, and many others, significant data privacy issues are raised
Security	CPS rely on heterogeneous applications and wireless communications, which often raise security issues. Security has become a global concern
Real-time	CPS must ensure they have the necessary bandwidth or system capacity to meet critical time-sensitive functions because failures at the time of actions can cause permanent damage

3 Methodology

From SOTA section we have demonstrated the efficacy of ML algorithms applied to DTs in Smart Grid, as well as possible attacks on these systems, particularly concerning the data poisoning or data modifications. In this section, we will present our system with the first aim of detecting and recovering datasets from possible attacks on the system. The discussion of the proposed system is limited to an architecture containing a single device, instead of a federation of them, but it can be easily extended to include additional devices. In order to reflect the changes in a physical system in our model we implemented a DT-based approach,

where each smart meter is identified by a digital twin. Upon these, as depicted in Fig. 2, we created an ML model based on a digital twin able to detect the request of energy from one source. Blockchain acts as a backup registry where it is possible to restore previous versions of the model whenever an attack on the data has been detected. In the following subsections, we will go deeper in describing the components of the proposed system.

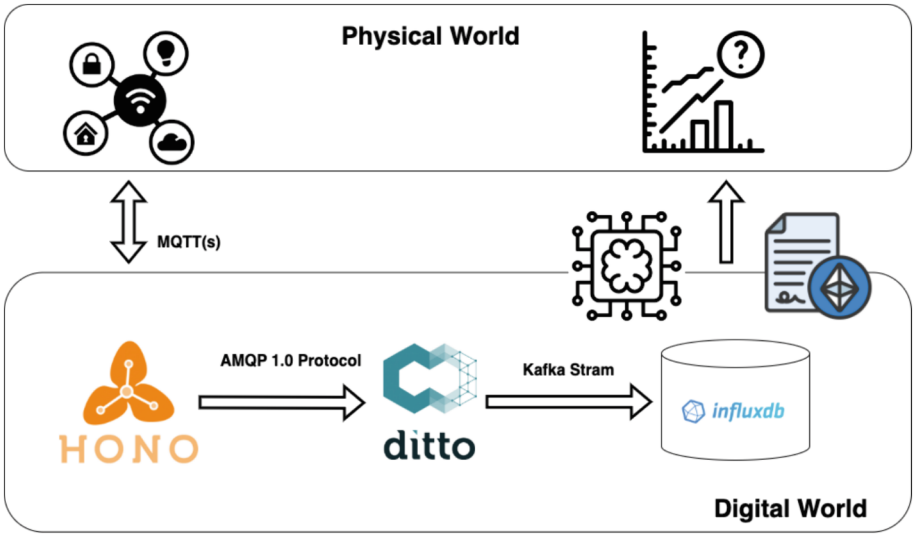

Fig. 2. Architecture of the Proposed System

3.1 Heterogenous Data Collections

One of the main challenges when considering typical DTs smart grid systems is related to the way in which IoT nodes are connected to the gateway. In the proposed system we choose Hono framework, which offers multiple communication protocols through the usage of adapter. Some example of supported protocol are HTTP, MQTT, CoAP, AMQP, and so on. In our system we will leverage this framework to create a reliable MQTT connection between the IoT node and the gateway. More in detail, to secure this communication we defined a Distributed Public Key Infrastructure (DPKI) approach, where each device holds an asymmetric key pair released by the authority. The management of certificates is done through the usage of a smart contract, as demonstrated in multiple approaches already existing in the literature described in [13]. The IoT Node will publish in a given topic served by Hono, authenticating itself using a TLS handshake. This handshake can be easily implemented in HTTP and MQTT, by securing the exchange of data between parties.

3.2 Digital Twin

We proposed a model where smart grid is represented by a digital twin. Particularly, we considers the architecture proposed in [5], where different aspects have been taken into account for representing the physical object. The idea is to have physical objects, all connected to the same gateway responsible for representing the current status. In our case it is implemented by Eclipse Ditto, which is able to include all the metadata connected to the physical entity. Before to define the digital twin, it is necessary to define a policy to assoicate with the physical thing that will be created with Ditto. An example is depicted in Fig. 3, where a policy called *my.test:policy* describes which is the owner of the policy and the permissions related with the operations. Each thing implementing this policy will follow all the permissions defined here. In this way it is possible to implement a mechanism of fine-grined policies, able to enhance the privacy of operations which is possible to perform on the physical object.

```
{"policyId": "my.test:policy","entries": {
   "owner": {
       "subjects": {
           "nginx:ditto": {
               "type": "nginx basic auth user"
           }
       },
       "resources": {
           "thing:/": {
               "grant": ["READ","WRITE"],
               "revoke": []
           },
           "policy:/": {
               "grant": ["READ","WRITE"],
               "revoke": []
           },
           "message:/": {
               "grant": ["READ","WRITE"],
               "revoke": []
           }
       }
   },
}
}
```

Fig. 3. Policy of IoT Node

Once defined policies, we defined attributes for the IoT node for the scope of our research, related to the power consumption. Notice that we want to forecast the overall consumption of energy within a smart home, which can be seen as a sum of the singular power consumption.

3.3 Real-Time Series Database

Managing huge quantity of data it is not an easy task and must be carefully implemented. The usage of InfluxDB, which is a real-time series database completely meet this requirement by providing a tool for collecting huge series of data. InfluxDB is a popular time-series database, plays a crucial role in the realm of energy prediction by efficiently storing and managing vast amounts of time-stamped data generated from various energy sources. In the context of energy prediction, data series refer to the sequential collection of energy consumption, production, and related metrics over time, forming the basis for predictive modeling and analysis. InfluxDB excels in handling the high volume and velocity of time-series data characteristic of energy systems, offering scalability, flexibility, and robust querying capabilities tailored to time-stamped datasets.

The integration of InfluxDB with data series for energy prediction enables organizations to leverage historical energy data to train machine learning models, develop statistical algorithms, and deploy predictive analytics solutions. By ingesting data from diverse sources such as smart meters, IoT sensors, weather stations, and renewable energy assets, InfluxDB provides a unified platform for aggregating, processing, and analyzing heterogeneous data streams critical for accurate prediction models.

One of the key advantages of using InfluxDB for energy prediction lies in its ability to handle real-time data ingestion and querying, facilitating timely insights and adaptive forecasting models. By leveraging continuous querying and retention policies, organizations can retain relevant historical data while efficiently managing storage costs and ensuring data accessibility for predictive analytics tasks.

3.4 Machine Learning Model

Typical smart grid architectures include a Machine Learning (ML) model able to perform predictions about a given task or behavior. Considering the case of energy forecasting and anomaly detection, we moved our focus to a Long-Short Term Memory (LSTM) model able to capture the correlation between time and trends in data. The model obtains the data read by the IoT sensors through the mechanism described before.

The model architecture is designed to accept input data in the format of (*number of features*, 1). In our scenario, as illustrated in Fig. 4, where the violet and black lines exhibit lower values, showcasing the influence of the day of the week on energy demand; we incorporated features such as day of the week, month, and hour of the day into our model. Then we placed two Convolutional Layers with ReLU activation, each followed by MaxPooling and Dropout layers. After that, flatten the output from the convolutional layers into a 1D vector. At the end of the model, we have one dense layer with a single neuron, serving as the output layer for regression.

Once we have added this information to the model, we have set up the model, and it is possible to proceed with the training phase. In this case, we proceed

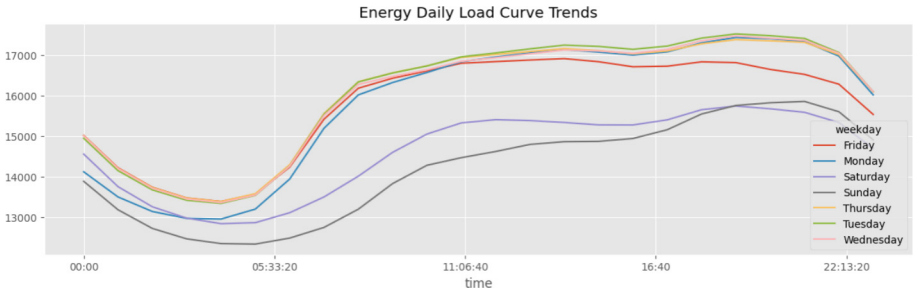

Fig. 4. Daily Load Trends

with a 80:20 split in order to validate the model and check for the initial accuracy. We will go deeper into analyzing the performance of the model in the results section, while now we focus on the mechanism used to gather data from DT and how to restore a previous version of the model in case of attacks.

3.5 Blockchain Backup

Although the described system effectively prevents attacks on communication, IoT nodes often remain susceptible to physical attacks. In such instances, attackers can manipulate the normal behavior of sensors or the microcontroller itself to transmit malicious data. In order to prevent possible attacks on the DTs and data poisoning attacks, aimed at disrupting the current knowledge available at the level of the digital world, it is necessary to implement a resilient mechanism able to provide data backup on possible attacks. Blockchain provides an immutable registry and a mechanism for the validation of the transaction which is highly resilient to attacks thanks to the distributed nature of the system.

Anyway, blockchain cannot be directly applied as storage due to the not permissive fee to pay for the transaction and for the storage of sensitive data, and we will leverage IPFS to store weights of the model as follows. To better explain the mechanism proposed, let us consider a constant time w. We set up a timer, which elapse each w minutes. In the case of the energy consumption model it is reasonable to think that this corresponds to a minute. At this time, the model will read the data from the DT and will store them in InfluxDB. After passing the entire day, it is ready to transmit the newer data to the model in order to perform reinforcement learning and improve the performance. At this point, in a traditional system, if the data received by the model have been poisoned or modified, then the accuracy of the model will decrease and the future predictions will be worse than the current ones. We will see an attack in the results section.

To prevent these attacks we proposed an architecture that include blockchain as a system to register the new weights of the ML model in IPFS. At the end of the day, whenever the InfluxDB need to transmit data to ML model, the model will contact the blockchain in order to assess the quality of current data and decide if accept the newer data. This can be done by performing a test

prediction in order to evaluate the quality of the new incoming data. If the current accuracy is found to be lower, indicating a potential poisoning attack, the backup mechanism will take place. This is done through a smart contract responsible for registering all the statuses of the ML model with the help of IPFS. As depicted in Fig. 5, the ML Model will upload the model parameters in IPFS as soon as it has a new value and performs reinforcement learning. Then it transmits the new Content ID (CID) to the Smart Contract, which will store the CID and will evaluate for the performance of the current model. To be more precise, this operation is performed by the ML Model which sends an accuracy value together with the new CID. Smart Contract saves all the accuracy values and will respond with the best weights between the newer and the previous one. As a note, the model under attack tends to overestimate the actual power consumption of the network yet it still manages to identify the underlying pattern of the dataset. The model, which leverages a backup mechanism, instead, achieves a good prediction with some underestimation in some phases, caused by the attacks received by the node.

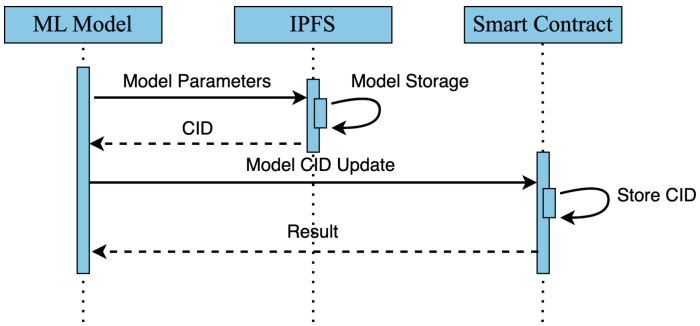

Fig. 5. Interaction between ML Model, IPFS and Smart Contract

4 Results

In order to evaluate the quality in terms of the security of the proposed system, we first introduce a possible attack aimed at disrupting the global model. Once the attack model is discussed, we validate the proposed approach by considering the Hourly Dataset [12]. It offers multiple sources of data, such as American Electric Power (AEP), Commonwealth Edison (ComEd), The Dayton Power and Light Company, Duke Energy Ohio/Kentucky (DEOK), and so on. We will focus on the first one, the AEP. It contains energy consumption from American citizens collected between 2004 and 2018. Despite this being an old dataset, we aim to validate attack detection and the backup system put in place through the usage of blockchain. The attack model outlined here pertains to the system discussed in the previous section and aims to demonstrate the impact of an attacker who intentionally alters the data collected by a smart meter within a federation. As

depicted by Fig. 6, we have two genuine smart meters performing local training and exchanging weights with the aggregator, and a third smart meter that acts as a malicious node (on the right). In this scenario, the attacker either gains access to the federation or physically compromises an authorized node. The implementation of the second attack involves the attacker disconnecting the wires and deliberately altering the data from the sensor to reduce its stability. At this point, InfluxDB will store the new data and according to the description given in the previous section, at the end of the day, it will transmit these data to the aggregator to update the global weights. If the incoming data does not reflect the current status of the system, then the novel weights and consequential local models will start to perform training on malicious data and will start to predict with less accuracy.

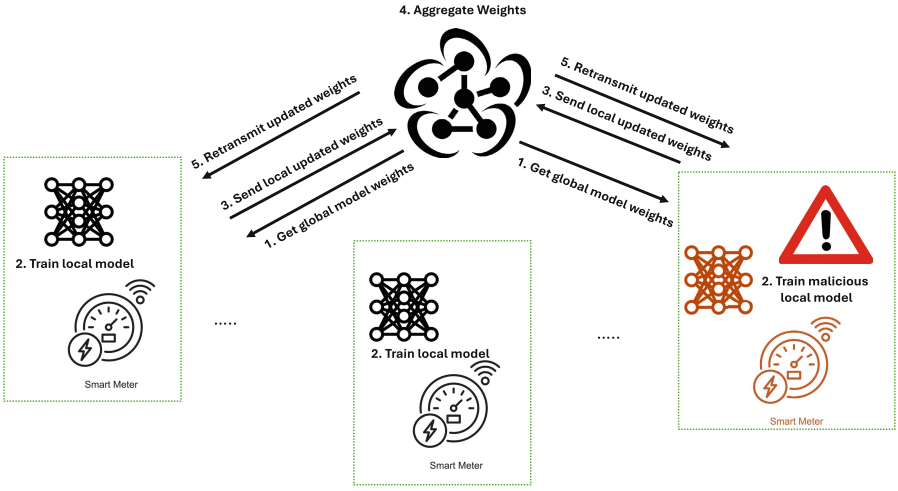

Fig. 6. Attack performed by malicious node (on the right) on the overall FL architecture.

A clear impact of the data poisoning attack is represented in Fig. 7. In Fig. 7a it is possible to notice a model applied to non-attacked data that behaves as a good model with interesting results on anomaly detection. Mean Square Error (MSE) scaled with the MinMax approach reveals a result of 0.002310 from the first model, indicating a pretty accurate prediction, with a really low error with respect to the actual values.

On the contrary, for the Fig. 7b, the model creates situations of overprovisioning and underprovisioning, leading to an increase in costs for the energy provider. MSE for the attacked model is 0.020164, which is 10 times higher with respect to the genuine model. Finally, the efficacy of our approach is depicted in Fig. 7c, where an MSE of 0.002780 has been obtained. Such an error validates our approach by marginally increasing the error faced with the genuine model.

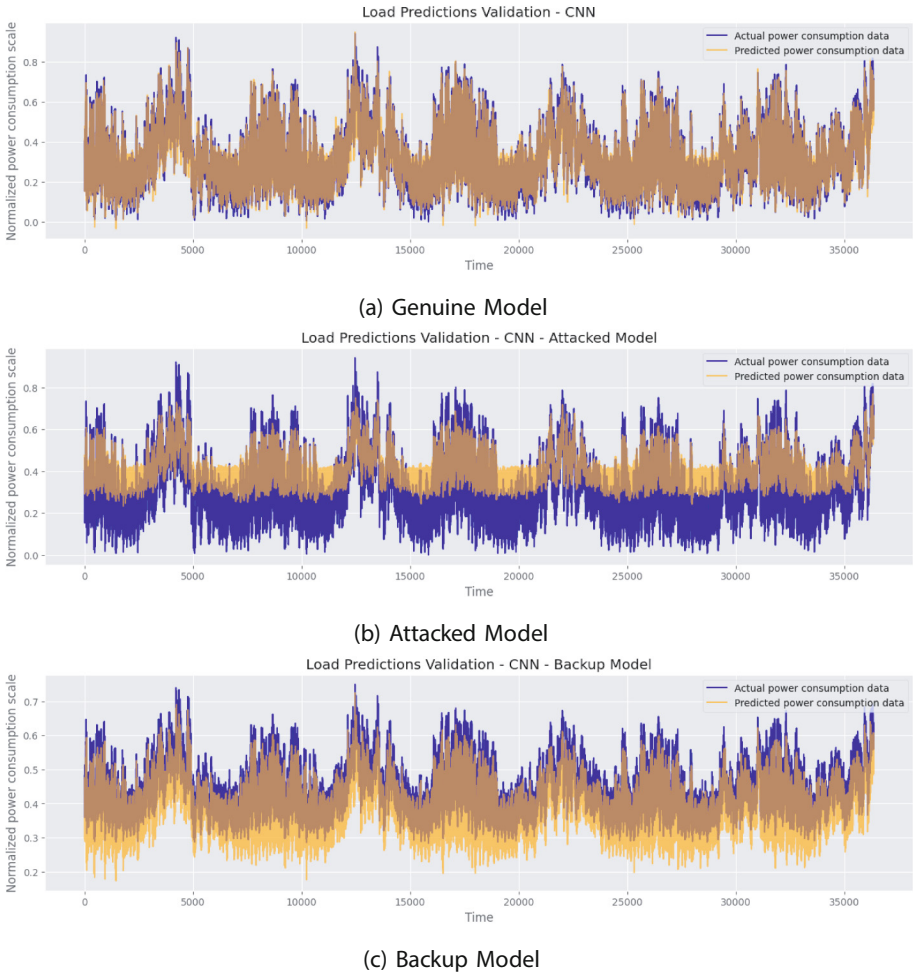

Fig. 7. Power Consumption Predictions

5 Conclusion

The current research demonstrated the efficacy of an interoperable and device-agnostic system to manage smart grid, able to manage threats related to data modification. Blockchain is a powerful technology that is able to restore previous versions of data efficiently. Results validate the proposed approach, by demonstrating a marginal error with respect to the genuine model. The limitations of the proposed approach are related to the data used to test the model, which is restricted to a dataset and might be enhanced with more recent data and data coming from the sensors. In the future, we aim to assess the quality of

the proposed approach in a federation of IoT devices where multiple devices are responsible for sensing the power requested by different sources guaranteeing non-IID property. Moreover, we planned to investigate another kind of attack aimed at disrupting smart grid communication or stealing sensitive information.

Acknowledgements. This work was supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government (MOTIE) (RS-2023-00303559, Study on developing cyber-physical attack response system and security management system to maximize real-time distributed resource availability).

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Sustainable Evolution of Long-Distance frEight paSsenger Transport (SOLIDEST 2024)



A Preliminary and Aggregate Analysis Relating to the Italian and Balkan Intermodal Corridors for the Development of International Freight Trade

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Abstract. In recent years, the maritime transport industry has found itself discussing the problem of international trade between Europe and Asia, namely the direct connection between Asian ports and the ports of the Northern Range. The existence of intermodal corridors affecting the Italian and Balkan peninsulas in southern Europe necessitates special attention. In fact, from the time of arrival in the ports of southern Europe until the arrival at the destinations of central Europe, special attention needs to be given to the study of the land components.

The primary goal of this research work is to analyse the key publications concerning the development of the TEN-T (Trans-European Network on Transportation) infrastructure network and the RFC (Railway Freight Corridors) railway services network in 2023. By implementing an aggregate analysis and reviewing the data concerning the supply of the two corridors currently available within the RFC network, the most noteworthy aspects in terms of benefits and critical issues were identified.

The key findings of this research, identify several significant existing challenges on both corridors due to their passage through many states and the uneven status of infrastructure. It is estimated that the two corridors have the potential of improving TEN-T infrastructure, which in turn improves RFC services. It is also highlighted that there is significant potential for growth in the Southern European regions' infrastructure and services, which might serve as a catalyst for the economic development of the areas under study (currently presenting marginal development). Ultimately, possible actions and strategies could provide advantages in terms of time and costs for freight transiting along the Euro-Mediterranean corridors.

Keyword: Intermodal Corridors · Maritime Transport System · TEN-T Networks · Railway Freight Corridors

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1 Introduction

Rail transport represents an alternative in line with community and international sustainability objectives. The ambitious framework guiding these aspirations is Agenda 2030, adopted by the United Nations in 2015. This transformative document, titled "Transforming our world: the 2030 Agenda for Sustainable Development", outlines 17 interconnected goals (SDGs) encompassing various aspects of sustainability. Each goal is further broken down into measurable indicators and targets, providing a clear roadmap for collective action [1–3].

In the context in question, it is useful to recall two objectives:

- Goal 13, "Take urgent action to combat climate change and its impacts", for its general implications on the reduction of CO2 emissions;
- Goal 9, "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation", which represents the focus from companies and therefore supply perspective.

Railway transportation is directly linked to both decarbonization and resilient infrastructure. The sustainability of railroad transportation is emphasized when compared to alternative transportation modes. The European Union (EU) has placed sustainability at the forefront of its transportation goals, outlined in the White Paper Roadmap to a Single European Transport Area [4]. Recognizing the critical role of interconnected infrastructure, the EU established the Trans-European Transport Network (TEN-T) to seamlessly link different countries and transportation modes. Within this network, Railway Freight Corridors (RFCs) play a crucial role in ensuring competitive and efficient freight movement [5]. In order to guarantee a competitive railway freight service in European network, Railway Freight corridors (RFCs) were established [6]. RFC and TEN-T corridors refer to different aspects of the transportation community system: while TEN-T refers to multimodal strategic infrastructure network, RFC refers to the railway operative freight service network.

This research delves into the potential of RFCs in two key regions: the Balkans and the Italian Peninsula. Both regions, strategically positioned at the southern gateway of the EU, vie for dominance in intermodal transportation. By comparing the existing RFC networks in these areas, our research aims to:

- Evaluate travel distances from Central and Eastern Europe to Southern Europe.
- Assess the capabilities of the present rail freight service network.
- Identify opportunities for improvement and optimization [7, 8].

The structure of the current paper is the following: Sect. 2 analyses in-depth the geographical area under study, the corridors studied, and the evolution of European network; Sect. 3 outlines the methodology used for the quantitative analysis; Sect. 4 presents the main findings of the comparison, which are then discussed in Sect. 5.

This research holds significant value for various stakeholders:

- Researchers: Gaining insights into the dynamics of freight transportation networks.
- Intermodal and Rail Freight Operators: Identifying opportunities to enhance efficiency and competitiveness.

- Public Authorities: Informing infrastructure investment decisions and policy development.

2 (General) Framework on TEN-T and RFC

The European Community was founded on trade and economic integration, but the Treaty of Maastricht in 1992 marked the beginning of Europe's true connection. As of 1992, the European Economic Community, focusing on aspects of economic integration became European Community.The same Treaty triggered the definition of the Trans-European Transport Network (TEN-T) to serve the needs of the EU Single Market (established in 1993) and the economic and social cohesion. The definition of the TEN-T was achieved in 1996 with the adoption of a relevant Decision [9]. This became the reference for the coordinated development of transport infrastructure for the various transport modes, setting the criteria for financing projects of common interest. At the same time, a catalogue of 14 priority projects was adopted. Then the decision was amended twice, in 2001 and 2004 [10, 11], the latter of which coincided with the EU enlargement with 10 new member states. Accordingly, the list of priority projects was extended to 30. The evolution of the TEN-T guidelines followed the EU enlargement process and hence they were amended again in 2007 due to the accession of Bulgaria and Romania. In 2010 it was recast in the interest of clarity [12], while in 2013 the TEN-T Regulation was adopted [13], in the same year of Croatia's accession to the EU. In a parallel process, the Pan-European Transport Networks, established through three Pan-European Transport Conferences (Prague in 1991, Crete in 1994 and Helsinki in 1997) and consisting of the TEN-T in EU countries, ten Pan-European Corridors and transport network components in EU candidate countries and four Pan-European Areas, became obsolete with the consecutive EU enlargements. The Pan-European Corridors were defined to facilitate the operation of the TEN-T in the non-EU regions with the development of relevant infrastructure in the EU acceding countries, as well as in the candidate or potential candidate countries for accession. In 2013, with the adoption of the TEN-T Regulation, a major change was the inclusion of indicative extensions of the TEN-T to neighboring countries, including to those in the Western Balkans region.

The TEN-T network is a tool for integration between various countries. The network involves transport infrastructures by rail, road, sea, inland waterways, as well as the specific infrastructures associated with them (sea and river ports, airports, railway stations terminals, urban nodes and border crossings). The network serves to coordinate the infrastructural efforts of the various countries involved, improve their accessibility, and enhance their competitiveness at both a national and international level. The TEN-T policy is a key community-level planning tool [14]. The network is defined through two levels: a central network and a global network. The core network acts as the backbone of the entire multimodal network, promoting sustainability and connectivity at a European level; the global network has the function of guaranteeing accessibility and connectivity to all regions of the EU, even the most peripheral. It is within the TEN-T that projects of international importance are defined, within the framework of the corridors defined the TEN-TRegulation. Nine corridors was envisaged to facilitate the implementation of the Core TEN-T and were integrated in the Connecting Europe Facility (CEF) Regulation 1316/2013: (a) Atlantic, (b) Baltic-Adriatic, (c) Mediterranean, (d) North Sea-Baltic, (e)

North Sea-Mediterranean, (f) Orient/ East-Med, (g) Rhine-Alpine, (h) Rine-Danube and (i) Scandinavian-Mediterranean [5, 15]. Currently, an expansion of the TEN-T network has been proposed, with the aim of modernizing the entire network and ensuring new sustainability standards. An amended proposal from the European Commission intends to include Moldova and Ukraine in the extended network, expanding the corridors of Eastern Europe to them [16], as shown in Fig. 1. Furthermore, this new regulation proposal was created with the aim of integrating the Core Network Corridors with the Rail Freights Corridors (RFCs) [17].

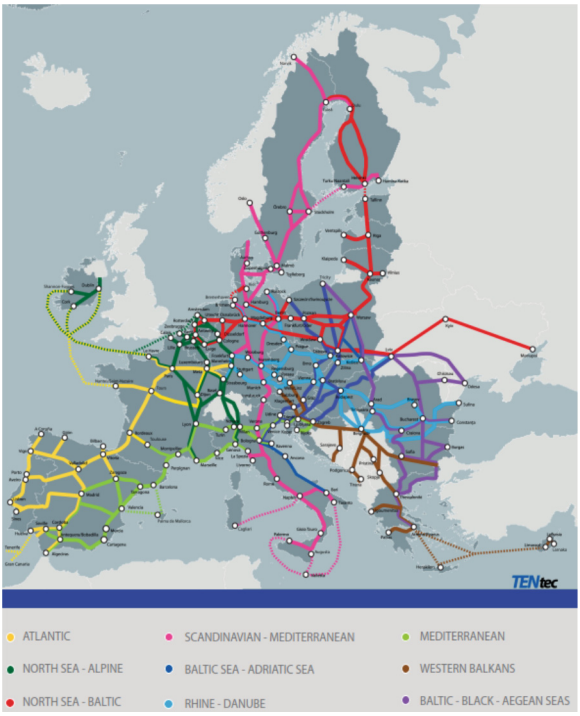

Fig. 1. TEN-T Corridors (Source: European Commission [18])

The TEN-T network therefore constitutes the main reference structure on a strategic scale for the European transport system. At the same time, it was necessary to define a network that could allow better use of the available railway infrastructures, allowing services to be provided which were competitive with all road services. The RFC network is the network that, on an operational scale, allows the best use of the available infrastructure. The RFC network is aimed at pursuing different objectives. In EU Regulation 913/2010 [6], various other aspects are referred to, in addition to that of competition with other modalities, which are central to the development of the network. These include improving connections between member countries and encouraging coordination between authorities of member countries and railway service managers. To this

end, it is emphasized that each established corridor is subject to a single corridor authority. It is underlined that, unlike the TEN-T network, the RFC network does not have competence over the design and planning component of new infrastructures. Figure 2 presents the corridors of the RFC network.

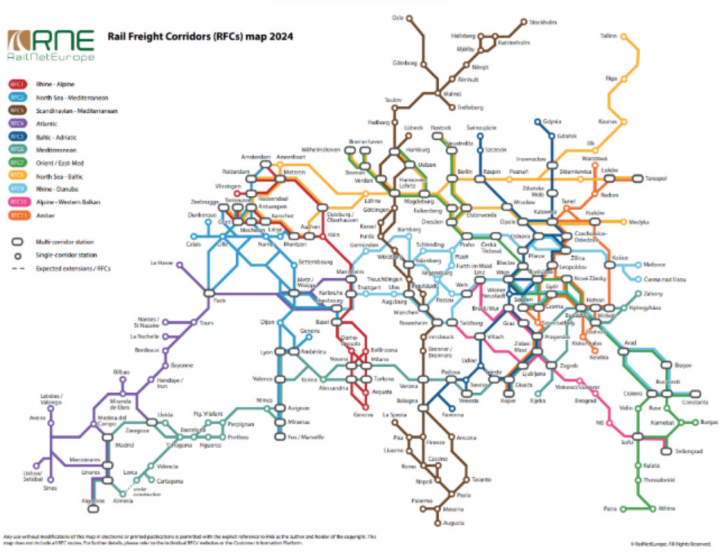

Fig. 2. RFCs (Source: RailNetEurope, 2024. https://rne.eu/corridor-management/rfc-network/ [19])

This paper takes a critical look at the current state of transport corridors in two strategic peninsulas: Italy and the Balkans. Its aim is to position these regions at the forefront of the discussion on efficient and sustainable freight movement between Europe and the East. While maritime transport currently dominates global trade [20], with the Suez Canal serving as a key artery [21], the future demands a multimodal approach. In this evolving landscape, the Mediterranean Sea emerges as a potential southern gateway to Europe. Its geographically advantageous location offers a unique opportunity to bridge the gap between East and Europe [22, 23, 24, 25]. Italy and the Balkans, strategically situated on either side of the Mediterranean, hold the potential to play a leading role in this transformation. By improving existing transport infrastructure, including railway freight corridors, these regions can create a competitive and efficient intermodal network. This, in turn, can attract trade flows and unlock significant economic benefits for both regions and Europe as a whole. In this context, reference is made to the RFC corridors which run through the two peninsulas, as presented in Table 1.

Table 1. Main RFCs considered

Corridor	Countries involved	Reference
RFC 3 Scandinavian-Mediterranean	Norway, Sweden, Denmark, Germany, Austria, Italy	[26]
RFC5 Baltic-Adriatic	Polonia, Czechia, Slovakia, Austria, Slovenia, Italy	[27]
RFC7 Orient – East/Med	Germany, Czechia, Slovakia, Austria, Hungary, Romania, Bulgaria, Greece	[28]
RFC10 Alpine-Western Balkan	Austria, Slovenia, Croatia, Serbia, Bulgaria	[29]

3 Methodology

To study the system under analysis, the main elements of graph theory for modeling the supply system are recalled. Consider a graph $G = G(N,L)$, it has $N = [n_1, n_2, \ldots, n_N]$ nodes and $L = [l_1, l_2, \ldots, l_j, \ldots, l_k, \ldots, l_L]$ links. Each link is characterized by a quantitative measurement c_l. Furthermore, let this quantitative measure be considered constant and independent of other attributes.

In the network thus defined, referring to Cascetta, 2013, the Dijkstra algorithm is considered for the calculation of the shortest paths between two known ones in the network [30]. So, C is considered equal to the length of the path of the arc to which it is associated. Starting from the definitions mentioned, the study comes through the following formulation:

- Scenario "0:" given a generic node o and a generic link l_j, given a set of destination $D = [d_1, d_2, \ldots, d_i \ldots, d_s]$, the paths originating in o, with destination d_i and passing through l_j are identified.
- Scenario "1": given a generic node o, generic links l_j, l_k, given a set of destination $D = [d_1, d_2, \ldots, d_i \ldots, d_s]$, the paths originating in o, with destination d_i and passing though l_j are identified; the paths originating in o, with destination di and passing through l_k are identified, under the condition $l_k \neq l_j$.
- Scenario "2": given a generic node o, generic links l_j, l_k and a set of destination $D = [d_1, d_2, \ldots, d_i \ldots, d_s]$; let $p(o, d_i, l_j)$ and $p(o, d_i, l_k)$ be the shortest paths previously identified; distances $D(p(o, d_i, l_j))$ and $D(p(o, d_i, l_k))$ are identified. Difference between distances is evaluated; condition for which this distance is lower than a specified quantity Δ is verified.
- Scenario "3": given generic nodes $o_1, o_2, \ldots, o_w,\ldots,o_h$, generic links $l_{j,ow}$, $l_{k,ow}$, given a set of destination $D = [d_1, d_2, \ldots, d_i \ldots, d_s]$, the paths originating in o_w, with destination d_i and passing though $l_{j,ow}$ are identified; the paths originating in o_w, with destination di and passing though $l_{k,ow}$ are identified, under the condition $l_{k,ow} \neq l_{j,ow}$.
- Scenario "4": given generic nodes $o_1, o_2, \ldots, o_w,\ldots,o_h$, generic links $l_{j,ow}$, $l_{k,ow}$ and a set of destination $D = [d_1, d_2, \ldots, d_i \ldots, d_s]$; let $p(o_w, d_i, l_{j,ow})$ and $p(o_w, d_i, l_{k,ow})$ be shortest paths previously identified. Distances $D(p(o_w, d_i, l_{j,ow}))$ and $D(p(o_w, d_i,$

$l_{k,ow}$)) are identified. Difference between distances is evaluated; condition for which this distance is lower than a specified quantity Δ is verified.

Different criteria for the destination nodes can be considered. A change in the set D imply a modification in the results of the study. Considering the formulation defined, Fig. 3 summarizes the methodological steps of the work.

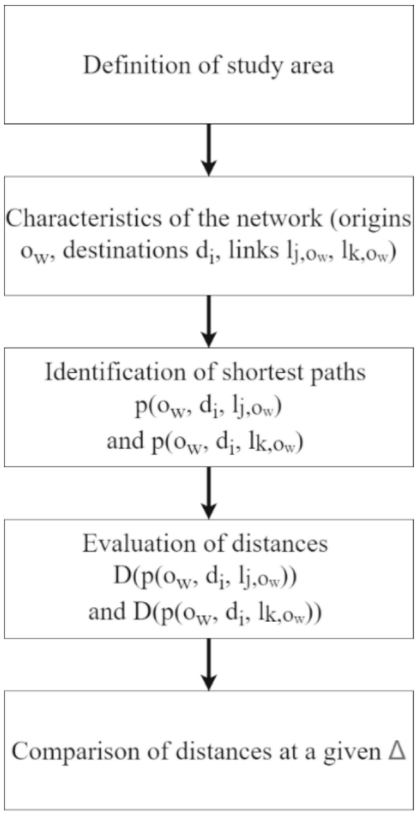

Fig. 3. Methodological framework

4 Results

Our research examines the possibility for railway corridors originating from Italy and the Balkans to become the leading and most preferable transport mode serving at the same time as the southern gateway for freight between Europe and the East. In this aspect, our research identified two cities as key players:

- Gioia Tauro, a strategic Italian port city, poised to leverage its efficient infrastructure, and

- Thessaloniki, a vibrant Greek metropolis, aiming to capitalize on its geographical proximity to Eastern markets.

Both cities set their sights on a lucrative destination: the central and eastern region of Germany, Austria, and Czechia. This area acts as a magnet for freight demand, attracting goods and services from across the continent. It's also the "battleground" where the two peninsulas compete for dominance in this crucial trade route. The corridors considered are the following:

- the Scandinavia-Mediterranean corridor is considered between Hamburg and Gioia Tauro, considering only the Adriatic line in Italy;
- the Baltic-Adriatic from Bologna to Ústí nad Orlicí in Czechia;
- the Alpine-Western Balkans from Sofia to Linz and Salzburg;
- the Orient/East-Med from Thessaloniki to Berlin and Hamburg.

The region under consideration might be a segment of Central Europe that includes the cities of Hamburg, Berlin, Budapest, Salzburg, and Bologna. Several different segments of RFC corridors are taken into consideration in order to formulate a connected network. The four primary corridors under consideration are oriented mostly North-South; additional links primarily follow the main direction of West to East. A portion of the Mediterranean, Rhine-Danube, Amber, and North Sea-Baltic corridors were taken into consideration. The network under consideration and the region are presented in Fig. 4. For modelling the problems, the network was discretized along the main nodes of the network, as suggested by RailNetEurope [33].

For the comparisons, the following assumptions were made:

- The origins are placed in Gioia Tauro (Italy) and Thessaloniki (Greece). They represent the land southern gateway of each peninsula;
- To correctly model the routes in Italy, the portion of the Scandinavian-Mediterranean between Ancona and Gioia Tauro was considered as common to both routes; between Ancona and Bologna, both routes share the route; the two corridors diverge at the Bologna node. For commodity's sake, points placed outside Italy are modelled in this way: routes that considered the Brennero node at the Italian-Austrian border are labelled "Scandinavian-Mediterranean"; routes that considered the Tarvisio or Villa Opicina node are labelled as "Baltic-Adriatic";
- To model the routes in the Balkans, a common portion between Thessaloniki and Sofia is considered, even if it only belongs to the Orient/East-Med corridors; the two corridors have no portions in common outside the Sofia node, within the network considered. Point placed outside of Greece and Bulgaria are labelled as follows: points reached through the Bulgaria/Serbian border at Kalotina/Dimitrovgrad are "Alpine-Western Balkans"; points reached through the Bulgaria/Romania border at Vidin/Golenți border are "Orient/East-Med";
- Destinations are chosen considering all the points, in the study area, in which RFCs have a discontinuity;
- For the definition of a competition area, $\Delta = 150$ km is considered. For each node, and for each corridor referring thee ach node, the average value of distance, from the origin to all the nodes analysed, is calculated. The difference between the lowest average and the medium average is approximately 200 km; the difference between

the highest and the middle average is 100 km; then it is considered, as Δ, the value of 150, that is the intermediate value between 200 km and 100 km.



Fig. 4. Network considered (Source: Authors' elaboration based on openstreetmap [31] and QGIS [32])

4.1 Scenarios 0 – 1 – 2 Balkans

Railway distances have been evaluated for Orient/East-Med and Alpine-Western Balkans corridors. Considering a $\Delta = 150$ km, the competition area for which distances from Thessaloniki through Bulgaria-Romania border (Orient/East-Med) and Bulgaria-Serbia border (Alpine-Western Balkans) is defined. Results are shown in Fig. 5.

The route from Bulgaria/Romania border is the dominant corridor for points between Sofia and Budapest. The route from Bulgaria/Serbia border is the dominant one until Wien, along the Alpine-Western Balkans route, and until Hannover, considering the continuation on other corridors, especially on the Scandinavian-Mediterranean one. The dominance of the Alpine-Western Balkans route, and its continuation, is extended to the South-West of Hungary, the greater portion of Austria and some areas of Germany. Also, Italy and other Balkans countries (Slovenia, Croatia) are comprised in this zone. A large area is made of points for which distances from Thessaloniki along the two corridors are lower than 150 km. This area comprises the North of Hungary, Slovakia, Czechia and almost the entire Eastern Germany, until the city of Hamburg in North-western Germany.

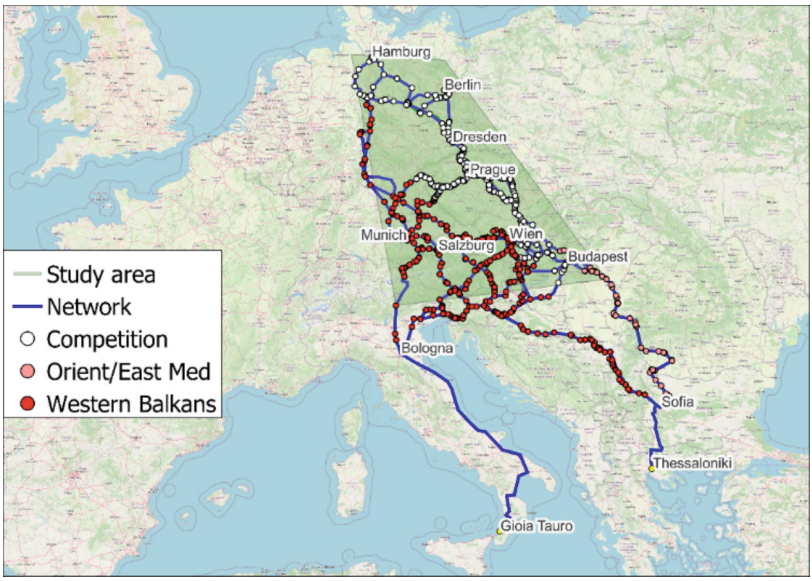

Fig. 5. Points from Thessaloniki (Source: Authors' elaboration based on openstreetmap [31] and QGIS [32])

4.2 Scenarios 0 – 1 – 2 Italy

Distances have been evaluated for Scandinavian-Mediterranean and Baltic-Adriatic corridors. A $\Delta = 150$ km, for defining the competition area between the two corridors is considered. Results are shown in Fig. 6.

Scandinavian-Mediterranean corridor is dominant for almost the entirety of Germany and a vast portion of Czechia, until Prague. Baltic-Adriatic is dominant for Balkans and, at north, the southern part of Slovakia, Austria and Hungary until Budapest. Central and northern part of Austria and Slovakia, among Eastern Czechia, are shaping the area of competition between the two corridors.

4.3 Scenarios 3 - 4 Greece vs. Italy

Considering both origins (Thessaloniki and Gioia Tauro) optimal routes are evaluated. Also, the area for which $\Delta = 150$ km is evaluated. This area is made of points for which distance from Thessaloniki and Gioia Tauro is less than 150 km, considering the shortest path. Results are shown in Fig. 7.

Corridors from Gioia Tauro are dominant mainly for points in Western Germany, Austria and Italy; on the other side, Balkans, Romania, Hungary and Eastern Germany are mainly dominated by the corridors from Greece. Competition area is the area comprised between Hamburg and Berlin, on the North of Germany; also, area between Prague, Linz, Ljubljana, Trieste, almost until Munich, Regensburg and the entirety of Czechia is a competition area between the two-node considered.

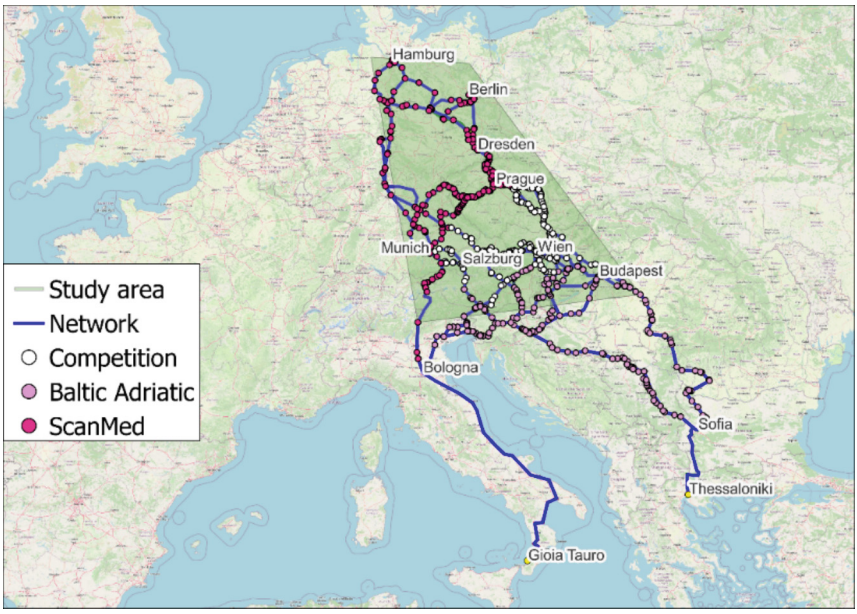

Fig. 6. Points from Gioia Tauro (Source: Authors' elaboration based on openstreetmap [31] and QGIS [32])

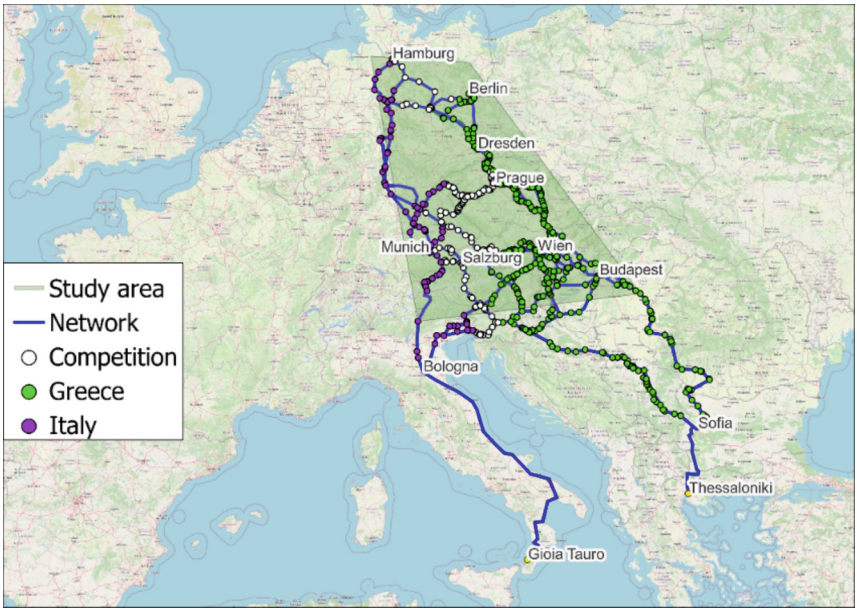

Fig. 7. Points from Thessaloniki and Gioia Tauro (Source: Authors' elaboration based on openstreetmap [31] and QGIS [32])

5 Discussion and Final Remarks

The findings of the above-described research are quite interesting. The Mediterranean countries can serve as the entry points for freight into the European Union thanks to the European Union's rail freight network. Two Italian and two Balkan corridors are taken into consideration. For the Balkans, Orient/East-Med and Alpine-Western Balkans, passing through borders that are, respectively, Bulgarian/Romanian and Bulgarian/Serbian. For Italy, Scandinavian-Mediterranean and Baltic-Adriatic considering the borders of Italy at Tarvisio or Villa Opicina and Brennero.

Thessaloniki was viewed as the origin hub for the Balkans. According to analysis, there are less kilometres between Serbia and Romania on the way to central Europe. Points closer to Thessaloniki through Serbia cover a larger area than those through Romania. There are several things to think about. Places on the Orient/East-Med between Budapest and Berlin/Hamburg are situated on the same corridors of the Bulgarian/Romanian border, even if they are in the competition region. As a result, it is evident that occasionally, network users may find it more beneficial to consider the Orient/East-Med alternative for destinations in Western Germany; focusing on a single corridor is simpler in terms of bureaucracy and administrative issues, and it may also be simpler for users and customers in general. Furthermore, Serbia is not a member of the European Union, adding an element of uncertainty in this research.

However, the Italian corridors display a sharper split, with the Baltic-Adriatic connecting eastern Europe in less than a hundred kilometres, while the Scandinavian-Mediterranean gives Germany priority. Austria, Slovakia, and Czechia all contain sizable areas that are in the competition zone. When the shortest routes between Thessaloniki and Gioia Tauro are compared, the Italian port is shown to be more important in western Germany, whilst the Greek port is more significant in the Balkan region, Hungary, and parts of Czechia, Slovakia, and Eastern Germany. There are still a number of other things to think about in this situation. Generally speaking, the Italian rail network has congestion, which makes the system less attractive for the transport industry; conversely, the infrastructure deficit in Greece frequently dissuades the use of these routes. It's important to keep in mind that Greek corridors may be integrated into intercontinental railway and intermodal corridors; in the context of intermodal corridors Europe-China, nodes in Greece, Bulgaria, and Romania may be gates in Europe for intermodal services from the North Sea and Caucasian region and for railway services arriving from Türkiye. This research presented a preliminary examination of these corridors in a static context, solely taking the distance attribute into account. Several elements may be added to avoid this limitation. Other factors could be considered, such as the quantity of distinct corridors, the duration of stops at borders, or other particular nodes. Additionally, demand components could be used to better understand the reasons rail freight services customers prefer RFC network.

The study is of interest for different categories of stakeholders; public authorities in the context of EU, for the description of different areas and their interest in the rail freight corridors; and logistic companies, for the analysis of the network and the indication of corridors suggested for different needs.

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Railway Demand Evaluation: HSR Induced Component

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Abstract. The introduction of High-Speed Rail (HSR) systems in different countries of the world has demonstrated to be a decisive solution for the sustainable development of the mobility and economic growth, and for the promotion of social inclusion. This paper aims to identify the main methodological approaches to evaluate travel demand induced by the presence of HSR services through a systematic review of the relevant scientific literature. The objective is the exploration of the proposed models and methodological gaps present in the existing research. The findings of this study provide a solid basis for future development in the study of induced demand generated by HSR services, suggesting necessary directions for the advancement of demand analysis methodologies, thus contributing to a more comprehensive analysis of the effects of high-speed rail systems.

Keyword: High-Speed Rail · HSR · passenger demand models · induced demand

1 Introduction

High-Speed Rail (HSR) transportation has gradually gained importance in the land global transport, emerging as a decisive solution to address mobility challenges in the 21st century. The technical definition of HSR varies from country to country. According to European Directive EU 2016/797 of the European Parliament and of the Council of 11 May 2016, within Annex I, the reference parameters for defining HSR railway lines [1] are: high-speed lines designed for speeds equal to or greater than 250 km/h; high-speed lines suitable for a speed of the order of 200 km/h; high-speed lines enhanced, which have special characteristics due to territorial contexts (of importance or urban planning), for which the speed varies according to the specificities of the place. In line with European legislation, the 2018 UIC (Union Internationale des Chemins de Fer) Directive established the commercial speed of 250 km/h as the main criterion for defining HSR [2]. The European Rail Infrastructure Managers in 2008 proposed a classification of railway lines according to demand segments and infrastructure characteristics, also proposing a network vision for 2035 [3]. In the case of high-speed trains, a maximum speed of 360 km/h by 2035 was envisaged.

The continuous evolution of HSR network planning offers opportunities for an increasingly efficient and extended rail service, which makes full use of both new high-speed infrastructure and existing conventional lines. This approach maximises the use of

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existing infrastructure, improving the efficiency and accessibility of the railway system as a whole. During the development of new lines, from the strategic planning phase to the executive design phase, it is essential to have a clear vision of the services that can be activated on the planned HSR lines and on the existing conventional railway lines [4]. The problem of operating models in the presence of HSR and conventional network was analysed in [5], which schematized four operating models:

– "Exclusive exploitation model": characterized by the clear division between HSR and conventional rail service, both with their own infrastructure (model adopted by Shinkansen technology in Japan);
– "Mixed high-speed model": HSR trains run on new dedicated infrastructure or on conventional sections of line (model adopted by France and Italy);
– "Mixed conventional model": some conventional trains run on HSR lines (model adopted in Spain);
– "Fully mixed conventional model": allows maximum flexibility, that is both HSR trains and conventional trains can travel on any type of infrastructure (Fig. 1).

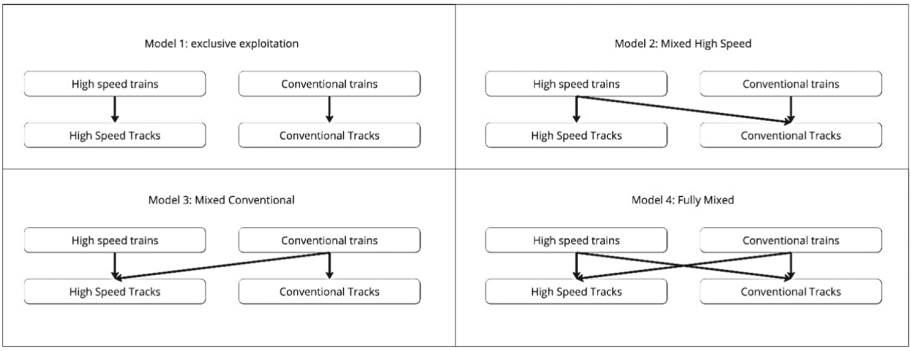

Fig. 1. Operational models for high-speed rail traffic [5].

The growth of HSR lines over the years has influenced the travel behaviour of users, leading to social, economic and environmental changes in the areas covered by the service. In fact, the reduction in journey times and the progressive increase in the frequency of HSR services compared to traditional services have determined effects that can be classified as internal and external in relation to socio-economic characteristics and transport services. Internal impacts concern the transport system, expressed in terms of level of demand, modal share and changes in transport accessibility. External impacts concern both the socio-economic, which also includes land use, as well as the environmental elements [6]. Among the socio-economic ones, the issue of social inclusion is closely linked to that of accessibility to services. The measure of accessibility is often used as an indicator of spatial equity because it reflects the ease with which people can reach specific destinations from a specific origin [7]. A high level of accessibility is crucial for improving the quality of life in cities because, with increased connections, people can carry out their activities at a lower cost (in terms of both money and time) [8].

HSR has effectively established itself as a new mode of transport, emerging as a new alternative to aircraft and conventional train. The reasons for this growing importance are related to environmental sustainability, operational efficiency, economic development, sustainable mobility and integration between the connected regions. Indeed, HSR is the most sustainable transport option compared to other modes such as aviation and cars for specific class of distances.

These features make HSR transport a decisive option for addressing climate change challenges. Increasing the share of passengers and freight transported by rail is a relevant key to achieving the 'zero emissions' targets of Goal 13 of Agenda 2030 [9]. The crucial element of the relevance of HSR is the significant reduction in travel times. The average speed of HSR services makes it possible to connect cities significantly faster than other means of transport (when the cities are far below a distance threshold), promoting greater connectivity between regions. The connection could also be estimated by means of the concept of centrality, in all its specifications, to verify the quality of the infrastructural networks and services [10, 11]. This not only improves mobility, but also stimulates economic development through increased accessibility to services and greater connectivity of industrial agglomerations with the distribution network. As a matter of fact, some studies [12–15] estimated the benefits in the case of a commercial port in connection with a Special Economic Zone (SEZ).

The realisation of HSR has impacts on the increase of GDP (Gross Domestic Product), in fact, economic benefits derive from the introduction of this service both in the short term, e.g. for the realisation of the projects themselves, and in the long term, due to employment growth through commercial, residential and industrial development along the HSR lines, which would also act as a driving force for tourist attractiveness [16]. In this sense, the implementation of the HSR network is an effective direction to the economic and social development problems of under-developed regions both in terms of competitiveness and connectivity. For example, the presence of HSR could produce in the cities of Southern Italy, a differential increase of 7 percentage points of GDP within 10 years [17].

The estimation of the impact of HSR on demand is crucial for the effective planning of new HSR lines, considering the expected social benefits of greater accessibility between connected cities, the economic benefits of increased mobility of people and goods and the environmental implications of reducing greenhouse gases compared to other modes of transport.

The estimation of new demand caused by the presence of HSR is therefore the main challenge in assessing how HSR influence sustainable development. In this sense, the phenomenon of induced demand is not limited to new passengers who would not have travelled without the HSR, but also includes those who, coming from other modes of transport or traditional rail services, increase the frequency of their travel due to the increased benefit of the HSR.

Although there are numerous studies in the literature investigating the competition of HSR with other transport modes, there are few works estimating the impact of HSR on long-term demand, which does not consider modal substitution but the net increase in demand generated by the presence of HSR. The aim of this paper is to identify the key

issues of the induced demand component, in order to provide a useful basis for additional investigations and analyses in the research topic of HSR-induced demand.

The research activity presented in this article is in line with other studies that deal with the impacts of HSR services. Rindone and Russo [18] performed a network analysis considering the existing HSR services in Southern Italy. Russo et al. [19] deal with an analysis of the dynamic structure a fares of HSR services in Italy. Panuccio [20] proposes a state-of-the-art on the sustainable development of railway nodes, with specific reference to the new HSR stations in Italy.

After this introduction, the paper is divided into four sections: Sect. 2 recalls the three demand components related to HSR; Sect. 3 reviews the literature concerning induced demand; Sect. 4 classifies the variables used by the authors to estimate induced demand; the last section is devoted to the conclusions derived from the review of the literature.

2 HSR Travel Demand Models

The introduction of HSR in several regions of the world has attracted considerable economic, social and environmental interest. In general, the presence of HSR generates three different components of travel demand [21]:

- Diverted demand;
- Induced demand;
- Economic growth demand.

Diverted demand refers to demand already present but diverted from other modes to HSR, therefore demand already present in car, bus, aeroplane, or other conventional rail services (intercity). The attributes influencing this type of demand are endogenous to the transport system, such as on-board travel time, ticket price, frequency of service, location and number of railway stations, but also the location of airports. Moreover, as shown by Givoni and Dobruszkes [22], demand diverted from other modes to HSR would present variations in relation to travel time. In particular, with regard to the impact of HSR on traffic by air mode, the study showed that: for travel times less than 2.5 h the choice of HSR is dominant, for travel times of around 3.5 h users' choices are equally distributed between HSR and aeroplane, while for travel times of more than 5 h users predominantly choose aeroplane.

The growth of HSR demand is a result not only of the modal diversion to HSR but also of HSR induced demand. According to Cascetta and Coppola [23], induced demand is classified into: direct, when changes in travel frequency occur; indirect, when it relates to an increase in mobility caused by changes in travellers' mobility choices or lifestyles.

Demand due to economic growth is influenced by national and international economic trends, considering that higher income leads to greater travel demand and vice versa. Russo et al. [24] classify the three HSR demand segments based on the choice dimensions schematised with partial-share demand models.

The travel demand is therefore influenced by the socio-economic characteristics of the users, the existing transport system and economic attributes, and the territory. According to the basic assumptions on which they are based, demand models can be classified into Statistical-Descriptive and Probabilistic-Behavioural models [25–27]. Descriptive

models focus on observed relationships between socio-economic variables, service levels and demand flows (or percentages); behavioural models derive from explicit assumptions about user behaviour and attempt to interpret it through probabilistic functions. In behavioural models, the choice of the alternative belonging to the set of choices perceived by the user is normally described by means of random utility models (RUM) [25–27], fuzzy utility models (FUM) [28–30] and quantum utility models (QUM) [31, 32]. The calibration of the models is approached in aggregated or disaggregated form. In the first case, aggregated and indirect information on user behaviour is used, typically data sets obtained from ticket sales or passenger flow counts, or from national statistics. Disaggregated models simulate the choice process of the individual decision-maker (user) and are classified into mono-modal, to analyse the effect of technological changes on a specific transport mode, and multi-modal, designed to simulate competition between HSR and other modes and/or rail services [23]. The disaggregated estimation of demand patterns is conducted through surveys that provide elementary information on the mobility behaviour of a sample of users. These surveys belong to two classes: surveys that reveal or demonstrate the current user behaviour in a real context are called Revealed Preference (RP); surveys concerning declared user behaviour in a hypothetical context are called Stated Preferences (SP) [27].

The three HSR demand components defined above are associated with one or more partial share models, which simulate one or more dimensions of trip [24]. Specifically, diverted demand can be estimated with mode-service-company-run choice models, while induced demand, both direct and indirect, can be estimated using trip generation and trip destination models. Travel demand generated by economic growth can be estimated as the result of the application of Spatial Economic Transport Interaction (SETI) models, simulating a transport-economy system [33].

3 Literature Review of Induced Demand

In the context of the planning and implementation of HSR services, the comprehension and the analysis of induced demand plays a fundamental role. This demand component emerges temporally following the diverted demand and prior to economic growth demand and turns out to be extremely important because it supports the increase in demand after the HSR has been opened. Accessibility has a key role in increasing demand, as the locational advantages provided by the expansion of HSR allow citizens living in the closest cities to travel more frequently and change destinations. However, the induced demand has been little investigated in the literature due to its complexity.

This section presents a review of the literature in order to analyze and synthesize the state of the art concerning the induced demand models proposed, with the aim of identifying the gaps in the evaluation of the percentage of induced demand generated by the presence of HSR.

In order to conduct an accurate analysis, some keyword search criteria were developed as a methodological basis for critically examining elements of the various papers and assessing their relevance to the topic.

A few papers were selected in which the topic of induced demand was addressed. The selected papers were analysed according to six categories (Table 1).

- Partial share (Generation or Distribution): simulated choice dimension.
- Country (C): differences between national contexts regarding the various elements of transport on a national scale (infrastructure, socio-economic context, etc.).
- Approach: proposed model for estimation of induced demand (Statistical-Descriptive or Probabilistic-Behavioural).
- Specification (S): presence of formal specification of the model.
- Calibration/Validation (C/V): description of the method and the reference set of data used for the model calibration and validation.
- Parameters (P): presence of the calibrated parameters.

Table 1. Classification of the literature about HSR induced demand.

Authors	C	Generation					Distribution				
		Approach		S	C/V	P	Approach		S	C/V	P
		S-D	P-B				S-D	P-B			
Yao & Morikawa (2005) [34]	J	x			x	Y		x		x	Y
Ben-Akiva et al. (2010) [21]	I	x			x	N					
Pagliara & Preston (2013) [35]	E	x		L-R	x	Y					
Cascetta & Coppola (2014) [23]	I		x	Logit	x	Y					
Leng et al. (2015) [36]	C	x		L-R		N					
Ren et al. (2019) [37]	C	x		L-R	x	Y					
Zhang et al. (2019) [38]	U		x	B-R	x	Y					
Avogadro et al. (2023) [39]	H	x		L-R	x	Y	x			x	Y

C = Country, S = Specification, C/V = Calibration/Validation, P = Parameters, J = Japan, I = Italy, E = England, C = China, U = USA, H = Holland.

The aim of this work is to provide a comprehensive review of the research about the induced demand by highlighting the progress in this topic over the last twenty years.

The main elements of the literature's review of induced demand have been focused through this classification. Table 1 summarizes the results obtained from the examination of each publication according to the defined criteria.

In a case study carried out in Japan, Yao and Morikawa [34] proposed an integrated model of intercity travel demand with a nested structure consisting of the following sub-models: route choice, mode choice, destination choice and travel choice. The authors' goal is to make the model sensitive to changes in travel conditions so that possible induced trips can be estimated. The authors calibrated the generation and distribution models. The distribution model, estimated through disaggregated data, is of the Logit type. The specification of the utility of destination choice includes variables accounting for the level of service and specific characteristics of the cities reached by the HSR service, and the explanatory variable (logsum) derived from the mode/route choice model. The authors did not report the specification of the model. The generation model was calibrated using a Statistical-Descriptive approach, where the attributes considered are: the accessibility for a person in the origin area multiplied by the population and the working population in the service sector. Accessibility is the logsum that measures the effects of mode/route and destination choices. The data used for the study came from RP-SP surveys and aggregate data. The authors estimated the generation model as an aggregate model. By measuring accessibility, the generation model becomes sensitive to variations in travel conditions, allowing the authors to estimate the elasticity of demand.

In the study of Ben-Akiva et al. [21], the induced demand model was defined as: "*the model which estimates the additional HSR demand due to the improvement of HSR level of services*". According to the results, the basis of the induced demand model is the relationship between current demand for HSR services, which is the dependent variable of the model, and independent variables such as current travel times and costs of HSR services, as well as the socio-economic variables of the population of the areas reached by HSR services.

In the study by Pagliara and Preston [35], induced demand is investigated by applying a gravitational model, with the aim of predicting the changes in the number of trips before and after the introduction of HSR services in Great Britain. The data used were provided by the Office of Rail Regulation (ORR) and represent the total number of trips made annually in the British railway stations. The study considers several origins and London as the only destination. The number of trips from station i is denoted by T_i and is given by:

$$lnT_i = \beta_0 + \beta_1 lnCP_i + \beta_2 ln\left(\sum\nolimits_{HSR} exp\left(U_{ij}\right)\right)_i + \beta_3 \ln(HSR)_i + \beta_4 \ln(districtHub)_i \quad (1)$$

where β_0 is the intercept, CP_i is the number of car parking areas available in the station i, *HSR* is a dummy variable that has value 1 for the station covered by the HSR service only and value 0 otherwise, *districtHub* is a dummy variable that has value 1 if the station is central to the district area and 0 otherwise. Finally, the logsum was calculated considering the travel time and fare for each station to London.

Cascetta and Coppola [23], in order to estimate the increase in HSR induced demand levels in Italy, calibrated travel frequency models belonging to the class of behavioural

models. The aim was to obtain the probability that, for a specific purpose and time period, a transport user makes a certain number of trips. The proposed trip-frequency model is as follows:

$$d_o[h] = \sum_i \sum_s n^i[o] m^i[osh] \tag{2}$$

where i is the generic user, o is the origin, h is the reference period, s is the travel purpose, $n^i[o]$ is the number of users belonging to class i present into the origin and $m^i[osh]$ is the number of trips made by the generic user equal to:

$$m^i[osh] = \sum_x \sum_d x p^i[x/odsh] \tag{3}$$

In Eq. (3), $p^i[x/odsh]$ is the probability that a generic user makes x trips, for purpose s and in period h, on the specific OD pair ("OD-based models"), obtained through a logit model:

$$p^i[x/odsh] = \frac{exp\left[V^i(x/odsh)\right]}{\sum_{x'=0,1,2+} exp\left[V^i(x\prime/odsh)\right]} \tag{4}$$

The authors chose as a reference period a winter period in which people travel to mountain destinations (the so-called "ski week") and two travel purposes ("business" and "non-business"). The choice set consists of the alternatives "no trip", "one trip per week" and "more than one trip per week" between origins and destinations represented by Italian administrative areas, called "province". They obtained the average number of trips made by each user as the weighted average of the number of trips x corresponding to frequency classes "0″,."1″ and "2 +", assigning weights to the probability of choosing each frequency class. The systematic utilities consider socioeconomic attributes (gender, professional status, level of degree) and variables associated with the level of service for the OD pair.

$$V(x = 0) = ASC_0 \tag{5}$$

$$\begin{aligned} V(x = 1) &= \beta_{ADD1} Add_{res}(o) + \beta_{male1} male + \beta_{degree1} degree \\ &+ \beta_{occ_{high1}} Occ_{high} + \beta_{logsum2} Logsum(o, d) + \beta_{sogliaT_{min120_1}} sogliaT120(o, d) \\ &+ ASC_1 \end{aligned} \tag{6}$$

$$\begin{aligned} V(x = 2+) &= \beta_{ADD2} Add_{res}(o) + \beta_{male2} male + \beta_{degree2} degree + \\ &\beta_{occ_{high2}} Occ_{high} + \beta_{logsum2} Logsum(o, d) + \beta_{sogliaT_{min120_2}} sogliaT120(o, d) \end{aligned} \tag{7}$$

with $Add_{res}(o)$, total employment in the province of residence "o", $Logsum(o, d)$ inclusive variable that depends on the level of service of the modes available in the OD pair, Occ_{high}, dummy variable that is equal to 1 if the user has a high professional status, $sogliaT120(o, d)$, dummy variable that is equal to 1 if the travel time on the OD pair is less than 120 min. The parameters were calibrated using the Maximum Likelihood method. Model estimates show a non-linear trend in the trip-frequency. In particular,

there is a significant increase in mobility below the minimum threshold of 120 min to travel between the OD pair.

Leng et al. [36] dealt with passenger flow forecasting for the entire Chinese HSR rail network, using trip generation forecasting as a reference. The induced demand flow is estimated for each O-D pair:

$$I_{OD} = I_{OD} \frac{TI}{\sum_{O=1}^{N} \sum_{D=1}^{N} I_{OD}} = I_{OD} \frac{T - TG - TD}{\sum_{O=1}^{N} \sum_{D=1}^{N} I_{OD}} \tag{8}$$

The authors indicate with I_{OD} the induced demand for the O-D pair. TI is the total induced demand which is equal to the total passenger demand (T) from which total economy-based demand (TG) and total diverted demand (TD) are subtracted. The estimated values are calculated by comparing the demand flows observed in 2008 with the demand flows observed in 2011.

The results of the study by Ren et al. [37] carried out on the 307 km Chengdu-Chongqing corridor show that the opening of an HSR line leads to a substantial increase in travel frequency not only for users travelling for personal reasons but also for commuters travelling for work. The model proposed by the authors is an Ordered Probit model specified as follows:

$$Y_i = \beta X_i + \varepsilon_i \tag{9}$$

where the dependent variable Y_i was measured by the variations in travel frequencies observed before and after the opening of HSR. The values of calibrated parameters are reported in the study. The authors also proposed an index to measure the change in the economic link between Chengdu and Chongqing:

$$R_{ij} = (\sqrt{P_i G_i} \times \sqrt{P_j G_j}) / D_{ij}^2 \tag{10}$$

where, i and j are the regions, P is the population, G is the GDP and D_{ij}^2 is shortest travel time by HSR between the two cities.

In the study conducted by Zhang et al. [38], a modelling framework is proposed for analysing induced travel demand in the context of a new transport mode in the Dallas-San Antonio corridor in Texas. Data were collected by an online survey that included questions on socio-economic factors, previous travel experiences, and hypothetical parameters of the new mode. Respondents included travellers on the corridor and residents in the study area. Each respondent answered eight questions on the frequency of their trips corresponding to different scenario configurations concerning the new HSR service. The data were analysed using econometric models. The authors selected a negative binomial panel-data model:

$$P = \frac{\Gamma(\lambda_{it} + y_{it})}{\Gamma(\lambda_{it})\Gamma(y_{it} + 1)} \left(\frac{1}{1 + \delta_i}\right)^{\lambda_{it}} \left(\frac{\delta_i}{1 + \delta_i}\right)^{y_{it}} \tag{11}$$

where y_{it} is number of stated additional trips for the t-th observation of the i-th respondent; Γ is a gamma distribution; δ_i is the dispersion parameter; $\lambda_{it} = \exp(X_{it}\beta)$; X_{it} is the

independent variables; β is the coefficient to be estimated. In addition, the authors quantified the induced travel demand ratio as:

$$Induced\ Demand\ Ratio = \frac{Induced\ travel\ demand}{Current\ Travel\ Market\ Size} \tag{12}$$

An important element introduced in the paper of Zhang et al. [38] is the possibility of calculating the induced demand in relation to all combinations of travel time and cost. The authors showed how induced demand is sensitive to the variation of these parameters.

Avogadro et al. [39] discussed various policy measures and their impact on modal choice between air and HSR markets between Amsterdam and London. The authors specified two aggregate models for a specific OD pair using a Statistical-Descriptive approach: distribution model and generation model. The data used for the study was provided by the International Passenger Survey (IPS), an aggregated database that provides information on the number and types of passengers entering and leaving the United Kingdom. The authors estimated the distribution model by regressing the difference between the modal share (air vs. HSR) according to the differences between the attributes. The generation model is specified as follows:

$$Q_{mt} = D_{mt} Los_{mt}^{\theta} = \exp(K_{mt}) Pop_{mt}^{\rho} GDP_{mt}^{\tau} Logsum_{mt}^{\theta} \tag{13}$$

where the potential demand on a specific OD pair, D_{mt}, is a function of population, *Pop*, and GDP per-capita, *GDP*; *m* is the sub-market (OD pair), *t* is the reference period, K_{mt} is a sub-market-specific constant and $Logsum_{mt}^{\theta}$ is the inclusive utility which measures the aggregate utility provided by the travel alternatives:

$$V_{i,mt} = \alpha_i + \beta \ln\left(freq_{i,mt}\right) + \beta traveltime_{i,mt} + \beta travelcost_{i,mt} + \beta HSR \times ln(freq_{i,mt}) \tag{14}$$

where *i* is the air/train modal alternative, $freq_{i,mt}$ is the frequency of the alternative *i* in sub-market *m*, $HSRln(freq_{i,mt})$ is an interaction term between frequency and HSR mode, $traveltime_{i,mt}$ is the travel time for the alternative *i* and $travelcost_{i,mt}$ is the fare for the trip alternative *i*. The models were both calibrated.

4 Discussion

The studies analysed in this paper represent the most significant advances in current knowledge regarding the estimation of induced demand generated by the presence of HSR. Five of these studies contain the calibrated parameters [23, 34, 37–39], reported in Tables 2 and 3.

The tables classify the variables used by the authors to estimate generation demand (Table 2) and distribution demand (Table 3). The proposed classes concern the territory's economy, the users' socio-economic condition, the level of service and the travel purposes. The variables may have different structures: Boolean (B) variables, Continuous (C) variables and Discrete (D) variables.

Table 2. Classification of variables used to estimate generation demand.

Class	Variable	[34]		[23]		[37]	[38]	[39]	
		B	NB	B	NB			B	NB
Territorial economy	GDP							B	B
	Employment			C	C				
	Population							B	B
	Work.pop.s.s.	C							
User Socio economic	Gender			B	B	B			
	Age					D	B		
	Education					D			
	Graduation			B	B				
	Professional s.			B	B				
	Career					D			
	Salary					D	C		
	Dist. Home						C		
	Vehicle/s						B		
LoS	Time			B	B	B	C		
	Tariff					B	C		
	Amenity					B			
	Punctuality					B			
	Safety					B			
	Frequency						C		
	Refund						B		
Logsum	Mode-choice			C	C			C	C
	LoS							C	C
	Access*pop.	C	C						
Purpose	Business					B			
	Study					B			
	Visiting friends					B			
	Shopping					B			
	Return home					B			

B = Boolean, C = Continuous, D = Discrete.

The comparison of the calibration results for estimating induced demand reveals some common variables used by the authors, which are mainly variables explaining the socio-economic characteristics of the transport users. In particular, the gender variable in Cascetta and Coppola [23] (see Eqs. 6 and 7) and in Ren et al. [37] is specified as a

Table 3. Classification of variables used to estimate distribution demand.

Class	Variable	[34]		[39]	
		B	NB	B	NB
Territorial economy	GDP	C			
	Business attactive	C			
	Non business attactive		C		
	Working population	C			
LoS	Time			C	C
	Tariff			C	C
	Frequency			C	C
Logsum	Mode-choice	C	C		

C = Continuous.

Boolean variable, which is equal to 1 if the user is a male, and 0 if the user is a female. The results of the calibration show that the value of the parameter is positive in the first case and negative in the second one. According to Ren et al. [37], the probability of increase the travel frequency in presence of HSR is higher among females in the Chinese market, while an opposite result has been obtained by Cascetta and Coppola [23] for the Italian market.

5 Conclusion

The study of the existing literature on the impacts that HSR generate on induced demand showed the presence of few works on this topic.

The induced demand generated by HSR in a territory is defined as the number of users who make new trips and increase the trip frequency on a given O-D relation. Considering the benefits related to accessibility, greenhouse gas reduction and economic development, the knowledge of the induced demand is crucial for the planning of the HSR network. The analysis presented in this paper described the current methodological advancement regarding HSR induced demand estimation. In particular, a summary of the results obtained in each paper was proposed. The comparison of the model results calibrated by a few authors revealed a discrepancy in the calibrated parameters. Among these, the "gender" parameter appears significant.

The conclusions derived from this literature review provide important insights for transport researchers, indicating the need for further research and analysis to deepen the understanding of the impact of HSR services on transport demand, especially considering the limited analysis of the induced demand component. More generally, the basic constraints consist in the difficulty to develop specific survey and subsequent analysis and modelling regarding the induced demand.

Future research will concern the construction of aggregate models for estimating the demand induced by the opening of HSR services in underdeveloped areas, with an

application to the Rome-Reggio Calabria relationship (Italy), with the aim of analysing the effects of High-Speed Railway systems on the variation of travel frequency.

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Dynamic Structure of Fares for High Speed Rail Services

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Abstract. The entering of High Speed Rail (HSR) passenger services caused competition in the market with other conventional rail services, and other transport modes. The dynamic structure of fares in the HSR services assume a crucial role in the supply of scheduled transport services and influence travelers' choice behavior. The HSR fare structures, similarly to the air services, is characterized by evolutions and changes over time due to several factors, such as travelers' behavior; strategies of the companies supplying the HSR services. The results reported in the paper contain a framework for analysis of the evolution of fares over time in relation to the day of ticket purchase and of the day of trip. A sample representation of a pilot case study implemented on the existing HSR line between Rome and Milan (Italy), where two HSR companies operate and compete each other, is presented.

The aim of the study is to identify the characteristics fares evolution over time in the HSR market. This work is useful for support transport planners and decision-makers for the ex-ante evaluation of fare structure in terms of users' behavior.

Keywords: High Speed Rail · method for dynamic fares analysis · fares structure

1 Introduction

Worldwide extension of High-Speed Rail (HSR) lines, according to last report of Union International des Chemins de Fer [1], is about 129,850 km in the world: 59,498 km in operation, 19,927 km under construction, 16,850 km planned, and 33,575 km planned over longer term. The largest network today is in China (40,493 km), followed by Spain (3,917 km), which has overtaken Japan (3,146 km) and then France (2,735 km). The HSR network in Italy includes 921 km in operation and about 327 km under construction [2].

According to the European Union [3] the rate of CO2 emissions in the transport sector is about 20% of the global emissions. In order to pursue sustainable development as a priority, it is necessary to refer to the Sustainable Development Goals of Agenda 2030 [4–6], in particular focusing on the Goals 9, 11 and 13.

According to the SDGs annual Report of United Nation [7] the global CO2 emissions from energy combustion and industrial processes resulted in strong growth in the last two decades, reaching the record of 36,8 billion metric tons in the year 2022. It is

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necessary to recall that in terms of CO2 emissions [8], HSR is more sustainable than other transport modes, impacting about, respectively, 75% and 70% less than air and car modes. Therefore, the HSR mode-service goes in the direction of reaching the targets identified in the above mentioned goals.

The opening of HSR lines caused an increment of transport demand namely on its the three components [9, 10]:

- diverted, from other modes or other rail services;
- induced, in terms of trip frequency and destination generated by increment of level of service (e.g. reduction of travel time) due to HSR;
- economy-based, in terms of trip frequency and destination generated by increment of economy in the cities, or areas, served by HSR.

The entering of HSR in the market caused competition in the intermodal level (e.g., mode choice level) and intramodal levels (e.g., service and company choice level). The fare structures of HSR services play a key role in both levels of competition [11] in the intercity context. According to [12], HSR mode-service is mainly chosen in context of short-medium travel times and distances, in particular at the national scale. Hence, with a travel time about 2 h, HSR is completely chosen rather than air, within a travel time between 2 and 3 h and half HSR is the dominant mode, and with more than 3 h and half of travel time the air mode is the principal alternative for travellers. The positive effects of HSR on travel demand may be amplified when the HSR stations are located not far to residential and work areas [13–16], and to ports and related areas [14, 17, 19].

In the context of demand analysis, it is important to investigate the characteristics of fare structures in the HSR market. The analysis of dynamic structure of fare is an important issue for the company's perspective, for the maximization of revenues and seat allocation; but also, for the travellers' perspective, for the minimization of travel cost (in this case the monetary cost of trip). The analysis and the determination of the patterns of dynamic fares in the HSR market has relevant impacts on the transport services scheduling and on travellers' choices of competing modes and services.

The contribution of this paper is to provide a framework which is characterized by a dynamic approach based on the evolution of tickets, according two time variables: the *day of ticket purchasing* and the *day of trip*. The paper is developed in relation to the gaps in the current literature about fare structures in the HSR mode-services. The gaps regard the insufficient level of analysis in the context of dynamic fare structures of HSR services.

The following part of the paper is organized as follows. Section 2 analyzes the state-of-the-art concerning the dynamic fare structures, mainly in the air transport markets. Section 3 contains the description of the experimental framework for the analysis of dynamic structure of fares and a pilot survey on the Rome-Milan relationship. Some preliminary remarks and the issues for future research are reported in the last section.

2 Literature Review

The existing literature shows that the fare structure analysis and its determination in the transportation market is mainly oriented for two research objectives: revenue management and seats allocation optimization [18–21].

The fare structures may be classified in two main classes: static and dynamic [22]. Static fare structures are mainly used in the conventional passenger rail and bus services, whereas dynamic fare structures historically characterized air services. In the last decades, the dynamic fare structure in the context of air transport market has been adopted in the High Speed Rail (HSR) market. The dynamic approach implies fares changes over time, that are regulated and are dependent from several factors. For instance, the Italian HSR companies declare that the determination of fare values mainly depends on the following elements: the runs, the days of the week, the class and the time between the day of ticket purchase and the day of the trip, according to NTV [23]; the market conditions, the occupancy level of the train during the period, the day or the hour of travel, "regardless of the distances travelled by the passenger", according to Trenitalia [24].

The literature is wide about the Air mode insights; hence the paper regards the analysis of the HSR case, however, are analyzed papers about Air considered relevant because of the method applied. The Table 1 contains the selected papers, classified by the Author(s), the year of publication, the mode analyzed (HSR or Air), the country of the case study, the type of analysis (user behavior or fare estimation) and the objective of the analysis (revenue management or seat allocation). The Table 1 shows that the papers mainly focus on the objective of the analysis, and few papers deepened the type of analysis, thus the fare estimation or the user behavior.

Table 1. Literature review on dynamic fare structure in rail and air markets.

Paper	Year	HSR	Air	Country	User behaviour	Fare estimation	RM/SA
Zheng J., Liu J. [11]	2016	x		China			x
Koenigsberg O., et al. [18]	2008		x	UK		x	x
Malighetti P., et al. [21]	2015		x	EU		x	x
Zheng J., et al. [22]	2017	x		China			x
Hetrakul P., Cirillo C. [25]	2014		x	n.a	x	x	x
Selcuk A., Avsar Z. [26]	2019	x		EU	x		x
Yao E., et al. [27]	2013	x		China	x		x
Xiao YB., et al. [28]	2008		x	China	x	x	x

With: RM = Revenue Management; SA = Seat Allocation; n.a. = not available.

Zheng J. and Liu L. (2016) [11] handle the fare structures in order to optimize fares with the aim of maximize revenues of companies, including the effects on demand. The case study analyses the time-series of ticket-sale data in the Chinese HSR market context. The authors stated that the travellers' tickets purchasing is conditioned by various factors,

such as fare purchasing behaviour of travellers, travel distance, number of runs that serve the same origin-destination relationship, trip purpose.

Zheng J. et al. (2017) [22] analyse the fare structures and optimal timing of pricing, considering the role of transport demand. The paper shows that company pricing strategy, in terms of number of seats that is predetermined and changeless, and number of fare classes, have impacts on the travellers' fare choice behaviour. The Chinese case study contains two experiments based on historical ticket data analysis of HSR lines, that consider a ticket-selling period and the demand density, defined as the number of tickets sold divided by ticket selling hours in a day. The authors propose a fare structure determination based on a clustering approach in which every class of fares is characterized by a given prize.

Koenigsberg et al. (2008) [18] deal with low-cost fare strategies in airline transportation by analysing the scenario of a last-minute and low-fare pricing policy in the context of short-haul flights. The structure of fares is analysed in a European case study, and it is based on the EasyJet pricing policy in contrast to traditional airline pricing strategies that offer last-minute tickets. The analysis of ticket fares over a period of observation shows the variation of the fares comparing to the seat occupation, thus the tickets sold of each flight. The fares' observation shows that the relevant variation about the seats evolution (tickets sold) occurs during the most distant period to the travel day characterized by lower average fares (behaviour of the non-business users), whereas the highest fares variation is observed approaching the flight day. The empirical results of the analysis show that the fares value, organized in several segments, depends on the remaining capacity at a given time over the selling period, introducing the phenomenon of last-minute discounting, hence an additional selling period in which the airline has unsold seats.

Malighetti et al. (2015) [21] studied the EasyJet pricing policy throughout methods for fare structures estimation considering the effects of the demand. The objective of the paper concerns the identification of elements of competition based on the surveyed average fares and the role of demand in the pricing strategy. The paper shows that the competition reduces average fares, (e.g., in the analysis period between 2008 and 2009 of almost 10%). The fares offered, for different routes and departure days, were daily surveyed on the company website. The results show that the ticket fares are higher and less discounted when there is a direct competition among airlines companies on a specific origin-destination relationship. The parameters of the calibrated model show the increasing of the slope of the fare curve with the decreasing of the distance between the day of trip and day of ticket purchasing.

Hetrakul and Cirillo (2014) [25] analyse the travellers' behaviour about ticket purchasing with the aim of the identification of the optimal Revenue Management (RM) strategy. The results of fare analysis show that, on average, the fare variations over time are related to the distance between the day of trip and the day of ticket purchasing, to the departure time during the day, to the day of the week. The authors assume that users' behaviour about ticket purchasing is based on the fare variations over time and on personal attitudes towards the trip, such as departure time of day, day of week, and trip distance.

Selcuk and Avsar (2019) [26] deal with the analysis of dynamic pricing in the context of air transportation with the aim of revenue management. They investigate the relationship between the aggregate demand and the fares evolution over time. The implementation of a procedure for real-time dynamic pricing in a Turkish case study shows the influence on the pricing policy, in terms of price variation, on the number of the remaining seats.

Yao E. et al. (2013) [27] analyse the High Speed Rail (HSR) pricing strategies at the mode competition level with the aim of revenue maximizing throughout seat allocation strategies. A discrete choice model (Nested Logit) was calibrated in order to identify the relationship between ticket fare and HSR market share, based on the stated preferences data. The results shows that the probability of the users' choice behaviour to choose the HSR depends on the travel time and travel cost of each available alternative (HSR, conventional rail, air, and road), the profession and age of travellers and the trip purpose. The authors performed a sensitivity analysis on the marker share depending on the fare variations.

Xiao Y.B. et al. (2008) [28] investigate travellers' behaviour about ticket purchasing by means of a classification based on two main criteria, which are: price-based choice, where the travellers choose a flight with the lowest fare available, independently of the departure time; and time-based choice, where the travellers choose the flight on the basis of their desired departure time, regardless to the amount of the fare. The case study concerns the definition of the pricing strategy of an airline company by optimizing the revenue management on multiple flights.

It is evident that several examined papers use the fare structure analysis in order to optimize fares in the context of the revenue management or seat allocation optimization, thus in the perspective of the company supplying the transport services. The analysis of dynamic fare structures with regards to the travellers' perspective, analysing the travellers' behaviour about ticket purchasing is weakly studied in literature. Therefore, the contribution of this paper is oriented to provide a framework useful for the identification of fares of HSR services variation criteria according to the users' perspective.

3 Framework for Analysis of Dynamic Fares

The section presents a framework characterized by a dynamic approach of the analysis of tickets, c, along two time variables defined as follows:

- *p, day of ticket purchase*, day when a traveller chooses to purchase a ticket of a trip on a HSR run (e.g. a traveller chooses to purchase at day $p^* = 16^{th}$ of August, 2022 an "economy" ticket on an HSR run travelling from Rome to Milan);
- *t, day of trip*, day when a traveller chooses to make a trip (e.g. a traveller chooses to make a trip at day $t^* = 3^{rd}$ of September 2022 on a HSR run travelling from Rome to Milan).

It is easy to derive a new variable defined as the time interval, k, between the day of the trip, t, and the day of ticket purchase, p:

$$k = t - p \left[\text{days}\right] \tag{1}$$

that synthetizes the two time variables (e.g., the time interval between the day of ticket purchase $p^* = 16^{th}$ of August, 2022 and the day of trip: $t^* = 3^{rd}$ of September, 2022 is $k^* = 21$ days).

According to the above definitions, the value of the purchased ticket depends on a function of the two time variables:

$$c = c(p,\ t) \tag{2}$$

Case 1: intersection between $c = c(p, t)$ and the plane parallel to the (c, p) plane. In this case the day of trip is fixed, and the resulting intersection is a curve providing the evolution of ticket depending on p.

$$c = c(p) \text{ for } t = t^* \tag{3}$$

Case 2: intersection between $c = c(p, t)$ and the parallel to the (c, t) plane. In this case the day of ticket purchase is fixed, and the resulting intersection is a curve providing the evolution of ticket depending on t.

$$c = c(t) \text{ for } p = p^* \tag{4}$$

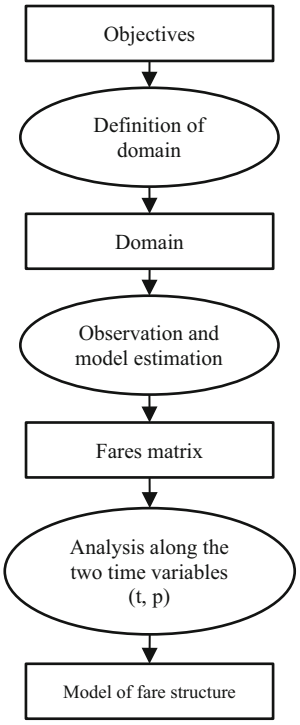

Fig. 1. Framework for analysis of dynamic fares

The proposed framework is composed by three steps (Fig. 1):

- definition of domain,
- observation and model estimation,
- analysis along the two time variables t, p.

Step 1: Definition of Domain. It is the first step after the definition of the objective(s), which may concern, for instance, the observation and the estimation of the patterns that determine the changes of fares with some characteristics associated to a given set of HSR services offered along a given origin-destination relationship.

According to the objectives, the definition of domain of analysis regards the following elements.

- *Number and type of HSR fares.* It is selected a reference fare to be analysed based on several criteria, for instance the cheapest fare of the economy class.
- *Day(s) of trip.* The day(s) of trip may be part of a set of days and may cover several days of the week, thus working days and/or holydays.
- *Day of ticket purchasing*. The day of ticket purchasing may also be part of a set of days and it allows to determine the distance between the day of ticket purchase and the day of trip. It is clear that the size of the set of days of ticket purchasing, p for a given t, should be enough extended to allow an accurate analysis of the dynamic structure of HSR fares.
- *Number of HSR runs.* A census analysis allows to analyse all the runs operating inside the day of trip, but this analysis could be too expensive in terms of resources. In order to conduct a sample analysis that considers the more representative runs of the day, the procedure may include several time windows, subdivided according to the objective of the analysis. The procedure applies a filter for the runs, belonging to the time window(s), in order to analyse the reference run assumed in relation to some criteria (e.g., minimum travel time, minimum number of intermediate stops).

Step 2: Observation and Model Estimation. The second step contains the observation of fares and a first elaboration of the observed data. The input of this step is the domain of analysis and the output obtained is an elaboration of observed fares.

The observation of fares, organized in a survey, may be conducted in several ways, by directly extracting the information from the companies' websites or by means of the support of automatic procedures (e.g. web scraping software). The data obtained are structured inside an observed fare matrix related to each HSR run, where the dimensions of row and columns are respectively the number of days of trip and the number of days of ticket purchasing. Therefore, the number of observed fare matrices obtained is equal to the number of monitored HSR runs.

The transition towards the model estimation involves the elaboration of the observed fare matrix, which concerns the alignment of the fares observed in different days of trip along each column associated to the day of ticket purchasing. Consequently, a new fare matrix is achieved. This new matrix shall be performed for each HSR run, monitored with its own characteristics (e.g. departure time, arrival time, number of intermediate stops).

The resulting elaborated matrix is the input of the successive steps of analysis, thus the analysis along the time dimension of the day of ticket purchasing (p) and along the time dimension of the day of trip (t) in order to estimate a model of fare structure.

Step 3: Analysis Along t and k. The fare structure analysis with the approach along p (day of ticket purchasing) is composed by several parts. The first part regards the calculation of the matrix containing the day-to-day variations of fares. The second part includes an additional filtering operation, by using a threshold which allows the identification of the first day registering significant fares variations; therefore, it is possible to identify different regions of fares. The next step concerns the development of curves representing the average pattern of fare structure inside the identified regions (e.g. the curve could be a sub-horizontal line: c = cost, in the region farther from the given day of trip t*). The output of this analysis gives back the estimated curve describing the dynamic fare structure along the time variable p.

The fare structure analysis characterized by the approach along t concerns in an initial calculation of descriptive statistics associated to the observed fares. The next part regards the analysis of fares frequencies with a clustering approach, grouping into a homogeneous number of classes. Therefore, each fare cluster is analysed and curves of the density of probability are estimated. The output of this analysis gives back the estimated pattern describing the dynamic fare structure along the time variable t.

4 Pilot Experimentation on the Rome-Milan Relationship

The framework described in Sect. 3 is tested in a pilot experimentation on the Italian High Speed Rail (HSR) relationship Rome-Milan in Italy (Fig. 2). The opening of the HSR line between Rome and Milan in 2009 generated a modal competition, causing the diversion of travel demand from air services and the induction of new traffic due to several factors such as the increased level of service offered by HSR (e.g. reduction of on-board travel time, reduction of access-egress times from HSR stations). According to [29] the passenger flows in the year 2008 were about 2,4 millions/year by air and 1,0 millions/year by conventional rail; whereas in the year 2018 the flows were around 1,2 millions/year by air and 3,6 millions/year by HSR.

The above demand flows data shows clearly that there is a diversion from air to HSR (considering the Conventional services equal to 0) of about 1,2 million passenger and the other rate of demand, that is about 1,4 million passengers, is due to the induced component of demand.

In Italy there are two HSR companies operating along this relationship, namely Trenitalia and Italo Nuovo Trasporto Viaggiatori (NTV), which compete each other. The frequency of HSR services was respectively 45 runs/day for Trenitalia and 33 runs/day for the NTV.Both companies operating in Italy organizes the ticket fares into two main branches, which are “Business” and “Economy”. On one hand, Trenitalia offers a wide set of fares classifiable mainly in which the ticket fare is determined on the basis of the classes (e.g., “Super Economy”, “Economy”, “Base”) and the levels of service (e.g., “Standard”, “Business” “Premium”,…), according to the services offered to the travelers. On the other hand, Italo NTV determine the ticket fares into three classes “Low Cost”,

"Economy" and "Flex", hence each of these is characterized by different levels of service (e.g., "Smart", "Prima Business", …), in relation to the services offered to the travelers. The availability of the tickets, thus the number of classes and the levels of service may numerically vary in relation to several criteria, for instance the time interval k (1), thus on the basis of the companies' pricing policy.

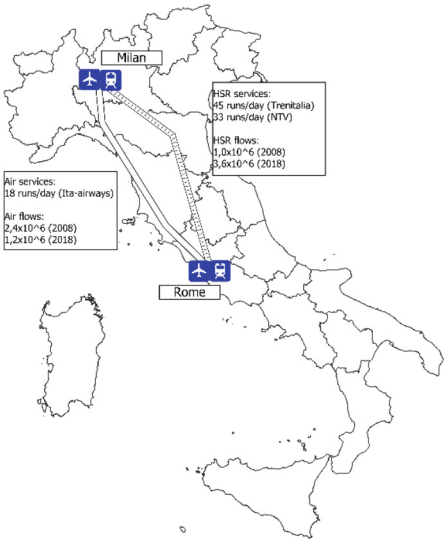

Fig. 2. Rome-Milan relationship

The paragraph describes the application of the first two steps of the framework presented in Sect. 3, which are: "definition of domain" and "observation and model estimation".

Step 1: Definition of Domain. The domain of analysis is formed by the following elements.

- *Number and type of HSR fares.* The fare "Super Economy – Standard" (in which "Super Economy", in row, is the fares' class and "Standard", in column, is the fares' level of service) offered by Trenitalia company is surveyed, which is the cheapest ticket available of the cheapest class (in row) fares offered at each day. Are excluded the fares of particular conditions, for instance: elder, or young passengers.
- *Day of trip.* The pilot case study considers a single day "t", assuming that a traveller chooses to make a trip at day $t^* = 3^{rd}$ of September, 2022 from Rome to Milan.
- *Day of ticket purchasing.* The observed set of days of ticket purchasing, p, concerns ranges from July the 26th of 2022 to September the 2nd of 2022, in which the survey of the selected fare in the selected day of trip is conducted.
- *Number of HSR runs.* The run $r^* = 9634$ was analysed from Rome to Milan relationship, operated by Trenitalia company belonging to the time window 6:00am.-9:00a.m., which consider the peak periods of traffic. The run 9634 is identified by the

criteria of the minimum intermediate stops, hence it is considered as a representative run in the defined time window.

Step 2: Observation and Model Estimation. The fares' observation was conducted by esk on the website of Trenitalia company in relation to the definition of domain.

The fare above mentioned, Super Economy-Standard, has been surveys during the period identified. In the case of absence of the fare in a day p, the decision was to survey the next fare belonging to the same class (e.g., "Super Economy" or "Economy"), and moreover in case of absence of the last fare belonging to the same class, the cheapest fare of the upper class was surveyed (e.g. "Super Economy-Premium").

As far as concerns the analysis along t, the diagram in Fig. 3 shows the evolution of the fares surveyed with the criteria above mentioned along the time variable *p* by considering the day of trip: ($t^* = 03^{rd}$ of September, 2022). If we define a day of ticket purchase, $p^* = 16^{th}$ of August, 2022, the distance between the given day of ticket purchase and the given day of trip, thus the interval $k^* = 3/09–16/08 = 21$ days.

Figure 2 shows that the fare structure is formed by two main regions:

- region 1, more distant from the day $t^* = 03^{rd}$ of September, 2022, is characterized by an evolution sub-horizontal, where the ticket fares are almost stable;
- region 2, closer to the day $t^* = 03^{rd}$ of September, 2022, where the fares evolution shows an increasing positive gradient due to the variation of the ticket fares.

It is possible to identify a threshold, correspondent to one or a group of days of ticket purchasing k*, that defines the boundary between the two above regions.

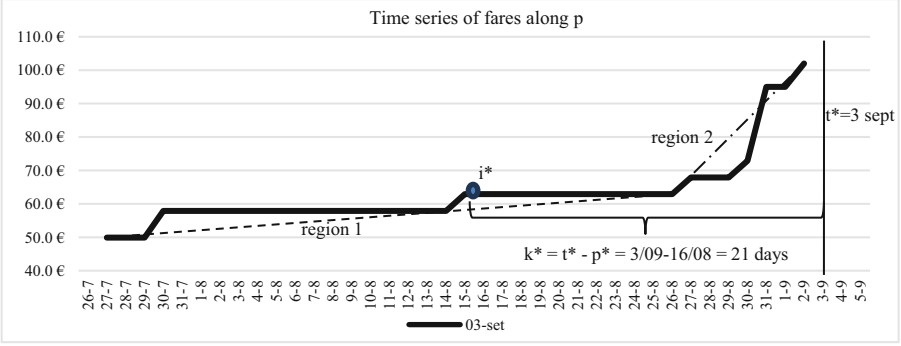

Fig. 3. Time-series of fares along p for a given $t^* = 03^{rd}$ of September, 2022

Regarding the analysis along the direction p, the Fig. 4 shows the pattern of the fares surveyed in the examined days of trip taking into account the time interval (1) $k^* = 21$.

The diagram should, but it is not univocally defined, a tendency where the fares' values increase in proximity of the weekend days and decrease during the working days. This trend must be further investigated with the support of a more extended range of observations.

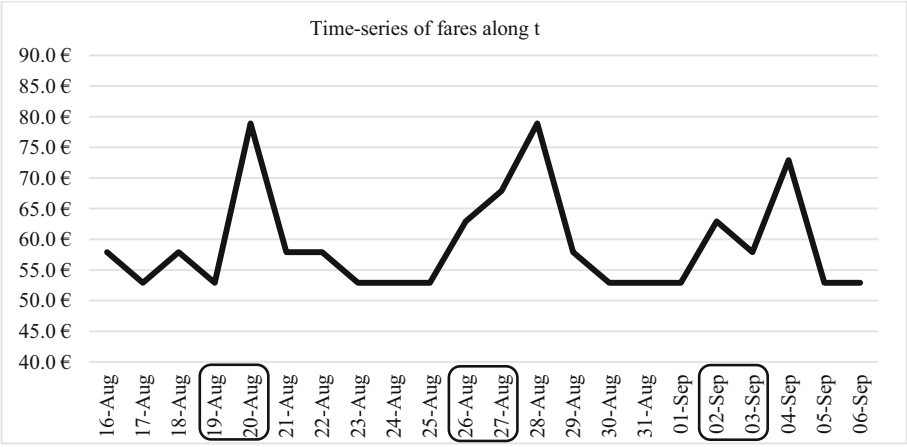

Fig. 4. Fares' time-series along t direction, for a given period k* = 21 days.

Table 2. Descriptive statistics of the time-series of fares along p (Fig. 3) and along t (Fig. 4)

	Figure 3 (p)	Figure 4 (t)
n.obs	37	22
Avg	64.8€	59.1€
Var	25.2	70.2
Min	62.9€	52.9€
Max	85.9€	78.9€
avrΔ(27/07–26/08)	1.35	n.a
avrΔ(27/08–02/09)	–	0.2
avrWE	66.2€	63.9€
avrWD	64.1€	57.3€

With: n.obs = number of observations; Avg = average; Var=variance; Min = minimum; Max = maximum; avrΔ = average gradient; avrWE = average in weekend days; avrWD = average in workdays; n.a. = not available

Finally, the Table 2 contains some descriptive statistics calculated for the time-series presented in Figs. 3 and 4. The results shows that the minimum value of fares is lower in the direction k* than in the direction t* while the maximum value of fares is higher

in the direction t* than the direction k*. The average variation is considerably greater for the t* direction, whereas on weekends and working days the average value of ticket fare is higher by analysing t* direction.

5 Conclusions

The paper deals with the analysis of the characteristics of the HSR fare structures in the context of the demand analysis. The analysis of dynamic structure of fare is an important issue in the transport supply and in travel demand estimation, because of the determination of the fares has an important impact on the transport services scheduling and on the users' choice behaviour.

The gaps in the current literature about fare structures shows that the theme of the analysis of fare structure patterns in the HSR market is not sufficiently studied. Thus, the paper contribution regards an experimental framework characterized by a double dynamic approach for analysis of HSR fares analysis, that concerns an analysis along the direction of the day of ticket purchasing and along the direction of the days of trip. The pilot experimentation on a HSR run along the Rome-Milan relationship in Italy shows a sample of dynamic structure of the fares. The variation of fares along k is characterized mainly by the distance between the day of travel and the day of ticket purchasing (the *i* time interval), and the day of the week (e.g., weekend days or workdays); whereas the variation of fares along t is characterized by the time interval *i*, the day of the week, the pricing policy of the HSR company.

Future research directions of development of the framework presented in this paper may concern the application of the steps concerning the specification and estimation of the curve of the fare structure that represent the data of the ticket cost observed during the period of analysis, thus the individuation of the variation criteria. Moreover, two or more types of economy and business fares will be analysed, representing the behaviour of two segments of travellers also in relation to fares of airline services.

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State of the Art of Sustainable Development of Railway Nodes: The High Speed Rail (HSR)

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Abstract. High Speed Rail (HSR) is a new mode of transport and has a significant impact on the territory. The urban plan, in respect of the technical standards set by the rules, does not provide any indication for the inclusion of an important node in the territory, such as a station of an HSR line. Even the Sustainable Urban Mobility Plans (SUMPs) designed for metropolitan areas, in their strategic choices, often do not give indications on the HSR. It therefore happens that the territories are distorted by the effects caused by the location of such an important infrastructural node. Furthermore, the stations of the HSR are designed by "archi-star" architects who give a significant formal and visual mark on the territory. The paper underlines the importance of HSR through the analysis of two case studies, the effects that HSR cause on the territory. The first case of the Mediopadana High Speed Rail station in Reggio Emilia analyses the impact caused on a moderately anthropized territory. The second case of the High Speed Rail station of Naples Afragola analyses the impact caused on a highly anthropized territory. The analysis of these two projects concludes with considerations regarding the opportunity of an integrated urban and transport planning.

Keywords: Integrated urban planning · sustainable mobility · landscape quality

1 Introduction

The territory is the visible expression of the transformations that man has planned over time; it tells the story of history. On it, the signs that have characterized the various socio-economic periods remain, demonstrating the fact that the territory is a great re-gister of economic dynamics, dictated by history [1].

It happens to observe buildings that remain on the territory, to testify the past reality (what was). These, at present, have lost the functions for which they were built: they are the disused areas. These abandoned areas, like the new infrastructural nodes, are the objects of interest of modern urban planning. The new focal points of urban regeneration plans [2].

In Italy, the territory is planned, mainly by means of legal instruments: urban plans and urban plans for sustainable mobility (SUMPs) [3, 4]. These tools ensure the best development, applying the law and indicating the project actions to be carried out. They

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are some of the main references for maximum integration between strategic choices and actions.

In recent years, important infrastructures, with a strong transformative impact, not only environmental, but also economic and social, have been realized after superior decisions respect to the local decision-makers. Examples include: infrastructure nodes, major urban projects, business center, service infrastructures, public services; sports structures, etc. As a result, territories are forced to change suddenly and do not follow the indications programmed by urban plans [5, 6].

These top-down choices, allowed by international and national directives; cause irreversible transformations, not planned by local urban communities [7]. Decisions to build huge infrastructures are generally made top-down. The territory is forced to host them. It must accept impactful and overwhelming actions. Ordinary structures are upset. The territory receives the infrastructure, without having time to metabolize the insertion, in compliance with the several compatibilities. The impact would be different if the infrastructure was decided by a regular strategic planning process [8]. Instead, the project will cause unexpected transformations. The systems will be disturbed; the reactions of urban development will be unpredictable; socioeconomic responses will be variable.

Cities are the result of transdisciplinary interactive processes. They have evolved over time: from the city of Ippodamo, the first model of urban structure, planned according to the orthogonal scheme (Cardo: North-South and Decumanus: East-West); up to the contemporary smart city, a system of interconnected systems [9]. The European Union (EU) defines "Urban Transport and Mobility" as one of the three fundamental pillars for the smart city [10]. The EU assigns a priority role to transport infrastructure to achieve sustainable development and pursue the 2030 Agenda goals [11].

In the past, transport infrastructures were designed exclusively with numerical calculations and quantitative evaluations. Now, in order to make strategic choices and pursue the goals of sustainable development, the quantitative evaluation is insufficient. The quantitative data must be integrated, by the qualitative data [12]. The logical scientific result will be linked to the markers on the quality of life for social well-being.

The various dimensions of urban life (environmental, economic, social and cultural) are interlinked and success in urban development can only be achieved through an integrated approach. The European Commission (EC) has adopted a number of proposals to improve quality of life. It is a new approach that focuses on the impact of new indicators for well-being. It captures real social progress by looking at the quality of life, social development and the improvement of citizens well-being [13].

The High-Speed Rail (HSR) line, which connects cities with adjacent areas, and with the rest of the country, is a substantial change, which has significant implications for the evolution of cities [14]. The HSR has become a decisive connection tool, both for innovation and development of the national territory and local systems. HSR is the indispensable connection of areas to determine social development and increase economic development [15]. Transport networks increase connectivity, stimulate economic growth and reshape the geographical distribution of economic activity inside and outside the cities. In Italy, at the moment, numerous HSR lines are being built and planned [16]. The location of the HSR stations is important, and it makes a difference to the host territory.

It can be said that the success or failure of investments on the HSR line depends on city-region-nation integration and station-city dynamics [17]. A further important element is the intermodal integration, in order to guarantee continuity solutions, between the HSR mode-service, the other transport mode (air, car, bus), the territory and the citizens [18, 19]. The construction of the HSR station has important impacts on the cities to which it is easily and quickly connected.

In the literature, the traditional urban plan does not have the elements for a global vision, to manage at the same time, the physical and functional characteristics of large infrastructures. The strategic planning for HSR fosters the interaction between local planning and multi-level governance [20].

The HSR station should become an integral part of the development process, and never be a 'white elephant project' or just a transit hub [21]. The significant elements that generate the attractiveness of the HSR station are: internal and external accessibility on a regional scale; intermodal interchange hub; functional interconnections with the territory system; connections with infrastructures services, facilities and urban equipment; presence of urban regeneration projects and smartness projects of potential development; the presence of a productive and proactive socio-economic background.

This paper will focus on the analysis of two cases of high-speed railway stations in Italy: 1) the Mediopadana station of Reggio Emilia; 2) the Afragola station of Naples.

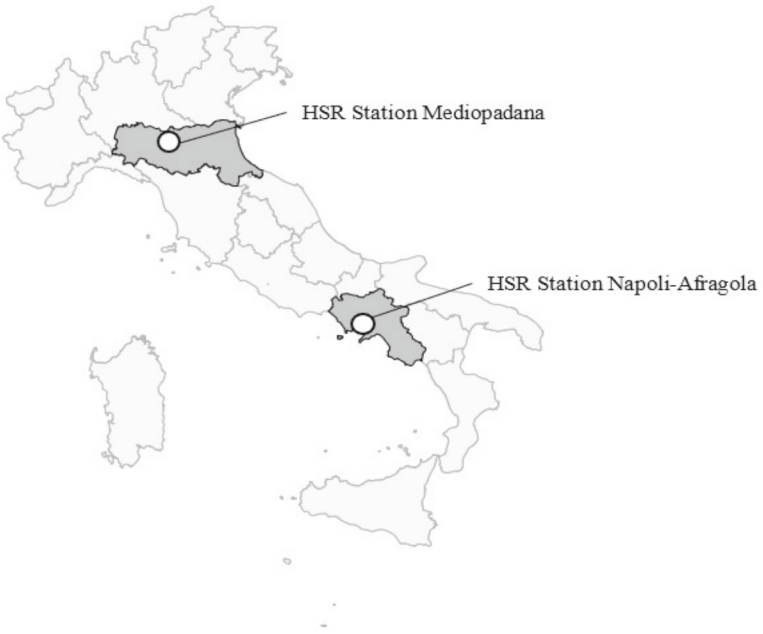

Fig. 1. Italy with the location of the HSR Station Mediopadana in Emilia Romagna and the HSR Station Napoli-Afragola in Campania

These two case studies were chosen because they are two modern stations, both designed by archistar, but located in socially and economically different territories. In

fact, the first station is in northern Italy, in the region with the highest Gross Domestic Product (GDP) per capita. The second station is in southern Italy, in the region with low GDP per capita. Figure 1 illustrates the location of the two stations in Italy.

The paper, through the two case studies, aims to confirm the importance of integrating urban planning choices with those of transport infrastructures, in a single integrated urban plan.

The construction of a new HSR station, if planned, fosters local economic growth. A comprehensive and integrated plan benefits innovation, the transformation of cities into smart cities, and the sustainable development of territories [22].

The structure of the paper is as follows. Section 2 illustrates the importance of HSR nodes. Section 3 illustrates the role of the HSR station Mediopadana for the national and local territory. Section 4 illustrates the role of the HSR station Napoli-Afragola for the national and local territory. Lastly, Sect. 5 shortly draws some conclusions.

2 HSR Stations: Architectural Design and Territorial Attractiveness

2.1 History of Urban Planning and Railway Stations Design

The railway system has always played the role of activator of urban development.

The first railway lines were built close to the mines during the Industrial Revolution of 1760, for the transport of coal. In 1801, the Surrey Iron Railway was launched, the first freight rail. In 1830 the first railway was opened, connecting Manchester to Birmingham. The development of the railway was the cause of the transformation of the territories. The new transport system was the beginning of the real change. The railway system, with its railway network, designed new plots on the territories and caused the foundation of new urban poles. The origins of urban planning are recognized in this period [23]. In fact, there was a need for a new discipline, between technique and norm, to plan, and at the same time, to control the dynamics of the territory. The quality of life and well-being are linked to the integrated actions, between the transport system and urban planning. The two disciplines, in order to perform at their best, must work together. Now, more than ever, there is a clear need to plan territories with integrated process planning [24].

The railway network is an indicative system for the socio-economic developments and transformations that characterize the sites. At the moment, HSR is an important opportunity for the development of territorial dynamics; for issues related to transport; for urban development and socio-economic growth of cities [25].

The location of the stations is the further input that the railway system inspires on territorial dynamics. The territory will take on a new meaning, both in form and function, completely dependent on the choice to locate the station. The determining factors for the success of station location are: high accessibility; implementation of an intermodal node; ability to generate new functions; offer of services and activities, in the adjacent urban systems if, of course, they are interconnected [26, 27].

New York's Grand Central Terminal is mentioned as a first example of part of railway network, with a function dedicated to daily commuting [28]. The project demonstrates the merit of the integrated technical choice, between urban planning and transport. In Europe,

HSR stations are mainly located as network hubs [29]. It is a multi-scale dimension, which allows the integration of multiple transport scale [30]. The station, intended as a hub, becomes a node of interest, especially for regional and national firms [31]. In many cases, the station assumes the additional role of place of new urban functions. The spaces of the station are used by citizens. Travelers' experience the spaces of the station, using services and functions, similar to those of the city. This new concept of station, as urban function, supports the concept that the station must be designed with the function of 'node and site' [32].

In Italy, the two new HSR stations, Mediopadana in Reggio Emilia, in the North, and Naples Afragola, in the Center of Italy, were built outside the city. They have been designed by international archistar. They are the implementation of valuable projects, for which the government and decision-makers have allocated relevant funds.

The stations are strong signs on the territory; visible far away and immediately recognizable. This type of choice testifies to the importance that decision-makers wanted to attribute to these places. These new 'nodes and sites' [32] are the physical and unequivocal demonstration of the superior and decisive role for the future development of the territory.

In recent years, two exemplary railway stations have been built in Italy. These works, designed by international architects, are the sign of a further historical moment that the nation is going through. The HSR station is an opportunity to bring together aesthetic-formal renewal with functional and technological innovation. Urban regeneration is revealed through the spectacularity of a strong architectural project, which combines technical function and formal symbol.

2.2 Attractiveness and Lacks

New HSR stations are catalysts for urban, economic and social development; both regionally and locally. If the station is accessible and is interconnected with other modal networks, it will increase the attractiveness for new projects and urban development [2]. The attractiveness of the territory is not a technical parameter, easy to calculate [33]. Precisely because territories are complex, evolving systems, involved in the transformative dynamics caused by historical-cultural, socio-economic and environmental phenomena, the effects of the inclusion of an extensive project are not certain. "Territorial attractiveness is a complex and multifaceted concept, which lend itself to several interpretations. It can be first intended as 'revealed attractiveness', which is associated with actual incoming flows (investments, workers, talented people, students, etc.) in a geographical area [34]. The existence of these flows reveals its attractiveness" [35].

In China, in order to revive the local economy, it was decided to build the new stations away from the urban center, to encourage the foundation of a new city around the station. The location of the HSR station is part of an industrial political choice, to attract new industries and population. The urban model of the new city, built near a mega infrastructure, determines a new model of development; activates a new supply for the territorial system [21, 24, 36].

In Italy, the economic trend and the urban development in recent years show that the inclusion of a new mega infrastructure can give rise, a new territorial identity, not always compatible, by the territorial systems that gravitate around it.

Territorial dynamics are sets of interconnected processes, which generate new identities, historically drawn from the constitutive characteristics of sites, landscape, historical and cultural resources and housing habits [37, 38]. Dropping an imposing infrastructure by a top-down approach, without using qualitative evaluation techniques, can cause the phenomenon of the 'cathedral in the desert'. The authentic development of the territory is achieved by following the objectives of sustainable development, based on the quality of life and well-being of citizens [39]. Indicators and targets need to be calculated, applying social criteria, in order to combine economic, social and environmental dimensions in a coactive way. The Operational Guidelines for the evaluation of public works of 9 September 2022, assess Social Sustainability. For the first time, it is mandatory to consider the social dimension of infrastructure [40].

The attractiveness of a railway station consists in its ability to attract users, services and investments [41]. In the literature, there is no single definition to describe attractiveness. For example, for the economic sector, it is supply and demand; for urban and regional studies, it is the ability of places to attract. It determines, on the same places, positive or negative impacts. The attractiveness, therefore, can be positive or negative, with respect to the effect that the node generates on sites; it is not a static datum [42].

The attractiveness is positive, if the station becomes a reference node for further investments; if it becomes a place of infrastructural, but also social and receptive connection; if it is a meaningful, vital and welcoming place. If it proposes urban functions for leisure, culture, commercial activities; if it is autonomous in its management, and increases the socio-economic development of the territorial context in which it is inserted. If it is a catalyst for new functions and is able to attract flows of tourists, visitors and inhabitants [43].

The presence of a mega-infrastructure can generate the urban process of territorial regeneration. It is the new supply. The HSR station, if it triggers the factors of positive attractiveness, generates the new model of global development; the influence of the advantages extends to the entire area of gravitation [21].

When the infrastructure generates this kind of integral development, then, the true theoretical concept of urban regeneration is fulfilled. Urban regeneration, in fact, intersects multiple factors. It is not only made up of static or architectural recovery; it is above all economic revival of the territory; it is the enhancement of the social framework; it is the assignment of a new identity, which becomes a driving force for the integral development of the global territorial system [44, 45].

The paper analyzes the cases of the two new stations: the Mediopadana in Emilia Romagna; and the Napoli-Afragola in Campania. The focus on the design and function of the stations pushes towards the goal of an integrated urban plan.

3 The HSR Station Mediopadana

3.1 Characteristics of the Architectural Design and Urban Transformations

The Mediopadana HSR station in Reggio Emilia is the only stop on the Milan-Bologna HSR line, built in 2008. The new railway line, which runs parallel to the A1 motorway, is one of the most popular contemporary architectural projects in Europe.

The station construction starts in 2010 for a total cost of 79 million euros, financed by Italian Ministry of Infrastructure and Transport and by the railway company Ferrovie di Stato. The station was opened in 2013 [46]. Reggio Emilia is a medium-sized city, with about 170,000 inhabitants. It is located along the historic infrastructural axis of the Via Emilia, between Milan and Bologna.

The Mediopadana area is made up of an urban network, densely urbanized and economically very important. The geographical area of the Mediopadana station has an enormous potential for development, with about 2,100,000 inhabitants [47].

The main cities of Parma, Modena, Mantova, Cremona, are among the richest in Italy. The province of Parma has a very strong industrial vocation. It is characterized by a modern agri-food industry (about 35% of the employed people). It produces world-famous excellences, such as Parmigiano and Zibello ham. Modena is considered the world capital of motoring. In the province of Modena, there are: Ferrari, Maserati, Pagani, Bugatti, and a few kilometers away, Lamborghini. Mantova is called the widespread urban museum, also for Sabbioneta: a perfect example of an ideal city; A model of urban planning of the Italian Renaissance. In 2008, UNESCO named the city a World Heritage Site.

The Mediopadana station was designed by the Spanish archistar Santiago Calatrava. It is an impressive architectural sign that testifies to its special function. The station is a steel structure 480 m (m) long, about 20 m high. The structure has a futuristic design. The roof is made up of repeated modules. The image is similar to a moving wave. In fact, depending on the perspective, the optical illusion changes the visual effect of the waves, alternating the static front with the dynamic front. This structure covers the tracks of the HSR line. The building is organized on two levels: the street level, which can be accessed from the outside, has services and commercial activities; the upper level, where are present the tracks. The two levels are connected by two escalators and two panoramic elevators. The Mediopadana HSR station is equipped with ancillary services both for passengers in transit and for those going to the city. It has a direct connection with the local railway lines and with urban and suburban bus lines; taxi; parking; car and bicycle rental areas [46].

3.2 Attractiveness and Lacks Territorial of Mediopadana Station

The Mediopadana area, in particular the one that develops along the Via Emilia, directly connected to the HS station, has experienced high and continuous development in recent years. This demonstrates the positive attractiveness of the HSR station in the adjacent area. The Mediopadana station has determined a strong, specific, attractiveness: it has transformed the territory; has assigned a new regional identity.

The geographical area on which the station is located is a high productive reality, with strong socio-economic relevance. It has accepted the mega infrastructure. The intervention was conceived according a top-down approach, with a successive bottom-up confirmation, and it has been integrated into the territory. Indeed it has become an opportunity for the development of the area. The location of a mega infrastructure in an economically advanced area has activated the process of integral development, enhancing the territorial resources, as well as the typical potential of the territory [48].

Integrated transport connection is considered to be the priority. The strategic location gives the station considerable importance. Its central position, both in relation to the A1 motorway and in relation to the railway network, emphasizes its role as a core for regional, national and international mobility.

The station is not directly connected to the regional railway lines (and this is a limit), but allows to reach Bologna in 20 min (min), Milan in 40 min, Florence in 50 min, Rome in 2 h (h)10 min and Naples in 3h 30min; as shown in Table 1.

The Mediopadana station is an important intermodal hub. The choice of location was decided to allow access to the station from all over the region [49].

The Mediopadana station has increased the accessibility of Reggio Emilia and its territory. The station has transformed the Mediopadana area into a functional region. The functional region is the perspective of the new urban plan. The political will of decision-makers transforms the territory into a smart territory. The strategic plan connects local resources and implements services and functions [50].

In recent years, the urban dynamics of the Emilia Romagna region have been more relevant than in other parts of Italy. Industrial growth has been continuous and has attracted national and international workforces, increasing urbanization. This had positive effects on economic growth, but at the same time has favored the phenomenon of territorial sprawl [51, 52].

The case study above analyzed, demonstrates the essential need to make integrated choices. The choices made with the integrated process planning do not contradict it. They contemplate the sustainable development of territories, they operate by integrating sectors, which of course cannot be ignored [53].

Table 1. The fastest lines connecting Mediopadana station and Napoli-Afragola with the principal Italian HSR stations

HSR Station	Milano	Bologna	Firenze	Roma	Napoli
Mediopadana- Napoli-Afragola	40 m 4 h 03 m	20 m 3 h 10 m	50 m 2 h 27 m	2 h 10 m 54 m	3 h 30 m

4 The HSR Station Napoli Afragola

4.1 Characteristics of the Architectural Design and Urban Transformations

The station of Napoli Afragola, is located along the HSR Roma-Napoli line. The station lies about 1 km from the historical center of Afragola and about 10 km from Naples Central Station (NA). Its location covers the territory located eastern from NA, in which medium and extensive urban settlements are widespread.

The station does not create an alternative pole with NA. It avoids having trains entering and exiting the NA, speeding up the trips along the North-South direction.

The fastest lines allow to reach Rome in 54 min, Florence in 2 h 27 min, Bologna in 3 h 10 min, Mediopadana area in 3 h 46 min, Milan in 4 h 3 min (to run a distance

of 654km), and Reggio Calabria in 4 h 6 min (to run a distance of 334 km); as shown in Table 1.

It is not directly connected with the regional railway lines, but it ensures the rail connection to the Naples Central.

It is considered one of the most important realizations of the European, Scandinavian Mediterranean TEN-T corridor. A first step for speeding up the connection between Rome and the Southern Italy. It has been named the 'gateway to the South': an important interchange node, for access to the Southern Italian regions [20, 54].

The station has a catchment area that includes the metropolitan city of Naples (about 2 million inhabitants), Caserta, Avellino, Benevento, Sannio and Irpinia. The potential inhabitants are estimated in about 3 million.

The territory is densely populated, but the economic context frame is not rich. Italian National Statistics consider the area as a low-income one. There are socio-environmental problems mainly linked to unemployment.

Napoli Afragola station is a strong territorial landmark, like the Mediopadana station. The station was designed by the archistar, Zaha Hadid Mohammad, from Iran. It was built by the Italian railway company Ferrovie di Stato for a total cost of about 60 million euros. The Naples Afragola station was inaugurated in 2017 [55].

The central part of the station is characterized by a large sinuous bridge, about 400 m long. This bridge crosses the railway tracks with an average height of about 9 m. It is organized on 4 levels and it spreads over an area of 30,000 M^2.

It is an exceptional work; it is made with large windows. The roof was made of Corion, an innovative material never used before for the coverage of such a large infrastructure. The curved surfaces are composed by 5,000 M^2 of glass, 5,000 tons of steel, 20,000 M^2 of Corion.

The infrastructure takes care of environmental sustainability: two solar roofs produce 200 megawatts per hour and a range of rainwater harvesting systems.

Services and commercial activities are present in the four levels of the station. The users are mainly long-distance travelers.

4.2 Attractiveness and Lacks Territorial of Station Napoli Afragola

The Naples-Afragola HSR station is an architectural jewel, with a huge potential catchment area, a gateway between Europe and the Southern Italian regions. The infrastructure, however, due to the state of urban decay of the surrounding area, appears to be in conflict with the area [56]. The work has been inserted in an area sadly called 'the land of fires', due to the past events, on the illegal disposal of waste. The station is surrounded by an area with low economic income, with urban and social problems.

The geographical area in which it lies grew in a spontaneous way out of any planned territorial development. The area lacks of urban services and infrastructures. Built settlements have expanded, over time, without adequate strategic smart planning [57].

The location was chosen to create a strategic intermodal node. The project has given the station considerable importance. Unfortunately, at present, the connections are insufficient; therefore, the node does not fully assume the role planned.

At the moment, the station is served only by local public transport with seven bus lines, waiting to complete the Cancello variant and the interconnection with the NA - Baiano of the Circumvesuviana line, the metropolitan railway network.

The station is not integrated with the surrounding area; it has not become a functional site. It remained a top-down, isolated decision, devoid of productive relations and interconnections with the gravitational territory [58].

The allocation of the mega infrastructure, in an economically depressed territory, has not been able to activate, on its own, the process of integrated development of the territory. It has failed to drive the economy; nor to activate processes of urban regeneration. This often happens in economically depressed areas, such as those in Southern Italy. Some similar effects have been evaluated for the case of the intercontinental port of Gioia Tauro and the SEZ [2, 21]. The lack of infrastructure and services does not allow the project to exert a positive attractiveness on the gravitation area [35, 42].

The scarcity of economic activities and the social difficulties in the adjacent area; the missing connections, with incomplete motorway junctions and insufficient public transport are the main causes why the station is unable to give the expected boost to the territory. A highly urbanized territory, with considerable potential for development due to the satisfy the mobility needs of a high number of travelers, appears scarcely used because, in reality, it is not adequately connected [59].

It was estimated to be a node of international trade; connection between the south, Italy and Europe. Unfortunately, it lacks of important parts. The station alone cannot activate the positive propulsion necessary for the increase of development.

5 Conclusions

From the comparison between the Mediopana high-speed rail stations of Reggio Emilia and Naples Afragola, it is possible to understand what are the elements that can determine the positive attractiveness of a mega infrastructure.

Both stations are designed by two famous archistar, who have created a modern and international image; they have combined aesthetic form, with function and technological innovation. The two infrastructures, although having the same objectives, did not produce the same effects. An important railway node, located in two territorial contexts with different characteristics, has generated different effects.

The first station is located in the North of Italy; in one of the richest regions, with an elitarian industrial and business system, appreciated in the world. The second station is located in the South of Italy; in an economically depressed territorial context; densely populated, lacking in services and infrastructure, unplanned.

A further consideration derives from the analysis of the typology of travelers [60]. In fact, travelers from the Mediopadana are mainly workers who have to reach the richest cities of the country. This data is interesting, because it gives to Mediopadana an important role on the regional scale; it offers a service to users on business trips. The Naples Afragola station is mainly used by travelers who need to reach cities outside the regional area.

Further factors implementing the positive attractiveness are the presence of land available to increase the already active process of urban regeneration. The presence of

parallel motorway junctions is also an attractive factor. In fact, the growth stimuli are stronger, when the motorway connection is integrated with a high-speed rail station [14]. The location of the HSR is a factor of activation of the true urban regeneration and integrated development of the territory, if the characterizing systems are interconnected; if there are functional connections to business centers, strategic centers, universities or other gravitation nodes [61].

In summary, the elements that generate the positive attractiveness of the infrastructure are: accessibility on a regional scale and interconnection with the territory; intermodal interchange hub; connections with infrastructures; facility of services; the pre-sence of urban regeneration projects; the presence of a productive and proactive socio-economic background.

All the elements combined together generate the ideal characteristics to make HSR an opportunity for innovation and sustainable development, an activating and implementing node of the urban regeneration process [62, 63].

The HSR station, if included in a strategic and integrated urban plan, stimulates local economic growth. The new conceptual approach integrates urban planning choices with the transport infrastructure system; therefore, it pushes towards technological innovation and transforms territories into smart. Urban regeneration interventions, with an integrated vision of the future, apply the categories of the smart city and achieve the objectives of sustainable development [11, 64]. Urban regeneration is essential to increase the quality of life of citizens [13, 39]. Moreover, if implemented with the principles of integrated urban planning, it will transform territories into smart and sustainable systems.

Territorial deficits can be solved with urban rebalancing actions. The integrated balance between quantitative and qualitative data makes it possible to create new models of urban development, for new territorial systems, such as those generated by the presence of a mega infrastructure.

The new supply of the high-speed station requires a new territorial model. Integrated urban model, for the new territory that increases around an important infrastructural node. The academic debate and project action are still divergent and fragmented, in providing the right knowledge to apply an integrated urban model [24] although the integration of spatial planning with transport planning is considered essential [19]. The planners must decide in an integrated way and take action in a current time, to resolve the needs that arise, against the predictions defined by the inactive sector plans.

The research supports this new conceptual approach, which is also coherent with the EU guidelines on qualitative indicators of well-being and smartness. The research focused on the integrating urban process planning with transport planning, but it cannot propose a model to be replicated, in the same way everywhere. The two case studies analyzed, and chosen for their contrasting location, support the conclusions.

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A Network Analysis for HSR Services in the South of Italy

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Abstract. Railway transport represents a travel alternative coherent with the European and international long-term sustainability perspectives. Different European countries are planning and developing the realization of High-Speed Rail (HSR) lines along the main Trans-European Network corridor. For instance, Italy is developing the design of the HSR line Salerno – Reggio Calabria to extend the current network towards the south of Italy. In this context, this paper presents a framework for performing a network analysis. Network analysis allows the evaluation of the centrality and connectivity of a network. Methods and specifications for calculating a set of indicators (degree centrality, strength centrality, eigenvector centrality) are proposed. The framework highlights the inputs, parameters and outputs needed for calculating the proposed indicators. A first pilot application of the framework regards the current railway services offered in the south of Italy. The resulting framework and relative methodology can be useful in a transportation planning process aimed at showing the current main gaps in terms of transport connectivity in the south of Italy. The framework and the results obtained from the pilot application can support decision-makers and takers involved in the railway transportation planning process aimed at increasing accessibility and sustainability goals for people's mobility in the region where HSR lines are developing.

Keywords: railway transport services · sustainable mobility · accessibility · network analysis · TEN-T

1 Introduction

Railway transport represents a travel alternative coherent with the European and international long-term sustainability perspectives. The main international instrument adopted which defines the sustainable development objectives is Agenda 2030 which considers 17 Sustainability Goals specified through indicators and targets [1].

Sustainable Development Goal 9, "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation" is focused on resilient infrastructure. High-Speed Railway (HSR) is heavily interested in pursuing this goal; also, Goal 13,

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"Take urgent action to combat climate change and its impacts" is about decarbonization. HSR is also a mode of transport that produces small amounts of CO2.

Different European Countries are working on the development of infrastructures and services belonging Trans European Transport Network (TEN-T) and relative core corridors [2]. This paper focuses on people's mobility on TEN-T corridors that cross the European Countries from south to north. The extension of HSR lines is one of the main European policies for implementing the TEN-T corridor concept.

For these reasons, there are different projects for extending the HSR lines in other parts of Europe. The final aim is to increase European cohesion, by enhancing accessibility and travel opportunities for European citizens.

The study of the evolution of railway networks must take into consideration the difference between HSR services and infrastructures, considering that there is no one-to-one relationship between the two components. By focusing on the Scandinavian–Mediterranean core corridor, Italy is developing the design of the HSR line Salerno – Reggio Calabria (infrastructure) to extend the current network towards the south of Italy [3]; now, southern Italy is served, however, by HSR services on conventional lines. It is possible to have a system where HSR services use conventional lines, a system where conventional services use HSR lines and a system where both services use both lines [4].

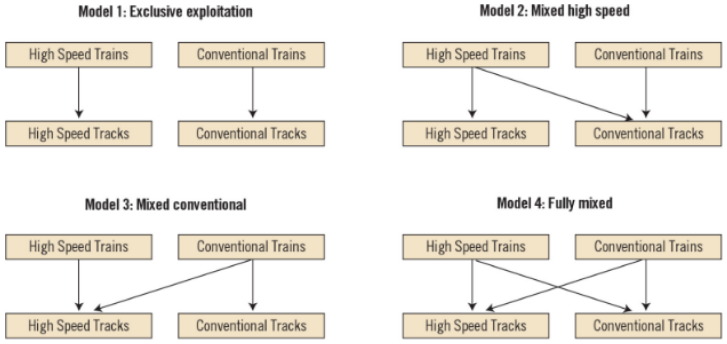

Fig. 1. HSR services according to the relationship with conventional services (Source: [4])

The final aim is to increase cohesion for southern regions (Campania, Apulia, Basilicata, Calabria and Sicily) that in the current situation are not served by HSR lines. In this context, this paper presents a framework for performing a network analysis that allows the evaluation of the centrality and connectivity of a network, in general, and of HSR transport network services in specific. The main aim is to understand the current state of HSR services in Southern Italy, in terms of connectivity and to underline first elements of accessibility. For pursuing these objectives, a network analysis specification is proposed for calculating a set of indicators (degree centrality, strength centrality, eigenvector centrality) in a pilot application performed for the South of Italy.

After this introduction, the paper has 4 sections. Section 2 reports the main related work on accessibility and network analysis. Section 3 describes the proposed framework for calculating indicators through a network analysis approach. Section 4 reports the main

results of a pilot application of the framework for the south of Italy. Section 5 discusses the obtained results with some final remarks.

Due to the topic covered, the paper is useful for researchers, railway service operators, infrastructure managers and public administrations.

2 Related Works

This research investigates the structure of HSR services in the southern regions of Italy, which, as described, represent the least accessible part of the country. This section recalls the main works on the topic of railway accessibility (Sect. 2.1) and railway connectivity (Sect. 2.2), underlining the role of these issues in the development of a territory.

2.1 Rail Transport Accessibility

Transport systems play a relevant role in enabling people and businesses to perform their daily activities. The final aim of transport infrastructures and services is to ensure accessibility that measures the ease of performing activities distributed in space and in time [5, 6]. Then, accessibility is a characteristic of one or more locations that are the origins or destinations of the trips performed by people or businesses. Accessibility indicators measure both the ease of a user in reaching localized opportunities in the area from their residence to carry out their activities (active accessibility), and the ease with which an activity located in a certain area (e.g. tourist) can be reached by potential users (passive accessibility) [7]. A location characterized by a high level of accessibility implies the possibility of having a great quantity of opportunities [8]. On the other hand, a poorly accessible territory is characterized by transport and mobility inequalities, and it risks social exclusion [9]. Then, accessibility is a possible measure of the interactions between transportation systems and territorial activities.

A classification of accessibility measures is proposed by Geurs and Wee [10] that consider: two perspectives in relation to infrastructures and services performances (infrastructure–based) or the spatially distributed activities (location–based); four components in relation to the opportunities at each destination (land-use), the travel disutilities from origin to destinations (transportation), the temporal constraints for performing a specific activity (temporal). Literature offers different specifications in relation to the two perspectives and the four components, providing assessment measurement of accessibility.

Some authors specify accessibility in relation to transport modes [5]. This paper focuses on the rail accessibility and the opportunities offered by High-Speed rail, by considering the empirical evidence in terms of impacts on socio-economic, territorial and transport systems in several countries, for instance, Italy [11–13]. In this context, rail connectivity, measured through a network analysis, plays a relevant role in the quantification of rail transport accessibility (see next section).

2.2 Rail Transport Connectivity

In the study and analysis of transport systems, it is of fundamental importance to determine the characteristics of the nodes, their centrality in the network and the characteristics of the interactions between them.

As will be discussed below, the mathematical degree of connection shows very well, and in different contexts, the social and economic integration of a territory.

Among the tools that allow the evaluation of the centrality and connectivity within a network, it is possible to refer to the network analysis. It is a method for modelling systems in which there are elements which, adopting certain criteria, can be defined as connected. There is a wide range of applications in the literature. This method was applied to evaluate economic trade between countries [14–16], both on a global and regional scale. There are also applications in social sciences [17, 18] and urban planning [19].

Given the possibility of describing systems of relationships, network analysis is widely used for analyses of transport systems.

Applications are also common for describing problems related to local public transportation [20, 21], air transport [22, 23] and maritime transport [24, 25].

The characteristics of network analysis are specifically suited for the analysis of relationships in the railway sector. Among the different applications proposed, examples of railway network analysis studies in India [26], Pakistan [27] and China [28] are highlighted.

The main element of network analysis applied to railway service systems is the definition of the elements and their mutual relationships. At least two methods are possible for representing the railway service network [29]:

- A first method where the network may be represented as *a bipartite train–station network*, with a set of nodes *S* representing stations and a set of nodes *T* representing train services; the link between generic station s ∈ S and generic train-service t ∈ T exists only if t makes a stop in s.
- The second method identifies the graph composed by a set of nodes S, representing stations considered; nodes i and j, both belonging to S, are connected if there exists at least one train service that makes a stop in both stations. The obtained network is referred to as the weighted station-station network. This second method is often used in modelling railway networks, as it provides a more immediate representation of the topology of services.

The framework proposed in this work refers to the second type of method mentioned, weighted station-station network.

3 The Proposed Framework

The proposed framework is aimed at analysing the railway services by using the network analysis system. It is organized into several steps summarized in Fig. 2. The HSR database and characteristics of both infrastructure and services are data needed in the first step, (1. Data collection – Sect. 3.1). Data are processed following the operations described in Sect. 3.2; the main objective is to transform the raw data into input data for network analysis. Network analysis is performed, and indicators associated with this are evaluated as final output (Sect. 3.3).

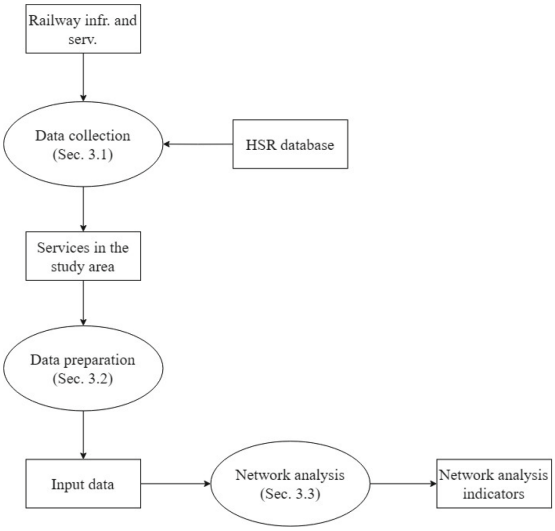

Fig. 2. The proposed framework

3.1 Data Collection

The elements to take into consideration are:

- A reference geographical area, where rail connectivity has to be studied;
- A reference time interval (t). Given the systematicity of railway service, it may be useful to consider an average weekday;
- At least one rail service operators, who manage railway services in the study area;
- A network of railway services operating within the study area in the time interval t; scheduled services that make at least two stops within the geographical area of reference are selected;
- A quantitative criterion to define the weights of each link on the network.

Let any pair of railway stations (i, j con $j \neq i$) located within the area be considered.

Let any pair of railway stations (i, j with $j \neq i$) present within the geographical area considered be given. Every railway service that, without interruptions, connects the pair (i, j) in the time interval t must be considered among the inputs.

A generic station is considered within the study if, in the time interval t, there is at least one service $r(t)_{i,j}$ that operates continuously serving both stations of a generic pair.

In the proposed framework, the frequency of services $f(t)_{i,j}$ is considered as the weight of the link.

3.2 Data Preparation

Once the basic elements have been described, it is necessary to define the adjacency matrix of the network; it can be obtained starting from the existence of at least one direct

connection between station i and station j in the time interval t. The adjacency matrix $A_{i,j}(t)$ is defined as

$$A_{ij}(t) = [a_{ij}(t)] \tag{1}$$

Where

$$a_{ij}(t) = \begin{cases} 1, & \exists r_{i,j}(t) \vee r_{j,i}(t) \neq 0, i \neq j \\ 0, & \nexists r_{i,j}(t) \vee r_{j,i}(t) \neq 0, i \neq j \end{cases} \tag{2}$$

Once the adjacency matrix has been defined, it is possible to describe an undirected graph G = (N, E), where N indicates the stations and E the connections between them through services without transfer.

For the study, it is also necessary to define the frequency of services between i and j as $f(t)_{ij}$, calculated as the sum of services without transfers between stations i and j operating in the time interval t.

3.3 Network Analysis

The indicators proposed below intend to recall the main quantities relating to connectivity.

The first element to define is the connectivity of an element within a network considering the number of other elements with which it is connected. Given a station node i, we intend to define the number of stations, whose generic is j, with which it is connected. This measure is defined starting from Total Degree Centrality, defined as

$$c_i(t) = \frac{\sum_j a_{ij}(t)}{N-1} \tag{3}$$

where the terms have known meaning.

The sum of the connections of node i defines the total number of nodes with which it is connected. The term in the denominator represents the total number of possible connections in a network of N nodes.

The total degree centrality allows the quantification of the number of destinations that can be reached starting from origin i, without transfers in the railway case. The main limitation of the total degree is linked to not attributing weight to these relationships. The existence of a single connection between i and j is enough to determine $a_{ij}(t) = 1$. This results in an increase in centrality (of both node i and node j) regardless of the number of links. This can give rise to distortions: two stations could share an equal total degree centrality value, but one of the two could have many more services than the other.

The second indicator proposed by the framework is proposed to better explain this aspect; the strength centrality measure is defined starting from frequency $f_{i,j}(t)$.

$$s_i(t) = \sum_j a_{ij}(t) f_{ij}(t) \tag{4}$$

The strength centrality indicator allows to take into account the intensity of the connections provided by the railway links. A node is more central depending on the

total number of services that connect it with the other nodes of the network. Reading the strength centrality therefore allows the centrality of the network nodes to be defined more completely.

A third indicator allows us to better define the influence of the node within the network. It defines itself

$$Av = \lambda v \tag{5}$$

Where

A is the adjacency matrix

v is the eigenvector associated to eigenvalue λ

Recalling Perron [25], it is possible to define several properties: a real square matrix with positive elements has a single largest real eigenvalue; the corresponding eigenvector has a strictly positive real eigenvector.

The positive eigenvalue, v_i, is the third indicator named the eigenvector centrality parameter. This indicator measures the centrality of a node i starting from the centrality of the node j with which it is connected. This measure is given by the sum of the centralities of neighbouring nodes multiplied by a normalization parameter. The indicator $v_i(t)$, measured for time t, therefore shows the centrality of a node while considering, at the same time, the centrality of its connections. This allows to provide further information for the case studied. Connecting a station i with a less central station j contributes less to the eigenvector centrality of station i.

Therefore, the third indicator can be connected to the first, because it provides indications on the presence or absence of services without transfers, but also allows to make basic assumptions on the degree of connection obtained by considering the interchanges.

The three proposed indicators will subsequently be implemented in a pilot study, the subject of the following section.

4 The Pilot Study

The pilot study covers current hybrid HSR services operating in the Southern regions and using both the HSR network and the conventional network where necessary, following the mixed high service model, as defined by Da Rus et al. [4]. The area considered includes the four southern regions, Campania, Apulia, Basilicata and Calabria. The study was extended to Molise and the southern part of Lazio and Abruzzo.

The area is considered less developed by European Union standards. All four regions are less developed; reference is made to the note from the European Parliament on the European Regional Development Fund [26], in which the criterion for access to funds is defined as a function of the region's GDP per capita/average EU GDP per capita ratio, as shown in Fig. 3.

The main objective of the pilot study is to test the proposed framework by analysing the network of direct HSR services within the study area considered. The aim is to highlight the main characteristics of centrality and connectivity of the network, in its current structure.

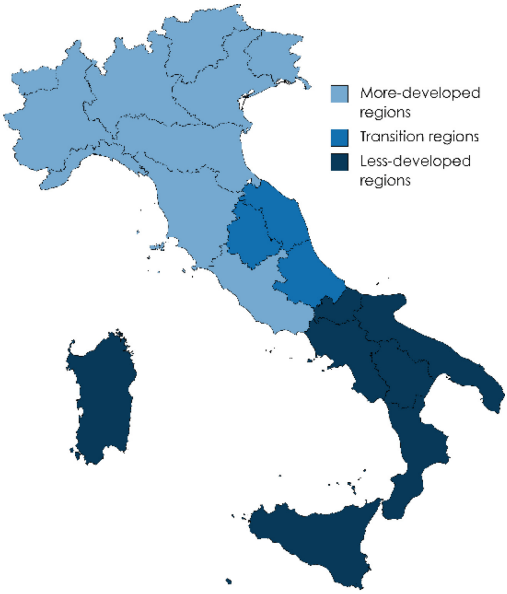

Fig. 3. – Italian Regions PO-FESR 2021-2027 (Source: author's elaboration based on Agenzia per la Coesione Territoriale, 2022) (Agenzia per la Coesione Territoriale, (2022). Programmazione 2021–2027, https://www.agenziacoesione.gov.it/lacoesione/le-politiche-di-coesione-in-italia-2014-2020/programmazione-2021-2027/,)

4.1 Data Collection

The study area includes the regions of central-southern Italy. The stations potentially affected by the study are all those south of the ideal axis that connects Rome Tiburtina/Termini with Pescara Centrale, served by at least one train classified by the operators as High Speed.

The time interval considered (t) is the average weekday of the winter period. Specifically, reference was made to Wednesday 7 February 2024.

The two railway service operators that manage high-speed services within the area considered were considered: Trenitalia and NTV. For Trenitalia, the highest-class services indicated as *FrecciaRossa* were considered; for NTV the services indicated as *Italo Alta Velocità* are considered.

Once the elements of the infrastructural network have been defined, it is possible to obtain the services, starting from the sites of the operators considered [27, 28].

The main services are divided along three lines:

- A Tyrrhenian route, which connects Reggio Calabria to Turin and Venice, and Sibari to Bolzano;
- An Adriatic route, which connects Apulia with the northeast (Venice) and the northwest (Turin);
- An Adriatic-Tyrrhenian route, which connects Apulia to Northern Italy through Rome.

Figure 4 represents the service network aggregated by region and by initial and final terminals.

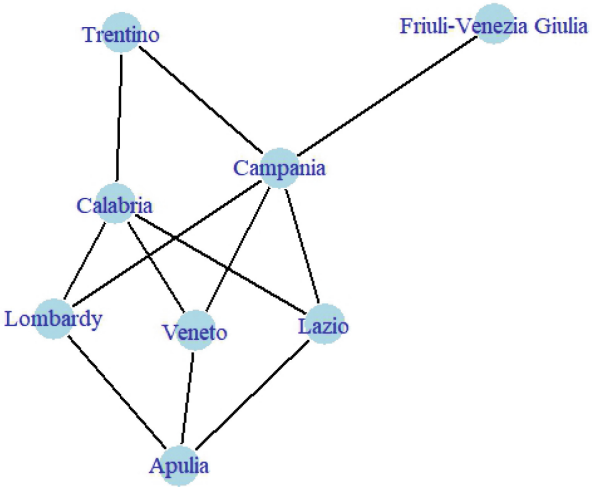

Fig. 4. Services network (by region e by O/D)

Starting from the selected services, the adjacency matrix represented in Table 1 was constructed, relating to regional connections.

Table 1. Adjacency matrix by regions and by O/D

	Apulia	Campania	Calabria	Friuli-Ven.Giu.	Lazio	Lombardy	Veneto	Trentino
Apulia	0	0	0	0	1	1	1	0
Campania	0	0	0	1	1	1	1	1
Calabria	0	0	0	0	1	1	1	1
Friuli-Ven.-Giu.	0	1	0	0	0	0	0	0
Lazio	1	1	1	0	0	0	0	0
Lombardy	1	1	1	0	0	0	0	0
Veneto	1	1	1	0	0	0	0	0
Trentino	0	1	1	0	0	0	0	0

The coverage of the HSR services selected for the study area is represented in Fig. 5.

4.2 Data Preparation

The sequence of trips belonging to the selected lines is processed to build the graph of existing railway relations. Following what is indicated in Sect. 3.2, the graph on



Fig. 5. HSR services in the south of Italy (Source: authors'elaboration based on QGIS [30] and OpenStreetMap [31])

which to evaluate centrality is the graph of relations without transfers. For the services considered, N = 41 nodes and E = 550 links are identified in the relationship graph. Figure 6 shows the relationship graph schematically. From a first visual reconnaissance of the relationship graph, the existence of two main routes of the network is highlighted: one along the Tyrrhenian axis and one along the Adriatic axis, highlighted in Fig. 6.

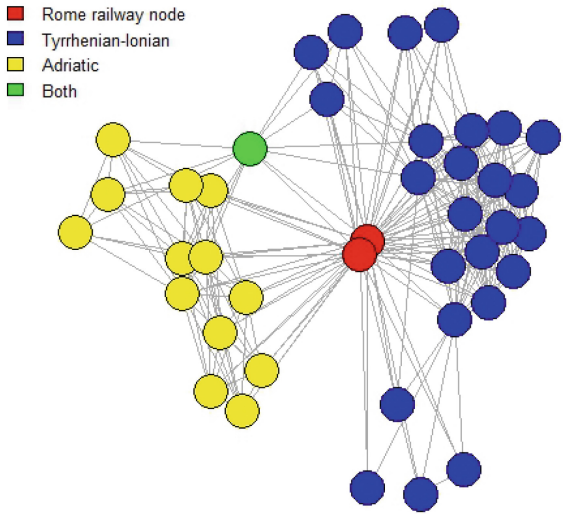

Fig. 6. Current HSR connections in the study area

4.3 Network Analysis

The values of the network analysis indicators (c_i, v_i and s_i), described in Sect. 3.3 are represented in Fig. 7.

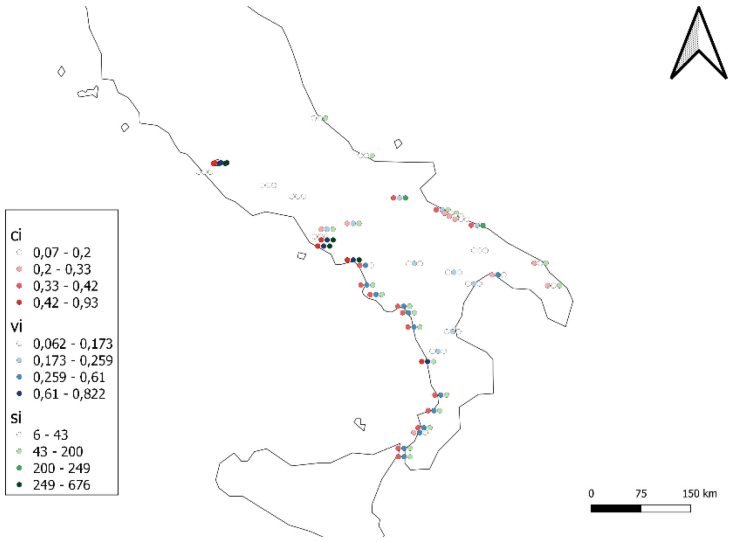

Fig. 7. Network analysis indicators (Source: authors'elaboration based on QGIS [30] and OpenStreetMap [31])

5 Discussion and Final Remarks

Territorial accessibility is one of the possible measures of the social component of sustainability. This paper focuses the attention on the structure of HSR services in southern Italy. In particular, network analysis was adopted to evaluate the connectivity offered by existing HSR links relative to the services.

The research focused on the proposal of a general framework and its application to a pilot case.

The first element to be considered relevant from the study regards mutual connections between railway stations (Sect. 4.2). In the current configuration there are no HSR services available between Naples and Bari, as well as between Bari and Reggio Calabria. The evaluation of the HSR railway network of Southern Italy alone would be practicable, and the corresponding graph is connected, thanks to the Taranto. Taranto is the only node connected with both Naples and Bari; but, at the same time it is not relevant in terms of number of services, as suggested by the very low value of s_i. With the aim to obtain a network truly representative of relationships, the network considered nodes in central-southern part of Italy (Rome, Termoli, Pescara). The nodes of Rome (Termini, Tiburtina) are the main center of the network. The Adriatic axis is connected to the Tyrrhenian-Ionian axis through the Foggia-Benevento-Caserta-Rome route. Then, a first result underlines the lack of HSR services connecting the territories of southern Italy by HSR services. Even if they are formally connected through Taranto, these connections have no utility for users.

The current structure of the services network produces high values of the centrality indicators for the Rome railway node. The two railway stations have the highest values (Roma Termini: $c_i = 0.925$, $s_i = 676$, $v_i = 0.822$; Roma Tiburtina: $c_i = 0.9$, $s_i = 464$, v_i

$= 0.8$). The evaluation of the indicators for the Adriatic axis and the Tyrrhenian-Ionian axis is influenced by the presence of the hub in the capital. However, it should be noted that the station of the Naples (Napoli Afragola station) hub has rather high values of the indicators ($c_i = 0.6$ and $v_i = 0.7$), also considering the number of stations served along the Tyrrhenian-Ionian route. This is also due to the very high number of interconnected services (s_i) towards Rome and the north of Italy and its crossing for connections with Basilicata and Calabria. The network of connections with the Adriatic has a lower number of nodes (14, out of a total of 41) and this negatively impacts the value of c_i and v_i. In particular, the eigenvector centrality value is lower for the main nodes (Bari Centrale, Lecce) due to the lack of more relevant direct connections such as Naples. On the other hand, the values of s_i are higher for the Bari Centrale and Foggia nodes than for the other nodes, indicating a clear hierarchy of nodes with respect to the number of connections. The considerations on the Adriatic can also apply to the territories located along the southern Tyrrhenian and Ionian Sea. The values of c_i and v_i are quite high for the main nodes (Paola, Reggio Calabria, Villa S. Giovanni and Rosarno), due to the high number of nodes (19 out of 40 for Paola, 17 out of 40 for Reggio, Villa and Rosarno) with which they are connected. A different result is obtained for the evaluation of s_i.

The total of relationships for these nodes is lower than the value obtained for Bari and Foggia, compared to a higher value of c_i and v_i; the s_i value of these stations (169 for Paola, 155 for the other 3) is lower than the value of the main Adriatic stations but slightly higher than the value of Lecce (129 reports/d). This aspect is more highlighted considering the values v_i. Nodes on the Southern Thyrrenian side have higher values than the nodes on Adriatic side.

Recalling the number of nodes for each of the two node clusters (26 for the Tyrrhenian Sea, 14 for the Adriatic, considering Taranto in both clusters), the summary considerations that emerge from the results of the centrality are:

- The two main hubs are the nodes of Rome and Naples areas;
- The nodes of the northern Tyrrhenian Sea have a high number of connections and a high number of relationships;
- The Adriatic nodes have a small number of connections within the system considered, but a fairly high number of relationships, considering the main stations;
- The nodes of the southern Tyrrhenian and Ionian Sea have a high number of connections, but a lower number of relationships.

It is necessary to underline the discrepancy between the value of centrality in the service network, the presence of HSR infrastructure and the population of the area served. The misalignment is evident in the case of the stations in upper Calabria (e.g. Amantea). A specific case is the Villa S. Giovanni railway station. The high value of c_i and v_i is linked to the high number of nodes present on the services considered; similarly, the value of s_i, the total of relationships, is slightly greater than that of other nodes; in light of this, it is necessary to consider how Villa S. Giovanni plays a role as the main hub for relations with Sicily, the fifth region of Southern Italy, not considered in this study due to the evident absence of continuity in railway connections.

Another distortion emerges in relation to the absence of high-speed infrastructure from Salerno to Reggio Calabria. The nodes with high centrality values in terms of HSR hybrid services (such as the nodes in Calabria) operate in a context in which there is no

high-speed railway infrastructure. For each analysed station, Fig. 8a shows the value of strength centrality and Fig. 8b represents the quantity of population potentially served with a car journey with a travel time of less than 50 min. Regarding the nodes of the Strait of Messina, the population residing 20 min away by car from the port of Messina is also considered. From the comparison between the values reported in Fig. 8a and 8b, it emerges that high values of centrality (42–200) do not ever correspond to high values of population. An example is the station of Maratea. It serves a population of approximately 65,000 inhabitants, very low compared to the area of Reggio Calabria or Villa S. Giovanni (more than 500,000 inhabitants). For a population of approximately 9–10 times the population of Maratea, these two stations have a value of s_i quite higher (155 for Villa and Reggio, 57 for Maratea), a value of c_i of the same order of magnitude (0.375 for Maratea, 0.425 for Reggio and Villa) and a value of v_i very similar (0.56 for Maratea, 0.61 for Reggio and Villa S. Giovanni). This gives a result about this area: considered a great difference in terms of population interested, Reggio di Calabria and Villa S. Giovanni offer only a small number of more services and approximately the same destinations of Maratea.

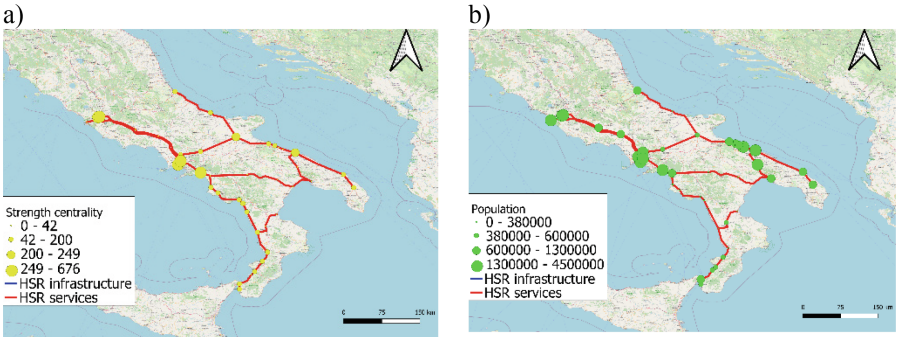

Fig. 8. Railway infrastructure network (centrality vs. population) in the south of Italy (Source: authors'elaboration based on QGIS [30] and OpenStreetMap [31])

Although some nodes analysed are very central in terms of services, the infrastructures have a conventional structure. Furthermore, the lack of a marked hierarchization of services on the Tyrrhenian axis is highlighted, with particular reference to the aforementioned node of Villa San Giovanni which, in addition to being attractive for the large southern part of Calabria, has a basin of influence that covers a good part of the Sicilian North-East.

The study has some limitations. For example, the study does not consider other transport service, including other classes of railway services (e.g. Frecciabianca). The resident population is only one of the possible territorial variables to consider. In the future, the analysis could be extended to other mobility components (e.g. tourist), considering that a part of the selected stations serves centres of high cultural, environmental and landscape interest.

The limitations highlighted for the Villa San Giovanni node translate into the need to develop a methodology that considers intermodality, as well as non-high-class high-speed services and conventional services.

Another possible line of research concerns the possibility of extending the proposed framework to connections with Northern Italy, considering the entire service network.

The work carried out is of interest for the developments of the ongoing design of the high-speed railway line that connects Salerno with Reggio Calabria. Furthermore, the results obtained are of interest to researchers and decision makers interested in territorial accessibility analyses.

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Framework for Life Cycle Railway Sustainability Assessment: A Methodological Approach Based on Advanced Methods and Tools

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Abstract. Railway corridors improvement and development are the most appropriate answer to the need of providing sustainable transportation of people and goods. Indeed, rail is the greener transportation mode since it contributes to the reduction of carbon footprint and energy consumption within the global transportation system. From this perspective, continuing to pursue sustainability objectives, any intervention on railway lines and particularly on track must be focused on the use of materials, components, and techniques able to guarantee the best environmental performances in service life span, also according to Agenda 2030 goal 13 action climate. To this purpose, the decision process at any life stage of construction and maintenance of the track can be supported by advanced methods and tools able to correctly address the right solutions through the quantitative assessment of the related environmental burdens. This study delivers a framework of methods and tools in use for the assessment of the sustainability. An application to a case study is also reported and discussed. Results demonstrated that there is room for the enhancement of environmental behavior of the track during its life cycle by means the suitable selection of materials and techniques for construction and maintenance. Further, the proposed methods have a great potential to support decision-makers.

Keywords: Railway · Track · Sustainability · Life Cycle Assessment · Circularity Index · Artificial Intelligence

1 Introduction

Climate change arisen by the increasing of greenhouse gas emissions (GHGs) emphasizes the urgent need for countries to prioritize sustainable transportation infrastructure as a crucial sector for climate action, as required by Agenda 2030 Goal 13. Indeed, transport represents almost a quarter of Europe's greenhouse gas emissions in addition to being the main cause of air pollution in cities [1]. On the other hand, climate change represents a threat for transport infrastructures they self, due to design features (e.g. low resistance to storms) or location (e.g. in flood-prone areas, landslides) that can make them vulnerable to climate actions Extreme weather events (extreme precipitation

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and floods, occurrences of extreme low or high temperatures, rising sea level, strong wind) resulting from changing climatic condition can damage or render unfit for use the infrastructures. The aspect of the climate change must be accounted together with the increasing awareness of the need of sustainable management and conservation of the resources. In this sense, apply the principles of circular economy and use energy from renewable sources are nowadays essential elements in the design, construction, and management of transport infrastructures.

Among the transportation mode, the rails satisfy the 8% of global passengers and freights demand and are responsible for only 4% of the total emissions generated by the whole transportation system. In this sense, it can affirm that rail is the main pillar of the transformative climate action in transport sector being the fastest and most cost-efficient way to decarbonize people's daily mobility and logistics chains [2, 3]. Railway corridors improvement and development are the most appropriate answer to the need of providing sustainable transportation of people and goods, for the lowest production of the emissions [4–7]. In rail lines enhancement and expansion, the sustainability must be considered as a pivot around which revolve the conception, construction and management phases. It is essential to take into consideration the entire life cycle of infrastructures to avoid the circumstance that optimal solutions in the short term are then unsustainable or less sustainable if regarded in the long-term of the service life.

One of the fundamental components of railways is the track for which the objectives of sustainability call for the careful and conscious adoption of solutions and materials able to improve more and more the environmental performances. In fact, the construction of new tracks and the maintenance of the existing ones are activities resource demanding and emissions discharging and therefore environmentally impacting [8].

In the sustainability assessment is fundamental to consider the life cycle of track, because at any stage of the life the decision-making process can affect the sustainability. More specifically, in design and construction stages, the selection of the more appropriate suitable track system (ballasted or ballastless) in function of the expected traffic, axle loads and train speeds, the type of materials and components and their supply mode and hauling distance as well as the construction schedule are elements which greatly affect the sustainability. In service life, maintenance strategies, materials, and equipment and machineries are important aspects to consider. At this stage is fundamental to forecast the degradation of the geometric and structural quality of the track and the maintenance interventions needed to ensure efficiency, safety, and regularity of the trains service. Track deterioration models mechanistic or physics-based, empirical, data-driven or hybrid or the ones based on Artificial Intelligence (AI) [9, 10] are useful tools in addressing the in-service behavior. In the end-of-life (EoL) the re-use/recycling of the dismantled materials and components, or the landfill, in case in whcih recycling/reuse is partially or totally not allowed, differently affect the sustainability.

This paper provides a framework of the methods for the assessment of the rail track sustainability in the life cycle. To demonstrate the suitability of the application of proposed approaches a case study referred to the comparison of two track systems, ballasted and ballastless, is reported and results discussed.

2 Track System: Materials and Components

The rail track is a complex system that consists of several components each of which plays a crucial role in ensuring the smooth and safe movement of the trains.

Two types of track systems operate in the word: ballasted and ballastless (see Figs. 1 and 2). Basically, in the first, the rails sit above sleepers, which distribute the load on a bed of ballast posed on subgrade soil; instead, in the second case, the rails are supported by concrete slabs which also rest on subgrade soil [11, 12].

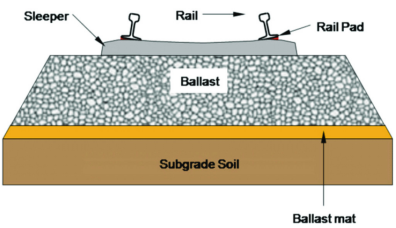

Fig. 1. Ballasted track system

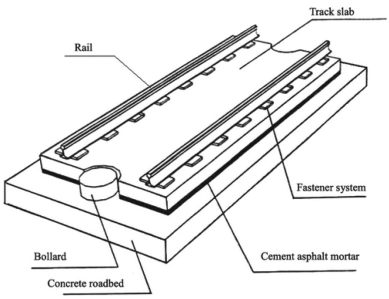

Fig. 2. Ballastless or slab track system

The two systems exhibit different performance in terms of service life and maintenance and in the selection of the more suitable system many important technical, economic and environmental factors have to be taken into account [12]. Their main components and function are synthetically reported in the Table 1.

The inevitable functional and structural decay of these components under the effect of train loads and speeds requires maintenance activities over the time aimed at extending the life of the rail component. Typical activity maintenance on track components are specified in the Table 1.

3 Life Cycle Stages of Rail Track

In the construction sector, looking at the whole project life cycle is a new trend in sustainability analysis. According to the current ISO 21931-2 [13], four stages characterize the life cycle of the track (see Fig. 3):

- the production stage which encompasses three modules: the raw material extraction (e.g. steel, cement, water, aggregate) (module A1), the transport of raw materials to components manufacturing factory (module A2), the components manufacturing (module A3) (e.g. rails, sleepers, ballast, fastening);
- the construction stage, divided in transport of components to construction site (module A4), and construction/installation process (module A5) (track construction);
- the use stage which includes use, maintenance, repair, replacement, refurbishment (modules B1-B5) of all track components and the operational energy and water use (modules B6 and B7);

Table 1. Railroad track component.

Component	Material	Function	Maintenance
Rails	Steel	Guidance Support Smoothness Safety	Grinding Lubrication Inspection
Fastenings	Steel	Rail Fixation Shock Absorption Load Distribution	Retightening Replacing Lubrification Corrosion and Rust Prevention
Sleepers	Wooden Concrete Steel	Rail support Load distribution Sound and Vibration Absorption	Cleaning Tamping Repositioning
Ballast	Crushed stone Gravel	Stability Drainage Load distribution Track alignment Vibration and Noise Reduction	Tamping Cleaning Resurfacing Monitoring
Slab	Concrete	Rail Fixation Rail support Load distribution	

- the end-of-life stage which considers deconstruction/demolition, transport, waste processing and disposal (modules C1-C4) of all components of the track.

Additional information beyond the life cycle and system boundaries, such as reuse, recycling, energy and other recovery, can be also considered (module D).

In addition to these stages, the previous non-construction stages are also crucial to obtain the most optimal solution for a given design task. The stages not related with the construction works are referred to the planning, the study/analysis and the design stage.

3.1 Framework for Track Sustainability Assessment

Figure 3 details the construction work of track and reports for each module the materials and components that must be considered. Further, specific milestones (cradle, gate, site, practical completion, end-of-life, grave) are identified. Based on these milestones, it can be considered different life cycle models to be implemented:

- Cradle-to-gate: is a partial life cycle assessment which considers only the phase resource extraction (cradle) to the factory gate (the transport to the construction site is excluded) (Stages 1). This assessment is sometimes the basis for environmental product declarations (EPD).

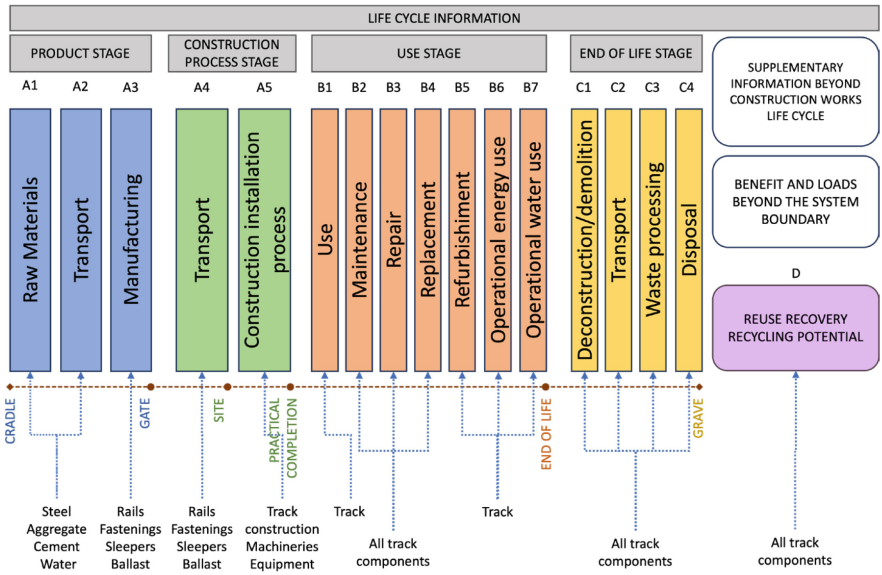

Fig. 3. Framework for the assessment of the environmental, social and economic performance of rail track.

- Cradle-to-grave: is a full life cycle assessment that includes all the four stages from resource extraction ('cradle') to disposal phase ('grave') and allows to estimate the complete environmental footprint, from start to end. (Stages 1–4).
- Cradle-to-cradle: is a particular cradle-to-grave assessment, where the end-of-life disposal step coincides with a recycling process that makes materials or components reusable for another product allowing therefore to "close the loop" (Stages 1–4, with 4 being equivalent to another Stage 1).

There are various life cycle assessments that aim to quantify and measure sustainability using a specific methodology and accurate data so that alternative solutions can be compared. It is noteworthy to highlight that the sustainability is founded on three fundamental pillars environmental, economic and social then discussions about achieving sustainability of rail track usually satisfy a holistic and integrated assessment of these three pillars [14, 15] (see Fig. 4).

Indeed, life cycle information allows to perform Life Cycle Sustainability Assessments (LCSA) focused on environmental (Life Cycle Assessment - LCA), economic (Life Cycle Cost - LCC) and social (Social - Life Cycle Analysis) aspects.

Life Cycle Assessment (LCA) is a comprehensive methodology used to evaluate and quantify the environmental impacts of products and services [16, 17]. LCA studies can help to address the decision-making process when applied to rail track by adding environmental factors to economic and mechanical performance [18–20]. An LCA study consists of four stages:

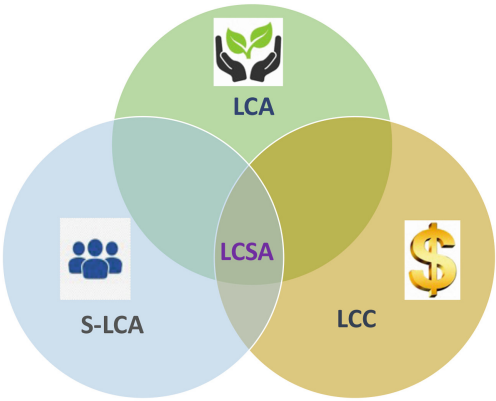

Fig. 4. Scheme for Life Cycle Sustainability Assessment (LCSA).

- Stage 1 - Goal and scope: which aim to define the objective of the study, the part of life cycle taken in assessment (i.e. cradle to gate or cradle to grave) and the functional unit to consider.
- Stage 2 - Inventory analysis: provides a description of the amount of material and energy flows with particular focus on the interaction with environment, on the consumed raw materials, and on emissions to the environment.
- Stage 3 - Impact assessment: the results of this step are associated to all impact categories considered; processes such as normalization and or weighting allow to assess the importance of every impact category.
- Stage 4 - Interpretation: this stage involves the critical appraisal of the life cycle outcomes, the determination of data sensitivity, and the result presentation.

As for Life Cycle Cost (LCC), according to ISO 15686-5 [21] it can be defined as "the cost of an asset or its parts throughout its life cycle, while fulfilling the performance requirements". The LCC analysis allows comparing the economic performance of different alternatives (e.g. ballasted/ballast-less track). Minimizing the track system life cycle costs (usually the present value PV) will increase the economic sustainability of the rail superstructure. The life cycle costs for each track solution encompass company (construction, inspection, maintenance, and renewal), user (time, accidents,….), and environmental (e.g., CO_2e emissions, etc.) costs. The trends of these cost during the lifespan allow to carry out complete evaluations for identifying the most convenient solution [22–24]. It is important to highlight that the expenditures happen at different moments of the life so that it can distinguished among the initial cost, usually corresponding with the construction cost, the recurrent costs due to maintenance and renewal, the disposal cost and the residual value at the end of life (Fig. 5). Discounting allows expressing future costs at today's equivalent by applying the discount (r) rate The amount of discount rate to be applied is often controversial and the accurate application of the right discount rate is, on the ither side, pivotal because it affects the results.

The social life cycle assessment (S-LCA) is a method able to assess the social and sociological aspects of a product and their actual and potential positive as well as negative

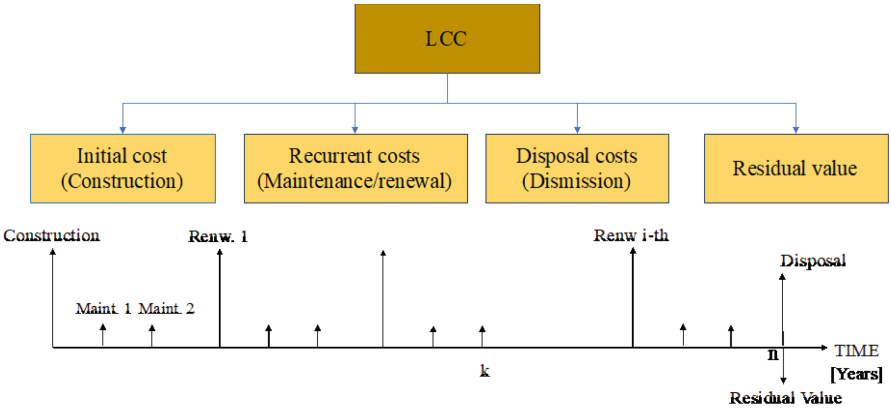

Fig. 5. Life Cycle Cost (LCC).

impacts along the lifespan. Data to perform S-LCA can be generic or site-specific, quantitative, semi-quantitative or qualitative, and results complements the LCA and LCC. The UNEP Guidelines for Social Life Cycle Assessment of Products [25] proposes a methodology to develop life cycle inventories starting from the identification of the stockholders (workers, local communities, society, consumers, value chain actors), the impact categories (human rights, working conditions, health and safety, cultural heritage, governance, socio economic repercussions), the subcategories, the inventory indicators and the inventory data. The social sustainability of track is the least represented in research, due to the complexity of quantification and interpretation of the impacts [14].

One of the critical aspects of the life cycle assessment of the rail track relies on the use stage and concerns the forecasting of the maintenance activities and renewal. Establish in advance at what time and where to carry out interventions on track is a task as difficult as it is important for reliable assessment of the life cycle performance and comparative evaluation among different alternatives.

Maintenance activities on track (renewal and re-construction) and its components (ballast cleaning, resurfacing, rail-head grinding) are costly and environmental impacting because of the use of resources and diesel power machineries [8].

To optimize the maintenance activity under all the standpoints technical, economic and environmental several issues must be addressed: planning of the inspection interval to detect the need of intervention, identification of the type of intervention and prioritization, timing and mode of intervention. Forecast track degradation by means a reliable model is the best way for identifying the appropriate time for condition-based maintenance in railway track.

The great quantity of materials used in construction and maintenance of rail tracks, calls for the application of the principles of Circular Economy: reducing, reusing, and recycling of the materials and the extending useful life through maintenance and repair (stage D). Circularity indices [26] providing information about the quantity, in percent, of recirculated material is in a product or component clearly express the circularity of a system. To this purpose the Circular Material Use rate (CMU rate), defines the ratio of the circular use of materials (U) to the overall material use (M) while the End-Of- Life Recycling Input Rate (EOL-RIR) measures, for a given raw material, how much of its input into the production system comes from recycling of “old scrap”.

Synthesis of method and tools for the sustainability assessment of the railway track is reported in Fig. 6.

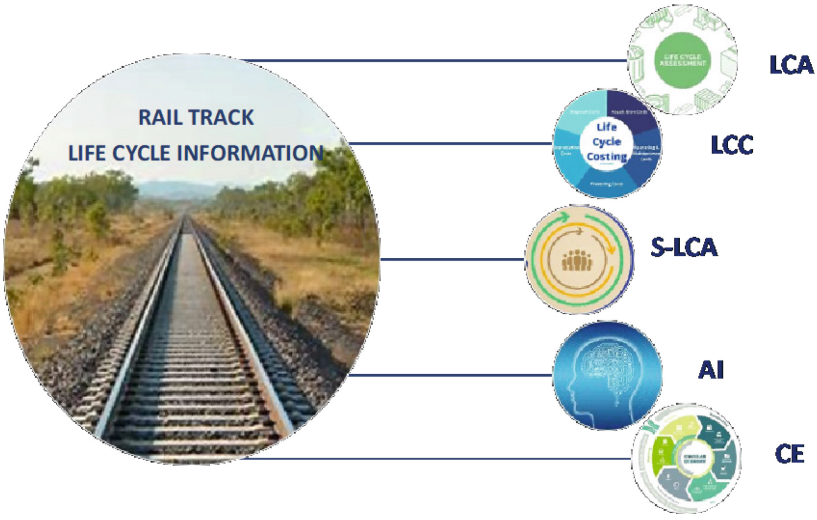

Fig. 6. Method and tools in the sustainability assessment of the rail track.

4 A Case Study on the Integrative Approach LCC-LCA

To prove the potentials of the methods discussed, an integrative approach LCC-LCA is applied to the case study of the comparison of two track system: the traditional ballasted track and innovative slab track [23, 24].

The appraisal of the two alternatives is referred to a double track line 1-km long. Main characteristics of the track components and related service are shown in Table 2.

The economic appraisals consider all the costs, from the construction to the end of life, split in costs of the company which built and manage the track (C_{comp}), costs of users (C_{users}) of the railway service, here referred to the cost of delay due to the maintenance and renewal activities which inevitably affect the regular service of the railway line, and environmental costs (C_{env}) here referred to the emissions of CO_2e arising from the construction and maintenance processes. The applied discount (r) rate is 4%. Figure 7 shows the trend of the total costs of the two alternatives the ballasted (continuous line) and the slab track (dashed line) in a lifespan comprised between 0 and 60 years.

It is worthy to note that at the end of the construction (year 0), the slab track exhibits a total cost 1.5 times higher than the one of the ballasted track, according with literature results. At year 0, the total cost consists of the construction cost and the environmental cost while the user cost is null. A breakeven of the total costs can be observed after about 26 years, after that the total cost of slab track remains lower, albeit slightly, than the ballasted one.

Table 2. Features of track component and expected life.

Track component	Type	Dimensions	Service life [Years]
Rail	60 E1	Mass = 60,1 kg/ml	28
Sleepers - Fastenings	RFI-260 VN AV equipped with the fastening system Vossloh W14	Length 2.60 m, mass 325 kg	40
Ballast	Crushed stones	Depth 500 mm	40
Subballast/ Road-bed	Cement layer	Depth 200 mm	40
Slab	Pre-stressed concrete linked with cylindrical bollard	4,93 m × 2,34 m × 0,19 m mass = 5 tons	60

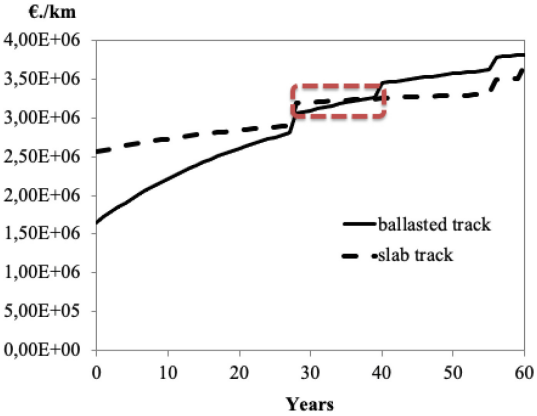

Fig. 7. Trend of total costs for ballasted and slab track.

For a better understanding of the sustainability of the two solutions, company costs, user costs and environmental costs have been calculated in different time frame 0, 30, and 60 years and represented the Figs. 8 and 9.

From the break-down of the costs it is possible to observe that the company costs (construction, maintenance and renewal), are lower at construction stage and in the short period for the ballasted track while reach a value 1.15 times higher than that of the slab track in long term because of the high frequency of maintenance activities. The user costs for ballasted track, lower in the short period, become, in the long-term perspective, 2.3 times higher than the ones exhibited by the slab track. The environmental costs display a reverse trend for the two solutions due to the carbon footprint of the cement/concrete that is very high if compared with the ballast. This makes the slab track less preferable, than the traditional ballasted track from the environmental standpoint.

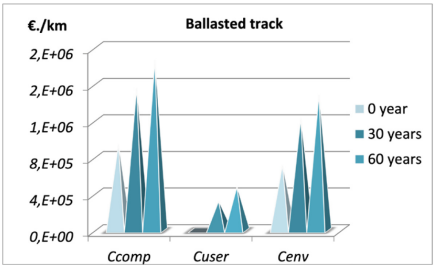

Fig. 8. Trend of costs for ballasted track.

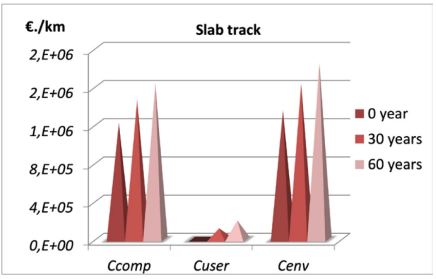

Fig. 9. Trend of costs for slab track.

The integrated evaluation of the environmental and economic aspects allows to do more complete considerations in the decision-making process of the selection of the more suitable solution.

5 Conclusion

This study delivers a framework of methods and tools in use for the sustainability assessment ai rail track. The proposed methods have a great potential to support decision-making process as demonstrated by the proposed case study where the LCC and LCA integrated method is applied. In fact, the results of the analyses carried out on the two ballasted and ballastless track systems, following the integrated method, confirms that a comprehensive evaluation of different track options needs the consideration of company, user and externality costs. This also applies when they compare alternative materials and components within the same track system. In fact, company, user and environmental costs govern the suitability of a track to fit technical as well as environmental demand. Considering and integrating technical and environmental issues is sometimes a trickly exercise, especially because several data are requested to do reliable evaluation, but it remains the right way for a comprehensive and complete comparison among different design and maintenance track solutions.

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

A Selection of Sustainability Parameters for a Comprehensive Assessment of Urban Transformations

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Abstract. Urban planning is commonly recognized as strategic to tackle the global challenge of sustainable development. However, the implementation of sustainability in the urban practice is complex, and the existing tools in support of sustainable urban transformations are often incomplete and fragmented: e.g., the compliance with the land-use containment parameters, the ecological balance computation, and the economic and financial evaluation, are only partial regulation tools introduced at the local scale for ensuring an "adequate" sustainability character to land-development projects. Such a fragmentation of efforts is also traceable in the research approaches: a great variety of perspectives and diversity of domains animate the academic debates on the sustainability performance assessment. As a consequence, we wonder about the possible definition of new synthetic frameworks: a comprehensive protocol in support of the sustainability assessment of urban renewal scenarios, at the disposal of Public Administrations. Aware of the many and specific assessment frameworks traceable in the literature, we propose an attempt to analyse and select existing indicators, starting from the collection of those already investigated by scholars over the years (i.e., during the last two decades of the 21st century). Therefore, the analysis has been performed on an extensive database consisting of over 600 items.

Keywords: Urban Regeneration · Sustainability Assessment · Indicators

1 Introduction

Cities are places where the greatest amount of GHG is emitted and, at the same time, they are the front line places to face the challenge of climate change. Their potential of reducing GHG emissions by simply applying sustainable urban planning models is around 23–26% by 2050, compared to the business-as-usual scenario [1]. The IPCC-AR6-WGIII recognized models of sustainable urban planning in compact, resource efficient, and walkable urban forms, which adopt mixed land use and transit-oriented development (TOD). Therefore, if well planned cities can be considered "the source of solutions to, rather that the cause of, the challenges our world is facing today" and

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urbanization itself can be "a powerful tool for sustainable development" [2]. In this view, urban spatial frameworks and planning and design instruments assume pivotal roles in managing the use of land and resources within cities, as already highlighted by the transformative commitments of the New Urban Agenda (adopted at the United Nations Conference on Housing and Sustainable Urban Development - Habitat III - in Quito, Ecuador, on 20 October 2016). Despite this high commitment, the promotion of new planning and design tools should be even more emphasized to overcome the theoretical-practical gap, which has already been observed between the strategic planning and design phases of sustainable development interventions [3–5]. As [4] reported, there is a general operational difficulty in implementing sustainability criteria to be applied in the evaluation of urban transformation projects.

Moreover, existing tools are often characterized by a high level of fragmentation, with very sectorial procedures, approaches and required competences. At the local level, cities and municipalities, such as in the Italian context of the present study, set their own procedures and monitoring tools in the attempt to pursue the objectives of sustainability in the implementation of urban projects. For example, referring to the case of the Lombardy Region (since legislations change from region to region), the land-use containment parameters (refers, e.g., to the Lombardy Region Law n.31/2014), the ecological balance computation (refers, e.g., to the STRAIN methodology approved by the DDG n.4517/2007 of the Lombardy Region) and the hydraulic invariance regulation (refers, e.g., to the Lombardy Region Regulation n.7/2017) are some examples of sectoral tools put in place by Italian territories for monitoring the environmental sustainability of urban interventions. On the other hand, if the economic and financial evaluation (refers, e.g., to the DGR n.7729/2022 of the Lombardy Region) may assure an adequate level of economic sustainability, there are no or few tools to monitor aspects of social sustainability. Only in some recent cases, evaluation forms (mostly qualitative) or technical reports have been introduced to verify the sustainability performance of projects during their implementation phase.

This overlap of different regulatory requirements and methodological frameworks increases the complexity: for Public Administrations to holistically assess and monitor the sustainability performance of urban transformations; and for the scientific community to develop new tools aimed at this purpose (closing the theoretical-practical gap already mentioned). Due to the high variety of knowledge involved, such a fragmentation of efforts is also traceable in the research approaches. As emerged also in the 17th Edition of the International Conference on Computational Science and Its Applications [6] (held in Trieste, Italy), a great variety of perspectives animates the academic debates on the theme of sustainability performance assessments, such as the domains of: energy saving and building renovation; sustainable mobility, ecosystem services and biodiversity preservation; mitigation and adaptation solutions; circular economy, risk management; etc. As a result, specific indicators are often proposed by experts to investigate different and important aspects of sustainability, such as the key performance indicators (KPIs) to assess: the ecological value of urban settlements, e.g., [7]; the renewable energy communities (REC), e.g., [8]; the level of circularity of interventions at the different urban scales, e.g., [9]; the accessibility and walkability of urban areas, e.g., [10, 11]; the liveability indicator of urban spaces, e.g., [12]; etc.

Therefore, for speaking of a comprehensive sustainability assessment, able of providing an ex-ante holistic evaluation of potential project scenarios, a unanimous effort in terms of contamination and interconnection of disciplines is required [4]. In the perspective of a greater integration of knowledge and frameworks, in a previous study (refer to [5]) we analysed the main research trends and progresses, (occurred in the last two decades of the 21st century) on the topic of sustainability assessment of urban transformations, with a focus on the existing evaluation tools suitable for the urban regeneration scale. Since many authors focused on developing specific evaluation systems, by means of multiple methodologies, criteria and sets of indicators (among which, [13–16] to mention a few), in this contribution we aim at studying, in more detail, their measurement systems. In particular, we collected, classified, analysed and selected all the indicators already investigated and proposed by scholars, through the creation of an extensive database. Among the research questions we posed, there are: "Are the sustainability dimensions equally investigated by the evaluation frameworks? Are the proposed indicators more qualitative or quantitative? Are there standardized and comparable measures?". The structure of this contribution will lead the reader through the description of the chosen methodological approach and materials (Sect. 2), the main findings on the proposed analysis (Sect. 3), as well as their discussion in the conclusions (Sect. 4).

2 Material and Methods

The methodological approach we selected to: (i) create an extensive database of existing set of indicators, coming from the literature, and (ii) analyse its main features, can be described through the following four steps (see Fig. 1).

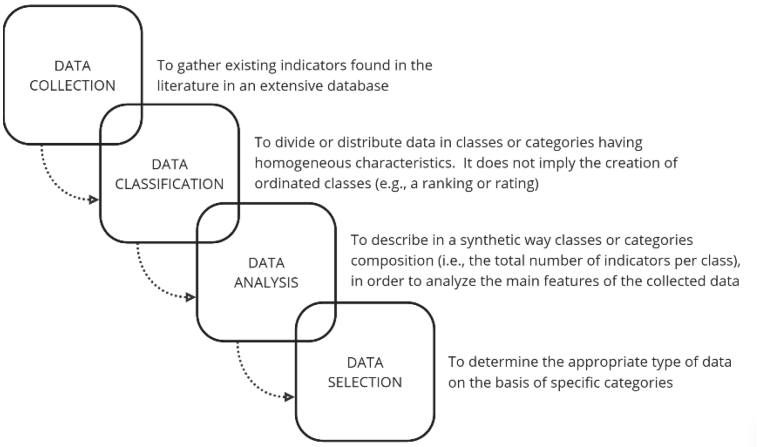

Fig. 1. The four-step methodological approach for the database creation and elaboration (i.e., classification, analysis and selection of data).

Data Collection. The preliminary phase concerned the collection of all the existing measures already investigated and used by scholars in the last two decades (published

between January 2000 and February 2023). In particular, the collected indicators were part of multiple assessment frameworks elaborated within the urban planning discipline for the sustainable development of neighbourhoods. Starting from a previous literature review of 99 publications (refer to [5]), more than 600 indicators were gathered and composed the initial database. The following basic information fields have been filled in, as reported in the publications of origin:

- Bibliographic reference;
- Year of the study;
- Country of the study;
- Case study of application (if applicable);
- Applied methodology for the evaluation model;
- Spatial scale of application (i.e., city scale, regeneration scale)
- Temporal phase of the application (i.e., ex-ante, in itinere, ex-post compared to the processes of urban planning and building realization);
- Criteria and sub-criteria;
- Indicators and their description;
- Measurement units;
- Data source (if applicable).

Data Classification. Having defined a first rough database, the main question we faced is "how to select measures from this long list of items in a reasonable way?". To answer this question, the following three attributes were considered necessary in order to start classifying data with homogeneous characteristics:

1. The sustainability dimension;
2. The type of data;
3. The feasibility of data collection.

The sustainability dimensions have been set according to the "quadruple bottom line" perspective [17]: the environmental, social and economic dimensions, as well as the governance. The allocation of indicators to each dimension has been carried out on the basis of predominant themes: each indicator has been classified according to its major effects on one or more dimensions. A maximum of two dimensions has been considered in the case of multiple effects; for this reason, intra-dimensions have been defined (e.g., socio-environmental, eco-environmental, etc.). Some indicators, however, do not have a precise scope and, since they could have general benefits suitable for all dimensions, they have been classified as "neutral". Table 1 shows the main topics that could be investigated in the assessment of each sustainability dimension.

Table 1. Sustainability Dimensions

Dimensions	Main topics included
Environmental	Types of intervention (new expansion or urban regeneration), reclamation of contaminated land, reclamation of building materials, waste production and management, energy building efficiency, production of renewable energy, bioclimatic design, compatibility with the urban context, natural element characteristics, green areas, degree of soil sealing, water use and drainage characteristics, presence of natural protected areas
Socio-Environmental	Types of land uses (residential, commercial, industrial, etc.), preservation and renovation of heritage buildings, utilities for basic housing, provision of public services, public transports and sharing mobility services, road safety and accessibility, active mobility services, quality of the outdoor spaces, landscape preservation, type of environmental pollution and climate change consequences with direct impacts on the well-being
Social	Housing affordability, public spaces accessibility, functional mix, social services, social attractiveness, meeting spaces, community involvement, healthiness of houses and places, social security
Socio-Economic	Job opportunities, fight against poverty, balance in income levels, population trends, level of users' satisfaction, touristic attractiveness
Economic	Total costs of the project, profitability of the intervention, economic and financial information, house occupancy, provisions for establishment of different businesses, partnership and collaboration
Eco-Environmental	Economic activities aiming at improving the environment, share of environmental protection investments
Governance	Data driven decision making, integration and coordination of administrative sectors, management measures, communication plans, restrictions and statutory requirements
Socio-Governance	Participatory processes, community and stakeholder engagement, partnership and collaboration
Env-Governance	Integration of environmental data in the site development plan, adoption of management plans or measures for environmental components, degree of ecosystem considerations
Eco-Governance	Resource allocation, coordination to promote the economic development of areas, reinforced coordination of fiscal and economic policies, management of financial aspects
Neutral	Density, flexibility, ability to be transformed, preservation of existing urban configurations, duration of the transformation, temporary uses, reduction of the risk exposure

As regards the type of data, indicators have been classified as "quantitative" if they express information that can be quantified (with numerical values), counted or measured, and used for mathematical calculations or statistical analyses. On the other hand, indicators have been classified as "qualitative" if they are descriptive in nature, that means they are expressed in terms of language, ordinal values or scores, rather than numerical values. Since the main distinction can be made by observing the measurement units, in some cases of non-traceability of the unit of measurement itself, it has been impossible to establish a priori the typology of data. In these non-specified cases, the nature of the indicators has been classified as "unknown".

Finally, the feasibility of data collection has been questioned according to the local specific context and spatial scale of urban regeneration. Table 2 lists the criteria used to define the feasibility of data collection.

Table 2. Feasibility of data collection

Feasibility	Description of the main cases
Yes	Data immediately available or measurable
Yes, redefining the measurement unit	Data available or potentially available, with not specified unit of measurement; data with unit of measurement to be modified (e.g., due to scale adaptability)
Potentially yes	Data not directly available; data collection and measurement require extra operations to be finalized (math calculations)
No	Data not measurable in the initial stages of urban transformation (ex-ante); data measurable only through questionnaires; data not well defined (too general or incomprehensible); data not available at the urban project scale; poor utility of the data for the sustainability evaluation

Before moving to the next phase, we could not forget some further specifications relating to the main "reference" framework for sustainability indicators, that is the United Nations' 2030 Agenda. In order to deal with the increasing heterogeneity in the indicator systems, the fourth of The Bellagio Sustainability Assessment and Measurement Principles (BellagioSTAMP) [18, 19] on "Framework and Indicators" recalled the importance of consider "standardized measurement methods, wherever possible, in the interest of comparability". For this reason, two additional attributes were considered for the data classification (reaching a total of five attributes considered, see page 4):

4. The relevance of indicators to the Sustainable Development Goals (SDGs) of the UNs' 2030 Agenda;
5. The correspondence between indicators and the framework for the SDGs official statistical monitoring at the national level.

As regards the relevance of indicators to the SDGs of the UNs' 2030 Agenda, we detected all the potential connections between the collected indicators and the 17 SDGs. Each connection indicator-SDG has been counted as one link and, on the whole, the percentage of indicators tied to each SDG may be estimated.

The correspondence between indicators and the framework for the SDGs official statistical monitoring at the national level has been studied by analysing the similarity in: the phenomena measured by indicators, their measurement units, and their spatial scales of application. Respectively, three categories have been defined: "no connection" (in the case of no links found between the collected indicators and the ones of the official statistical framework for SDGs); "similar indicators" (in the case of similar phenomena monitored, but different measurement units); and "indicators to be downscaled" (if the measurement units are the same, but not the applied spatial scale).

The potential benefit of considering these additional attributes in the classification consists in the comparison of the collected measures with both (i) the globally defined SDGs and (ii) the frameworks for their official statistical monitoring. Since the statistical measures for the SDGs official monitoring are generally available at the national scale (i.e., the country level) and, only partially, at the local scale (i.e., the city level) [20], it would be interesting to verify their potential use or implementation at the urban scale.

Data Analysis. The third phase consisted in the synthetic description of the database main features, according to the attributes presented above. The results of this analysis are going to be widely illustrated in the Sect. 2.

Data Selection. At this point, in order to determine the appropriate type of measurements to be taken into consideration for the sustainability assessment of urban transformations, we expressed some preferences upon specific data attributes. In particular, these categories have been excluded to perform a first data selection: the non-feasibility of data collection, and the "unknown" type of data. Additionally, all the duplicated data (i.e., identical indicators traceable in multiple existing frameworks, or similar indicators aimed at measuring the same phenomenon) have been excluded from the database. The results of the data selection phase, as well as of the data analysis, are going to be shown in the following Section.

3 Results

The results of the present research are illustrated in this Section according to the four-step methodological approach: after a brief depiction of the data collection phase, a synthetic description of the database main features (i.e., the data analysis) is reported in accordance with the five attributes defined in the previous phase (i.e., the data classification); finally, similar analyses have been repeated for the selected indicators (i.e., after the data selection phase).

As previously mentioned, starting from the literature review of 99 publications (refer to [5]), 28 contributions have proven to be of interest in the collection of different set of indicators. In total, 661 indicators composed the initial rough database, with an average of 34,3 indicators per each evaluation framework analysed. Regarding the year of publication, the higher research production on this topic have been observed in the

period 2011–2015. By considering the geographic context of the reference revision of the literature, that concerns developed countries (as defined by the UNs' Report "World Economic Situation and Prospects 2023" [21]), the majority of studies came from the United Kingdom.

An interesting feature to report here, is the temporal phase of application of the analysed evaluation frameworks (see Fig. 2). Compared to the processes of urban planning and building realisation, they could be applied: ex-ante, in itinere, ex-post, in two-phases (i.e., ex-ante and in itinere, in itinere and ex-post), or in a dynamic way (if the monitoring activity is intended to be dynamically repeated throughout whole process).

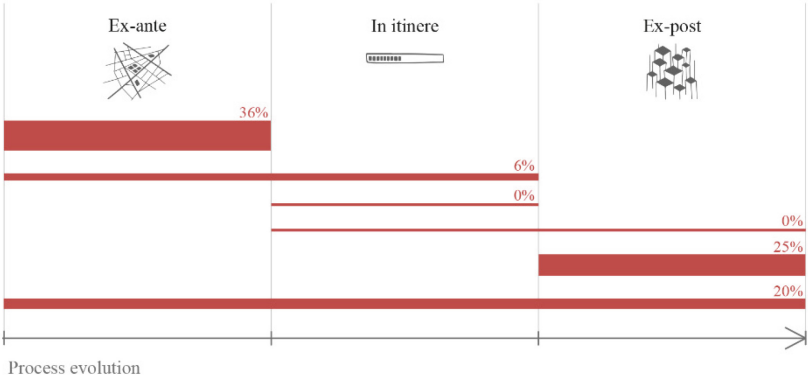

Fig. 2. The temporal phase of application of different indicators compared to the processes of urban planning and building realisation.

In the majority of cases, indicators are expected to be applied in the initial phases (around the 36% ex-ante) or in the final ones (around the 25% ex-post); and a smaller quantity (around the 20%) is designed to be adopted in a dynamic way. For the remaining 19% of indicators, this information was missing.

Data Analysis. As regards the results of the analysis, first of all, the main features of the 661 data collected are here reported in accordance with the sustainability dimensions and the quali-quantitative type of data (see Fig. 3).

The graph shows a great majority of social and environmental data (233 and 167 indicators respectively), compared to the others dimensions. However, such a high number of social indicators is justified by the presence (in the considered literature review) of studies specifically focused on measuring the social sustainability [22, 23] (that proposed 85 indicators in total). By considering the type of data, there are 147 total qualitative indicators, 165 quantitative indicators, and 349 unclassifiable or "unknown" data.

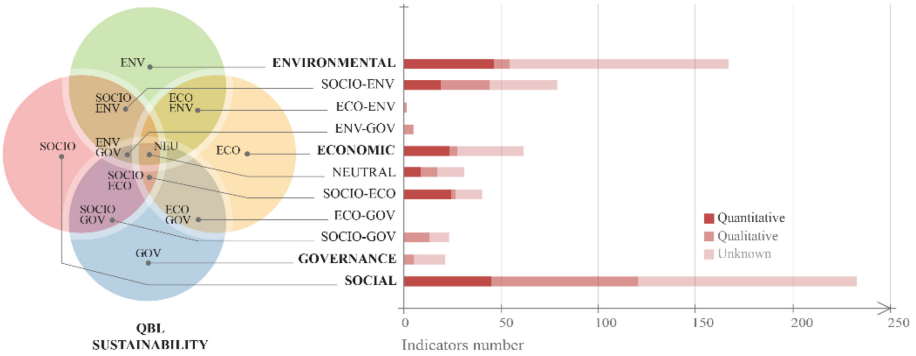

Fig. 3. The number of total indicators per each sustainability dimension and intra-dimension (according to the Quadruple Bottom Line – QBL), and per type of data (i.e., qualitative, quantitative or unknown).

Speaking about the feasibility of data collection, as a matter of fact, we predominantly considered the Italian local context of the present study. Results show that almost half of the indicators (306 out of 661) requires data that are not measurable, not available or useless for our scope (see Table 3).

Table 3. Number of feasible data to be collected

Feasibility	Number of indicators
Yes	102
Yes, redefining the measurement unit	214
Potentially yes	39
No	306

Data Selection. The exclusion of (i) the non-feasible data to be collected, the (ii) "unknown" type of data, and (iii) the duplicated data, has led to the selection of 134 indicators of synthesis. Figure 4 illustrates the same analysis proposed in Fig. 3, but performed only for the 134 selected indicators (please, play attention to the different interval scale on the horizontal axis). Results do not demonstrate relevant changes in the relative composition of sustainability dimensions (with the greatest classes represented by social and environmental indicators), and in the type of data (with 91 quantitative measures and 43 qualitative ones). In more details, the selected indicators per sustainability dimensions amount for: 43 social, 31 environmental, 11 economic, 4 governance, 22 socio-environmental, 9 socio-economic, 2 socio-governance, 5 env-governance, and 7 neutral (see the Appendix for the entire list of selected indicators).

Finally, the following Figs. 5 and 6 respectively illustrate the relevance of indicators to the SDGs of the UNs' 2030 Agenda, and their correspondence with the framework for the SDGs official statistical monitoring at the national level.

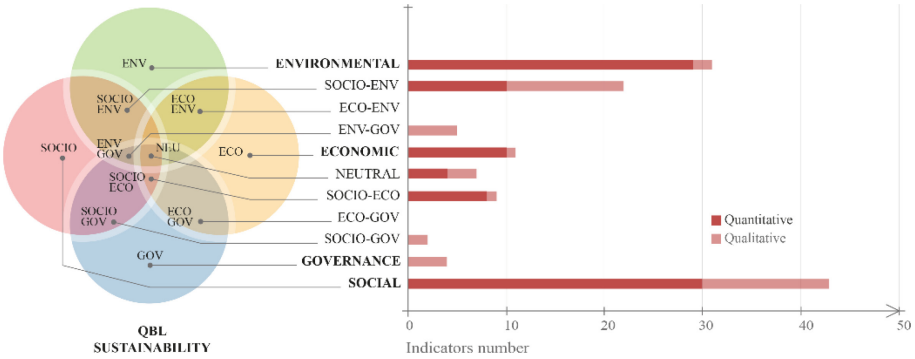

Fig. 4. The number of selected indicators per each sustainability dimension and intra-dimension (according to the Quadruple Bottom Line – QBL), and per type of data (i.e., qualitative or quantitative).

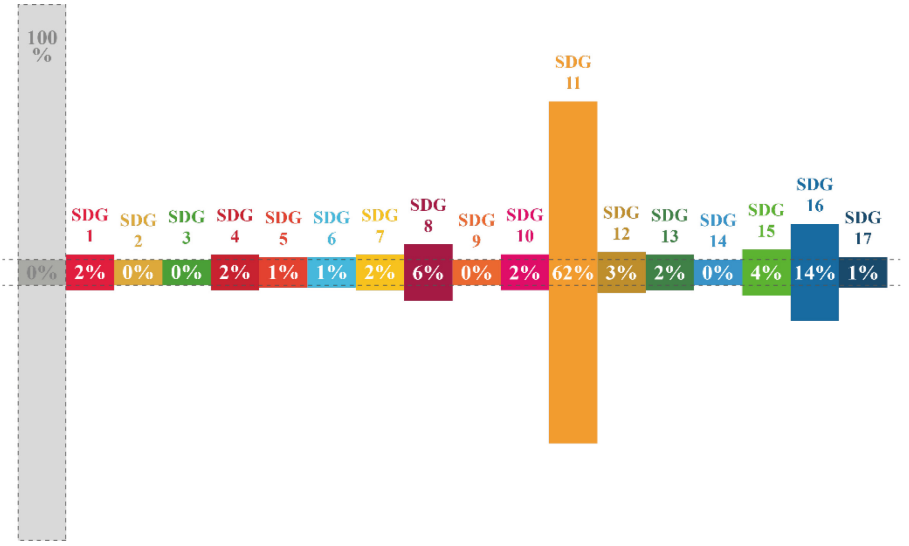

Fig. 5. The relevance of indicators to the SDGs of the UNs' 2030 Agenda (in percentage).

The potential connections identified between the 134 selected indicators and the 17 SDGs show: a predominant and high number of indicators linked to the SDG11 on "Sustainable cities and communities" (around the 62% of measures could be related or have an impact on this goal); at the second position, a relatively small amount of indicators tied to the SDG16 on "Peace, justice and strong institutions" (around the 14%); and a very small number of indicators connected to the others SDGs (less than the 6%).

As regard the official statistical frameworks for monitoring SDGs, they were initially defined by the United Nations Statistics Division (UNSTAT) at the international level, and were subsequently declined by different Member States' statistics institutes at the national level. Since the latter are based on the same foundations of UNSTAT, here we studied the correspondence with the official national framework in the context of the present study (i.e., Italy). As previously mentioned, the benefit would be to analyse the potential application of official statistical measures at the urban scale (currently absent). Therefore, we considered the ISTAT-SDGs official framework developed by the Italian Institute of Statistics (ISTAT) [24]. The results of the indicators' correspondence with the ISTAT-SDGs official framework are shown in Fig. 6.

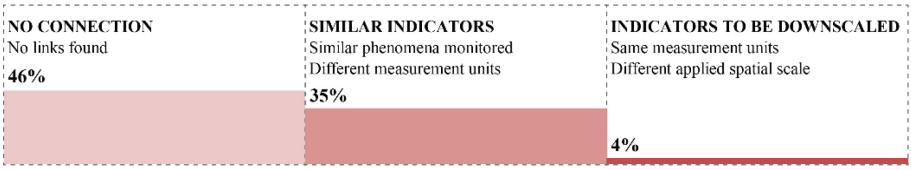

Fig. 6. The correspondence between indicators and the ISTAT-SDGs official framework of the Italian Institute of Statistic (in percentage).

The three observed categories (in Fig. 6) show a low presence of official ISTAT-SDGs indicators that could be used in place of the selected indicators, in order to monitor the selected phenomena (around the 46% of selected indicators has no connections with the ISTAT-SDGs framework). Similar ISTAT-SDGs indicators could be used for monitoring around the 35% of selected indicators; while the category "indicators to be downscaled" riches only the 4% of selected indicators. The Appendix reports the entire list of selected indicators with reference to the relevance to the UNs' SDGs, and to the correspondence with the ISTAT-SDGs statistical measures (when present).

4 Conclusions

The promotion of new urban planning and design tools can certainly be depicted as an essential instrument to support the sustainable transformation of our cities. However, the high level of fragmentation and complexity in the regulatory framework often leads to face operational difficulties in the planning practice. For this reason, the implementation of sustainability criteria and of holistic assessment procedures may support the decision-making process on urban projects.

In this contribution, we have proposed a general four-step methodology to collect, classify, analyse and select indicators, that aims at assessing the sustainability of urban transformations, and we have shown the main features of these measurement systems. Taking advantage of the previous literature review we have conducted on the topic of existing sustainability evaluation tools at the urban regeneration scale, 134 out of 661 indicators have been selected. The main attributes considered for the data classification (not to be intended as ordinated classes) and for the data analysis are: the sustainability dimension; the type of data; the feasibility of data collection; the relevance of indicators to the Sustainable Development Goals (SDGs) of the UNs' 2030 Agenda; and the correspondence between indicators and the framework for the SDGs official statistical monitoring at the national level.

In response to our initial questions, the results of our analysis have shown that:

- Sustainability dimensions are not equally monitored by the measurement systems proposed in the scientific literature, with a preponderance of environmental and social indicators;
- Quantitative data slightly exceed the qualitative ones in both the situations (before and after the selection of feasible indicators);
- A relative small amount of data could be directly linked to or substituted by official statistics already in use in the national context; however, it is important to encourage comparability of measures collected at the different scales also using redundancy.

Our contribution is far from being exhaustive, due to the fragmentation and numerosity of assessment frameworks and procedures already developed by the scientific community. Moreover, the present database does not include other frameworks developed by third parties, such as the numerous sustainability certification systems that mostly belong to the private sector (e.g., BREEM Communities, LEED Neighborhoods, CASBEE Urban Development, GREEN STAR Communities, DGNB Urban District, etc.). Nevertheless, the abundance of possible data to be considered to holistically assess the sustainability of urban projects, as well as the site-specific characteristics of places, decision-makers and their decision habits, lead us to focus on methodologies to explore this theme, rather than on specific and well defined tools.

Further prospectives on this topic will include a deepen reflection on the meaningfulness of inferences that potentially derived from the use of indicators and evaluation systems, and that can guide important decisions on urban development.

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

Appendix

(See Table 4)

Table 4. Selected indicators with reference to: the sustainability dimension, the relevance to the UNs' SDGs, and the correspondence with the ISTAT-SDGs statistical measures (see [24] for reference codes of metadata).

Sustainability Dimensions	Indicators (Measurement Units)	Relevance to the UNs' SDGs ISTAT-SDGs measures (if present)		
Environmental	Global warming potential (kgeqCO2/m^{2}CAy)	SDG 11	SDG 13 13.2.2.4	
Environmental	Average annual emissions of NO2 (μgNO2/m^3; mgNO2/m^3)	SDG 11 11.6.2.7	SDG 13 13.2.2.7	
Environmental	Acidification potential (kgeqSO2/m^{2}CAy)	SDG 13 13.2.2.6		
Environmental	Change in volume of storm water run-off post-development	SDG 11 11.3.1.1	SDG 15 15.3.1.1	
Environmental	Construction and demolition waste recycled (%)	SDG 12 12.5.1.5		
Environmental	Floor area ratio (m^2/m^2)	SDG 11 11.3.1.1		
Environmental	Green public areas (%)	SDG 11 11.7.1.1	SDG 15	
Environmental	Green surfaces (%)	SDG 11 11.7.1.1	SDG 15	
Environmental	Increase of mixed land uses (m^2/m^2)	SDG 11		
Environmental	Infiltration surface and stormwater use (%)	SDG 11 11.3.1.1		
Environmental	Harmonization with the context (qualitative scale)	SDG 11		
Environmental	Land devoted to roads (%)	SDG 11		
Environmental	Number of parking spaces (n. spaces)	SDG 11		
Environmental	Percent of building(s) shell and non-shell reused (%)	SDG 11		
Environmental	Permeable surface / Territorial surface (m^2/m^2)	SDG 11 11.3.1.1		
Environmental	Ratio of open spaces to built form (%)	SDG 11 11.7.1.1	SDG 15	
Environmental	Ratio of redeveloped buildings to new build (%)	SDG 11		

(*continued*)

Table 4. (*continued*)

Sustainability Dimensions	Indicators (Measurement Units)	Relevance to the UNs' SDGs ISTAT-SDGs measures (if present)		
Environmental	Reclamation of building materials (%)	SDG 12 12.5.1.5		
Environmental	Reclamation of contaminated land (%)	SDG 11	SDG 15	
Environmental	Residential car-parking provision (n. spaces)	SDG 11		
Environmental	Retention of environmental features (%)	SDG 11 11.3.1.1		
Environmental	Territorial index (m^3/m)	SDG 11 11.3.1.1		
Environmental	Waste production (kg; tons)	SDG 11 11.6.1.2	SDG 12 12.5.1.4	
Environmental	Waste disposal (%)	SDG 11 11.6.1.1	SDG 12 12.5.1.1	
Environmental	Urban gardens (m^2)	SDG 11 11.7.1.1	SDG 15	
Environmental	Working car-parking provision (n. spaces/m^2)	SDG 11		
Environmental	Energetic quality (qualitative scale)	SDG 7 7.2.1.2		
Environmental	Energy consumption (kWh/m^2; CO2/m^2)	SDG 7 7.2.1.1/7.2.1.2/ 7.2.1.5/7.3.1.4		
Environmental	Reduction in energy use	SDG 7 7.2.1.1/7.2.1.2/ 7.2.1.5/7.3.1.4		
Environmental	Per capita water use (l/inhabitant/day)	SDG 6 6.1.1.1		
Environmental	Reduction in water use	SDG 6 6.1.1.1		
Socio-Env	Acoustic emission (dBA)	SDG 11 11.1.1.3		
Socio-Env	Average distance to a public transport stop (m)	SDG 1 1.4.1.4	SDG 11 11.2.1.1	
Socio-Env	Quality of service in public transport (qualitative scale)	SDG 11		

(*continued*)

Table 4. (*continued*)

Sustainability Dimensions	Indicators (Measurement Units)	Relevance to the UNs' SDGs ISTAT-SDGs measures (if present)		
Socio-Env	Tying status with "soft" mobility networks (qualitative scale)	SDG 11		
Socio-Env	Street layout: integration with existing streets, paths and surrounding development (qualitative scale)	SDG 11		
Socio-Env	Street layout: friendly streets for pedestrian, cycle and vehicle (qualitative scale)	SDG 11		
Socio-Env	Street layout: support to people with limited physical mobility (qualitative scale)	SDG 4 4.a.1.1	SDG 10	SDG 11
Socio-Env	Integration of land use and public transport (qualitative scale)	SDG 11		
Socio-Env	Work travelling habits (qualitative scale)	SDG 11 11.2.1.2/11.2.1.3		
Socio-Env	Leisure travelling habits (qualitative scale)	SDG 11 11.2.1.5		
Socio-Env	Average emissions of noise during the day (dBA)	SDG 11 11.1.1.3		
Socio-Env	Average emissions of noise during the night (dBA)	SDG 11 11.1.1.3		
Socio-Env	Car sharing / Bike sharing (n. car/bike sharing points)	SDG 11		
Socio-Env	Degree of prevention of light emissions (qualitative scale)	SDG 7	SDG 11	
Socio-Env	Conservation of built heritage resources (%)	SDG 11		
Socio-Env	Quality of outdoor spaces (qualitative scale)	SDG 11		
Socio-Env	Community space (qualitative scale)	SDG 11		
Socio-Env	Enhancement of cultural heritage (qualitative scale)	SDG 11		
Socio-Env	Land dedicated to pedestrians (%)	SDG 11		
Socio-Env	Occupancy levels (%)	SDG 11		

(*continued*)

Table 4. (*continued*)

Sustainability Dimensions	Indicators (Measurement Units)	Relevance to the UNs' SDGs ISTAT-SDGs measures (if present)		
Socio-Env	Public transport links (m)	SDG 11 11.2.1.1/11.2.1.4		
Socio-Env	Slow mobility (m^2)	SDG 11		
Social	Access to aggregation spaces (qualitative scale)	SDG 11	SDG 16 16.6.2.3	
Social	Access to cultural facilities (min)	SDG 11	SDG 16 16.6.2.3	
Social	Access to educational needs (min)	SDG 11	SDG 16 16.6.2.3	
Social	Access to leisure and entertainment facilities (min)	SDG 11	SDG 16 16.6.2.3	
Social	Access to medical facilities (min)	SDG 11	SDG 16 16.6.2.3	
Social	Access to open space (min)	SDG 11	SDG 16 16.6.2.3	
Social	Access to retail facilities (min)	SDG 11	SDG 16 16.6.2.3	
Social	Accessibility and public transport (qualitative scale)	SDG 1 1.4.1.4	SDG 11 11.2.1.1	SDG 16 16.6.2.3
Social	Affordable housing as percent of total residential stock (%)	SDG 1 1.4.1.1	SDG 11	
Social	Average distance to a commercial zone (m)	SDG 11	SDG 16 16.6.2.3	
Social	Average distance to a cultural centre (m)	SDG 11	SDG 16 16.6.2.3	
Social	Average distance to a high school (m)	SDG 11	SDG 16 16.6.2.3	
Social	Average distance to a junior high/middle school (m)	SDG 11	SDG 16 16.6.2.3	
Social	Average distance to a kindergarten (m)	SDG 11	SDG 16 16.6.2.3	
Social	Average distance to a nursery (m)	SDG 11	SDG 16 16.6.2.3	
Social	Average distance to a public park (m)	SDG 11	SDG 16 16.6.2.3	

(*continued*)

Table 4. (*continued*)

Sustainability Dimensions	Indicators (Measurement Units)	Relevance to the UNs' SDGs ISTAT-SDGs measures (if present)		
Social	Average distance to a recreational green/natural area (m)	SDG 11 11.7.1.1	SDG 16 16.6.2.3	
Social	Universal access (qualitative scale)	SDG 4 4.a.1.1	SDG 10	SDG 11
Social	Average distance to a sport centre (m)	SDG 11	SDG 16 16.6.2.3	
Social	Average distance to an elementary school (m)	SDG 11	SDG 16 16.6.2.3	
Social	Buffer and common space (qualitative scale)	SDG 11		
Social	Co-housing inhabitants (n. residents)	SDG 11		
Social	Co-working spaces ($mm^2$2)	SDG 8		
Social	Increase of accessibility to urban functions (n. functions within a distance; n. served residents)	SDG 11	SDG 16 16.6.2.3	
Social	Number of uses of green space (n. uses)	SDG 11		
Social	Number of uses of the site (n. uses)	SDG 11		
Social	Percent of occupants with views to outside (%)	SDG 11 11.1.1.1		
Social	Retail facilities located on site (qualitative scale)	SDG 11	SDG 16 16.6.2.3	
Social	Public / Private spaces (m^2/m^2)	SDG 11		
Social	Residential areas (m^2)	SDG 11		
Social	Residential development (%)	SDG 11		
Social	Retail areas (m^2)	SDG 11		
Social	Functional mix (qualitative scale)	SDG 11		
Social	Social mixing (qualitative scale)	SDG 11		
Social	Social attractiveness (qualitative scale)	SDG 11		
Social	Diversity (qualitative scale)	SDG 1 1.2.2.1/1.2.2.2	SDG 10	SDG 11
Social	Acceptability to stakeholders (%)	SDG 11	SDG 17	
Social	Degree of security (qualitative scale)	SDG 5	SDG 11	SDG 16 16.1.4.1

(*continued*)

Table 4. (*continued*)

Sustainability Dimensions	Indicators (Measurement Units)	Relevance to the UNs' SDGs ISTAT-SDGs measures (if present)		
Social	Resilience (qualitative scale)	SDG 11		
Social	Services for the population (m^2)	SDG 11		
Social	Sport and leisure areas (m^2)	SDG 11		
Social	Walking distance to green space (min)	SDG 11 11.7.1.1	SDG 16 16.6.2.3	
Social	Art and culture (qualitative scale)	SDG 4		
Socio-Eco	Net employment density (job/ha)	SDG 8		
Socio-Eco	New jobs (n. new jobs)	SDG 8		
Socio-Eco	Number of jobs created per 1000 square meters (n. jobs/1000m^2)	SDG 8		
Socio-Eco	Number of new enterprises created (n. new enterprises)	SDG 8		
Socio-Eco	Net jobs created (%)	SDG 8		
Socio-Eco	Number of new enterprises created (%)	SDG 8		
Socio-Eco	Quality of jobs created (%)	SDG 8		
Socio-Eco	Incorporation of training programmes (qualitative scale)	SDG 4 4.3.1.1	SDG 8	
Socio-Eco	Knowledge-based economy (n. jobs)			
Economic	Construction cost (euro/m^2)			
Economic	Investment cost (euro)			
Economic	Investment cost (euro/m^2)			
Economic	Level of occupancy (%)			
Economic	Annual operating costs (euro/m^2)			
Economic	Maintenance cost (qualitative scale)			
Economic	Percent increase in site property value (%)			
Economic	Internal rate of return			
Economic	Total economic value (euro)			
Economic	Rent premium (i.e., vs. comparable site)			
Economic	Gross rental yield (%)			

(*continued*)

Table 4. (*continued*)

Sustainability Dimensions	Indicators (Measurement Units)	Relevance to the UNs' SDGs ISTAT-SDGs measures (if present)		
Governance	Degree of access to information (qualitative scale)			
Governance	Degree of collaboration of professionals (qualitative scale)	SDG 11	SDG 17	
Governance	Degree of integration of an evaluation process (qualitative scale)			
Governance	Consistency with constraints (qualitative scale)			
Socio-Gov	Active community organizations (qualitative scale)	SDG 11		
Socio-Gov	Degree of participation of population (qualitative scale)	SDG 11		
Env-Gov	Logic of project footprint (qualitative scale)	SDG 11		
Env-Gov	Degree of residual contamination (qualitative scale)	SDG 11		
Env-Gov	Management of construction disturbances (qualitative scale)	SDG 11		
Env-Gov	Degree of ecosystem considerations (qualitative scale)	SDG 11 11.4.1.1	SDG 15	
Env-Gov	Management of construction waste (qualitative scale)	SDG 12 12.5.1.5		
Neutral	Flexibility (qualitative scale)	SDG 11		
Neutral	Transformability index (qualitative scale)	SDG 11		
Neutral	Degree of site remediation (qualitative scale)	SDG 11		
Neutral	Net population density (inhabitants/ha; inhabitants/m^2)	SDG 11		
Neutral	Reduction of seismic risk exposure (inhabitants/inhabitants)	SDG 11 11.1.1.1	SDG 13 13.1.1.11	
Neutral	Regeneration (m^2/m^2)	SDG 11		
Neutral	Population retention (n. population)			

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Supporting Sustainability: The Case Study of the Abruzzo Regional Sustainable Development Strategy

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Abstract. The concept of sustainable development, catalyzed by global initiatives such as the Millennium Development Goals and the 2030 Agenda's sustainable development goals (SDGs), has reshaped international cultural, political, and social thinking. Recognizing the pivotal role of subnational entities in achieving these goals, there is an increasing emphasis on aligning sustainability objectives with local strategies and actions.

In Italy, the National Strategy for Sustainable Development (NSSD) entails a concerted effort to coordinate national and local initiatives, promoting collaboration across governmental and non-governmental sectors. Nevertheless, one of the main challenges is still the integration of sustainable development principles into regional and provincial planning processes. This study focuses on the analytical and programmatic steps that supported the integration of sustainable development objectives into the Abruzzo regional sustainable development strategy (RSSD). Through projects resulting from different agreements between the Abruzzo region and the Department of Civil, Construction-Architectural and Environmental Engineering (DICEAA) of the University of L'Aquila, a series of tools and guidelines have been developed. Specifically, the main outcomes of the "Review of the system of regional indicators in the context of the implementation of regional strategies for sustainable development" and the "Sustainability, Resilience, adaptation for the protection of ecosystems and physical reconstruction in Central Italy" (Sost.EN.&Re) projects have been deepened.

The result is a regional strategy for sustainable development enriched by the most recent approaches and methodologies in the field of sustainable planning.

Keywords: Sustainable development · Regional strategy for sustainable development · Sustainable planning

1 Introduction

Starting from the'80 (Brundtland report), the sustainable development concept has increasingly affected global cultural, political, and social thinking [1, 2].

The widespread awareness about inequalities, limited resources, and vulnerability of political, economic, and social systems found full application in one of the most important

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international organizations: the United Nations (UN). From this organization, at the beginning of the XXI century, the millennium development goals (MDGs) have been proposed [3]. The MDGs represent 8 points through which address policies of developing countries, to reach security, prosperity, and equality by 2015 [4]. Nevertheless, they didn't find full application in the states' agendas, due to the weak will and the poor resources to implement them [5].

A new drive came in 2015, with the 2030 Agenda. Through this document, the UN member states committed to taking a series of steps to "shift the world to a sustainable and resilient path" by 2030 [6].

To lead the member states through the sustainable development concept, 17 sustainable development goals (SDGs) have been proposed. Together with the SDGs, a set of 169 targets has been provided [7].

In the 2030 Agenda's SDGs, the path traced to reach sustainable development strongly relies on the concept of nature protection and enhancement, brought to the attention of global policies. This goal, first expressed in the MDG 7 "Ensure environmental sustainability", has then been further explored and articulated in the 2030 agenda's SDGs 13 "climate action", 14 "life below water" and 15 "life on land" [8].

Today the objectives set by the MDGs and then by the 2030 agenda can be achieved only through local and regional governments [9, 10]. At the same time, to be achieved, sustainability goals must be translated into actions that take place on a small to medium scale [11].

To be aligned, local government levels must be able to rely on commonly defined procedures and tools, capable of quantifying and monitoring land dynamics. The latter originate within municipal boundaries, although their effects involve multiple local administrations [12].

In Italy, the SDGs have become the objectives upon which the Italian National Strategy for Sustainable Development (NSSD) has been set up. The latter represents an action program to promote the national economic, social, and environmental spheres. Specifically, the strategy coordinates national and local initiatives, promoting collaborations between governmental and non-governmental bodies, and between companies and citizens [13].

The NSSD also envisages the adoption of the regional and provincial strategies for sustainable development (RSSD and PSSD respectively) within 12 months of the approval of the national strategy. Nevertheless, regional sustainable development strategies are still not fully implemented into regional and provincial planning, with a lack of fundamental SDGs-derived concepts [14].

The present contribution traces the steps (analytical and programmatic) that allowed the concept of protection and enhancement of natural capital to converge into the Abruzzo regional sustainable development strategy (RSSD). Through the establishment of national and regional tenders and projects, it has been possible to define, for the Abruzzo region (central Italy), a series of tools that have later converged into the RSSD structure.

Specifically, the "Review of the system of regional indicators in the context of the implementation of regional strategies for sustainable development" and the "Sustainability, Resilience, adaptation for the protection of ecosystems and physical reconstruction in Central Italy" (Sost.EN.&Re) projects have been deepened.

From the Review of the system of regional indicators, a set of indicators to evaluate the correspondence between regional planning and the SDGs has been realized.

The Sost.EN.&Re focused on the realization of the so-called "Planning Tool Mosaic" (PTM) and the ecological network, providing some guidelines useful for implementing them at a regional scale. Together with them, a console of indicators for monitoring the sustainability of transformations has been provided.

All these products have converged into the Abruzzo regional sustainable development strategy (RSSD), deepened in the last section (Fig. 1).

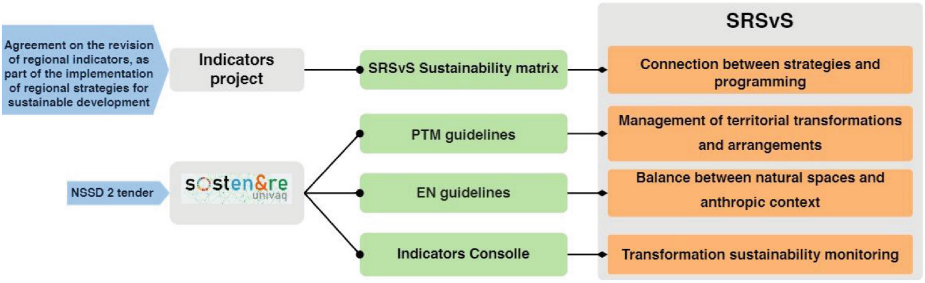

Fig. 1. Agreement, tenders, and project workflow

The paper is structured as follows: Sect. 2 delves the conditions of the study area, providing information about the regional territory. Section 3 sets out the "Review of the system of regional indicators in the context of the implementation of regional strategies for sustainable development" project. Its main product is the so-called Indicators database. Section 4 details the Sost.EN.&Re project, its main objectives, and operational points. Section 5 discusses the operational aspects of the instruments described above, as part of the regional strategy for sustainable development. Section 6 concludes the contribution by exploring the next steps for the full implementation of the Abruzzo regional strategy for sustainable development.

2 Study Area

The Abruzzo region, in central Italy, extends for over 10000 Km^2. It is one of the Italian regions with the highest percentage of protected areas (35.8% of the terrestrial areas and 1.36% of the marine areas) (Fig. 2) [15]. Its history is strictly associated with the protection of the natural environment since the institution of one of the first two national protected areas in 1922: the Abruzzo, Lazio and Molise National Park [16]. After this, several other protected areas were established, reaching the current configuration with a total of 58 protected sites, with an extension of 390,493 hectares.

Nevertheless, the achievement of the objectives set by the 2030 Agenda could not be reached due to the isolation that has characterized these areas over time. In Abruzzo, land consumption shows no signs of decreasing [17]. Furthermore, transformative dynamics driven by private interests do not help to manage problems whose scale of interest goes beyond local borders, which can define fragmentation of the natural matrix [18].

The result is a territorial framework lacking the technologies and information necessary to support a regional strategy capable of defining common methods for achieving sustainability objectives.

Added to this are the most recent calamitous events that have affected central Italy, defining the need for a development paradigm restructuring, directed towards the themes of reconstruction, resilience, and adaptation [19].

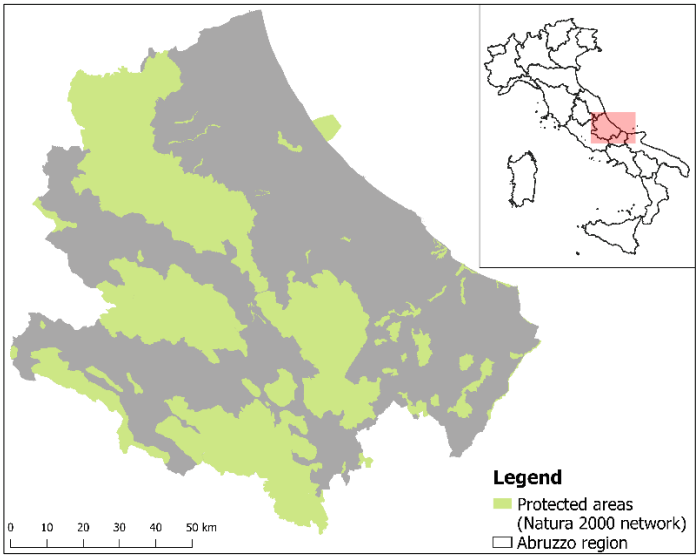

Fig. 2. Study area

3 The "Review of the System of Regional Indicators in the Context of the Implementation of Regional Strategies for Sustainable Development" Project

The systematic use of indicators in the field of environmental and social policies is becoming more and more frequent. Nevertheless, in over half a century of Italian urban and territorial planning, there is still scarce availability of procedures for measuring, monitoring, and analyzing the effects of the various operational tools [20].

Simultaneously, the transformed and potentially transformable territorial matrix must be considered as a priority. Here, land planning can lead to a worsening of the natural conditions [21].

Furthermore, the continuous reference to the 11th and 15th SDGs entails the necessity to face new environmental challenges, through an integrated approach between ecosystem functions, the associated services, and urban resilience [8]. Being the SDGs based on universally recognized principles, it is fundamental to decline regional planning drives, defining the scopes of sustainable planning.

In this regard, the collaboration agreement between the Abruzzo region and The Department of Civil Engineering, construction, architecture, and Environment (DICEAA) of the University of L'Aquila set up the preliminary activities, necessary to fulfill the realization of the regional strategy for sustainable development.

Specifically, the DICEAA undertook to produce the positioning of the regional planning tools concerning the NSSD goals and the 2030 agenda's SDGs.

The correspondence between the SDGs and the regional planning tools has been evaluated through a regional sustainability matrix. The latter identified the links between regional planning and programming, regional investment plans, and the forecasts envisaged by the NSSD.

Contextually, a survey of sustainability indicators already in use by various public and/or private entities nationwide has been undertaken. In this phase, indicators have been retrieved on Italian institutional websites such as ISTAT (National Institute of Statistics) (https://www.istat.it/) and ISPRA (Italian Institute for Environmental Protection and Research) (https://www.isprambiente.gov.it/it).

The reconnaissance process to identify the set of regional indicators started from the parameters already used in the monitoring process. Specifically, the following sectoral tools have been considered:

- Regional landscape plan;
- Flood risk management plan;
- Basin excerpt plan for the hydrogeological structure;
- Flood defense excerpt plan;
- Regional reference framework;
- State maritime plan;
- Coastal defense plan;
- Water protection plan;
- Regional mining activities plan;
- Regional Plan for the Protection of Air Quality;
- Regional integrated waste management plan;
- Regional energy plan;
- Regional hunting fauna plan;
- Gran Sasso and Monti della Laga National Park plan;
- Majella National Park plan;
- Abruzzo, Lazio and Molise National Park plan.

In this phase, through a matrix of coherence, the convergence between the objectives of the regional plans and those of the 2030 Agenda and the NSSD has been verified.

Subsequently, to build the directory of indicators, attention has been focused on the ones coming from the ISTAT and ISPRA institutes, as well as on the indicators retrieved on the websites of private foundations or sector projects, between various public and private bodies (Fig. 3).

The sets of indicators from non-institutional sources that have been used in the subsequent phase of implementation of the RSSD comprehend:

- The Italian Sustainable Development Index, developed by the SusDeF Foundation (Sustainable Development Foundation), is based on environmental indicators relating to impacts – positive or negative – in terms of emissions, consumption of raw materials, etc., according to the Environmental Footprint approach) (https://www.fondazionesvilupposostenibile.org/)
- Indicators on sustainability policies: the 101 municipal indicators identified by the Italian Local Autonomies (ALI) League (https://aliautonomie.it/)
- Indicators on urban regeneration, identified by the Association of Abandoned Urban Areas (AUDIS) (http://audis.it/home)
- Indicators on urban metabolism, consumption of matter and energy, etc., also concerning the fragmentation/compactness/shape/disposition of the urban system, analyzed in the European Project SUME – Sustainable Urban Metabolism for Europe, FP7/2007–2013.

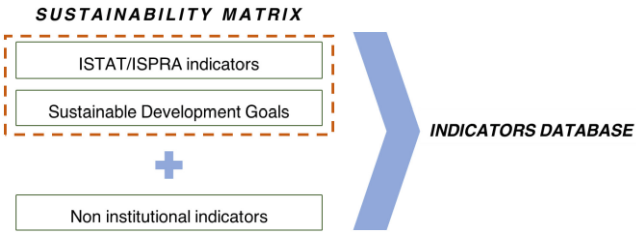

Fig. 3. Indicators database workflow. Through a sustainability matrix, the correspondence between institutional indicators and the sustainable development Goals has been deepened. The next phase of database construction envisaged the implementation of the institutional indicators with the ones coming from private foundations or sector projects.

The research set up 55 indicators linked to the sustainable development goals.

The database will be a useful tool to support local authorities align their plans and programs to the sustainability objectives set by the NSSD and the 2030 Agenda.

As part of the above-mentioned preliminary actions for the implementation of the RSSD, the proposed set of indicators represents a first dynamic and updatable outline of the needs of regional planning, concerning the adaptation to the NSSD. If needed, it will be possible to expand the indicators offer, after a consultation with the competent authorities. The procedure structured through this collaboration allowed to dispose of a tool under which regional planning can update itself, concerning these fundamental themes with an acceptable commitment.

Shortly, the necessary step must be a review of the indicators aimed at defining them not only on a regional basis but also referring to other territorial scales.

4 The Sost.EN.&Re Project

To fulfill the objectives set by the 2030 Agenda, in 2019 the Ministry of the Environment (MITE) promoted the so-called "NSSD2" tender, equal to 3,000,000 euros [22]. The latter has funded 26 projects, divided into two categories:

Category 1: Projects to support the RSSD and PSSD development and implementation. The proposals supported the development of technical contents for the definition of regional and provincial strategies; the development of scientific contributions to support and enhance sustainable development strategies; and the scientific dissemination of the definition and implementation processes.

Category 2: Projects on priority themes for the implementation of the NSSD.

The "Sustainability, Resilience, adaptation for the protection of ecosystems and physical reconstruction in Central Italy" (Sost.EN.&Re) project fits into the first category of the tender issued by MITE, to promote and implement in the Abruzzo region the subsequent SDGs [23]:

- 11 "Make cities and human settlements inclusive, safe, resilient, and sustainable."
- 15 "Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss"

The object of formulating a series of guidelines to support the processes for the regional implementation of the National Strategy for Sustainable Development (NSSD) has been articulated into three key points:

1. Drafting of a Technical Mosaicking Protocol for municipal urban planning tools (planning tool mosaic guidelines).
2. Development of a methodology for the inclusion of the Ecological Network (EN) in regional legislation and criteria for evaluating the ecosystem occlusion of infrastructures (ecological network guidelines).
3. Development of a console of indicators for monitoring the sustainability of transformations.

The division into three main operational points arises from the awareness that sustainable development can only be achieved by considering all the actors, synergies, and trade-offs that act on territorial dynamics [24]. A holistic approach requires an analytical panel that characterizes both settlement dynamics and pressures on the environmental system [25, 26]. Such knowledge is fundamental to achieving a structural connection of the portions of territory, each characterized according to its contribution.

4.1 Planning Tool Mosaic Guidelines

A Sustainable development strategy, in addition to focusing its attention on the connections between protected areas, must investigate the forms and dynamics of planning, capable of defining fragmentation and isolation conditions [18]. Here, the interactions between the socio-ecological spheres, the protection of biodiversity, and the associated

ecological functions play a key role in defining the dynamics between a more densely anthropized environment and the areas belonging to the EN [24].

In a country like Italy, where the highest levels of planning have had only rare opportunities to condition decisions at lower levels, there has been an almost total autonomy of municipalities. The latter autonomously manage local transformations, without superordinate strategic control [27]. The consequence is a condition in which each of the 7896 municipalities transforms its territory, without having adequate awareness of what is happening (or is expected) in the neighboring territories [28]. It is also impossible to understand what will happen on the territory, in the geographical dimension that transcends the single municipality. Furthermore, many Italian municipalities have planning tools approved several years ago. Here, the forecasts have been sized based on social and economic evidence, certainly different from today [29].

These conditions do not favor the adoption of measures aimed at improving environmental and urban quality, whose implementation must take place in the upper planning levels and at scales that go beyond municipal boundaries [28].

At the same time, several objectives of the territorial sphere, such as the zero-land take by 2050, or the decrease of anthropogenic pressure in protected areas, now require adequate levels of knowledge. It is necessary to allow potential transformation trajectories to be traced both geographically and in quantitative terms [26]. By doing this, it will be possible to develop appropriate policies to contain potential negative effects.

To support the enhancement of such conditions, the Sost.EN.&Re project established a technical device called the "Planning Tools Mosaic" (PTM). The PTM is a standardized and homogeneous framework for municipal planning tools contents (i.e. the zoning, the related legends, and the technical standards that define urban planning loads) [27]. It consists of digitalization and attribute table population operations in GIS environment. Following the guidelines provided by the Sost.EN.&Re project, the information to be put into the single municipal planning tool are: i) Name of the municipality, ii) National municipal ID code, iii) type of planning tool, iv) the year since which the tool is in force, v) zonal typology related to the single area (polygon), iv) technical implementation standards, which defines the in force standards for each zone. Subsequently, in the "zoning" column a standardization of the zoning, referring to the ministerial decree 1444/68 [30], has been realized (Fig. 4). The presence of the original zoning allows to deepen the actions envisaged by the single municipality. Simultaneously, the standardized zoning classes allow to properly compare different municipalities, disposing of a regional, standardized database.

This kind of system is easily implementable and provides not only error reporting but also the corrective actions to be applied. This different approach would have numerous advantages in the medium and long term, but it is resource-intensive in the initial stages, requiring training courses for technical staff. Once fully operational, the platform will enable the pursuit of planning effectiveness and flexibility, with notable simplifications such as reducing the number of procedures and decreasing the time required for instrument approval procedures [31].

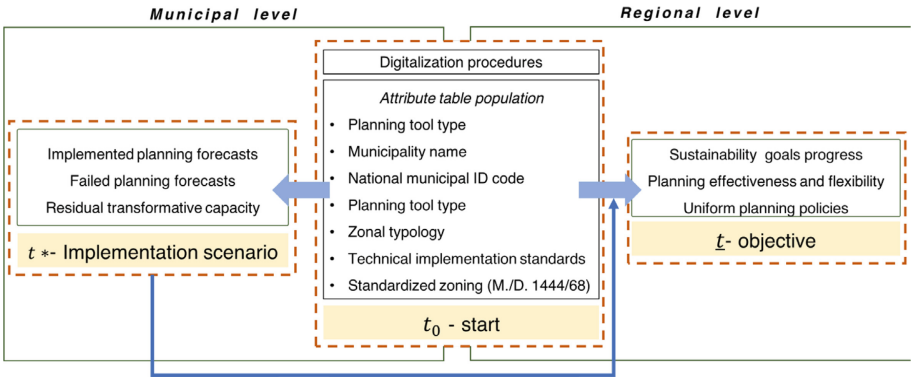

Fig. 4. Planning tool mosaic workflow. The digitalization procedure is the core of this tool. The information to be put in this phase will be functional to make the single planning tool comparable and updatable. Through this tool, it will be possible to compare different territorial scopes (municipalities), as well as to quantitatively assess failed, residual, and implemented planning forecasts.

4.2 Ecological Network Guidelines

During the nineties, Ecological Networks (EN) began to establish in Europe as a central topic of environmental policies. One of the first important initiatives has been the EECONET program (1990) (The European Ecological Network)[32]. EECONET aimed to promote the valorization of biodiversity through the implementation of a European ecological network, to guide the evolution of protected and rural areas policies [33]. In 1996 the European Council promoted the Pan-European Biological and Landscape Diversity Strategy (PEBLDS) [34], to implement the convention of biological diversity (CBD) [35]. A PEBLDS key element was the development of the Pan European Ecological Network (PEEN), which is composed of central areas, corridors and buffer areas, and, where necessary, restoration areas. The PEEN was articulated into three projects, corresponding to central-eastern, southeastern, and western Europe [36, 37].

In Italy, a fundamental contribution to the ecological networks came from the National Ecological Network Project (REN) [38]. The objective of the REN was to locate a network, based on the national areas with different priorities of conservation. The REN also paid specific attention to the connections between protected areas (PAs), to minimize habitat fragmentation [39].

From these projects, the common take-home message is that the EN tool must be projected towards a scenario that allows the protection of key areas, to support and maintain high biodiversity values and the connection between PAs.

Today it is necessary to extend the "classic" theories through which ENs are set up. It is necessary to consider the role that ENs have in improving the conditions of natural capital and ecosystem functions. Specifically, the latter must be protected and enhanced beyond the protected areas and large parks boundaries [40]. For this reason, new EN models cannot disregard the detailed knowledge of the drivers involved in land transformation, which produce and nourish environmental fragmentation [41]. Within the path towards sustainable development, it is necessary to maintain the conditions

that allow biodiversity evolution. To achieve this objective, it is important to ensure the physical and spatial connection between protected areas, which otherwise would be isolated by the outside land dynamics [18].

In this regard, the Sost.EN.&Re project has developed the guidelines for regional EN implementation. Specifically, an evaluation criterion for ecosystem occlusion of infrastructures has been proposed. It is well known that the road infrastructure network can involve a large part of the territory, interacting with the environmental system [42].

Between protected areas, passages that connect different habitats need to be managed with structural interventions. For this reason, the preliminary phase of recognition of large road infrastructures, such as motorways and railways, is fundamental. These elements are to be considered the Main Infrastructural Barriers (BIPs), whose characteristics define landscape fragmentation. Indeed, the highway roadway, together with the railway tracks, often sets a total physical occlusion of the habitat continuity. This is due to the continuous side fences, whose presence is aimed at preventing the casual or intentional entry of people and animals [43].

In these cases, habitat connectivity subsists only when the motorway or railway passes through a tunnel or viaduct. For this reason, their location and survey constitute a fundamental step since the early stages of the definition of potential ecological corridors.

At the same time, the BIPs reveal the limits of the "regional macro-districts". The latter represent the functional areas that must necessarily be connected, to fulfill conservation policies.

After identifying priority gaps, the ecosystem occlusion profile (PdO) tool quantifies the impact of infrastructures on ecosystem integrity. The PdO is a diagram that analyzes the degree of interference set by the road along its longitudinal axis [44]. It consists of considering the extent and type of the obstacles that are present both left and right of the roadway (retaining walls, networks, new road dividers jersey, guardrails etc.). Subsequently, it is evaluated the possibility of overcoming the obstacles by appropriately selected species (Fig. 5).

This procedure constitutes a valid method for obtaining information on the permeability of an area crossed by an infrastructure. It provides usable data on a large scale, indicating which are the areas of maximum probability of wildlife passage. On a detailed scale, it is useful to indicate whether and where the infrastructure can be crossed.

The above-mentioned procedure refers to the Road Ecology discipline [45]. Road Ecology analyzes the interaction between organisms, the environment, roads, and vehicles. It explores the relationships between the natural environment and the infrastructural network, seeking solutions that can be applied in the design phase of roads, motorways, and railways, or aimed at mitigating the effects of the already present ones.

Together with a "snapshot" of the actual criticalities set by infrastructures and local planning tools, it is necessary to qualitatively and quantitatively describe urban settlements and the dynamics to which they are subject and which they nourish [26]. This aspect has been deepened in the last output of the Sost.EN.&Re project, the indicators console.

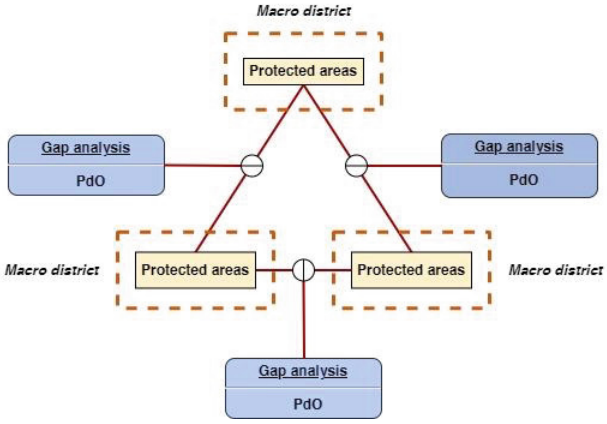

Fig. 5. Ecological network structure. The macro districts, defined by the fragmenting capacity of the infrastructural network, are connected through the so-called "priority gaps". The latter, through the PdO tool, will be deepened, according to the necessary actions to maintain and enhance such connections.

4.3 Indicators Console

Municipal planning tools define different types of intervention on the territory, based on local political and popular will. Without the possibility to quantify the consequences on the territory in the short and long term, local planning tools would lack a real strategic vision.

The indicators engineering can be defined as the operation of designing sets of indicators capable of capturing and describing any changes in land use, assuring interoperability and transparency of information [26].

It can provide wide support to enhance the descriptive capacity of land dynamics. Today various indices are being used both to model settlements and to describe the demographic-environmental conditions that the latter experience and nurture [25, 26].

To monitor the sustainability of transformations, the Sost.EN.&Re project envisaged the creation of a console of indicators.

The indicators console has been set up starting from several experiences that took place in the last decades across the entire national territory, and more limited geographical areas [25, 26]. The parameters listed vary from the simplest and most consolidated ones to more complex indexes concerning the pressure/interference of settlement on the territory and ecosystems. The console contains two macro-categories of indicators:

Settlement Model and Dynamics Indicators: These indicators can provide a summary framework of the settlement system.

Settlement Pressure on Environmental Systems Indicators: These indicators concern settlement pressure/interference on land and ecosystems (e.g., indices of fragmentation and insularity).

The console has been structured to provide key information about the type of indicator, and the scale of application. To support indicators adoption further information about the data and the sources required to calculate them has been realized.

For each parameter, information about the type of indicator (the above-mentioned macro categories), its adherence to the DPSIR (Drivers, Pressure, State, Impact, Response) model, the spatial dimension in which it can be applied (regional, municipal, etc.), and the source of the data necessary to populate it have been considered (Fig. 6).

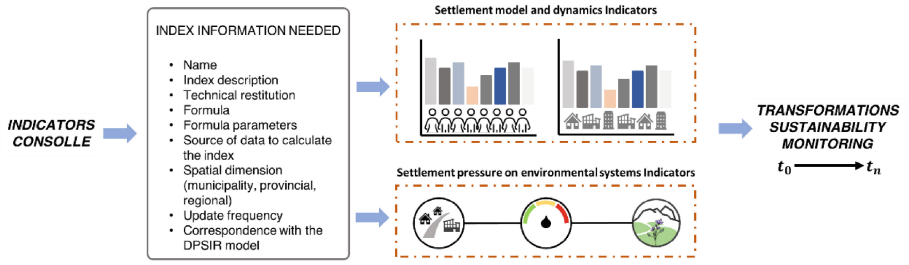

Fig. 6. Indicators console workflow. To put the single indicator into the console several information are needed. Subsequently indicators will be inserted either in the "settlement ond dynamics indicators" or in the "Settlement pressure on environmental systems indicators" classes.

If put together, the settlement model and dynamics Indicators can provide a framework of the settlement system, concerning the implementation of the urbanized territory's current planning. Similarly, simultaneously considering several "settlement pressure on environmental systems" indicators will provide a framework of the current configurations, whose effects could potentially lead to environmental fragmentation and PAs insularization.

Both these categories of indicators can be jointly used to monitor changes in land dynamics in a certain time frame, considering the initial measures as the reference status, and comparing their changes in values during a timeframe.

5 Discussions

The RSSD represents the implementing tool that defines the regional framework for land planning, and environmental evaluation processes. At the same time, the document must ensure coherence with the NSSD and the 2030 Agenda SDGs.

Based on the "abruzzo prossimo" document [46], the RSSD identifies the following specific objectives:

1. Structure a guideline for the integration of the SDGs of the 2030 Agenda into the regional policies, plans, and projects.
2. Increase the resilience of territories regarding extreme events or disasters, focusing on prevention strategies.

3. Guarantee guidance, evaluation, monitoring, and control in decision-making by subordinate entities, and promote the sharing of experiences and technical-scientific information on environmental assessment.
4. Implement, within an organic strategy, regional initiatives to achieve ongoing SDGs.
5. Promote sustainability by facilitating the participation of relevant authorities and the public in the decision-making process.

From an organizational standpoint, in December 2018, the Abruzzo Region signed a Collaboration Agreement with the MATTM (now Ministry of the Environment and Energy Security - MASE) for the definition of the RSSD [47]. The RSSD has seen the establishment of a steering committee, to coordinate activities among the administrative entities involved. Various collaborations have emerged among administration institutes (Regions, Municipalities, etc.), the Environmental Education Centers (CEA), and the University of L'Aquila (Department of Civil, Construction-Architectural and Environmental Engineering - DICEAA).

The first version of the RSSD has been approved in October 2021 [47]. A second Collaboration Agreement with MATTM was signed in April 2020, and the final RSSD was published with [48]. A second Collaboration Agreement with MATTM was signed in April 2020 [49], and the final RSSD was published with [48].

From the review of the system of regional indicators, the recognition of several institutional indicators, and the development of a sustainability matrix allowed the establishment of a multi-level linkage and alignment between Regional Planning, Investment Programs, and National and Regional Strategies. This activity has been later enriched also by non-institutional indicators, to provide the RSSD with a set of indicators useful for evaluating the sustainability of regional planning with the SDGs of the 2030 Agenda.

By doing this, the RSSD will be able to compare its local-scale objectives with those in the sustainability matrix, updating its planning/programming according to the SDGs. This will enable stakeholders to verify the consistency between the 2030 Agendas' SGDs and the regional strategies, as well as the identification of indicators useful for monitoring the actions related to these objectives. Both the matrix and the indicators are dynamic and updatable, according to the needs of regional planning. It will be possible to expand the console of indicators through revision phases and according to the authorities' needs. To maximize interoperability with other territorial and administrative institutes, ISTAT and ISPRA datasets have been used, since the early stages of the Regional Strategy.

From the PTM, the standardization of local planning tools contributes to creating shared knowledge about the potential for territorial transformation. Through the PTM it will be possible to gain an evolving perspective of land dynamics, overcoming the current opacity that characterizes local planning. This will also allow potential interventions through awareness-building, participation, and monitoring actions [27]. Finally, the synthesis into the macro-categories defined by the ministerial decree 1444/68 allows high effective comparability among different municipalities. The zonal standardization further supports the common assessment of local planning tools, highlighting any unrealized transformation, whose effects could potentially lead to increased supra-municipal pressure on environmental systems.

The major challenge in adopting this approach lies in the outdated methods for storing and utilizing information at the local authority level (municipalities). Although GIS

systems can help reduce archiving costs, simultaneously increasing analysis potential, these actions must be preceded by training of the public administration personnel [31, 50]. This aspect should not be underestimated. Indeed, due to its initial costs and difficulties, the reluctance to switch to more effective tools with potentially more complex methodologies could hinder their adoption [51].

In addition, planning forecasts could also potentially lead to environmental fragmentation and the isolation of ecologically sensitive areas [52].

The structure of an effective ecological network, aimed at protecting and improving environmental quality, is therefore based on the interconnection of high ecological value areas.

In this regard, the EN guidelines proposed in the Sost.EN.&Re project aimed to introduce, operationalize, and adopt an interdisciplinary approach that considers pressures and threats resulting from the presence of infrastructures and settlements.

Here, the integration of the ecological network into the regional strategy represents an essential and binding element in driving future sustainable development [53].

6 Conclusions

The proposed tools extend conservation practices on the connections between protected areas. The methodology has been developed to define an effective ecological network, focusing on the corridors considered essential for maintaining habitat continuity [36]. Protecting these corridors will be the responsibility of local authorities, preserving the natural value of the areas involved and improving the conditions of the ecological network [54].

Nevertheless, an assessment of the current situation is not sufficient to ensure high levels of sustainability in the long term. The application of indicator engineering techniques to spatial planning and governance is crucial not only to achieve sustainability goals but also to monitor transformations [55].

In this sense, the proposed console of indicators inside the Sost.EN.&Re project must be considered an investment for the administration. To have significant results, indicators must be able to generate prevailing trends for an adequate period [56].

Finally, the reference set must be sufficiently large to allow an efficient control of the phenomena.

Thanks to the ability to build realistic scenarios and projections of planning policies with the indicators console, it will be possible to verify their alignment with local development needs [57]. It will be also possible to compare planning policies with the historical trends of the main transformation drivers, as well as to assess their potential deviation from superordinate sustainability policies.

In conclusion, the Regional Sustainable Development Strategy for Abruzzo can today dispose of a series of tools useful for Public Administrations, to integrate sustainability principles into their policies, with particular attention to the themes of ecosystem connectivity, and the efficiency and sustainability of territorial transformation processes.

Future actions from the Abruzzo region will need to be aimed at putting in action all the proposed tools, as well as administratively introducing the necessary changes into regional and local planning.

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Enhancing Vulture's Territorial Assets Through Tourism Ecosystems for Spatial Development

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Abstract. Tourism is acknowledged as a pivotal sector for fostering the promotion and development of territorial assets supported by European and national policies. Nevertheless, it is fundamental to address pressing concerns pertaining to the management of local resources and institutional capacity for strategic planning to ensure sustainable success in the long-term perspective. Effective monitoring, adaptation, and collaboration play crucial roles in mitigating these challenges and attaining the envisioned goals of the strategy. However, the organization and management of the territorial capitals currently lack a clear definition, exacerbated by a fragmented approach. In the territorial planning process, determining the implications of tourism-based actions remains a challenge in the debate. This study contributes to structure and implement tourist ecosystems through the application of a structured theoretical model at the local level and the introduction of principles inherit smart tourism management in the tourism value chain. The analytical part of the research focuses on spatial identification of the components that structure the complex tourist ecosystem, follows the discussion of the structural matrix of the system, traceable in a case study as result, and finally the principles of smart planning opens to the future perspective of the research. Through the experimentation of this approach, the research aims to critically reassess the role of tourism in public investment decisions and offer innovative directions for planning in the European industrial strategy.

Keywords: Tourism ecosystems · Sustainability · Strategic planning

1 Introduction

The tourism ecosystem [1, 2] represents a general concept underlying the complex structure linking territorial features, cultural and natural values, private and public operators and citizens in defining the tourism phenomena intended as a component of territorial strategic assets. Relevant instance to innovate tourism planning and governance

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as a component of sustainable development policies focusses in the current debate on a dual transition towards becoming a greener and more digitized industry in order to enhance ecosystem resilience and accomplish the objectives outlined by the Green Deal [3] and the EU digital decade. The Commission advocates for a bottom-up approach [4–6], involving stakeholders in the co-creation [7, 8] of a transition pathway for the sector. Despite the efforts by public bodies and operators' network to promote sustainable tourism [9, 10], there remains a fragmented framework for developing effective and sustainable strategies within the context of territorial development. This fragmentation hampers the exchange of information, comparison of approaches, and sharing of insights within the tourism industry. With sustainability as its central focus, the proposed approach study serves as a support for bolstering territorial planning development.

Henceforth, the formulation of sustainable development strategies, aligning with the overarching objectives of the Green Deal, necessitates recognition of the values inherent within a local context. Building upon these initial observations, a concrete strategic vision for territorial development emerges, emphasizing the reinforcement of territorial systems intertwined with cultural dimension.

Digital technologies serve as pivotal tools to enhance existing planning methodologies within a broader, more influential framework.

The local tourism sector can experience substantial benefits through the implementation of smart tourism initiatives. These initiatives encompass integrating online booking systems for accommodations, tours, and activities to streamline the planning process for tourists and enhance revenue generation for local businesses. Additionally, the implementation of digital initiatives aimed at promoting cultural and natural heritage, such as virtual tours, augmented reality experiences, and interactive exhibitions, can further enhance visitor experiences. Moreover, the introduction of sustainable tourism practices serves to minimize the environmental impact of tourism activities while supporting initiatives focused on conserving natural resources and protecting biodiversity.

The work is structured in 3 section: the first, introduce the taxonomy presented in the analytical framework serves to structure the analysis of the area, facilitating a systematic assessment of its components and dynamics; the second, rely on the application of the theoretical and analytical framework aimed at identifying specialized tourism ecosystems, which is a component of the pilot research project conducted by Gatto and Scorza [11]. The proposed case study entails an examination of the specialized adventure tourism system in the Vulture area of the Basilicata region. These territorial assets play a pivotal role in regional development policies pertaining to the revitalization of rural inland areas.

The third section suggests the key components of smart tourism, which are instrumental in incentivizing the digital transition of the industry in the selected areas.

2 The Concept of a Tourism Ecosystem

The tourism ecosystem functions as a network comprising stakeholders, services, and attractions associated with the tourism sector within a local territorial asset. Identifying this ecosystem through its various components and understanding their interconnections serves as a valuable tool for supporting territorial planning, with an increasing emphasis

on sustainability [2, 12–16]. This methodology lays the groundwork for identifying dynamic systems applicable across diverse contexts, structured in two integrated steps. First, by employing a clear taxonomy derived from a literature review, and second, by spatially identifying the components of the micro/macro tourism system [2, 17].

To comprehensively examine potential gaps and overlaps within data sources, a detailed taxonomy has been developed. Taxonomies, in general, depict a hierarchical structure of classes or types of objects within a knowledge domain, utilizing controlled vocabulary to facilitate the retrieval of related information. The primary objective of the developed taxonomy is to unveil connections between data sources, illuminating the expansion of categories and identifying potential gaps that require attention. The role of the taxonomy is to precisely categorize entities into specific classes. The proposed taxonomy is grounded in three main ontological classes:

– "Specialized Tourism Destination Area" (D): It embodies a concentration or cluster of specialized attractions, services, including accommodation, restaurants, and culinary offerings, as well as accessibility factors.
– "Specialized Tourism System" (TS): The concept of a Specialized Tourism System, within the framework of spatial territorial analysis, refers to the spatial identification of one or more specialized destination areas where is dominant a category of tourism.
– "Tourism Ecosystem" (ES): "*A tourist ecosystem is defined as a network of interrelated and interdependent nodes that characterize one or more tourist destinations area providing benefits in a territorial development scenario.*"

  Protagonists of the cluster at the basis of the cooperation and coordination of territorial areas include tour operators, SMEs, institutional stakeholders of the local population and in general of the actors involved in sectors of the tourism dimension.

3 Key Components of Smart Tourism

Smart tourism, which leverages technology to enhance tourism experiences and destination management, is evolving rapidly. To understand the benefits of integrating new technologies in tourism, we analyze its key components:

– digitization for improved accessibility of sites: initially, smart tourism focused on digitizing tourism services and improving connectivity through platforms and applications, with the development of tourism websites, mobile apps and QR codes for easy access to information. As smart tourism progressed, so did the collection and analysis of data to personalize experiences and improve decision-making, predicting tourism trends and optimizing resource allocation, to the integration of emerging technologies such as AI, IoT, AR/VR and blockchain for intelligent destination management and monitoring, and new immersive cultural experiences and virtual tours.
– sustainability for resilience and risk management: with growing concerns about environmental impact, smart tourism is increasingly focusing on sustainability and responsible practices with the promotion of environmentally friendly transport options, implementation of measures to mitigate over tourism with destination diversification. Resilience and risk management have become an integral part of smart tourism strategies, with real-time monitoring and early warning systems.

– community engagement and co-creation for heritage enhancement: the increasing emphasis on involving local communities and tourists in the co-creation of tourism experiences encourages community participation in tourism planning and development, with the implementation of platforms to share feedback and contribute to destination improvement and the facilitation of cultural exchange and immersive experiences through community-based tourism initiatives.

The evolution of smart tourism involves moving from basic digitisation to a more holistic approach that integrates advanced technologies, sustainability practices, community engagement and resilience planning. By focusing on these strategic keys, destinations can adapt and thrive in a changing tourism landscape, such as in Vulture - Alto Bradano.

4 Vulture - Alto Bradano, a Relevant Case Study

The area under study is part of the Vulture-Alto Bradano territory in Basilicata Region (Italy). Specifically the route runs through the area of the municipalities of Barile, Rionero in Vulture, Atella and Filiano. These municipalities are part of the Vulture Regional Natural Park, a protected natural area established in November 2017 that covers a total of 57 496 hectares. The area is characterized by diverse landscapes and rich biodiversity, alternating between mountains and hills, flowering meadows and rivers, lakes and dense forests. The main attractions of the area are Mount Vulture, Mount S. Michele, the Abbey of San Michele Arcangelo and the Monticchio Lakes.

The taxonomy proposed in the analytical framework structures the analysis of the area. It emerged that the accessibility sector (15%) appears weaker compared to the attractions (39%) and services (46%) sectors, which are more or less balanced. From stakeholder and SWOT analyses, it is evident that the natural, scenic, and cultural potential provided by the Vulture area contrasts with the lack of valorization of the territory itself. Additionally, it presents an organized system of protected areas (Natura 2000 Network), excellent quality-to-price ratio of local services, and a local tourist identity. Under the lens of the downscaling of the New Urban Agenda (NUA) [18–21] key sustainability dimensions were extracted. The second phase rely in the design of action for strategic tourism planning based on two categories. The result is a territorial intervention plan comparable with other running projects of the same study-area highlighting the alternative perspective for sustainable development centered on residents' and tourists' well-being.

In the next figure it represented the analytical territorial interpretation, based on a site specific identification of the tourism ecosystem including attractors, services and accessibility nodes. It is the results of the methodological approach proposed by Gatto et al. [1, 2] as a result of a wider research funded by Italian Ministry "Tech 4 you".

The result is a comprehensive design based on site-specific features mapped and analyzed in a systemic perspective. Additionally, it could represent a way to generate a territorial strategic design based on a specialized tourism offer describing a territorial tourism system. The opportunity to discuss and to co-design with local actors this preliminary scheme will realize in practice the tourism ecosystem according to our

methodology. Such perspective represents the next stage of the research and a way to realize an inclusive territorial design process (Fig. 1).

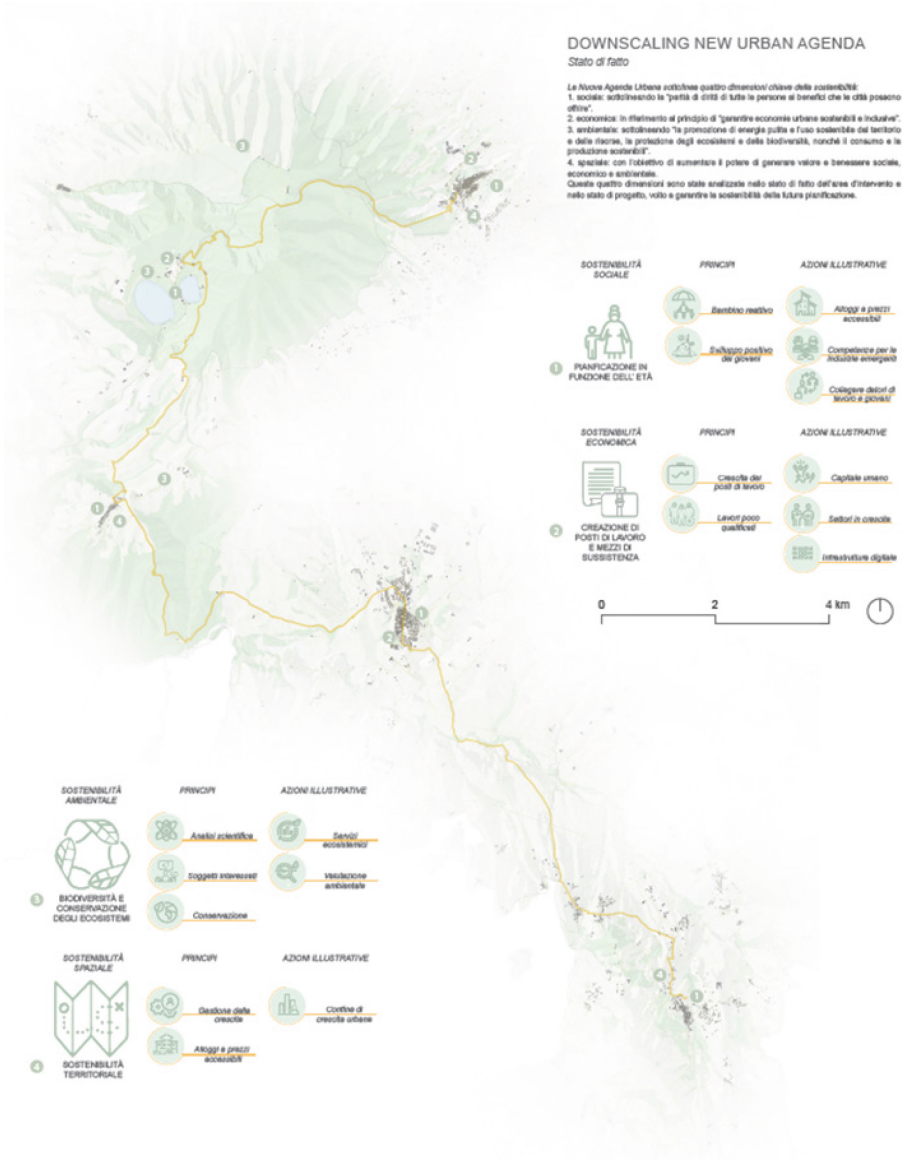

Fig. 1. Evaluation of the tourism system through the principles of the new urban agenda and identification of actions along the identified trekking route.

5 Conclusions

The proposed approach, grounded in the "tourism ecosystem" framework, serves as a facilitative platform to underpin tourism policies and guide multi-stakeholder decision-making processes in the planning of public investments for tourism development, with a focus on achieving greater effectiveness and sustainability. Despite the prevailing narrative within current regional development programs [22–24], which advocate for the development of inland areas through tourism by proposing new public investments in territorial attractions, facilities, and services, there remains a need for a more comprehensive assessment of local tourism ecosystems. Such an assessment could bolster both the quality of territorial planning and the efficacy of income generation derived from local tourism chains.

Concerning the specific case study, it is possible to underline that for the identified trekking route, it integrates the system of natural and cultural attractions, developing greater sensitivity to the issue of environmental sustainability with project actions that deal with:

1. Regeneration and design of thematic routes
2. Design of hotspots (flexible in uses) and free campsites.
3. Regeneration and enhancement of existing natural and cultural attractions.
4. Creation of new types of free services and enhancement of existing services.
5. New modes of sustainable mobility in strategic locations.

The recent implementation of the national policy, known as the "Borghi-call by Italian Ministry of Culture," illustrates this concept vividly. This policy allocates significant investments (20 million euros per project) to targeted competitive initiatives, which are evaluated through a robust impact monitoring matrix. The findings from the selected case study demonstrate how a tourism ecosystem approach can yield more targeted impacts with relatively minor public investments. This initial conclusion serves as a catalyst for broader discussions on the pivotal role of tourism in driving local development universally, regardless of specific structural features inherent to particular locations. It underscores a fundamental concern within planning disciplines, highlighting the potential benefits of adopting the proposed structured approach as a Decision Support System for future mainstream policies and programs.

By implementing these smart tourism initiatives, Vulture Alto Bradano can improve its competitiveness as a tourist destination, enhance visitor satisfaction and contribute to sustainable economic development while preserving its cultural and natural heritage. Promoting partnerships with local communities, businesses and stakeholders ensures that economic benefits are distributed fairly, without neglecting the safety and well-being of tourists and residents.

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"Ecomuseo dell'Acqua": An Indivisible Unit of Strategic Sustainable Planning

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Abstract. The paper introduces an experimental approach aimed at delineating strategies for urban regeneration with a focus on nature-based leisure, recreational, and outdoor activities within the framework of downscaling the New Urban Agenda 2030. The objective of this research project is to develop and implement practical tools for applying the principles outlined in the New Urban Agenda (NUA) within diverse territorial components. These components encompass not only anthropic elements, such as urban infrastructure and built environments, but also natural elements, including ecological systems and landscapes. This approach is pivotal in guiding the programming and execution of the sustainable project proposals, which is deeply rooted in addressing the specific needs of the locality and its residents. A core emphasis of the project lies in ensuring equitable access for all individuals, considering factors such as proximity to populated areas, availability of parking, clearly identifiable access points, and accessible restroom facilities during the selection of project areas. Furthermore, the design of these routes aims to offer diverse options in terms of length and accessibility. Ultimately, the project seeks to generate public value and potential benefits for the local community. This comprehensive approach strives to harmonize efforts towards heritage conservation, enhancement, and effective management, all while ensuring the appropriate allocation and investment of public resources.

1 Introduction

The New Urban Agenda (NUA) [1, 2] represents a widely embraced framework that has fostered the development of fresh agreements among various stakeholder groups engaged in urban planning and territorial management. Linked with global sustainability objectives, the NUA has engendered a novel form of commitment in public decision-making [3]. Described by the United Nations as a global pledge to advance sustainable urban development, the NUA aims to cultivate inclusive, safe, resilient, and sustainable cities and human settlements. It deals with tackling global challenges by fostering local innovations in urban management practices. While there exists no comprehensive conceptualization on how to downscale NUA principles and objectives, recent research

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indicates that sustainable development design demands additional and varied tools. A study conducted exemplified the efficacy of an approach in adapting NUA principles and laid the groundwork for devising new tools to bolster the emerging generation of territorial technicians, particularly engineers and architects [3–9]. It provides a framework for guiding policies and programs aimed at fostering sustainable growth in cities and human settlements worldwide. Within this comprehensive agenda, several key dimensions of sustainability (Fig. 1) have been highlighted, each playing a crucial role in shaping the urban landscape of tomorrow.



Fig. 1. Key dimensions of sustainability from NUA Handbook

One significant dimension addressed in the NUA social sustainability is "*Planning for migrants, ethnic minorities and persons with disabilities*" (Table 1). This dimension underscores the importance of ensuring that urban spaces and infrastructure are designed to be inclusive and accessible for all members of society, regardless of their physical abilities. By prioritizing accessibility in urban planning and design, cities can create environments that empower individuals with disabilities to fully participate in and contribute to community life.

Table 1. Social sustainability | selected components from NUA Handbook

Planning for migrants, ethnic minorities and persons with disabilities		
Principles	Universal design	*"Accessible and disability-inclusive urban planning is "universal design" and can be realized everywhere"*
Illustrative actions	Transit equity	*"Plan for transit equity for marginalized groups and especially persons with disabilities."*

Another crucial aspect emphasized in the NUA is "Job creation and livelihoods" Sustainable urban development involves not only the physical transformation of cities but also the promotion of economic opportunities for residents. By fostering entrepreneurship, supporting small businesses, and investing in job training and skills development,

cities can create vibrant and resilient economies that benefit all members of society (Table 2).

Table 2. Economic sustainability | selected components from NUA Handbook

Job creation and livelihoods		
Principles	Policy design	*"A sound economic development strategy includes stakeholders in policy design."*
Illustrative actions	Growth sectors	*"To create new jobs, link with other "growth" sectors such as infrastructure, renewable energy, education, and so on."*

Biodiversity and ecosystem conservation are also key considerations within the NUA. As urban areas expand, preserving natural habitats and green spaces becomes increasingly important for maintaining biodiversity, mitigating climate change, and enhancing the overall quality of life for urban residents. By incorporating green infrastructure, such as parks, wetlands, and green roofs, cities can promote ecological resilience and provide valuable ecosystem services to their inhabitants (Table 3).

Table 3. Environmental sustainability | selected components from NUA Handbook

Biodiversity and ecosystem conservation		
Principles	Conservation	*"Conserve natural areas and assets providing critical ecosystem services through land management and landuse planning."*
Illustrative actions	Incentives	*"Develop incentives for stakeholders to comply with biodiversity & ecosystem preservation goals."*

While the objectives outlined above identify the dimensions, principles, and actions related to sustainable development, the means of implementation (Fig. 2) are the tools, techniques, and specific actions that cities and urban actors can use at national, supranational, and local levels to achieve these objectives.

Culture and health are two soft macro-measure highlighted in the NUA for urban development. Recognizing the importance of cultural heritage and identity, as well as promoting health and well-being, is essential for creating livable and resilient cities. By supporting cultural initiatives, preserving historic sites, and providing access to healthcare services, cities can nurture vibrant and healthy communities where people can thrive.

Transportation and mobility are critical components of sustainable urban development addressed in the NUA. By promoting sustainable modes of transportation, such as walking, cycling, and public transit, cities can reduce greenhouse gas emissions, alleviate traffic congestion, and improve air quality. Investing in efficient and accessible



Fig. 2. Means of implementation from NUA Handbook

transportation systems can enhance mobility for all residents while reducing reliance on private cars and fossil fuels.

In conclusion, the NUA offers a comprehensive framework for addressing the multi-faceted challenges of urbanization and advancing sustainable development in cities and human settlements worldwide. By focusing on key dimensions such as accessibility, economic opportunity, biodiversity conservation, transportation, culture, and health, cities can chart a course towards a more equitable, resilient, and sustainable future. "While the objectives outlined above identify the dimensions, principles, and actions related to sustainable development, the means of implementation are the tools, techniques, and specific actions that cities and urban actors can use at national, supranational, and local levels to achieve these objectives".

The following sections showcase a case of local downscaled selected components.

The analysis of the Val D'Agri Park context, in Basilicata, provides an opportunity to highlight the variables of sustainable strategic design according to the principles and means described. Section 2 highlights the choice of the future intervention path through an analysis of elements that depict territorial dynamics related to accessibility and environmental characteristics. Section three introduces the means of implementation and knowledge at the local scale for defining an eco-museum. The final part discusses and concludes the research themes, highlighting the critical aspects and future developments of the study.

2 Accessibility is a Necessary Prerequisite for Usability

The contribution focuses on trails and itineraries primarily of a naturalistic nature where recreational activities can be carried out, allowing people to interact with nature.

The proposed project starts from the premise that it is necessary to optimize and plan interventions in the realization of itineraries so that they can serve as connecting elements between territorial components (both natural and human-made). The approach strategy is crucial in the planning and implementation of an idea, upon which a specific design process must be based. The idea arises from the need to interpret the needs of a place

and its citizens, integrating and bringing together technological design with traditional design.

The premise for the realization of a project involving trails and their related recreational areas is to ensure free access for everyone, taking into account the necessary accessibility features [10–12]. The requirements considered in the identification of the route and the areas subject to design can be distinguished into intrinsic, which are identified among the contextual characteristics, and extrinsic, which are identified among the specific qualities of the intervention area.

The extrinsic requirements are listed as follows:

- Proximity to inhabited centres, easily accessible scattered houses;
- Presence, near points of easy access, of parking lots with spaces reserved for holders of disabled parking permits;
- Presence of connecting paths to public services and public use structures, accessible to anyone's needs;
- Presence of equipped areas, appropriately sized and furnished, located near the route in question;
- Presence of informative points providing precise indications on the routes to follow and visit, aiming to guide users based on their physical abilities, energy levels, and personal needs.

The intrinsic requirements are listed as follows:

- Recognizable and identifiable access points;
- Morphological features of the trails, regarding the forms that make up the terrain relief (elevation changes and slopes), the length of the route, and the level of difficulty (tourist or hiking itinerary);
- Landscape quality (natural, semi-natural, and anthropic) and its physical and material, immaterial, and perceptual components, specific to the intervention area and encountered along the route (e.g., wooded areas, peculiar geographical features, hydrographic networks, springs, historical-cultural points of interest);
- Components of the cultural heritage (e.g., tree elements of particular naturalistic and/or testimonial value, crops of remarkable landscape and environmental value, historical and/or archaeological settlements, historical-cultural points of interest);
- Furnishing elements (fixed or movable artefacts) contributing to enhancing the usability and quality of the area in question, valorising the territory and considering the needs of the citizens (e.g., fountains, benches, waste containers, public lighting systems).

3 Place's Identity and Collective Needs

The design actions stem from the analysis and interpretive evaluation of a place, its physical identity, and its vocation. The proposed eco-museum described below is based on this premise. The pilot case has been identified within the trails located within the National Park of the Lucanian Apennines Val d'Agri Lagonegrese [13, 14], whose perimeter encompasses some of the highest peaks of the Lucanian Apennines. The Park was established by Presidential Decree on December 8, 2007. It is located in the southwest of the Basilicata region, covering an area of 68,996 hectares and including 29 municipalities in the province of Potenza.

"*The preservation of natural and environmental values as well as historical, cultural, and traditional anthropological values entrusted to the Park Authority is pursued through the instrument of the Park Plan* [15]*."*

In particular, not only must the general organization of the territory, constraints, and land use designations be regulated, but also "c) vehicular and pedestrian accessibility systems with particular attention to routes, accesses, and facilities reserved for disabled individuals, handicapped individuals, and the elderly; d) equipment and services systems for the management and social function of the park, museums, visitor centers, information offices, camping areas, agro-tourism activities; e) guidelines and criteria for interventions on flora, fauna, and the natural environment in general." The symbiosis between humans and the environment, a distinctive characteristic of the Park, represents an opportunity for the promotion of sustainable and lasting development initiatives, in harmony with the territory's vocation and the needs of the community. The set mission, within the scope of the design choice, is represented by the realization of an ecomuseum, whose concept goes beyond the traditional idea of a museum.

"*The Ecomuseum is a participatory practice for the enhancement of material and immaterial cultural heritage, developed and elaborated by an organized subject, expression of a local community, in the perspective of sustainable development. (carta di Catania)"* Its essential components are: the reference territory, the population, the real supporter and advocate of the project, and the heritage, the set of components that communities recognize, protect, and promote.

The ecomuseum proposal aims to identify, rediscover, enhance, and reconnect naturalistic routes and contextual areas. With this proposal, the intention is to safeguard and make recognizable the system of paths and the values of the reference territory in relation to those expressed by the communities [16].

Specifically, reference is made to a system of paths identified and named "Water Ecomuseum," for the territorial specification described below. The northern part of the Park territory is crossed by watercourses with an Ionian outfall, including the initial stretch of the Basento river and one of its tributaries, the Rifreddo stream. In the central part flows the middle-upper stretch of the Agri river, where several streams Cavolo, Alli, Maglia, Trigella, and Raganello converge. To these is added the artificial reservoir of Pertusillo in the municipality of Spinoso and the reservoir of Marsico Nuovo, the institutional seat of the Park.

The components included in the ecomuseum territory are: landscape assets (including geological singularities, monumental trees, viewpoints accessible to the public, from which one can enjoy the spectacle of panoramic beauties), arable lands, open spaces and their detectable biotopes, rivers, streams, watercourses, territories covered by forests and woods, wetlands, monuments, and places of interest. The complex of cultural resources present in the area of interest and the reference areas are connected through a specific fruition path.

The system of paths identified and implementable over time meets the extrinsic and intrinsic requirements previously outlined (Fig. 3). The design actions are represented along the path by episodic and consequential elements. The enhancement of the path system and the design of the reference areas are planned, with different purposes and objectives, but all part of a single design system. The participation of the population in

its development is allowed through various means of expression, essentially based on the reality of the places. The idea, therefore, of designing an ecomuseum system of paths, is inherent in the new way of conceiving the territory and the populations that own and enjoy its assets.

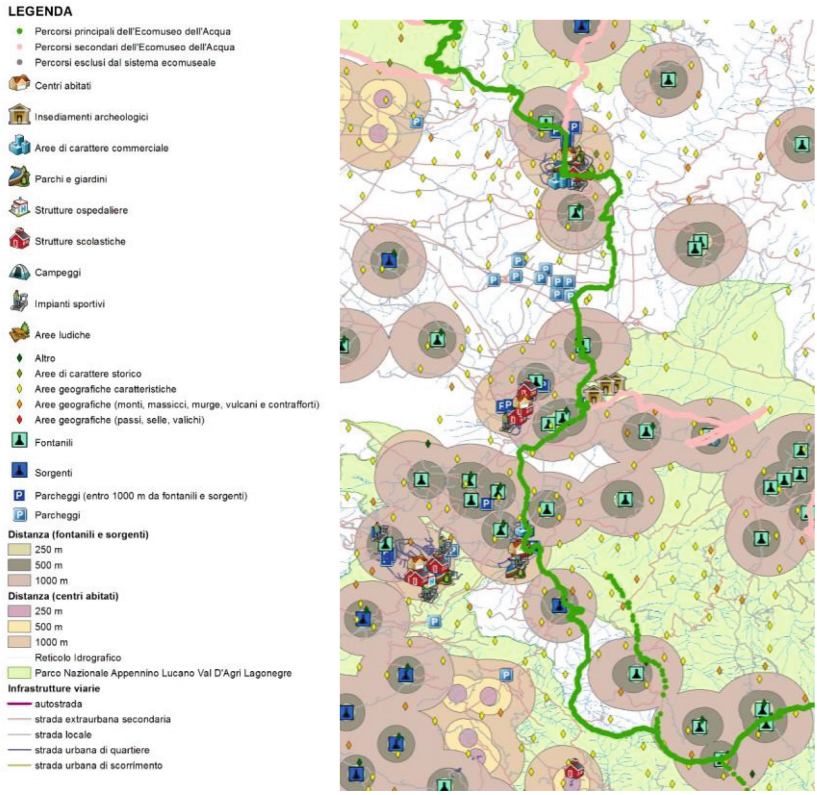

Fig. 3. The system of paths identified and implementable over time meets the extrinsic and intrinsic requirements previously outlined.

4 Discussion and Conclusions

The article explores a new experimental method aimed at developing strategies to revitalize natural areas in Basilicata. The goal is to address the strategic concerns of a specific group of marginalized territory users, conserve natural habitats, and promote integrated development of stakeholders. The approach is based on the principles of the National Urban Agenda (NUA), which are "downscaled" to the local level. The methodology begins by defining the target population of territory users using principles such as "Planning for Migrants, Ethnic Minorities, and Persons with Disabilities", Job Creation and Livelihoods, and Biodiversity and Ecosystem Conservation. Collaborative

design frameworks are strongly recommended, and a decisive approach is required to effectively implement such a proposal. The main focus of this study is on the emerging technical requirements for territorial context analysis aimed at developing a sustainable study and defining tangible interventions and soft skills that align with the mentioned principles. The research experiment has revealed several distinct advantages compared to traditional project approaches. Specifically, the approach allows for a broader and more comprehensive understanding of the specific problems and issues that need to be addressed [17–20]. It correlates problems, local conditions, and potential solutions, and uses a reference matrix based on NUA principles to structure tangible actions and soft skills, as well as development goals. The robust accounting system of the reference matrix provides strong evidence of the project's quality. However, the limitations of the study concern the still too generic dimension of the approach, which shows a weakness in its selection matrix of NUA components to be adapted to the reference context. This research provides a significant contribution to the ongoing discussion on tools and methodologies to support the downsizing of the NUA at the local level, using innovative technologies in the thematic domain of urban design [21–23].

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Territorial Regeneration in the Crater Municipalities After the Earthquake of L'Aquila: Social Challenges and Innovative Approaches

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Abstract. The earthquake that struck L'Aquila and its surrounding area in 2009 caused considerable devastation, leading to the establishment of Special Offices for Reconstruction. In addition to restoring the built heritage, these offices tackle pre-existing challenges such as combating social exclusion, and demographic decline, and preserving cultural heritage. While these challenges are not direct consequences of the earthquake, they have been exacerbated by it. Addressing them while ensuring respect for the sustainability goals outlined in the United Nations' 2030 Agenda is essential. Key strategies include promoting sustainable tourism, involving the community in decision-making processes, and using technological tools such as WebGis platforms for data collection and analysis, as well as social inclusion. Several projects are outlined to illustrate participatory design aimed at urban regeneration, and social revitalization, and how these can contribute to the characterization of the territory. This contribution underscores the importance of inclusive approaches and innovative solutions to contribute, within the post-earthquake reconstruction context, to achieving the Sustainable Development Goals (SDGs).

Keywords: Territorial Regeneration · Social Challenges · Participatory Planning

1 Introduction

On April 6, 2009, L'Aquila and its surroundings were struck by a devastating earthquake (Mw = 6.3), resulting in significant casualties, injuries, displacement of residents, and extensive damage to infrastructure and cultural heritage [1]. This event marked a turning point, dividing time into "before" and "after," exacerbating existing issues such as inner-city marginalization, demographic decline [2], heritage abandonment, and unchecked urban sprawl [3]. The new settlement structure has triggered phenomena of various kinds: extreme fragmentation of construction, especially in the flat areas of the basin of the Aterno River, further decrease in average residential densities, quantitative erosion

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of agricultural surfaces, and degradation of the agricultural landscape and associated local ecosystems, fragmentation of the remaining ecological continuities between the major naturalistic polarities of the Central Apennines, adversely affecting the European-level biodiversity [4]. Following the earthquake, Law No. 134/2012 put an end to the emergency state, and established the Special Office for the Reconstruction of L'Aquila [5] and the Special Office for the Reconstruction of the Crater Municipalities [6] to oversee reconstruction efforts. While the first Office focuses on L'Aquila's reconstruction, the second Office oversees 56 Crater municipalities and over 100 municipalities outside of it (see Fig. 2). This article will mainly focus on the activities carried out and coordinated by the Special Office for the Reconstruction of the Crater Municipalities (see Fig. 1), "Special Office" from now on.

In this severely affected region, there's a pressing need to rebuild social cohesion, enhance territorial attractiveness, and stimulate local economies in line with the Sustainable Development Goals (SDGs) and local socio-economic needs. The local population must be the cornerstone for expressing the potential of sustainable socio-economic development.

This work does not present a case study but aims to showcase a reality that, with multidisciplinary tools, proposes a reconstruction and regeneration of the territory according to sustainability criteria.



Fig. 1. Goal – Action – Tool of the Special Office

Section 2 explains the intervention context of the Special Office, its governance, and the expansion of its mission that characterizes the office. Section 3 outlines the goals of the 2030 Agenda relevant to the main activities of the Special Office related to sustainable development actions in the territory. Section 4 showcases the management and social tools used in pursuing these actions. Finally, comments and related conclusions are contained in Sect. 5.

2 Reconstruction and Territorial Regeneration

The governance level of the Special Office pertains to a supra-municipal area that encompasses 56 municipalities. The Crater area is divided into 8 Homogeneous Areas, each representing an aggregation of municipalities based on geographical proximity and territorial vocation affinity. This allows for inter-municipal coordination of reconstruction actions and the development of local territorial systems.

The Crater is in the Apennine area of Central Italy, in the innermost zone of the Abruzzo Region. In this case, settlement dynamics are diversified compared to those of the municipality of L'Aquila. Except for major attracting poles, the jurisdictional area mostly consists of intermediate, belt, and peripheral areas [7]. Indeed, all the issues of inner areas in terms of essential services (healthcare, mobility, school services) are highlighted, leading to population marginalization and depopulation towards areas richer in services [8].

According to the Habitat and Birds Directives [9, 10] and Italian law [11], the area is characterized by a high degree of naturalness: there are 3 National Parks and 1 Regional Park: the Abruzzo, Lazio and Molise National Park (EUAP0001), the Gran Sasso and Monti della Laga National Park (EUAP0007), the Maiella National Park (EUAP0013), and the Sirente-Velino Regional Park (EUAP0173), along with other reserves and natural areas. They form the most important environmental matrix with a high heterogeneity of flora and fauna [12, 13]. Moreover, they constitute attracting poles for nature tourism, an aspect not to be overlooked as it characterizes the attractiveness potential, and uniqueness of this territory.

Over the years, the Special Office has expanded its scope and restructured its organization. It has become a key player in its governance model, initially focusing on reconstruction processes and later on the implementation of large-scale development projects. Its actions adhering the institution's political and legislative mandate and promote flexibility, adaptability, multi-level action, and a collaborative place-based approach. These characteristics allow the Special Office to create innovative processes aimed at culturally based territorial development. In the process of expanding its activities, the Special Office evolved from support for municipalities to take on responsibilities for public procurement. It shifted from being a Grant Office of the Ministry of Tourism for municipalities to offering technical assistance to local governments in the design, management, and implementation of scouting initiatives. The renewed status as a Public Administration (PA) has led these activities to be part of a broader plan for the cultural enhancement of the territory, accompanied by participatory planning with citizens and local stakeholders in urban regeneration programs.

In this way, the Special Office transcends the boundaries of ordinary governance by intervening transversally among planning levels. It not only facilitates the reconstruction process but also addresses the socioeconomic and quality of life needs of local communities. This approach, which includes urban regeneration, is defined in the literature as Territorial Regeneration. It addresses the systemic and structural conditions of a territory related to settlement systems and related functions, service provision, and ecological components. It is an approach that must be managed at a territorial scale to find the correct dimension of application [14–16], which in this case is supra-municipal.

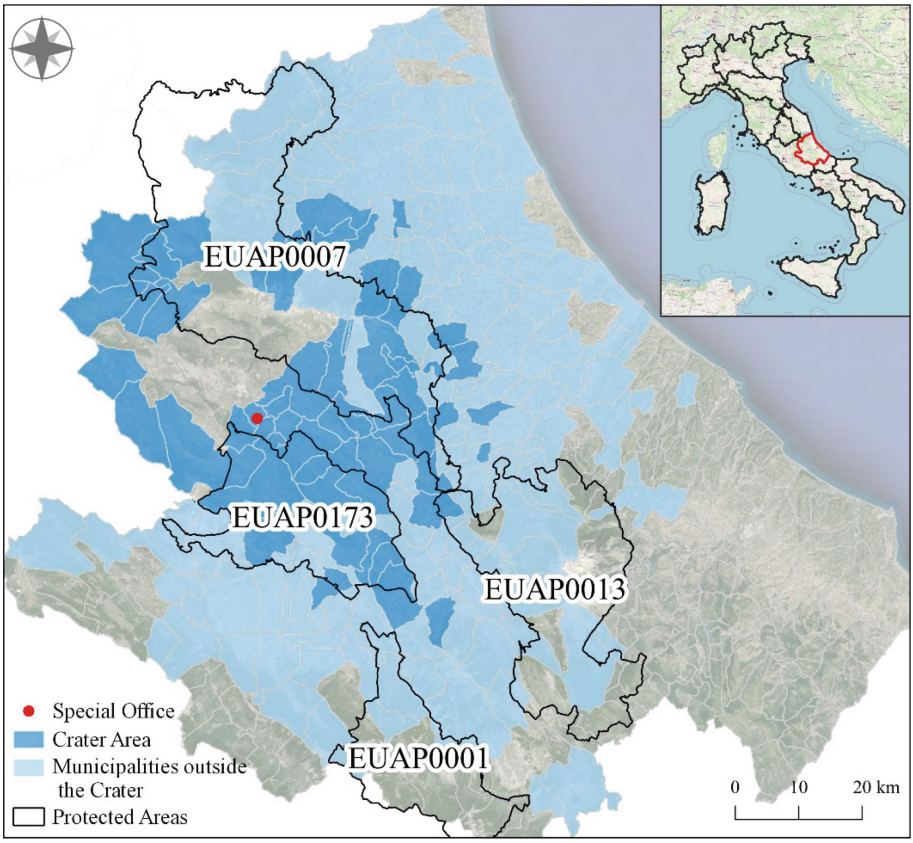

Fig. 2. Identification of the Crater area: the municipalities in dark blue are the areas with major damages and those in light blue are those with minor ones/ damages.

3 Sustainability and Social Challenges

The 2030 Agenda defines objectives and actions to ensure sustainable development globally, aiming to end poverty, combat inequalities, and enhance social and economic development while emphasizing crucial aspects such as climate change and environmental protection. This paper refers to SDGs No. 8 and No. 11.

SDG No. 8 aims to promote sustained, inclusive, and sustainable economic growth by implementing policies to promote sustainable tourism, create jobs, and promote local culture and products. Through access to national funds and programs, the Special Office is implementing Integrated Tourism Projects to revitalize the social and economic fabric of the Crater territory. These projects complement and enhance the reconstruction actions of municipalities, in line with the predominant tourist vocation of the relevant Homogeneous Areas.

The Integrated Tourism Projects aim to enhance:

- Historical, cultural, and religious tourism. The goal is to enhance archaeological sites, castles, fortifications, and cultural heritage.
- Nature-based tourism. Promotion of areas with high environmental value, historical-environmental paths, and mountain tourism.
- Village tourism, traditional, and food and wine traditions. Enhancement of historic villages, traditional festivals, and high-quality local productions.

Promoting sustainable tourism implies a long-term vision that includes tourism experiences with minimal environmental impact and that actively involves local communities in decision-making processes, thus ensuring a fair distribution of economic benefits [17].

Goal 11 emphasizes the need to focus on the dimension of cities and communities to make settlements inclusive, safe, resilient, and sustainable. Sustainability cannot be separated from the social sphere and consequently from the population living in the territory. Especially in this context, involving local realities allows for a bottom-up approach and makes citizens the true protagonists of actions in the territory [18].

In practice, Goal No. 11 includes participatory planning [19] in which the citizens and stakeholders are involved at multiple levels. The OECD Recommendation of the Council on Open Government (2017) distinguishes three levels of participation with increasing degrees: one-way information from planners to citizens, two-way consultation between institutions and citizens, and engagement with citizens and stakeholders. In this latter case, the subjects receive the necessary resources to collaborate during all decision-making phases, and in the design and provision of services. Special attention must be paid to the balance between these three figures because their approach to the problem and solutions, as well as their educational background, may differ [20].

The following paragraph presents some examples of useful tools in territorial administration, including community meetings. Through a process of direct and inclusive involvement, communities can articulate their visions for urban development, identify priorities and critical areas, and contribute to the design and implementation of tailored solutions. This approach not only enhances the quality of decision-making but also fosters a sense of ownership and responsibility towards the urban environment [21]. While detailed results and reports of these events will not be discussed in this paper, they serve as exemplars of projects promoting inclusion and sustainable management of the territory.

4 Technological Approaches

One of the challenges imposed by the goals of the 2030 Agenda is to build increasingly resilient and interconnected cities. There is a need to manage a vast amount of data while simultaneously ensuring interoperability among different sources. Smart city concepts have long been discussed, emphasizing how Information and Communication Technology (ICT) can enhance the quality of cities and the well-being of citizens [22, 23]. Moreover, ICTs can play a fundamental role in the development of cultural tourism [24]. This concept can be applied to a much broader context, such as the Crater of 2009, comprising multiple urban areas undergoing reconstruction. Thus, there is a transition from “smart cities” to “smart land” [25, 26].

In addition to the tools that will be described in the following sections, the Special Office materializes this approach through an integrated system of supra-municipal scale video surveillance. Through the implementation of other technologies, the realization of additional services for the population is envisaged, along with monitoring and analysis aimed at improving social connections within the territory.

4.1 WebGis Platform

To collect data and perform spatial analyses, the Geographical Information System (GIS) can be employed. Its purpose is to manipulate and analyze data, providing a quantitative interpretation to identify territorial dynamics. WebGis platforms have made remote access widely available, enabling anyone with an internet connection and a device to access and process the provided data.

Through a collaboration between the Special Office and the University of L'Aquila, the latter has developed a platform to manage the practices and data of the Special Office. This system facilitates the storage of a large amount of data and ensures interoperability among them. It allows for quick and simultaneous data querying from various remote office locations and facilitates monitoring of reconstruction processes (information by Technical Report). Equally important is the management of an interface for citizens to access various levels of information.

Furthermore, this platform can integrate information and data collected from participatory meetings. To standardize and digitize the data, participatory meetings can be structured through Online Participatory Technologies (OPTs) [27]. Some of these technologies involve the use of GIS software, but attention must be paid to the individuals involved. It is expected that some participants may not be familiar with this software, or they may not like to dedicate their time to learning how to use it [28].

4.2 Participatory Planning with the Municipality of Santo Stefano Di Sessanio

The municipality of Santo Stefano di Sessanio (province of L'Aquila) has an area of about 33 sq km and most of the territory is at an altitude of more than 1300 m a.s.l..

The center town (see Fig. 3) is at 1100 m a.s.l. with 114 inhabitants (at 01-01-2023) [29] and it is among the least populated municipalities in the province. It is also included in the list of the "Most Beautiful Villages in Italy" [30].

This experimental project unfolds through a series of meetings with the local community, administrators, and local authorities to identify urban regeneration action and social, economic, and cultural revitalization of the municipality. The aim is to foster cooperation and cohesion in the community and responsibility towards the urban commons. Figure 4 illustrates the main phases of the participatory planning process.



Fig. 3. Location map of the Municipality of Santo Stefano di Sessanio. The image was reworked by the authors based on the following sources: "Visit San Demetrio" and "iStock".

4.3 The "Cammini Degli Altipiani" Project and the Operative Mapping

This project involves the creation of 4 paths that develop over 42 municipalities inside and outside the Crater. The paths (see Fig. 5), create a route of about 340 km to optimize and enhance the resources of the territory and promote tourism through slow mobility.

From the beginning of the project, a significant amount of georeferenced and digitized data has been collected, ranging from the background of the area to the use of VGI data (OpenStreetMap, OutdoorActive, Koomot, etc.) to identify interferences with the road network and to define heatmaps of area. Due to the vector nature of the data, it will be possible to integrate this level of information into the platform.

In the following stage of territory characterization, there was an Operative Mapping meeting that involved stakeholders, authorities, and associations in the area. The phases of this meeting are detailed in Fig. 6.

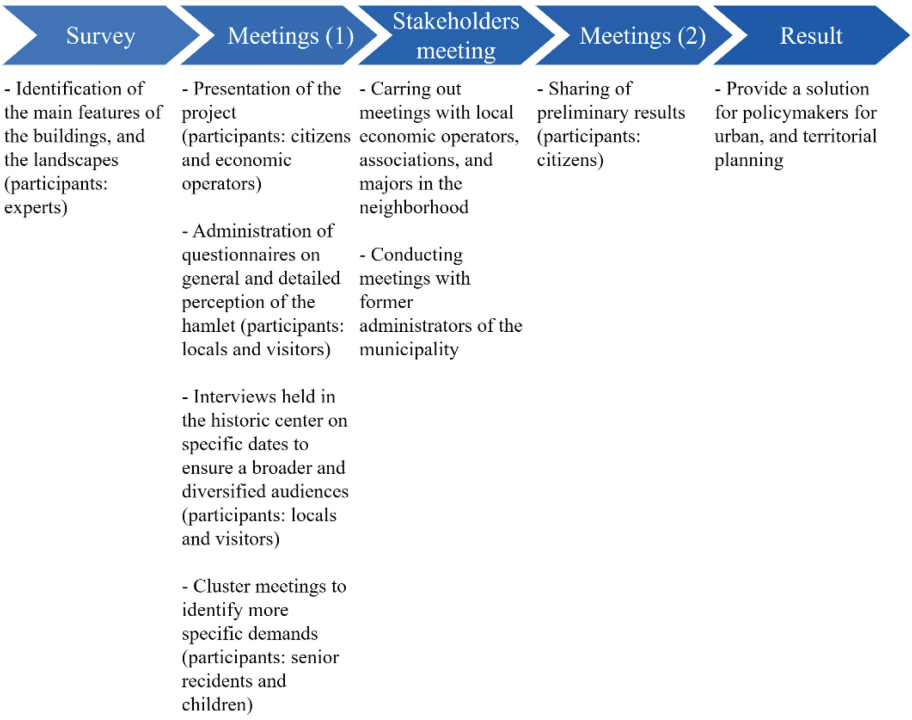

Fig. 4. Steps of the participatory planning of Santo Stefano di Sessanio

The goal of this meeting is to contribute, starting from the needs that visitors may encounter, and the services and activities already available in the area, to the implementation of an integrated service system for the 4 paths.

4.4 Cultural Events Billboard

The Cultural Events Billboard [31] is a tool that, through a user-friendly WebGis platform, collects cultural initiatives and any other event scheduled in the area, facilitating their organization and dissemination.

The website allows municipalities and associations to keep their events updated. Organizations need to make a request to the Special Office and fill out a form with detailed event information, including type, access costs, accessibility for people with disabilities, and the event's location. Users can easily find and interact with events through an interactive map of the municipalities or by filtering based on event type or date. Additionally, events can be shared on social media platforms for wider reach.



Fig. 5. The "Cammini degli altipiani" project by the Special Office (the tracks are still in the approval process)

The use of Cultural Events Billboard has two main implications. In the former case, creating a unified platform for the promotion of the area allows users to view activities beyond the individual municipalities. Secondly, the synergistic work between the Special Office and organizers can facilitate the collaborative scheduling of events and the management of periods with an excess or lack of offerings. The choice of the WebGis platform allows for interoperability between data and sources, their standardization, and an intuitively user-friendly mode of operation.

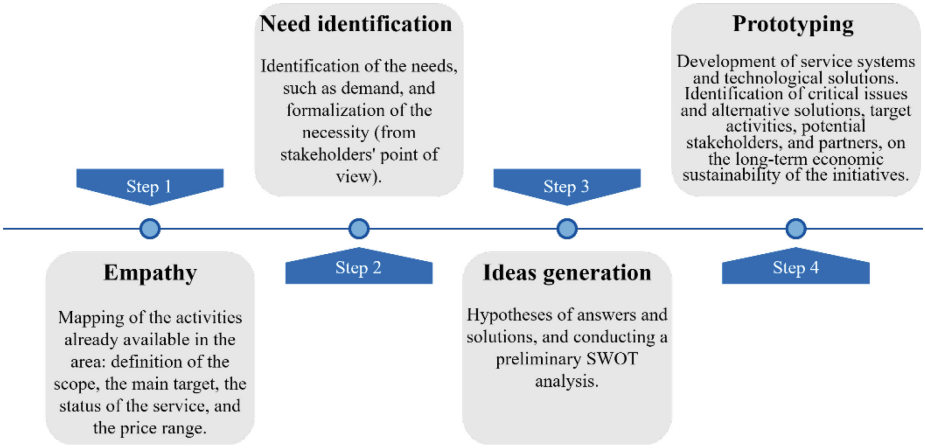

Fig. 6. Steps of the Operative Mapping

5 Conclusion

The post-earthquake experience has highlighted the need for careful and inclusive governance. The Special Office has had to address challenges not only related to physical reconstruction but also to the social and economic recovery of the affected communities through the coordination of activities and territorial development projects. The United Nations' 2030 Agenda has drawn attention to the need to pursue sustainable development that encompasses social, economic, and environmental aspects. In this context, the multidisciplinary approach adopted in addressing post-earthquake challenges has promoted the integration of territorial regeneration policies and socioeconomic development, with a particular emphasis on sustainable tourism as a driver of economic growth and social inclusion.

A key element in the territorial regeneration process is the active participation of local communities and stakeholders. The adoption of participatory approaches allows for the direct involvement of citizens in decisions regarding the development of their territory, ensuring a greater sense of belonging and responsibility. Furthermore, the inclusion of diverse perspectives and expertise fosters innovation and the creation of solutions adaptable to the specific needs of the local context.

As previously mentioned, the area of interest is characterized by demographic decline, with local communities sometimes comprising as few as a hundred inhabitants. Consequently, participatory meetings may encounter limitations, such as low turnout at informational and planning sessions.

To foster participation, it can be helpful to begin with a pre-operational phase focused on raising awareness and understanding of these types of gatherings and the topics they will cover. Associations and organizations involved in social issues can play a crucial role in this phase. They can act as mediators between the population, helping to spread awareness and sensitivity to these topics, and as intermediaries with planners to express the needs of local communities.

The subjective nature of opinions and ideas is inherent in the bottom-up approach. Therefore, a careful post-processing phase is necessary to analyze the collected data and provide an accurate interpretation of the phenomena of the territory.

To improve the efficiency of these processes, the use of technological tools, such as the WebGis platform, facilitates the collection, analysis, and sharing of territorial data, enabling a more efficient and transparent management of reconstruction and development activities. These tools streamline citizen participation in participatory planning processes through remote access to information and also offer the opportunity for active contribution using dedicated Online Participatory Technologies. At the same time, involving GIS system experts alongside participants is essential to prevent discrepancies arising from differences in proficiency levels.

In conclusion, this work demonstrates how the adoption of integrated and inclusive approaches in the management of reconstruction and territorial regeneration processes can contribute to achieving sustainable development goals and improving the quality of life of local communities.

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Specifics of Smart Cities Development in Europe (SPEED 2024)



Can Be Small Municipalities Smart?

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Abstract. Open governance, the involvement of stakeholders in addressing local policy challenges, and local and municipal tools supporting the application of democratic principles in local self-government remain consistently relevant topics of research. With the influence of advancements in science and new information and communication technologies, public administration management tools are taking on new forms, posing a challenge at all levels of public administration, including local, regional, and national levels. The aim of this paper is to examine the potential for their use and systematic development within the small local governments of the Slovak Republic, as well as to investigate the factors influencing the adoption of modern tools in the practices of Slovak municipalities, which is based on an analysis of smart governance implementation. With regard to this, our research fills the gap, since most smart city studies are predominantly conducted on a sample of large cities. The paper presents findings of secondary research conducted on a sample of 253 municipalities in Slovakia with populations of up to 4,999. It discusses the factors that influence the concept of smart governance and define the challenges of smart governance development within the framework of small local municipalities.

Keywords: Toolkit · Smart Governance · Municipalities

1 Introduction

Involvement of citizens and other stakeholders into the administration of public affairs has been a challenge in many countries. The Covid-19 pandemics had shown that the previous system of public governance needs improvements and implementation of new features and elements in order to be effective in new conditions. Development of new information and communication technologies is an opportunity for public administration bodies to include stakeholders in the democratic management of public affairs.

It is necessary to explain that the term governance is identified with all forms of democratic management of public affairs, including the involvement of a diversified portfolio of stakeholders in these processes. We understand it as a form of governance where, in addition to paid managers, other actors are also involved in governance and have taken advantage of the opportunity to participate in governance provided by the principles

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of democracy with the common social, economic and environmental objectives (Pierre, Guy Peters 2020). In this sense, smart governance is a new approach to management of public affairs based on the use of modern information and communication technologies with the involvement of relevant actors based on the evaluation of available information and data.

The smart city concept (as well as smart governance) is more associated with the large cities by a great share of research papers and case studies. However, our research (Borseková et al. 2018; Lopez et al. 2017) showed that there is no disadvantage in building smart cities for medium-sized cities in comparison to bigger cities. Some studies confirm that the smart city intervention can help small and rural municipalities to curb the problems of managing the limited resources available as well as in service delivery (Mashau, Kroeze, Howard 2021). That is why the presented research results in next section focus on mapping the situation that concerns implementation of smart governance in small local municipalities, which also covers the research gap with regard to this issue.

The paper presents the research results of survey conducted in the Slovak Republic, which is characterized by the large number of municipalities with small number of citizens. Regarding the Slovak municipalities, this concept is still relatively new. There is not paid adequate attention to this issue and that is why we focused on the potential for the use and systematic development of smart governance within the small local municipalities (villages), as well as on investigation the factors influencing the adoption of modern tools in the practices of Slovak municipalities. This approach also brings new view on the application of smart governance in small municipalities.

The paper is organized as follows. Section 2 is theoretically oriented on definition of smart governance and its tools in local municipalities. Section 3 details the methodology of realized researches and characterizes the data used. The third section is devoted to presentation of the research results and their critical analysis. To conclude the paper, we summarize the challenges of smart governance implementation within the framework of small local municipalities.

2 Smart Governance and Its Tools in Local Municipalities

The concept of smart city governed by smart government is intensively researched during last 20 years. The research shifted from the focus on the techno-economically driven approach to more decentralised, anthropocentric approach fostering the collaboration and community involvement (Zhao, Fashohla, Olarewaju, Onwumere 2021). It also became a part of public policy agenda at the national and international level that strongly influence the progress in local governance and implementation of innovative participative and cooperative tools.

Smart governance in local municipality presents a procedural interplay among diverse stakeholders, managed with technology and data, based on relevant legislation and policies, to achieve benefits or procedural changes (Ruhland 2018). It should contribute to more efficient resource management reflected (Hajek, Youssef, Hajkova 2022) in the sustainable development and increased quality of life (Caragliu et al. 2011; Bakici et al. 2013).

Essential in building a smart governance system are political and city leadership efforts to foster collaboration and empower residents, entrepreneurs, and communities, implementing these opportunities through relevant tools and methods (Vaňová 2021; Lee, Lee 2014; Lombardi et al. 2011). This necessitates establishing appropriate legislative, organizational, financial, and technological frameworks. Nam, Pardo (2011), Mellouli et al. (2014), Maheshwari, Janssen (2014), Nam, Pardo (2014). Smart city governance involves managing urban infrastructure, resources, and intangible capital, aligned with shared visions and strategies (Nam, Pardo 2011; Mellouli et al. 2014; Lee, Lee 2014; Lombardi et al. 2011; Lopez, Oliveira, 2017). Smart governance requires long-term commitment and shared understanding, vision, strategy, and responsibility. Kumar (2017), Zanella et al. (2014), Caragliu et al. (2011). The importance of these factors is confirmed also by research in small municipalities, where also the environmental factor is distinguished (Mashau, Kroeze, Howard 2021; Ibrahim, M., El-Zaart, A. and Adams, C. 2018; Chichernea, V. 2015). Also the authors (Bokun, Nazarko 2023; Kumavat et al. 2021; de Viron and Mudri 2019) researching the concept of smart villages supported their definitions and stress the importance of integrated and interdisciplinary approach in their management.

The core of smart governance is a collaborative governance that brings together multiple stakeholders (e.g. citizens, municipalities, entrepreneurs, parliamentarians, employees, financial institutions, NGOs, government offices, media, universities, and others) together in common forums with public agencies to engage in consensus-oriented decision-making and active co-creation that lead to the sheared learning (Vitálišová 2015; Ansell, Gash 2008; Ruohomaa, Mäntyneva and Salminen 2018; Allahar 2020). Citizen or other stakeholder is an active partner that contribute to co-create the solutions for complex problems of urban policies and projects based on self-regulations and mutual trust (Przeybilovicz, Cunha 2022). The strategic asset that modifies the traditional interactions between government and stakeholders to the dynamic and smart collaboration are ICTs (Albino et al. 2015; Misuraca et al. 2011; Baccarne et al. 2014; Scholl, Scholl 2017; Osella et al. 2016; Guenduez et al. 2018). ICT induces co-creation and catalyses social actors in smart urban governance, eventually challenging existing governance modes (Przeybilovicz, Cunha 2022). However, the importance of ICTs is equal to the right leadership of the city and deep collaboration among participation in an appropriate helix-style collaborative arrangement (Allahar 2020).

Smart governance uses innovative tools to involve stakeholders in delivering public services, addressing policy issues, and making government more transparent. This includes traditional and new participation and co-creation methods (as described in research by Castelnovo et al. 2015; Castelnovo 2016; Vitálišová et al. 2021). They contribute to increasing stakeholder participation through openness and transparency, thus creating an image of municipal accountability, thereby improving the quality of stakeholder-government relations.

There's no one-size-fits-all approach to smart governance tools. These tools are used in different combinations depending on the stage of stakeholder engagement (Vitálišová et al., 2022). The right mix of tools (informing, negotiating, coordinating, etc.) is crucial for building relationships with stakeholders (Peters 2003; Cresbo & Cabral 2010; Schaap et al. 2014). Thus, smart governance becomes a process of continuous improvement based on mutual communication, which requires time, flexibility and reputation (Franzke, Roeder 2014; Pianzola, Ladner 2014; Michels, Montfort, & Pianzola 2014).

The OECD (2020) categorizes smart governance tools based on their application in stakeholder engagement. These categories include communication, consultation, participation in policy-making, representation, partnership, and co-production/co-decision. Simonofski et al. (2019) offer another perspective with three main categories: tools for participatory democracy (citizen involvement), tools for co-producing public services, and tools that leverage ICT to make citizens active participants in smart city infrastructure and data collection. The first group consists of tools to promote participatory democracy represented by citizen involvement in governance. The second group consists of tools promoting the co-production of public services. The third group of tools considers the impact of the development of ICTs, where the citizen is an active part of the infrastructure of smart cities, a source of information that facilitates the management of public affairs.

The set of tools in our research were identified based on the literature review oriented on the definition of the smart governance tools (inter alia Bolívar 2015; López-Quiles, Bolívar 2018; OECD 2020; Simonofski et al. 2019; OECD 2020; Castelnovo et al. 2015; Estevez, Janowski 2013; Chourabi et al. 2012; Wijnhoven et al. 2015; Gil-Garcia et al. 2015; Johannessen, Berntzen 2018; De Guimarães 2020; Vaňová 2021). Subsequently, their composition was verified by the Dephi methods among international experts (see also Vitálišová et al. 2023). Because the research studies indicate that the existing models of smart governance and their tools are too complex and too extensive for smaller municipalities (Iammarino et al. 2019; Weck & Beißwenger 2014; Anschütz, Ebner, Smolnik 2024), we are primarily trying to identify the composition of the used tools in the small municipalities of the Slovak Republic and the level of their implementation in this paper.

3 Material and Methodology

The research focused on mapping the utilization of smart governance tools in Slovak local municipalities with a current population of up to 4,999 inhabitants. The smart governance tools were defined in compliance with foreign and domestic scientific and professional literature sources. In total, 32 tools of modern self-government were examined, and categorized into four groups: tools supporting transparency, tools of democracy (participation), tools of communication, and tools of education and co-creation of public services. Data collection was carried out between February and August 2021. In case municipalities engaged these tools, data were gathered through observation that was based on the study of websites, strategic municipality documents, or other relevant reports (national, regional).

The total number of the municipalities of the Slovak Republic is 2890 including villages and cities. Their composition is fragmented. Generally, we consider Slovakia to be a rural country, due to the fact that out of 141 cities only 2 cities have more than 100 000 inhabitants. In the research, we focused only on the villages with up to 4999 inhabitants, which we consider as small villages, and we excluded the cities. In this case, the number of municipalities is 2752, what is 95,23% of the total number of Slovak municipalities. All municipalities regardless the size or localization have to operate within the same institutional and legislative framework. The research samples consist of

253 municipalities in the Slovak Republic across five size categories, with populations of up to 4,999 inhabitants (Table 1). According to the Chi-square test result, the research sample is representative in terms of the size category and location of the municipalities relative to the spatial division of the Slovak Republic into Western, Central, and Eastern Slovakia. Hence, the research findings can be extrapolated to all small Slovak villages.

Table 1. Composition of the research sample by size category and area

Area	Region	Local municipality size category					Total
		to 199	200–499	500–999	1 000–1999	2 000–4 999	
Western Slovakia	Bratislava	0	1	1	1	2	80
	Trnava	0	2	3	4	6	
	Trenčín	2	7	13	9	2	
	Nitra	1	4	12	8	2	
Central Slovakia	Banská Bystrica	9	13	15	6	5	90
	Žilina	4	9	10	9	10	
Eastern Slovakia	Prešov	9	16	10	7	5	83
	Košice	3	9	15	7	2	
Slovak Republic		28	61	79	51	34	253

To analyze the secondary data, we employed various mathematical and statistical methods, with a particular focus on descriptive statistics and correlation analysis. Based on the results of the analysis, we have categorized the municipalities using the "smart governance traffic light" system. This system enables to assess the level of smart governance development in individual municipalities. The methodology behind the smart governance traffic light involves classifying municipalities into three categories based on the percentage of defined tools they utilize in each category. Municipalities marked in red indicate a lack of smart governance activities. These municipalities utilize 0%–30% of smart governance tools. Those marked in yellow are in the developmental stage of smart governance adoption, utilizing 31%–60% of the defined tools. Finally, municipalities marked in green demonstrate active engagement in smart governance initiatives, utilizing 61%–100% of the defined tools. The final section of the paper discusses and summarizes the most significant research findings, along with the primary challenges in the development of smart governance within Slovakian municipalities.

The research can be considered as a pilot one, because there is no evidence about the similar studies conducted in the conditions of the Slovak Republic, which means that we do not consider the spatial distribution and proximity to cities within presented research results.

4 Research Findings and Discussion

The transformation and development of municipalities are strongly influenced by technological advancements, digitalization, and the concept of "smartness" across various areas, spanning from decision-making to the delivery of public services. This relatively recent phenomenon has led to the adoption of smart governance tools in the practices of Slovak municipalities.

Regarding the specific smart governance tools analyzed, the utilization levels within the transparency tools category (Fig. 1) are relatively low. Among these tools, the 3D mapping system is the most commonly used, implemented in 41.50% of municipalities. Databases for sharing information within the municipal authority and organizations established by the local municipality are implemented in 26.88% of municipalities.

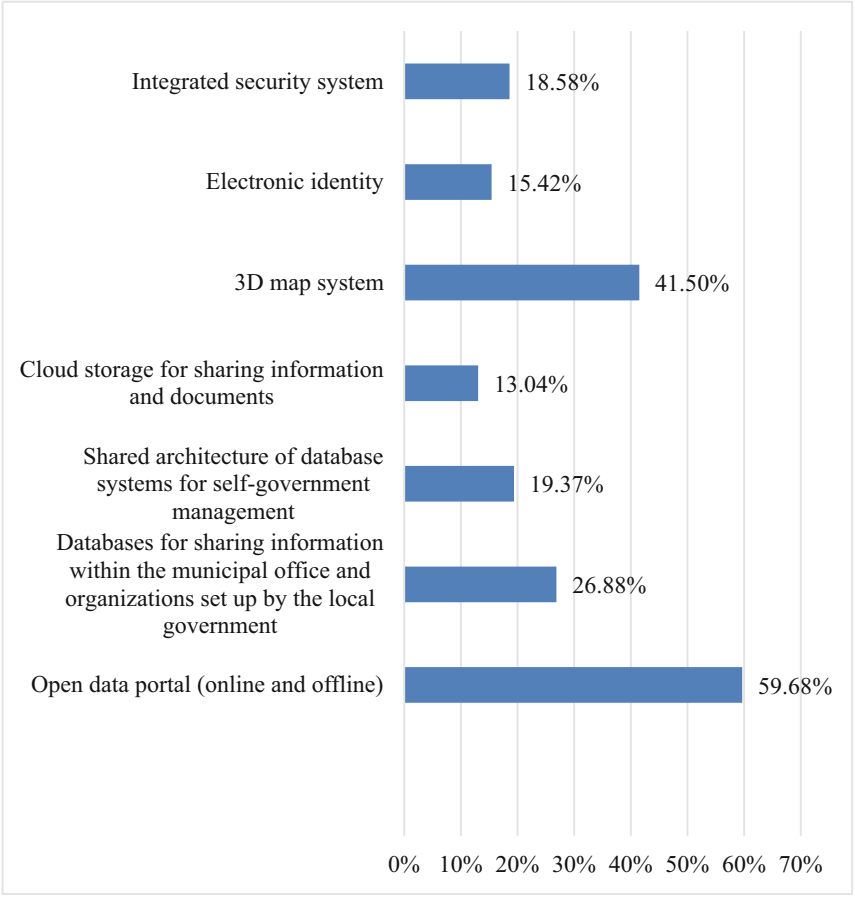

Fig. 1. Transparency tools.

However, integrated security systems, electronic identity systems, cloud storage, and shared database architectures for local municipal management systems – all of which are essential prerequisites for implementing digital forms of smart governance tools – are present in less than a quarter of municipalities. Additionally, none of the small Slovak municipalities utilize open data through an open data portal concerning local municipality affairs, either online or offline.

Similar to the transparency tools, the utilization of individual tools for promoting participatory democracy (Fig. 2) is relatively low in small municipalities in the Slovak Republic. Less than a quarter of municipalities employ all tools to promote participatory democracy. The least widespread tools are electronic e-democracy tools, primarily represented in Slovakia by electronic petitions and electronic voting forms. This is also due to the absence of electronic public elections in the Slovak Republic. The representation of each tool varies across size categories, and their implementation is not correlated with the municipality's size category.

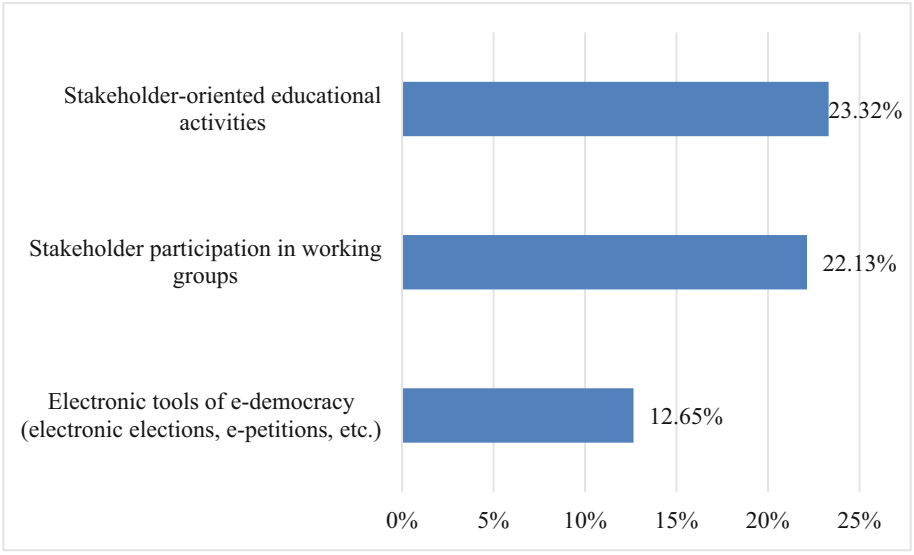

Fig. 2. Tools to promote participatory democracy.

Among the instruments for co-producing public services (Fig. 3), electronic/digital public services are particularly prevalent, with 47.83% of municipalities that offer them. However, it remains unclear how many local municipalities provide these public services beyond the scope outlined in the Act of the National Assembly of the Slovak Republic No. 305/2013 Coll., also known as the e-Government Act. These public services can be facilitated through the Data Centre of Municipalities and Cities (hereafter referred to as "DCOM"), a supra-ministerial information system catering to local municipalities and encompassing the entire range of responsibilities inherent to local municipalities.

Another tool utilized for co-producing public services is a participation in the exchange of experience and knowledge within the local municipality territory, employed

by 35.18% of municipalities. Notably, there is a relatively low proportion of municipalities employing participatory planning in municipal development (28.06%), despite the fact that, according to the methodology, it is recommended to integrate the knowledge and experience of citizens and other development stakeholders, which should stem from participatory processes. The involvement of socio-economic partners in drafting strategy is crucial for its wide acceptance, serving as a mean to achieve consensus and a prerequisite for the participation of socio-economic partners in its implementation.

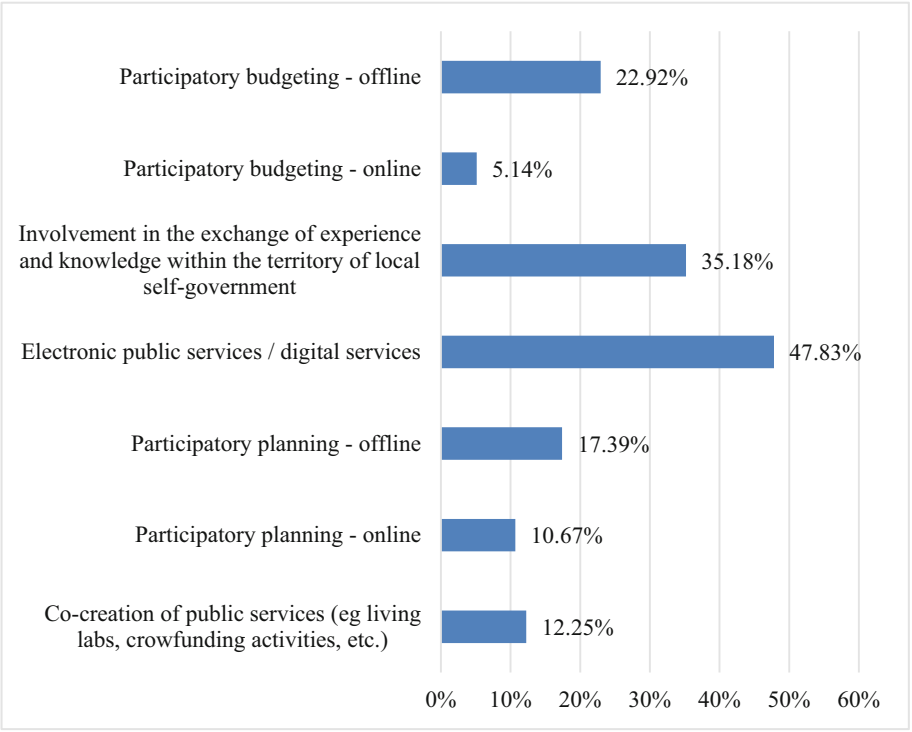

Fig. 3. Co-production tools for public services.

Physical participation in participatory planning is implemented by 17.39% of municipalities, while the online form is adopted by 10.67%. Although participatory budgeting is not mandatory for municipalities, 28.06% of them engage it. Of these, 22.92% utilize a form of physical participation in budgeting, while 5.14% utilize various online platforms and apps, typically based on freely available software solutions. Co-creation and co-production of public services, such as through living labs and crowdfunding activities are implemented by only 12.25% of municipalities. It is worth noting that a detailed examination of all these activities, in comparison to the theory of co-production, would likely reveal an even lower percentage of municipalities engaged in such practices.

Electronic/digital public services are more commonly provided by municipalities in larger size categories, as well as engaging in the exchange of experience and knowledge

within the local municipality territory. Furthermore, the representation of other tools is relatively consistent across the size categories of municipalities. Interestingly, participatory budgeting is more prevalent in the smallest size category of municipalities, despite the common issue in Slovakia, especially in small municipalities, of financing not only development activities but also the original competences mandated by law.

Among the communication tools (Fig. 4), the predominant ones include organizing events, which are implemented to different extents by all municipalities, and the municipality's website, which is established by 99.21% of municipalities. Surprisingly, three municipalities still have no website despite the digital age and the increasing trend towards digitization and the advancement of information and communication technologies.

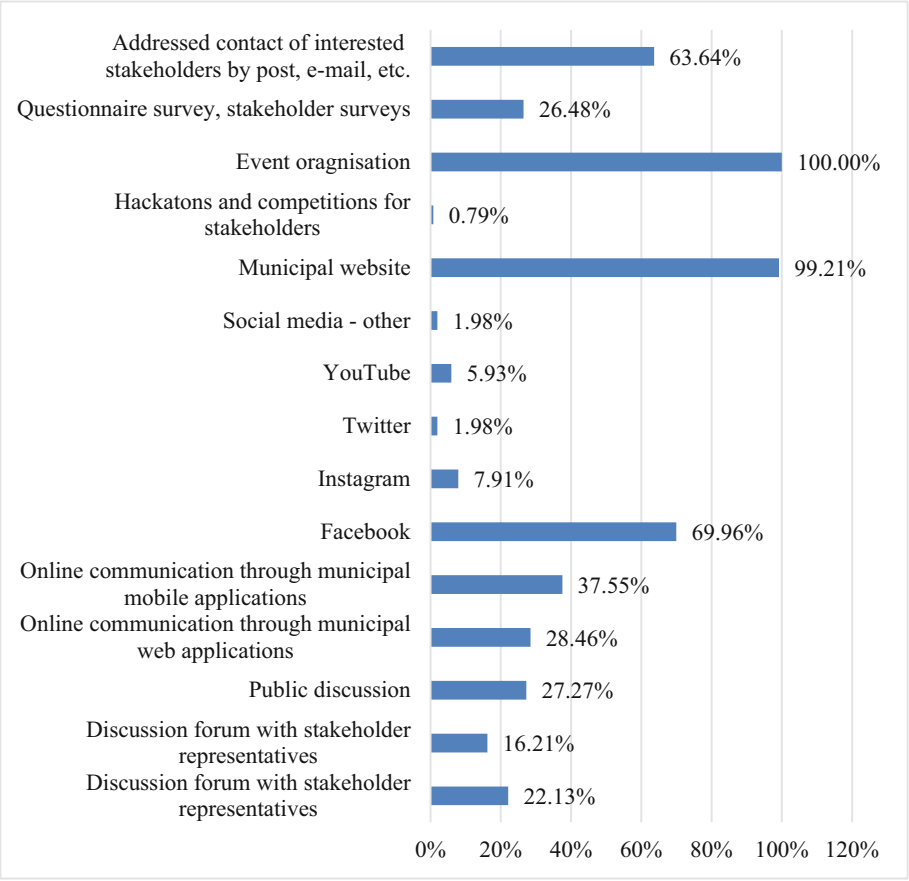

Fig. 4. Communication tools.

A positive aspect concerns the fact that 70% of municipalities maintain a profile on the Facebook social network. Other social media platforms are represented to a much lesser extent within municipalities. Among the communication tools, several are relatively

underrepresented in municipalities: public discussions (27.27%), questionnaire surveys (26.48%), online stakeholder feedback systems (22.13%), and discussion forums with stakeholder representatives (16.21%). Only two municipalities utilize hackathons and competitions for stakeholders as a part of their communication activities.

Interestingly, 64% of municipalities still rely on direct contact with stakeholders in traditional forms, notably by post or email, particularly prevalent in smaller-sized municipalities. This reliance on traditional communication methods may potentially hinder online communication, such as through mobile apps (37.55%) and web apps (28.46%). However, it can be assumed that this tendency is influenced by the age composition of the population in these municipalities.

When examining the communication activities of local municipalities, it is crucial to bear in mind that despite the advancements in information and communication technologies and the emergence of the "digital" generation, all citizens, irrespective of age or social status, should have access to information. This access is mandated by Article 26(4) of the Slovak Constitution. It poses a challenge for both municipalities and the state itself, not only in the provision of information, but also in the realm of further education aimed at acquiring digital skills and facilitating access to the Internet and ICT.

Of all the surveyed smart governance tools, Slovak municipalities with a population of up to 4,999 primarily utilize electronic/digital public services, 3D mapping systems, the municipality's website, communication with stakeholders via mail, email, and similar means, and online communication through mobile apps and social media platforms, specifically Facebook. Generally, as the size category of municipalities decreases, the use of each tool diminishes. This correlation was confirmed by the results of the correlation analysis, which indicated a weak direct linear dependence for up to 28 instruments.

The research also identified other factors that may influence tool implementation, such as the age and educational attainment of the mayor, as well as the existence of municipal development documents. For instance, the surveyed Slovak municipalities (253 in total) are governed by male mayors (67%) and female mayors (33%) (Fig. 5). However, the conducted research did not demonstrate a correlation between the gender of the mayor and the adoption of modern tools in the practices of Slovak municipalities.

The mayor of a municipality is an elected official expected to work professionally for the development of the municipality in line with the needs and interests of its inhabitants (Palúš, Hencovská 2013). Thus, this involves the implementation of smart governance tools into the practices of Slovak municipalities and the exercise of public power itself. Therefore, mayors should be competent individuals with appropriate education and expertise.

While current Slovak legislation does not mandate a minimum level of education or the demonstration of professional knowledge for elected representatives' duties, the educational background of mayors is notably positive. Over 56% of mayors possess a university degree, 40% have a secondary education, and none of the mayors in the research sample hold only a primary level of education (Fig. 6). Although a relatively high level of educational attainment among mayors is not a guarantee of expertise or effective municipal management, it does provide a foundation for general knowledge and further training. For only 23 tools, the correlation analysis revealed a weak direct dependence

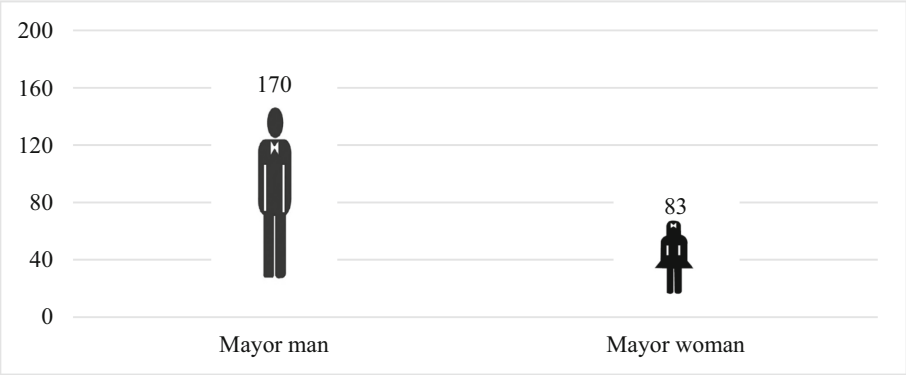

Fig. 5. Structure of mayors according to gender

between the mayor's highest level of education and the degree of implementation of modern tools in the practices of Slovak municipalities.

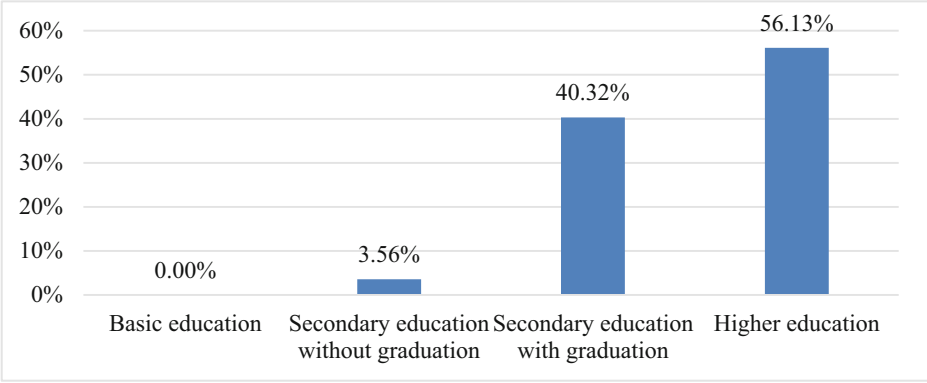

Fig. 6. Structure of mayors according to level of education.

As the research results show, we may observe a challenge with the average age of mayors (that is 51), which is relatively high. This is largely attributed to the trend of the gradual ageing of the population in small municipalities and the migration of young people from municipalities to cities in pursuit of education, employment, and a higher standard of living. The results of the correlation analysis indicate that the mayor's age plays a significant role in the implementation of modern tools in the practices of Slovak municipalities. For only 23 tools, the correlation analysis confirmed a weak direct relationship between the mayor's age and the implementation of modern tools.

A factor that could influence the implementation of smart governance tools in Slovak municipalities is a presence of a strategic document addressing the issue of smart municipalities or smart governance. According to the research findings, only seven (2.78%) small municipalities in Slovakia have developed a smart governance or smart municipality strategy, with four of them being in the largest size category. Additionally, it is

noteworthy that only 78.26% of municipalities possess a strategic development document of the municipality - the Programme of Economic and Social Development of the Municipality (hereafter referred to as "PHRSR"). Despite the requirement for municipalities to have a PHRSR in order to access resources from the state budget, the European Structural and Investment Funds (hereafter referred to as "ESIF"), and additional resources for development projects in the municipality (as stipulated by the Act of the National Assembly of the Slovak Republic No. 539/2008 Coll. on the promotion of regional development, as amended), not all municipalities have one in place.

As the size category of municipalities increases, there is a corresponding rise in the proportion of municipalities that have elaborated a Programme of Economic and Social Development of the Municipality (PHRSR), primarily due to the complexity of the elaboration process. Drafting a strategic development document is a demanding endeavour that necessitates substantial personnel and financial resources, which many municipalities, particularly the smallest ones in Slovakia, may lack. Additionally, there exists a challenge with motivating elected representatives of smaller municipalities to prepare a PHRSR, particularly if they lack sufficient financial resources to contribute to funding development activities from the state budget, European Structural and Investment Funds (ESIF), or other supplementary sources. The correlation analysis indicated a weak direct dependence between the completion of the PHRSR and the implementation of modern tools in practice for up to 23 tools.

The results of the "smart governance traffic light system" (Fig. 7) indicate that over 50% of municipalities are not actively pursuing smart governance initiatives in the realms of co-production tools and participatory democracy tools.

Within these categories, a considerable proportion of municipalities (more than 30% of Slovak municipalities) are currently in the process of developing smart governance within their self-government processes. Only around 10% of Slovak municipalities demonstrate a genuinely "smart" approach to governance within the co-production and participatory democracy toolsets. In the case of transparency and communication tools, over 50% of municipalities are in the developmental phase of adopting smart governance practices. However, while up to 43% of municipalities have yet to incorporate smart governance activities within the transparency tool category, only 8% of municipalities remain in this initial phase regarding communication tools. Additionally, 28% of municipalities are actively implementing smart governance approaches within their communication.

Correlation analysis within the framework of "smart governance traffic light" has also identified factors influencing the implementation of various smart governance tool groups by small Slovak municipalities. Alongside municipality size, the practical implementation of communication tools is influenced by the mayor's gender, regional affiliation, and the presence of strategic municipal documents (such as smart city or smart governance concepts and PHRSR). Research indicates that larger municipalities implement more often communication tools. Similarly, municipalities with developed strategic documents are more adept at applying smart governance communication tools. Interestingly, municipalities with male mayors tend to utilize communication tools more frequently.

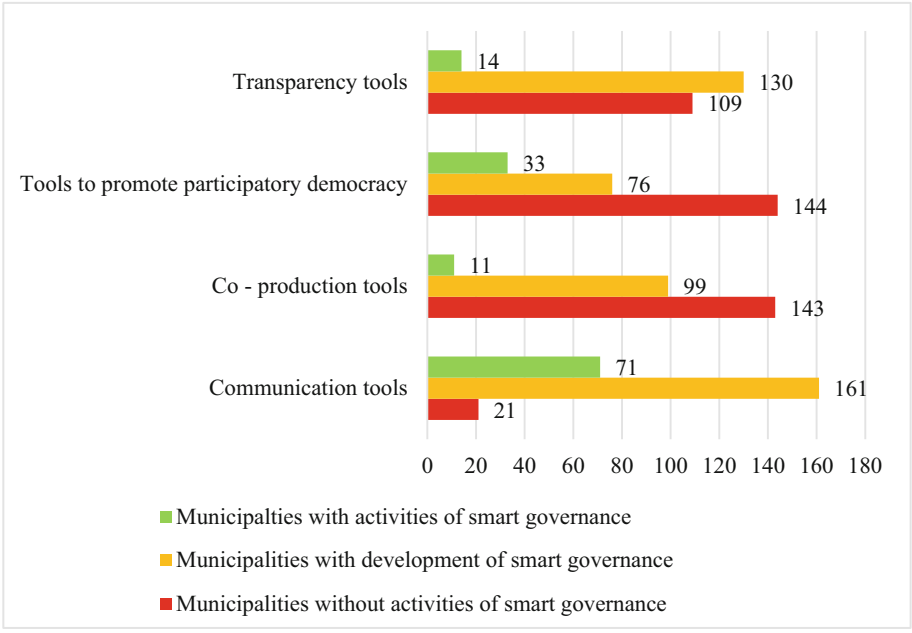

Fig. 7. Smart governance traffic light system

Moreover, there is a direct negative correlation between communication tools implementation and the regions of the municipalities, with tool usage increasing from east to west Slovakia.

Regional affiliation, municipality size, and the creation of PHRSR also impact the co-production tool group. In addition to these factors, the age of the mayor influences the implementation of co-production tools, with older mayors demonstrating higher usage rates of co-production tools.

Furthermore, the mayor's level of education affects the participation tool group, alongside municipality size and the presence of PHRSR. A mayor's educational attainment correlates with a greater implementation rate of participation tools. Lastly, alongside municipality size, the application of transparency tools is influenced by the mayor's age.

5 Conclusions

The research examines the adoption of smart governance tools in small local municipalities - villages (with less than 4,999 inhabitants) in Slovakia. The results show that while some tools are being used, their overall utilization remains relatively low.

The least widespread tools in small municipalities are e-democracy tools, but the inadequate utilization is also in case of the electronic/digital public services and direct forms. This may be related to the size of the municipalities studied and their financial and technical resources. We assume that the management of small and medium-sized

municipalities often believes that there is no need to prioritize digital forms of communication and public services due to the size of the territory/number of inhabitants in a small settlement. Another reason given by the management of small municipalities is an age structure of the population. By the research results, people of post-productive age represent on average more than a quarter of the population in smaller municipalities. It is generally assumed, and confirmed by our research that these people have lower levels of digital literacy. However, in the future, the management will have to expand the offer, as the number of users with digital skills is constantly increasing.

Communication is focused heavily on traditional forms. Despite the high use of websites and some social media, many local governments still rely on email communication and traditional forms of communication, which potentially hinders the availability of information for certain demographic groups, especially people of post-productive age and socially disadvantaged groups.

The insufficient use of transparency tools is a significant problem. Only a few local governments use tools such as open data portals or cloud storage, which hinders transparency efforts and slows down digitization and the building of an open data system.

Tools such as e-democracy platforms and electronic voting are rarely used, which indicates limited citizen participation in decision-making and limits the increase in engagement in the context of participatory democracy.

Another problem is a low co-production of public services in small local governments. While some local governments offer electronic public services and share knowledge, others have problems with the implementation of participatory planning or participation in general.

The results show that the size of the municipality affects the level of use of smart governance tools. Larger municipalities tend to use smarter governance tools more than smaller ones. In terms of the nature of the tools, the size of the municipality has a greater impact on the use of communication tools and tools focused on participatory processes.

Although a significant gender dependency has not been identified, the age of the mayor and the level of education may have an impact on the implementation of smart governance tools. The research also shows that the age of the mayor has an impact on the use of transparency tools and partly also on the co-production of public services, while the dependency on participation tools is mainly demonstrated in relation to the mayor's education.

According to our findings, another important factor in smart governance implementation is an existence of strategic documents. The results show that the existence of a development plan seems to be positively associated with the implementation of smart governance tools.

Based on our findings and empirical evidence, we have identified the following challenges for small local municipalities in Slovakia in the area of smart governance tools. The current challenge is to bridge the digital divide between users of smart governance tools through inclusion. It is important to use such forms of tools that ensure fair access to information and communication technologies for all citizens. The second current challenge is a continuous strengthening of digital literacy. Support for the development

of digital skills should be provided both among the inhabitants and employees of local governments, as it is necessary for the effective use of smart governance tools.

However, small local governments will not be able to cope with these challenges without targeted support from the state. Support and resources tailored to the specific needs of small local municipalities can help overcome specific challenges and help them move forward in smart governance.

Overall, the research emphasizes the need for further efforts to support the adoption of smart governance tools in Slovak local governments. By addressing the identified problems and providing targeted support, local governments can use these tools to enhance and increase transparency, citizen participation in governance and public service delivery, which will ultimately lead to improved governance and quality of life for their residents.

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Planning Sustainable and Resilient Waterfronts in the Mediterranean _ Insights from Athens and Lisbon

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Abstract. Urban waterfront development is a major challenge in spatial planning around the world, given the ongoing climate crisis. Mediterranean cities, particularly those with a historic center and a port, are important due to the increasing trends of coastalization, touristification, and overtourism, all of which threaten the local identity, sustainability, and resilience of their waterfronts. The article compares Athens and Lisbon to determine whether and how development and planning practices and policies affect the quality and sustainability of coastal ecosystems. A special focus is given to how both cities have ensured the spatial continuity of their waterfronts and their integration into the urban fabric and daily life. To address the research question, a multifactorial methodology, based on spatial criteria, is developed to assess the two cases and identify essential factors in their waterfronts' quality and dynamics. The proposed methodology seeks to divide the Athens and Lisbon waterfronts into pockets so as to better understand their characteristics and assess the role of planning in their sustainability. Key parameters related to waterfront planning that played a critical role in shaping the research context are: I) its existence and connection to urban planning; II) its ability to address current challenges and ensure the public character of the shore; and III) implementation barriers and local consequences. The article concludes with findings that open new paths of research and consideration on waterfront planning and its role in urban development.

Keywords: coastal cities · sustainable urban development · waterfront planning · spatial policies · typological classification · resilient cities and communities

1 Introduction

Waterfront planning is at the forefront of research interest due to the critical role it plays in coastal developmental policies. However, it has gained special importance in the last 20 years, owing to the climate and energy crises as well as rising trends of coastalization, touristification, and overtourism, all of which threaten the identity, viability, and resilience of coastal cities and their waterfronts [1–4]. Indubitably, the current conjuncture has led to significant changes in the relevant problematic, affecting the formulation

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of coastal policies at the international and European levels. The concern focuses on how coastal cities can effectively deal with these challenges while preserving their identity [5]. The answer is not easy. Nonetheless, the key issue is the need to reconsider coastal planning with a focus on adaptability to constantly changing circumstances, as well as the prioritization of the following principles: a) protecting the coastline; b) managing natural and cultural resources; c) adapting to climate change impacts; d) ensuring vibrant public coastal areas; and e) reinforcing new governance structures and participatory processes.

Contemporary evidence indicates that the qualities and vulnerabilities of each case preclude the unquestioned implementation of development and planning models that do not correspond with the unique characteristics of the locales and their ecosystems [6–9]. Experience has shown that preserving the sustainability of urban coastal fronts is only possible if they are integrated into the overall planning of their cities. Basic issues in this direction include ensuring the waterfronts' spatial continuity and integration into the city, and utilizing public space as a uniting feature between sea and city.

In this context, two cities are chosen: Athens and Lisbon, which have similar qualities and dynamics but appear to be taking distinct approaches to the development and planning of their waterfronts. The goal of their simultaneous monitoring is to identify good practices and potential barriers to ensuring their quality and local identity [5]. On the one hand, Athens' waterfront has numerous unresolved concerns such as coastline deterioration, coastalization, multifunctionality and incompatible uses, accessibility, sustainable mobility, and a lack of public space. Nonetheless, the successful completion of continuing interventions is projected to preserve the spatial continuity of the urban coastal front, even if its connection to the city's key locations remains a low priority. On the other hand, Lisbon can serve as a good paradigm, as it has made significant progress in ensuring the connectivity of its riverfront to the city.

The two cases are studied using a multifactorial methodology and spatial criteria that were successfully applied in Athens [10] and are now being tested in Lisbon with the goal of drawing conclusions about the sustainability of the two cities' coastal planning (Sect. 2.2). The typological classification of Athens' and Lisbon's waterfronts is presented as an essential tool for better understanding and evaluating their spatial continuity and integration into the city. Key parameters related to waterfront planning that played a critical role in shaping the research context were: I) its existence and connection to urban planning; II) its ability to solve current challenges (e.g. climate crisis, green development, blue economy) and ensure the public character of the shore; and III) implementation barriers and local consequences (i.e. participants, stakeholders, spatial focus areas, sectoral priorities, citizen participation). The goal of combining the above parameters is to assess the effectiveness of coastal planning at the local and supralocal levels for achieving *sustainability* (i.e. quality, spatial continuity, city integration, etc.) and *resilience objectives* (i.e. climate adaptation, energy neutrality, circular economy, sea level rise, water quality, disaster management etc.). It is stated that this correlating method yields significant discoveries that will add to current discussion and open up new challenging paths in the creation of a more comprehensive coastal policy.

The research on the two waterfronts concentrates on the era following the 1980s, when the current dispute about their development began. References are also made to earlier periods where planning interventions influenced waterfront identity and its

supra-local role (i.e. the early 1900s, a period linked with the installation of significant infrastructure projects such as embankments, marina development, road/railway extensions, etc.).

The article is divided into seven sections. The first presents the research object; the second refers to the spatial field of study and the research methodology; the third covers the issue of sustainable waterfront development management and the importance of planning (discussion, policies); the fourth investigates the spatial transformations on the waterfronts of Athens and Lisbon and evaluates the factors that contributed to the current situation and its dynamics; The fifth defines the proposed methodology for the typological classification of their waterfronts, with the goal of understanding their specificities and evaluating the role of planning in their sustainability and resilience; the sixth presents the findings from the parallel investigations, while the seventh expresses thoughts on a more sustainable waterfront development.

2 Spatial Reference and Methodology

This section briefly describes the spatial field of investigation (Athens and Lisbon) and the research methodology (Sects. 2.1 and 2.2, respectively).

2.1 Athens' and Lisbon's Waterfronts as Research Laboratories

The selection of Athens and Lisbon was not at random. Both cities are coastal capitals of Mediterranean countries (Greece, Portugal) with a rich natural and cultural heritage, a long coastline dotted with cities and settlements, and a vibrant network of international ports. Both cities have historic centres and ports that play an important role in the global transport network. In addition, Athens and Lisbon have waterfronts that are diversified and very fragile. However, they are also active because of the supralocal uses they incorporate, mainly in the shipping, tourism and services sectors. At the same time, the study sites have similar population densities and dynamic trends in coastal development, tourism and overtourism. The Athens waterfront studied is part of five of the six coastal municipalities of the South Athens regional unit (i.e. Kallithea, Moschato-Tavros, Palaio Faliro, Alimos and Elliniko-Argyroupoli), while the Lisbon waterfront belongs to the homonymous municipality, which is divided into 24 sub-units known as "freguesias" (Fig. 1).

In order to provide a more comprehensive assessment of the two cases, the study was carried out at two geographical levels (metropolitan - municipal/inter-municipal). The focus was on their waterfronts (Figs. 1 and 2). More specifically:

Metropolitan Region: In the Athens Metropolitan Region, the western end of the study area (Faliro) is 5 km from the port of Piraeus and 9 km from the historic centre of the city. Instead, a part of the Lisbon Metropolitan Region's waterfront serves as a port [i.e. container terminals (*Alcantara* central area, *Beato* eastern district), cruise terminals (*Santa Apollonia*), and three terminals for maritime connections to the southern part of the Tagus (one in the western part of *Belém* and two in the central)]. The historic centre is adjacent to the riverfront (*Baixa* area), and *Praça do Comércio* serves as the city's main opening to the river.

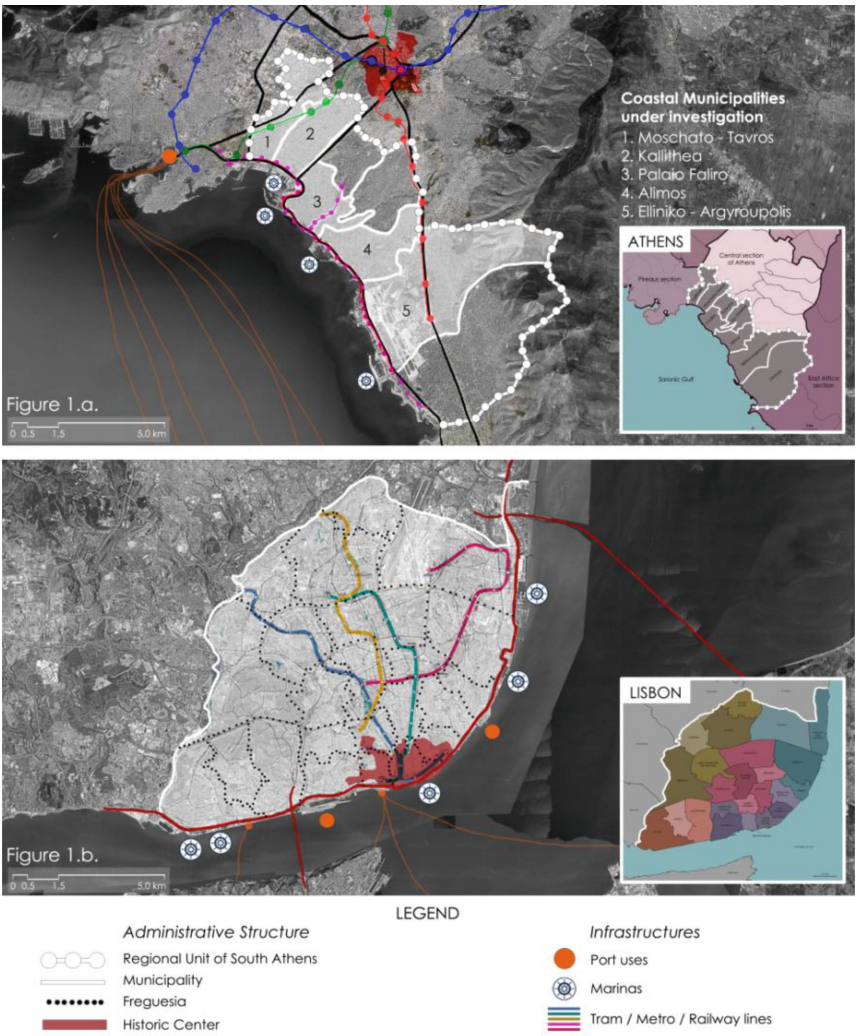

Fig. 1. (a) Athens (Regional Unit of South Athens) and (b) Lisbon [own elaboration]

Municipalities*:* The two waterfronts studied are characterised by two poles of supralocal extent. Athens' two poles are *Faliro* (west) and *Helliniko* (east), while Lisbon's are *Belém* (west) and *The Park of Nations* (east). These spatial units are of particular relevance because they serve as the cities' main watergates; yet, planning decisions have resulted in differing perspectives on their long-term viability and effective transformation into landmarks. The *Praça do Comércio* in Lisbon serves as both a recreational destination and a landmark. In contrast, works on the rehabilitation of *Faliro Bay* and *Helliniko* continues in Athens, with persistent conflicts over the *Helliniko* coastline's public nature and future physiognomy. In both cases, the study focuses on the waterfronts between

the coastal avenue and the water, i.e. the Saronic Gulf in Athens and the Tagus River in Lisbon.

2.2 Methodological Approach and Main Steps of Investigation

The proposed methodology seeks to analyze and asses the spatial-functional evolution of the studied waterfronts. Special emphasis is placed on: a) the development model / investment strategy; b) planning concepts (direction and priorities); c) management methodology; d) land ownership / development policy; and e) legal framework. The methodology was previously tested on the Athens waterfront and is currently being applied in Lisbon. The aim is to link the two cases and draw conclusions on the sustainability of their waterfronts and the key factors that have contributed to this.

In the context of this spatiotemporal methodology, the main exploration parameters were: (a) ***coastline*** (geomorphological features, natural and cultural wealth, degree of alteration); (b) ***coastal urbanization*** (form, structure, intensity, type, dynamics, rate of change); (c) ***transport networks*** [category (roads, public transportation means, etc.), organisation/correlations (hubs-flows), range of service)]; (d) ***technical infrastructure projects*** (type, location, extent, range); and (e) ***human activities and functions*** (i.e. type, intensity, compatibility, range) focusing on those, that have determined the supra-locality of the investigated areas (i.e. services, trade, culture, sport, recreation, tourism). The above parameters provide the framework for defining the reference themes relating to the factors driving the development of the areas (1st study) and the criteria for assessing the spatial and functional transformations that have taken place in the coastal municipalities studied (2nd study) and their waterfronts (3rd study). The criteria are: (i) ***coastline***; (ii) ***natural and cultural wealth***; (iii) ***centrality of the location*** (linked to and dependent on the prevailing conditions of accessibility, connectivity, proximity); (iv) ***density of the built-up area***; (v) ***use of land/buildings***; and (vi) ***public space***. In order to put this methodology into practice, specific surveys were carried out to estimate/evaluate spatio-functional transformations and to study development and planning options at the spatial level of the coastal municipalities of the study areas, as well as to identify pockets using a typological classification [10].

The implementation of the methodology in the two cases resulted in discrete coastal areas (pockets) with different levels of vulnerability/dynamics. Three pockets have been identified on the Athens seafront (i.e. $\mathbf{A^{Ath}}$, $\mathbf{B^{Ath}}$ and $\mathbf{C^{Ath}}$), and five on the Lisbon's riverfront (i.e. $\mathbf{A^{L}}$, $\mathbf{B^{L}}$, $\mathbf{C^{L}}$, $\mathbf{D^{L}}$ and $\mathbf{E^{L}}$), with varied planning priorities due to diverse features/needs (Sect. 5). Both investigations relied on geographical analysis and evaluation methods. Primary sources included literature, legislation, planning proposals, aerial photographs, databases and fieldwork.

3 Sustainable Waterfront Planning: The Current Debate

This section provides a brief overview of current debate on sustainable waterfront development and policies, focusing on the last two decades, and concludes with two key planning concerns.

3.1 The Discussion

In the 1970s, coastal planning put economic expansion ahead of environmental and cultural preservation. Since 1980, waterfront planning has grown dramatically, with a focus on spatial concerns. The emphasis was on revitalizing urban coastal fronts with architectural interventions that would increase competitiveness by using natural and cultural assets. Until the 2000s, there was concern about the environmental impact of maintaining the coastal areas' natural balance and biodiversity [13, 14]. From 2000 to 2020, coastal planning approaches became more multidisciplinary and flexible. As a result, a more in-depth conversation about coastal planning arose, with the purpose of addressing current issues such as climate adaptation, energy neutrality, sustainable resource management, and the incorporation of waterfront planning into overall city planning [15–17]. In this regard, waterfront master plans have begun to include critical themes such as water management, the circular economy, and sustainable mobility, all within the larger context of green and blue economy, natural disaster management, and Agenda 2030's 17 sustainable development goals.

To this end, it is essential to preserve the spatial continuity of the coastal fronts and their unique interaction with the water, and efforts are underway to integrate the fronts into the urban fabric and the daily lives of residents /visitors. Public space, land use planning, and coastal accessibility are becoming increasingly significant [10, 18, 19]. Undoubtedly, the current discourse highlights the importance of maintaining connected waterfronts and integrating them into the urban fabric through liveable public spaces, sustainable mobility and soft multifunctionality. The focus is on disaster management, building the resilience of local communities and integrating coastal and marine planning through a multi-criteria approach that takes into account environmental, cultural and socio-economic considerations [10, 20, 21].

3.2 The Policy Scenery

The presentation is divided into two main levels: global and European, with key topics including coastal and marine management, environmental protection (natural and cultural), climate change adaptation, and natural disaster management. Specifically:

Global Level: Sustainable development initiatives have existed since the 1970s. Since then, regulations have been devised to control coastal and maritime areas and protect environmental quality through territorial resource management [22–25]. Between 1980 and 2000, there was a focus on integrated coastal resource protection, which included initiatives to connect the land and marine environments [26]. During the same period, biodiversity and the natural and cultural environment were popular topics [27, 28], and policies addressing climate mitigation [29] and natural disaster management [30] were established. During 2000 - 2020, there was a significant gap in integrated coastal zone management, with no new policies developed despite 20 years of policy modifications. The goals/objectives for coastal planning state initiatives in a larger policy framework [31]. However, the development model focuses on more integrated approaches to sustainable development, climate change, resilience, as well as natural disaster management [10, 32–34].

European-EU Level: A similar, holistic approach to Europe and the EU (as part of related research [10]) focuses on safeguarding both natural and cultural assets in the 1970s and 1980s [35, 36]. Integrated Coastal Zone Management (ICZM) developed as an essential protection/control strategy in the 1990s, with suggestions for implementation issued many years later [37]. Since 2000, the maritime space has attracted significant attention [38, 39], and rules addressing climate change are being adopted [40–42]. The convergence of development-oriented policies towards an integrated coastal and maritime policy framework, as well as a gradual transition to energy neutrality, is currently ongoing [44, 45].

3.3 Key Planning Concerns for Resilient Waterfronts

The following concerns emerge from the simultaneous follow-up to the current debate on the development and planning of waterfronts and related policies:

Development perspective: Environmental protection, climate adaptation, energy neutrality, cultural heritage management, and other critical characteristics should all be considered when developing a sustainable waterfront. To achieve sustainability and resilience, the concerns identified above require a transition to a completely new perception that focuses on new government structures and participatory planning.

Planning perspective: Spatial planning (density, land uses, mobility, connectivity, accessibility, public space, etc.) and coastal carrying capacity evaluation (evaluation methodologies, criteria, and indicators) should be prioritized. The emphasis should be on a multi-factorial study of the spatial-functional transformations of coastal fronts over time (timeline), in order to identify the critical factors that have played a key role in this direction.

4 Assessing the Dynamics of Athens' and Lisbon's Waterfronts

This section examines Athens and Lisbon at the metropolitan and municipal/intermunicipal levels, with emphasis on the latter. Firstly, it outlines their characteristics, transitions, and trends. Secondly, it focuses on waterfront master plans and planning, referring to their broader area or specific sectors (i.e. transportation, infrastructures).

4.1 Features, Particularities and Spatio-Functional Transformations

After applying the proposed methodology and the criteria (Sect. 2.2.) in both cases, the following outcomes are reached (Fig. 2):

Athens. From the end of the war until the 1960s, the Athens waterfront remained natural and the coastal area became a famous tourist destination. The city-sea dynamic changed dramatically in the 1960s, when the coastal zone became both a transit center (with motorways and the Hellinikon airport) and a recreational and tourist destination. After 1970, the urbanisation of the waterfront increased due to the expansion of vacation homes and tourism. During this decade and beyond, the coastal topography underwent

significant transformations as a result of initiatives such as embankments (particularly in Faliro Bay), new roadways (e.g. Vouliagmenis Avenue), marina development (e.g. Palaio Faliro and Alimos), the operation of the Hippodrome (current Stavros Niarchos Foundation Cultural Center), and sports facilities.

Lisbon. The development of the city's port led to the construction of huge embankments (1887), occupying a significant part of the coastal zone for industrial purposes. In the late 1930s, the Portuguese World Exhibition in *Belém*, together with the development of the embankments and coastal boulevards in front of *Praça do Comércio*, shaped the cultural and recreational character of the waterfront. By the late 1970s, the port had built commercial stations and infrastructure such as the metro system and the main bridge linking the city to the south side of the river. Lisbon's deindustrialisation in the 1980s led to urban voids, especially in the eastern part of the city. Expo'98 reinvigorated the relationship between the city and water, leading to the establishment of *Parque das Nações*. In the 2010s, the historic quarter was rebuilt, changing *Praça do Comércio* into a liveable open public space (Fig. 2). Nine green corridors were created in 2012 (with more under construction) to connect key areas of the city, including the riverfront, while addressing climate change mitigation/adaptation.

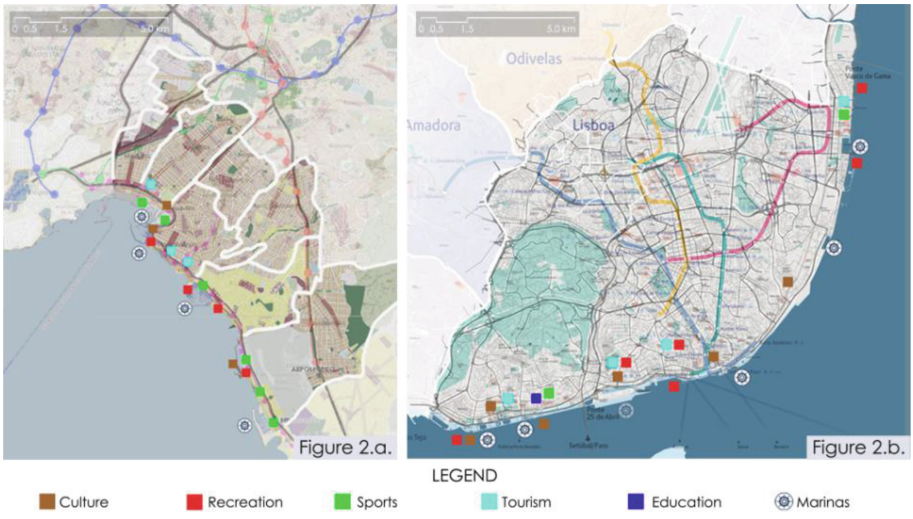

Fig. 2. Human Activities of Supralocal Scope in: (a) Athens and (b) Lisbon [own elaboration]

Particularly interesting is the comparative monitoring of the two cases, from which the following emerges:

Athens and Lisbon. Following the concise demonstration of their transformations, some disparities may be identified between the two case studies. Specifically:

In the 1970s, the Athens waterfront underwent significant changes, with natural shorelines preserved in certain parts. The area is rich in both natural and cultural features, but access to it is limited due to transport and connectivity issues. Density along the coast

varies between municipalities. The urban coastal zone is highly concentrated. There are few public spaces with a local character [19]. Both *Faliro* and *Elliniko* will be transformed into large green parks.

Lisbon's waterfront, on the other hand, has evolved since the late eighteenth century, with different areas designated to serve the Port. The city's cultural significance is evident in the central and western coastal areas, although the entire riverfront retains a cohesive identity thanks to efficient transport and sustainable movement. There is a significant population above the coastal road. This is despite the fact that the coastal zone has several high quality public spaces.

4.2 The Effects of Development and Spatial Policies on Waterfronts' Identity

After reviewing the characteristics and features of the Athens and Lisbon coastlines (Sect. 4.1.), the focus of this section is to assess the impact of the development and planning alternatives that have been put forward and implemented so far on the structure, character and dynamics of the two examples.

Athens. There have been several different plans for the Athens waterfront. The Stavros Niarchos Foundation Cultural Centre (SFNCC), the Olympic facilities and the marinas are examples of supra-national developments that have increased the significance of the seafront, while at the same time posing serious local consciences and risks. The current approach to the area is fragmented. It lacks a coherent vision. The coastal zone is referred to as a hyper-local zone in the Athens-Attica Regulatory Plan (Law 4277/2014), but there are no defined guidelines and it has not been amended. Except for Elliniko-Argyroupoli, the current General Urban Plans (GUPs) do not include the waterfront. The Presidential Decree of 2004 (Government Gazette 254/D/2004), the only attempt at an integrated planning strategy for the coastal area from Faliro to Agia Marina in Kropia, excludes Faliro and Elliniko, which are treated independently. The lack of comprehensive, clearly defined long-term planning at regional and inter-municipal level makes cooperation and coordination between stakeholders problematic.

Lisbon. Lisbon's coastal planning reflects an ambitious and unified vision, and the 2008 General Intervention Plan for the Waterfront (PGIFR) guides its implementation. It also appears to be consistent across the different planning stages since the 1990s. At the same time, the 1992 Lisbon Strategic Plan (PEL) set out a new urban development framework that focused on connecting the city to the river while protecting the port. Its urban planning decisions were incorporated into the 1994 General Municipal Plan (PDM), which included proposals to increase river connectivity. This logic is in line with current planning approaches (Strategic Vision: Lisbon 2002–2012, Lisbon Strategic Map 2010–2024, PDM of 2020) and promotes sustainable development, preservation of local identity, environmental sustainability and promotion of culture. Planning projects benefit from cooperation between a single municipality and the port authority. This leads to more efficient decision-making processes.

Athens and Lisbon. The comparative monitoring of the two cities confirms the significance of the above conclusions, which show that:

On the one hand, Athens' waterfront landscape is constantly evolving. This has attracted the interest of investors and a great deal of planning. Over the last sixty years, significant supralocal infrastructure has been developed. These include the international airport, marinas, Olympic facilities and the Stavros Niarchos Foundation Cultural Centre. Fragmented coastal planning, lack of vision and inefficient management prevent spatial continuity and integration of the waterfront into Athens city.

On the other hand, the strategy of Lisbon is more coherent and better coordinated. The city's planning activities are evidence of a commitment to the preservation of the area's cultural and historical identity, while at the same time promoting long-term growth. The successful regeneration of a riverfront is based on a clear vision, long-term planning concepts and efficient decision-making processes. These guarantee its integration into the city and everyday life.

5 Athens' and Lisbon's Waterfronts Spatial Continuity and Integration into the City: A Typological Classification Based on Spatial Criteria

This section briefly presents the results of the classification of the Athens and Lisbon waterfronts using the specified criteria [(i)-(vi)] (Sect. 2.2). The goal is to highlight the unique aspects of each case (pockets and features), while also highlighting pockets with similar demands and dynamics in both cities.

5.1 Athens: A Seafront in Transition

The study found three distinct areas ('pockets') inside Athens' shoreline and defined them based on their distinctive features/dynamics, as follows: **Pocket A^{Ath}**: *Culture and Recreation Center of Faliro*; **Pocket** B^{Ath}: *Coastal Zone of Local/Supralocal Character in Transition*; and **Pocket C^{Ath}**: *Metropolitan Pole: Recreation Park of Elliniko-Agios Kosmas*. **Pockets A^{Ath}** and **C^{Ath}** have the potential to be supranational poles. However **Pocket B^{Ath}** has a local and supralocal scope [10]. Specifically:

Pocket A^{Ath}: *Culture and Recreation Center of Faliro:* This area, which administratively belongs to the municipalities of Moschato-Tavros and Kallithea, is very important for two reasons. First, it serves as the main gate to the sea for the historic city of Athens (via Syngros Av). Second, the supralocal aspect of its operations makes it a unique landmark. In particular, the coexistence of leisure and sports infrastructures, as well as tourism and cultural activities, creates an ideal environment for the development of a super-local coastal pole that will have a significant impact on the seascape, especially once the planned marine park with indoor and outdoor facilities is completed.

Pocket B^{Ath}**:** *Coastal Zone of Local/Supralocal Character in Transition* This area belongs to the municipalities of Palaio Faliro and Alimos. It is characterised by a distinct spatial and functional organisation, natural and cultural attractions and landscapes, and potential for recreation, sports and tourism development. The link between the city and the sea has been gradually restored in various sub-areas, creating favourable conditions for the future.

Pocket C^{Ath}: *Metropolitan Pole: Recreation Park of Elliniko - Agios Kosmas* This area administratively belongs to the municipality of Elliniko-Argyroupoli. This part defines a high concentration of conflicting coastal activities: recreation and sport (i.e. Olympic facilities). However, what made this stretch of coastline famous throughout the world is the ongoing debate about the regeneration of the area of the former Athens International Airport, until it was relocated to Spata (*Eleftherios Venizelos*). According to current plans, this place will be the city's new landmark. A series of interventions (e.g. architectural, urban, transport, etc.) will be crucial in this direction, as well as an increase in tourism, sports/leisure activities and the construction of a coastal park to connect the city to the sea (part of Poseidonos Avenue will be underground).

5.2 Lisbon: A Liveable Riverfront

The study pointed out five distinct areas ('pockets') along Lisbon's riverfront based on their features/dynamics, as follows: **Pocket A^L**: *Belém Cultural Center*; **Pocket B^L**: *Alcantara Port Uses Area*; **Pocket C^L**: *Coastal Historic Center Area*; **Pocket D^L**: *Beato Port Uses Area*; and **Pocket E^L**: *Metropolitan Pole of the Park of Nations*. **Pockets A^L**, **C^L**, and **E^L** are supranational poles, whereas **pockets B^L** and **D^L** are parts of the urban riverfront with mainly port-related functions. More specifically:

Pocket A^L: *Belém Cultural Center:* is a dynamic site with a high degree of spatial coherence along the riverbank. In terms of the specific part's connection to the city, the 'upstream' and 'downstream' parts of the coastal boulevard have been treated as a single unit in terms of use (mainly cultural and recreational) and public space. However, the coastal road and railway lines act as barriers.

Pocket B^L: *Alcantara Port Uses Area:* has seen significant infrastructure development in recent years, particularly in transport and public services. In addition to the port's uses and administrative services, the renovation of old buildings has revitalised the immediate cultural and social urban environment. New parks and recreational areas have linked the coastal zone to the urban fabric, providing spatial continuity in areas without port activity.

Pocket C^L: *Coastal Historic Center Area:* represents the opening of the city to the water. It is a supralocal pole in the immediate proximity of the historic center, with cultural, commercial, and touristic significance. The area maintains spatial continuity and integrates with the urban environment. The narrow coastal road and lack of railway along the riverbank, together with planned efforts to improve the public realm and support sustainable mobility, appear to be positively integrating the area into the city.

Pocket D^L: *Beato Port Uses Area* is primarily used for port operations. The western edge (close to the historic city centre) includes a cruise terminal and public space, providing spatial coherence with other redevelopments around the central square. To the east, the *Santa Apollonia* railway station (above the coastal road) and the port container depot (below the coastal road) separate this area from the urban fabric.

Pocket E^L: *Metropolitan Pole of the Park of the Nations*: it was built in the area where the Expo of 1998 was set up for the first time. The Expo has played a significant role in changing the character of the surrounding area, mainly by incorporating residential,

business, leisure and tourism activities. Although there is spatial continuity with a well-planned public realm, there is a lack of integration into the urban fabric. The area has taken on the characteristics of an isolated urban environment. It faces difficulties at a local level, despite sufficient hyper-local accessibility.

5.3 Athens and Lisbon: A Comparative Approach of Their Waterfronts

Following the study of 'pockets' on the investigated waterfronts, it appears that both cases have considerable similarities (Fig. 3).

First, certain areas of waterfronts have been identified as potentially supralocal poles, namely **Pockets A^{Ath}** (*Faliro Bay*) and **C^{Ath}** (*Elliniko*) in Athens, and **Pockets A^{L}** (*Belém*), **C^{L}** (*Historic Center*), and **E^{L}** (*The Park of the Nations*) in Lisbon. On the one hand, **Pockets A^{Ath}** (*Faliro Bay*) and **C^{L}** (*Historic Center*) share parallels in how they depict the city's relationship with the water, while both emphasize sports, culture, and recreation. On the other hand, **Pockets C^{Ath}** (*Elliniko*) and **E^{L}** (*The Park of the Nations*) arise independently of the metropolis that basically surrounds them, without necessarily forming interaction and networking links. The result is a unique situation: Autonomous neighborhoods are organised within the urban fabric of their cities.

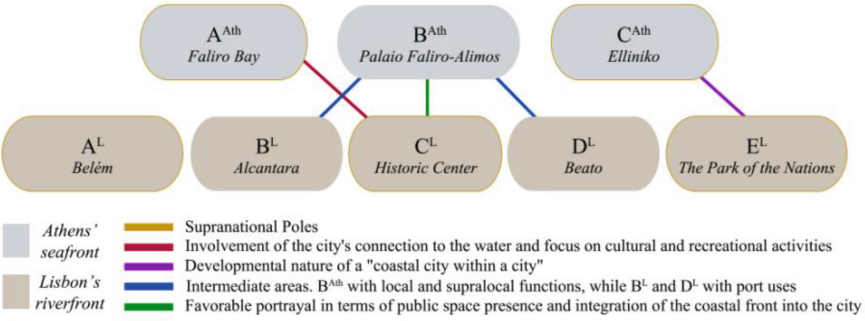

Fig. 3. Comparative analysis of Athens and Lisbon waterfront pockets [own elaboration]

Second, in terms of the wider areas surrounding the identified pockets, the following are highlighted: **Pocket B^{Ath}** (*Palaio Faliro-Alimos*) in Athens' waterfront balances local and supralocal functions, while **Pockets B^{L}** (*Alcantara*) and **D^{L}** (*Beato*) in Lisbon's waterfront face serious urban sustainability, waterfront access and environmental quality challenges due to intensive port activity.

Third, the spatial continuity of the waterfronts and their integration into the urban fabric is a concern in both cities. Public space plays an important role in both cities. In Athens, the arrangement of public space along the coast is inadequate, despite previous attempts to maintain spatial continuity along the water. Unfortunately, the issue of connecting the waterfront to surrounding public spaces does not seem to be resolved in the overall logic of green corridor design. Regarding the two super-local waterfronts [i.e. **Pockets A^{Ath}** (*Faliro*) and **C^{Ath}** (*Elliniko*)], public space concepts are promising, but

no significant action has been taken. On the other hand, Lisbon has made tremendous progress in developing the entire riverfront, with the exception of **Pocket D^L** (*Beato*), while in Pocket C^L (*Historic Center*) there have been notable efforts to integrate the urban front into the metropolis.

6 Concluding Remarks

The following are the findings from the correlated follow-up of the two cases in the broader context suggested by the key parameters (I, II and III) that have established the basic framework of the investigation (Sect. 2.2.):

- ***I) The existence of waterfront planning and its connection to urban planning***

  Waterfront Planning: Both cities have plans for their waterfronts. In Athens, however, these plans are generally out of date and fragmented. In Lisbon case, however, coastal planning is based on a more comprehensive rationale.

  Coastal and City Planning: In Athens, the coastal front is separated from urban planning. This affects spatial and socio-economic coherence of the city. In Lisbon, on the other hand, despite the existence of specific plans that deal mainly with the port, there are links between the riverfront and the city as a whole. This is beneficial to the quality and sustainability of the waterfront.

  Vision: Athens lacks a coherent, long-term vision for its waterfront and its relationship with the city. Lisbon, however, has a more comprehensive approach in recognition of the importance of its waterfront to the growth of the city.

  Focus Sectors: Athens seeks economic growth mainly through the expansion of tourism/recreation, but culture is not promoted in terms of sustainability or landscape protection. Lisbon, on the other hand, encourages the promotion of local identity and the landscape in order to boost tourism.

  Participants -Stakeholders: In Athens, there is a permanent inter-municipal problem, which raises concerns about cooperation. In Lisbon, despite incompatible objectives, significant progress has been made in co-operation between the municipality and the port authority.

- ***II) The ability of waterfront planning to address current challenges and ensure the public character of the shore***

  Climate - Energy Neutrality: Athens is in the early stages. Infrastructure projects (e.g. sewerage, flood protection, undergrounding of coastal road sections) are under development, while consultations on sustainable mobility plans are ongoing. Lisbon, on the other hand, seems to have demonstrated a more proactive approach, taking into account environmental factors and promoting energy efficiency solutions. This includes implementing green corridors and tree planting initiatives (throughout the city and along the water) to mitigate the adverse effects of pollution and climate change. To reduce the risk of damage from flash floods, natural drainage systems and nine rainwater retention stations are being implemented.

  Natural and Cultural Heritage and Landscape: Athens is at an early stage in addressing these issues, while Lisbon has made significant progress since 2008 with green initiatives in urban planning, renewable energy and water management (Tagus estuary clean-up and wastewater reuse), as well as the circular economy.

Coastalization: In Athens, the increase in coastal urbanisation has resulted in dense urban areas with insufficient open spaces for public use and recreation. Lisbon, on the other hand, by providing accessible open spaces and well-designed public footpaths throughout the city and coastal zone, has made concerted efforts to minimise the impact of coastal urbanisation.

Supralocal vs. Local: The Athens waterfront faces significant problems. These include the creation of large-scale activities and infrastructure that are incompatible with residential areas, and overexploitation of resources, which often leads to conflict. The current range of functions and the complexity of transport networks (e.g. roads, public transport networks, and marinas) exacerbate spatial pressures. This has a number of local impacts on both the environment and the city. On the other hand, Lisbon is better placed to deal with some of these problems because of the hyper-localised nature of its riverfront.

The Public Character of the Shore: Some areas of the Athens seafront are preserved. In particular, the **Pocket B^{Ath}** (*Palaio-Faliro-Alimos*) provides access to the sea, while the **Pocket C^{Ath}** (*Elliniko*) faces obstacles such as limited accessibility, inadequate networking, poor quality and security issues. On the other hand, Lisbon stands out for maintaining a strong public character along its entire riverside, with the exception of the parts designated for port use. The commitment to public space is evident in the continuous accessibility and open nature of the waterfront, fostering a sense of community and providing recreational opportunities for residents / visitors.

- ***III) Implementation barriers in waterfront planning and local consequences***

Pockets: In Athens, regeneration initiatives in the **Pockets A^{Ath}** (*Faliro*) and **C^{Ath}** (*Elliniko*) are not progressing as planned. On the other hand, projects concerning Poseidon Avenue and wider water management to prevent flooding are underway. **Pocket B^{Ath}** (*Palaio Faliro-Alimos*) has a better situation, especially in areas where the city-sea connection has started to work. In the case of Lisbon, there is significant planning activity in the **Pockets A^{L}** (*Belém*), **C^{L}** (*Historic Center*) and **E^{L}** (*The Park of the Nations*). On the other hand, the implementation of regeneration plans in **Pockets B^{L}** (*Alcantara*) and **D^{L}** (Beato) is very limited due to their focus on port facilities.

Planning Priorities: In the Athens waterfront, in the **Pocket B^{Ath}** (*Palaio Faliro-Alimos*), the focus should be on preserving the coastline, protecting natural resources and providing quality public spaces. The ongoing planning in **Pockets A^{Ath}** (*Faliro*) and **C^{Ath}** (*Elliniko*) is expected to deliver results in the coming years. On the other hand, along Lisbon's riverbank, planning strategies in **Pockets A^{L}** (*Belém*) and **C^{L}** (*Historic Center*) seek to sustain cultural identity while creating vibrant public spaces. **Pocket's E^{L}** (*The Park of the Nations*) regeneration plan is carried out independently of city planning, with a focus on the establishment of a vibrant urban core featuring recreational activities and facilities. Finally, **Pockets B^{L}** (*Alcantara*) and **D^{L}** (*Beato*) demonstrate a variety of environmentally friendly port management practices, with a focus on community sustainability.

7 Planning Sustainable Urban Waterfronts: Open Issues

The simultaneous examination of the three key parameters (I, II and III) in both cities described above (Sect. 6) raises the unresolved question of how to ensure liveable waterfront planning. In this context, the planning challenges of sustainability are the preservation of the spatial continuity and integration of the waterfront into the urban fabric, while the resilience issues are mainly climate adaptation and energy neutrality, circular economy, water quality and disaster management. In this respect, the main findings from the two cities include the following:

Sustainability objectives*:* Both Athens and Lisbon include themes in their waterfront master plans to ensure the spatial continuity of the waterfront and varying degrees of integration into the city. The difference is that Athens' waterfront development is based on a more fragmented planning strategy, i.e. focusing on specific areas without a clear vision for the entire waterfront. Thus, the Athens waterfront has sections where steps have been taken to ensure sustainability by creating liveable urban spaces and coastal routes, as in **Pocket B^{Ath}** (Palaio Faliro-Alimos), while **Pockets A^{Ath}** (*Faliro*) and **C^{Ath}** (*Elliniko*) still have a long way to go, despite having master plans. In contrast, spatial continuity is guaranteed along a significant part of the Lisbon riverfront. Barriers are mainly located in the **Pockets B^{L}** (*Alcantara*) and **D^{L}** (*Beato*), where port functions are concentrated. The links between the riverfront and the urban fabric are maintained mainly through the public space, the land uses (leisure and cultural functions) and the quality of access in the **Pockets A^{L}** (*Belém*) and **C^{L}** (*Historic Center*), especially in the latter. The results show a significant difference in the way the two cities manage their waterfront gateways, i.e. **Pocket A^{Ath}** (*Faliro*) in Athens and **Pocket C^{L}** (*Historic Center*) in Lisbon, respectively.

Resilience objectives: There are major discrepancies along this axis. On the one hand, the adopted waterfront strategies in Athens show little concern for resilience objectives. It is only in the last decade that comprehensive green transport strategies and large-scale infrastructure projects with positive environmental impacts have been developed. In Lisbon, on the other hand, two components have been identified that have played an important role in making Lisbon the European Green Capital 2020. Firstly, the promotion of walking, cycling and public transport as means of sustainable mobility; and secondly, the focus on public space as a means of creating a vibrant network of green corridors along the waterfront and across the city.

The comparative study between Athens and Lisbon revealed weaknesses in the planning of the Athens waterfront. These weaknesses are mainly due to the lack of a clearly defined vision, inconsistent planning decisions, lack of implementation of strategic regional planning and lack of cooperation between administrative groups and key stakeholders. The research also found that the development of the Lisbon riverfront appears to be a success story, demonstrating interesting concepts of spatial continuity and integration into the city through an overall long-term strategy and mutually reinforcing best practices.

Regardless of how effectively the waterfronts have been used in the urban regeneration of the two cities, the study found that coastal planning must take into account the challenges posed by the current climate/energy and socio-economic crises [4, 10]. In these circumstances, coastal communities need to treat their waterfronts as an essential

natural and cultural element [5, 18]. Such an initiative requires close cooperation and sharing of best practices. In this respect, it is crucial to take into account local differences rather than the unquestioning adoption of development models. Last but not least, creating new and flexible governance structures and adopting democratic and participatory planning are equally important parameters.

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Evaluation of Geometric and Photometric Data Augmentation for Pedestrian Detection with Thermal Cameras

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Abstract. The capability to detect pedestrians using video surveillance systems is a fundamental task to assess the number of people in particular areas and to enable other applications like people tracking and trajectory estimation. Thanks to recent advancements of object detectors based on deep learning approaches, it is possible to localize pedestrians in recorded images with good accuracy. However, some limitations still exist. Most of the proposed solutions at the state-of-the-art deal with color RGB images, that could present privacy issues, hampering the deployment of such solutions. Moreover, changing the application scenario could worsen the performance, requiring time consuming fine tuning and transfer learning operation. In this paper, we respond to these issues by using thermal images analysis that can guarantee a higher privacy preservation instead of RGB data. In addition, a deep study on data augmentation techniques has been provided to generate more flexible trained models that could simplify their adoption in different scenarios without requiring additional acquisition, labeling work and fine tuning.

Keyword: Pedestrian Detection · Data Augmentation · Thermal Imaging

1 Introduction

Computer vision systems are increasingly deployed both in public and private sectors and video surveillance [1, 2], for example, to assess the presences and the flows of people, in several application scenarios of security [3], retails [4], mobility [5], etc. To detect the pedestrians by video cameras, many computer vision methods for object detection have been developed leveraging on machine learning solutions based on convolutional neural networks (CNN) [6]. Among the several proposed architectures, the YOLO approach [7] appeared to be one of the best solutions mostly thanks to efficient computational parameters guarantying higher detection speed with respect to other proposed region-detection methods [8–10], which is a fundamental characteristic for realizing real application scenarios, possibly requiring on-the-edge computations. Recently, different versions and different variants of the YOLO architecture emerged, in most cases increasing precision performance or optimizing computational aspects [11, 12].

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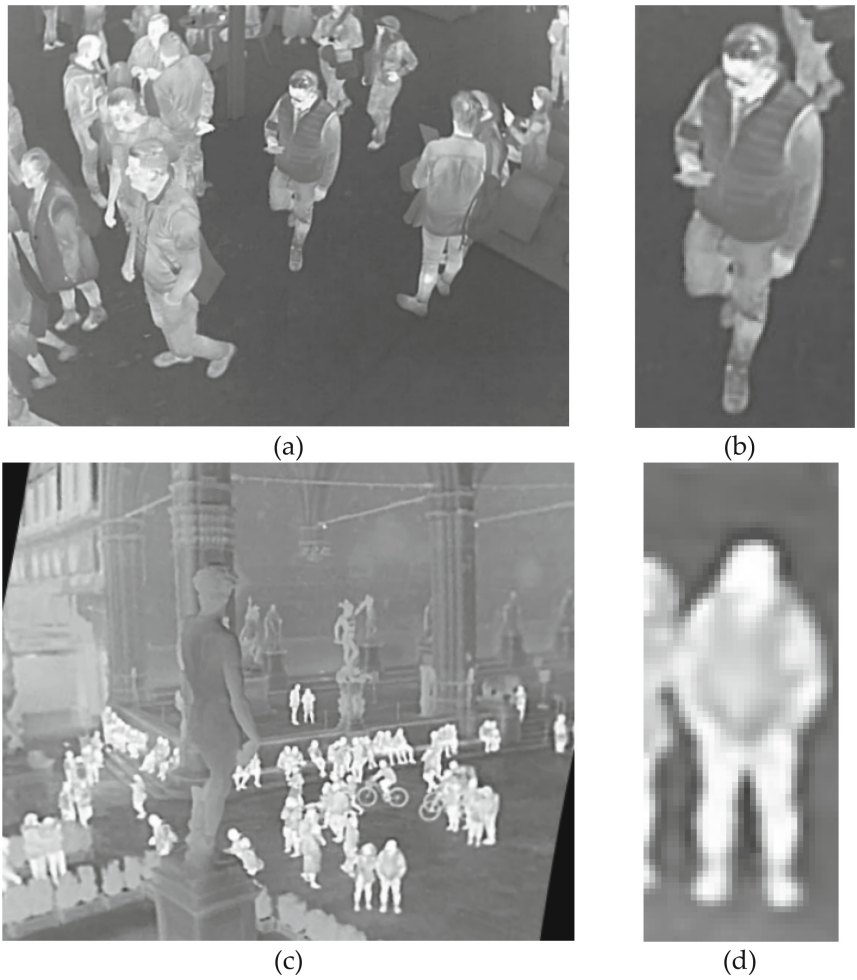
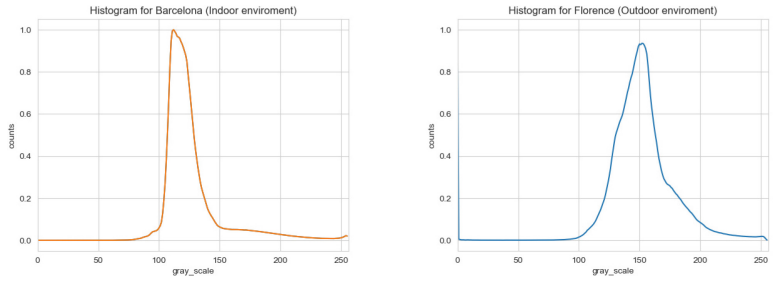


Fig. 1. (a) example of a thermal image acquired by a thermal camera near to the subject sampled from the Barcelona dataset, and (b) detail of a pedestrian in the scene. (c) a different example captured by a thermal camera placed far from the scene (Florence dataset), and (d) a single pedestrian in the scene.

Usually, CNN image object detectors are designed to work on color RGB images. However, video surveillance systems have to work in challenging scenarios, often experimenting difficult light conditions [13] that could hinder the performance by altering the photometric characteristics of the image. Moreover, color images are not privacy preserving – in fact, in most cases people identities can be recognized and matched with some database [14, 15] – and their utilization in video surveillance can impose the use of anonymization solution (for example the blurring of faces) in order to respect privacy regulation, e.g., GDPR [16]. On the contrary, thermal cameras can provide an alternative solution to mitigate those problems. Since thermal imaging capture the heat signature



(a) (b)

Fig. 2. Cumulative histograms of the intensity distribution taken with the same Thermal camera (AXIS Q1952) of the indoor Barcelona (a) and outdoor Florence (b) datasets.

of the elements in the scene, it can help to build a robust detection method less affected by lighting conditions, and can reduce the critical privacy related issues of GDPR [17]. Nevertheless, the adoption of thermal cameras for people detection can still be challenging in particular when addressing domain shifts between data used for training and the actual application scenario, since the information collected is less. For example, changes in the environment, weather, and time of day, the camera position with respect to the scene, the number of persons in the scene, etc., can lead to a performance decrease [18]. For example, as it has been represented in Fig. 1 which depicts two thermal images, (a)/(b) are extracted from indoor case at an Expo (Barcelona dataset) and captured with a camera close to the scene, while the other (c)/(d) are samples from Florence dataset, obtained from a camera placed at greater distance. As, it can be noticed, they present strong visual differences due to the scale change. Pedestrians captured from close cameras (see Fig. 1b) show sharp edges and clear details while, when the camera is far from the scene, persons appear blurred with less characteristic features (see Fig. 1d). Moreover, with different camera placements that can produce images with different field of view, people can appear almost uniformly scattered over the image (see Fig. 1a) or be concentrated in specific part of the image, as in Fig. 1c where persons are found in the lower part. Still observing Figs. 1a and 1c, it can be noted that the two datasets exhibit also different intensities conditions, since images are captured in indoor and outdoor scenarios respectively. Indeed, we reported in Fig. 2 the cumulative histograms obtained by calculating the grayscale histogram for all images in both the Barcelona and Florence datasets and then summing up the values. The Barcelona dataset mainly includes pixels with values ranging from 100 to 150, see Fig. 2a, while the Florence dataset shows a higher concentration of pixel with values between 100 and 200, see Fig. 2b, demonstrating the photometric difference between the two datasets. To address such difficulties when using color images, data augmentation techniques [19] have been proposed to improve the generalization capabilities of the trained model creating additional examples by altering the original images in the training set using geometric or photometric transformations. While several works studied the data augmentation for color images [20–22], less attention has been devoted on assessing its importance for thermal images.

In this paper, we propose a thorough experimental validation of the effect of data augmentation for people detection with thermal cameras. This work extends out previous

analysis [22] – where we investigated the effect of geometric augmentation (i.e., scaling and shifting) – by addressing photometric changes. The main contribution of this paper are:

- The definition of photometric augmentation procedures to create novel training examples with different lighting conditions;
- An in-deep assessment of results of training using the photometric augmented datasets with respect to two datasets not used to train the former neural network model;

This research was carried out in the context of CN MOST, the Italian National Center on Sustainable Mobility [23]. The work has been developed exploiting the Snap4City platform of DISIT lab for data collection and management [24, 25].

The paper is organized as follows: in Sect. 2, the geometric and the photometric augmentation algorithms are presented, while experimental results are reported in Sect. 3. Conclusions are drawn in Sect. 4.

2 Materials and Methods

In this section, the data augmentation and preprocessing algorithms used to produce the geometric and photometric transformed images are presented in detail.

2.1 Geometric Data Transformation

The geometric augmentation takes into account two main transformations: scale and shift. The former is used to train the CNN by using pedestrians appearing with different size in the image. The latter addresses the problem of finding people in specific part of the image. In order to produce such augmented examples, a set of original images are scaled and then the resized patch is put in different positions in the original image canvas padding with zeros the rest of the image. See Fig. 3 for an example.

More in detail, the procedure takes as input an annotated image dataset, and two vectors: the *resizeFactors* vector, that contains the scaling factors, and the *paddingPositions* vector that is a list of strings representing the positions where the resized image should be placed. At first an empty set called $\widehat{D}$ is created. For each resize factor and position strategy an image with its bounding box annotations is extracted from the original dataset D. Then, various functions are applied to manipulate the image and its bounding boxes. As a first step, the images are scaled according to the specified resize factor. Then, to remove possible aliasing and artifacts due to the subsampling, a Gaussian smoothing is applied using a 3×3 kernel. A horizontal flip effect in our experiments has been applied randomly with a probability of 0.5, to further augment the datasets. Finally, the subsampled image is placed in given position on the original image canvas and zero-padding is applied to the rest of the image to simulate a shift of the image content, and to avoid the trained detector focusing on empty areas in search of pedestrian. Note that, all these transformations work on the images and on the respective annotations that must remain consistent. Objects as their bounding boxes resulting after the transformation with an area inferior to 100 pixels are removed to avoid numerical instability and false negatives. Finally, images without bounding boxes are removed from the data set $\widehat{D}$. In Fig. 4, the pseudocode of the geometric augmentation procedure is reported.



Fig. 3. Example of images generated with the geometric data augmentation procedure. In (a) the original image, while (b), (c), and (d) presents three transformed examples by using scaling, shifting, and flipping.

2.2 Photometric Data Transformation

In order to obtain a trained model more robust with respect to photometric changes due to different illuminations in a real scenario, we implement and test two different approaches.

A first solution has been based on a brightness and contrast transformation. We used the augmentation method provided by the Albumentations library, which implements the following equation:

$$\hat{I} = (1 + \alpha) * I + \beta * I_{MAX} \tag{1}$$

where: I and $\hat{I}$ are the original and the modified image, respectively; α is the brightness parameter and β the contrast. I_{MAX} the is maximum admissible value that can be found in I according to its data type (i.e., $I_{MAX} = 255$ when I is encoded with unsigned integer at 8-bit). Intensity values falling out the admissible range (e.g., [0, 255]) after the transformation are clipped to the valid range.

The second solution has been an intensity normalization approach, where the images are normalized to have zero mean and unit standard deviation by using:

$$\hat{I} = \frac{I - \mu(I)}{\sigma(I)} \tag{2}$$

where: I and $\hat{I}$ are the original and the modified image respectively, while $\mu(I)$ is the mean value of I and $\sigma(I)$ the standard deviation. The idea is to create modified images with similar intensity distributions to reduce the impact of different illumination. Note that, in this case, the transformation is applied both on training and validation data.

3 Experimental Results and Assessment

In this section, the carried out experimental analysis is described. At first, the datasets used for training and testing are presented. Then, the used CNN architecture and the implemented training procedure is described. Finally, quantitative results are reported and discussed.

Algorithm 1: Geometric augmentation procedure

Data: D: dataset, *resizeFactor*: list of floats, *paddingPositions*: list of strings
Result: $\hat{D}$: augmented dataset
$\hat{D} \leftarrow \{\}$
for $R \in$ *resizeFactors* **do**
  for $P \in$ *paddingPositions* **do**
    for $I, B \in D$ **do**
      $\hat{I} \leftarrow$ *resizeImage*(I, R);
      $\hat{B} \leftarrow$ *resizeBBoxs*(B, R);
      $\hat{I} \leftarrow$ *gaussianBlur*($\hat{I}$,$K \leftarrow 3$);
      $\hat{I} \leftarrow$ *horizontalFlip*($\hat{I}$, $prob \leftarrow 0.5$);
      $\hat{B} \leftarrow$ *horizontalFlipBBox*($\hat{B}$, $prob \leftarrow 0.5$);
      $\hat{I} \leftarrow$ *zeroPadding* ($\hat{I}$, P);
      $\hat{B} \leftarrow$ *zeroPadding* ($\hat{B}$, P);
      for $\hat{B}_i \in \hat{B}$ **do**
        if $\hat{B}_i.area \leq 100$ **then** $\hat{B}.remove(\hat{B}_i)$; **end**
      end
      $\hat{D}.append(\hat{I}, \hat{B})$;
    end
  end
end
for $\hat{I}, \hat{B} \in \hat{D}$ **do**
  if $\hat{B}.length = 0$ **then** $\hat{D}.remove(\hat{I}, \hat{B})$; **end**
end

Fig. 4. Pseudocode of the geometric augmentation algorithm.

3.1 Datasets

The main datasets used for the training phase are freely the available datasets: LLVIP (Low Light Vehicle Identification and Verification Program) [26], and Teledyne FLIR-ADAS (Advanced Driver Assistance Systems) [27]. LLVIP is a dataset counting about 15000 images with multiple object category annotations, acquired with infrared cameras with different lighting conditions. The second dataset, Teledyne FLIR-ADAS, includes more than 10000 thermal images taken under different lighting and visibility conditions with respective annotations. LLVIP and FLIR-ADAS were used to develop and test video surveillance systems and advanced driver assistance systems such as pedestrian and cyclist detection. Both datasets have been filtered to extract from them only the images with pedestrians.

Table 1. Description of the original datasets used.

Dataset	Number of Train examples	Number of Validation examples	Image kind
LLVIP	12025	3463	Infrared
FLIR ADAS	10742	1144	Thermal
Florence	175	44	Thermal
Barcelona	169	43	Thermal

For the evaluation phase we used two thermal imaging datasets acquired under different conditions: indoor in Barcelona and outdoor in Florence by the same thermal camera AXIS Q1952 with wide-angle lens, see respectively Figs. 1a and 1c for sample images. Barcelona dataset has been obtained by randomly selecting 212 images from 392 videos taken during the annual Smart City Conference in Barcelona from Nov. 15, 2022, to Nov. 17, 2022. The videos were recorded in an indoor scenario, with no natural light source and no controlled temperature, from a thermal camera mounted on a tripod at a height of 3.5 m over the intersection of two large corridors. Pedestrians appear uniformly scattered over the images. Florence dataset consists of images taken by a thermal imaging camera placed around 30 m above the ground in Piazza della Signoria in Florence on six days from 14/07/2022 to 19/07/2022. As for Barcelona, 219 images were randomly sampled from the recorded videos. In this case, people appear very small and only in the lower part of the scene, the scene is very crowded and, being an outdoor environment, the lighting of the scene is very dynamic, changing from daylight to night, illuminated by streetlamps. The temperature also changes, increasing during the day and decreasing at night (the day videos are also taken when the sun is heating and illuminating the square and large portion of the images). Manual labeling was performed using bounding boxes for both the Barcelona and Florence datasets.

As anticipated in the Introduction, the above-described datasets strongly differ in terms of geometrical and photometrical characteristics (see the examples in Fig. 1 and histograms of Fig. 2). These datasets represent a relevant test benchmark for the experiments since they depict two different environments for characteristics and offer the possibility to test the generalization that can be achieved using data augmentation. In the following Sections, a particular care has been devoted to the training process using different augmented versions of the LLVIP and FLIR-ADAS dataset to test the proposed augmentations. Table 1 shows the number of training and validation examples for each dataset. Note that the augmentation procedures are only applied on the LLVIP and FLIR-ADAS training sets.

3.2 YOLOv5

In this work, the YOLOv5 neural network [28] was used, which is made up of 3 main parts: CSPDarknet [29], PANet [30], and the final Yolo layer. CSPDarknet, designed to provide a balance between accuracy and speed, is used as a backbone for the feature extraction. The PANet includes a series of modules that connect the backbone to the Yolo layer that is responsible for producing the predictions and assess the object classes by using a combination of convolutions, batch normalization and activation functions. The Yolov5 loss is composed by three loss functions, as shown in Eq. 3:

$$Loss = l_{box} + l_{cls} + l_{obj} \tag{3}$$

where: l_{box} is the bounding box regression loss, l_{cls} is the classification loss, and l_{obj} is the confidence loss.

In our experiment, a YOLOv5 pretrained on COCO [31] dataset has been used. All the training carried out in this work are the finetuning processes of the network weights (models) by using different versions of the LLVIP and FLIR-ADAS datasets, with and

without data augmentations described in the previous section. For the training, the default hyperparameters of the YOLOv5 has been used, except for the batch size which has been set at 64, and the number of epochs set at 1000. Early stopping with a patience of 50 was used to stop the training when no improvements in the loss function were detected.

3.3 Evaluation Metric

In order to assess the results coming from the experiments, the average precision (AP) metric has been adopted. It is defined as the area under the precision/recall curve $p(r)$:

$$AP = \int_{r=0}^{1} p(r)dr \tag{4}$$

Precision is obtained as the ratio between the true positive (TP) detections over the sum of true positive and false positive (FP); Recall is the ratio of true positive results over the sum of true positive and false negative (FN). To evaluate the TP, FP, and FN the Intersection over Union (IoU) between the ground truth bounding boxes and the predicted ones has been used to measure the area that two bounding boxes have in common. Higher IoU scores indicate better detection results. After selecting a threshold for the IoU, a detection having an IoU equal or greater than the threshold is classified as a TP, otherwise as a FP. FN are missed detections. For all experiments, AP@50 has been considered, i.e., a threshold of 0.5 was used to determine the TP and FP considering the IoU scores. Higher AP@50 scores indicate better performance.

Table 2. Results in terms of AP@50 of the YOLO models trained with LLVIP and FLIR-ADAS, when they are used for people detection in different domains as Florence and Barcellona data sets.

Models created with train dataset	Validation on same dataset (AP@50)	Validation on Barcelona (AP@50)	Validation on Florence (AP@50)
Model LLVIP	0.967	0.732	0.305
Model FLIR-ADAS	0.831	0.719	0.576

3.4 Experimental Analysis

As a baseline reference, in Table 2, the results obtained using the YOLOv5 trained on the original LLVIP and FLIR-ADAS are reported. Results are shown for the models obtained by using the datasets used for training and for both Barcelona and Florence datasets (not used during training). As it can be seen, the performance on the model produced by using training sets LLVIP and FLIR-ADAS with the corresponding validations data set are very good. On the other hand, the results obtained by the trained models by using the new above-mentioned datasets coming from different domains produces a relevant drop in the AP, in particular for the Florence dataset.

Assessment of Geometric Augmentation Impact

A new set of models has been produced by using the generation of the augmented datasets ($LLVIP_{Geom}$ and $FLIR\text{-}ADAS_{Geom}$, respectively) with the procedure described in Sect. 2.1. They have been named as Model $LLVIP_{Geom}$ and Model $FLIR\text{-}ADAS_{Geom}$. As a first step, we assessed if the use of augmented examples would degrade the performance on the corresponding validation datasets since examples with a greater variance are used in training. To this end, in Table 4, the obtained results are reported. As can be seen, there are no evident loss in the performance: a decrease of 0.001, and 0.014 have been measured respectively using Model $LLVIP_{Geom}$ and Model $FLIR\text{-}ADAS_{Geom}$ with respect to the results obtained with the corresponding original dataset for validation, the same used to produce column "validation on same dataset" in Table 2. We can conclude that the geometric augmentation does not have provoked negative impact on the detection results.

Moreover, it is also interesting to verify if the results obtained using the new models trained by using the augmented datasets improve with respect to the different domain of data sets named Barcelona and Florence. The results are reported in Table 3, where for convenience we included the results of Barcelona and Florence on the net trained without augmentation, provided in former Table 2.

Table 3. Impact of training with geometrically augmented examples. Results provided in terms of AP@50.

Model created with train dataset	Validation on the original dataset (AP@50)
Model LLVIP	0.967
Model $LLVIP_{Geom}$	0.966
Model FLIR-ADAS	0.831
Model $FLIR\text{-}ADAS_{Geom}$	0.817

Table 4. Impact of geometric augmentation on Barcelona and Florence. Results are provided in terms of AP@50.

Model created with train dataset	Validation on Barcellona (AP@50)	Validation on Florence (AP@50)
Model LLVIP	0.732	0.305
Model $LLVIP_{Geom}$	0.738	0.450
Model FLIR-ADAS	0.719	0.576
Model $FLIR\text{-}ADAS_{Geom}$	0.773	0.546

In Table 3, for the Barcellona dataset, the geometric augmentation improves the results for both Model LLVIP and Model FLIR-ADAS with AP@50 respectively passing from 0.732 to 0.738 (with an increase of 0.006) and from 0.719 to 0.773 (with an increase of 0.054). For the Florence dataset instead, there is a strong improvement when using Model LLVIP with the AP@50 rising from 0.305 to 0.450 (0.145 higher), while a decrease of 0.030 was measured using Model FLIR-ADAS. This decrement was probably due to the fact Model FLIR-ADAS and its datasets includes bounding boxes (of pedestrian) of smaller size with respect to those which are present in the LLVIP dataset (see Fig. 5). Therefore, performing the downscaling in the geometric augmentation can lead to very small pedestrians appearing in the FLIR-ADAS images, so small that some of them disappear during the augmentation procedure and the remaining information/shapes are not sufficiently representative to help in detecting people in the Florence dataset.

Assessment of Photometric Augmentation Impact

For the assessment of photometric augmentation impacts, we tested different combinations of range of values for parameters of brightness (α) and contrast (β):

$$(\alpha, \beta) \in [(0.2, 0.0), (0.0, 0.2), (0.2, 0.2), (0.5, 0.2), (0.2, 0.5)]$$

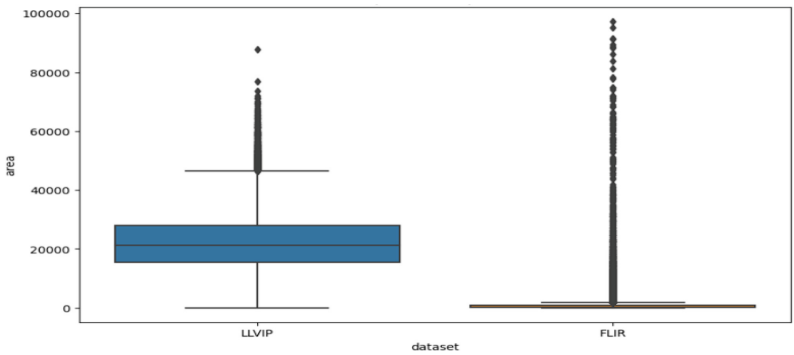


Fig. 5. Ranges of the bounding box dimension (area) comparison between LLVIP and FLIR-ADAS original datasets.

The applied $\left(\widehat{\alpha}, \widehat{\beta}\right)$, in the data sets, have been randomly extracted from intervals defined by the set parameters: $\widehat{\alpha} \in (-\alpha, +\alpha)$ and $\widehat{\beta} \in (-\beta, +\beta)$. These combinations generated specific $\text{LLVIP}_{\text{Photo}}$ and $\text{FLIR-ADAS}_{\text{Photo}}$ datasets from the corresponding originals and they have been used to generate a set of corresponding YOLO Models.

The assessment of the resulting Models $\text{LLVIP}_{\text{Photo}}$ (α, β) and Models $\text{FLIR-ADAS}_{\text{Photo}}$ (α, β) are reported in Table 5. As it can be seen, comparing results presented in Table 4 with respect to those of Table 5, the results provided by using the original validation data set have been improved for the LLVIP and get worst for the FLIR-ADAS.

Moreover, comparing the results presented in Table 3 with respect to those of Table 5, the improvement of precision with respect to the different domains of Barcellona has been registered only for most of the FLIR-ADAS$_{Photo}$ (α, β), namely those with (0.2, 0.0), (0.0, 2.0), (0.2, 0.2), (0.2, 0.5), where AP@50 of 0.722, 0.729, 0.737, and 0.751 were achieved (with an improvement of 0.003, 0.010, 0.018, and 0.032 respectively). All the other cases led to inferior performance with respect to those of Table 3.

Table 5. Impact of photometric augmentation of the original LLVIP and FLIR-ADAS data sets and their corresponding YOLO Models in person detection with respect on Barcelona and Florence data sets. In bold the cases in which the baseline has been improved. Results are provided in terms of AP@50.

Model created with			Validation on the same dataset (AP@50)	Validation on Barcellona (AP@50)	Validation on Florence (AP@50)
Train dataset	α	β			
Model LLVIP$_{Photo}$	0.2	0.0	0.973	0.634	0.175
Model LLVIP$_{Photo}$	0.0	0.2	0.970	0.617	0.173
Model LLVIP$_{Photo}$	0.2	0.2	0.973	0.652	0.183
Model LLVIP$_{Photo}$	0.5	0.2	0.967	0.556	0.138
Model LLVIP$_{Photo}$	0.2	0.5	0.975	0.620	0.179
Model FLIR-ADAS$_{Photo}$	0.2	0.0	0.808	**0.722**	0.504
Model FLIR-ADAS$_{Photo}$	0.0	0.2	0.810	**0.729**	0.515
Model FLIR-ADAS$_{Photo}$	0.2	0.2	0.808	**0.737**	0.502
Model FLIR-ADAS$_{Photo}$	0.5	0.2	0.808	0.699	0.529
Model FLIR-ADAS$_{Photo}$	0.2	0.5	0.805	**0.751**	0.573

Table 6. Impact of image normalization by mean and standard deviation on Barcelona and Florence. Results are provided in terms of AP@50.

Model created with train dataset	Validation on the same dataset (AP@50)	Validation on Barcellona (AP@50)	Validation on Florence (AP@50)
Model LLVIP μ, σ	0.942	0.533	0.067
Model FLIR-ADAS μ, σ	0.759	0.609	0.451

Finally, in Table 6 results using the image normalization by mean and standard deviation according to Eq. 2, are reported. In this case, each image of the training datasets (LLVIP and FLIR-ADAS) and of the validation datasets (Barcelona and Florence) have been normalized using the mean and the standard deviation of the intensity values. Note that each image is normalized independently using its mean and standard deviation. As

can be seen, results do not improve performance with respect to the baselines results presented in Table 2: after training by using the normalized LLVIP dataset the obtained AP@50 resulted to be 0.533 and 0.067 by validating the model with the normalized version of the data sets Barcellona and Florence, respectively. Using the normalized FLIR-ADAS to train the YOLO network, we achieved an AP@50 score of 0.609 for Barcelona, 0.451 for Florence.

From these results we can argue that the generative approaches for altering the photometric characteristics of the images of LLVIP and FLIR-ADAS dataset do not provide consistent generalization in the trained models that do not improve with respect to the baselines. This can be due to particular characteristics of thermal images where the intensities are not related to lighting effects but instead are descriptions of the temperatures of the elements in the scene. Therefore, applying transformation valid for color RGB images on thermal data could spoil sensitive information and cause inferior detection performance.

4 Conclusions

In this paper, a study on augmentation techniques for generating extended data sets for pedestrian detection using thermal images was presented. We investigated the effects of geometric and photometric transformations of freely available datasets (LLVIP and FLIR-ADAS) used to train the detector, evaluating the results with respect to two different datasets (Barcelona and Florence) with different characteristics and not seen during training. Results have shown that the geometric augmentations can provide some benefits by creating new examples with different pedestrian sizes appearing in different image regions, improving the performance on data from different domains, and providing more flexibility. On the other hand, photometric alterations that can work on color RGB images were found inadequate to deal with changes in intensities in thermal data, probably due to the different photometric characteristic between color images, where intensity are related to lighting effects, and thermal images, where the intensities depend on the temperature of the scene elements.

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Smart and Sustainable Island Communities (SSIC 2024)

Spatial Data Management and Scenario Planning for Paving Sustainable Future Trails in Insular Territories - Case Study Milos Island, Greece

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Abstract. Regional development and cohesion policies in the European Union (EU) aim at reducing disparities among regions and promoting economic, social and territorial cohesion. Recently, relevant initiatives pay particular attention to insular regions as distinct examples of vulnerable and lagging-behind territories. These policies also emphasize place-based approaches as the means for the needs and challenges of diverse types of regions to be effectively addressed. This, in turn, calls for delving into spatial/developmental peculiarities; and utilizing planning tools that are capable of handling complexity and uncertainty related to the future of studied regions within the rapidly evolving external decision environment. That said, this work sets the stage for an in-depth exploration of future sustainable developmental pathways of insular contexts, using Milos Island, Greece as an example. Spatial data management, scenario planning/visualization and multicriteria evaluation provide the means for a foresight exercise that grasps and assesses diverse sustainable, spatially-defined developmental trails of Milos Island. As key drivers of change for the scenario building endeavour, strategic EU/national policy directions compatible to the islands' context are utilized, namely the Green and Blue Growth strategies; and an effort to downscale them in the case study context is carried out. Scenarios produced are evaluated by use of multicriteria analysis (MCA), highlighting social, economic and environmental dimensions. Integration of spatial data management, scenario planning/visualization and MCA render planning outcomes and related policy decisions more robust, justifiable, fair and transparent.

Keywords: Island territories · Spatial data management · Scenario planning · Blue and Green Growth

1 Setting the Scene

Insular regions in the Mediterranean are outstanding examples of areas endowed with exquisite tangible and intangible, land and maritime, natural and cultural resources [1], rendering these regions highly-rated destinations in the global scenery. Nevertheless,

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islands in general and Mediterranean islands in particular are also perceived as distinct examples of lagging-behind spatial entities in developmental terms [2]. The reason for that lies on their geographical peculiarities and especially their isolation from the mainland, raising a number of developmental barriers, summed up under the "insularity" concept [1]. Insularity, in its very essence, is closely connected with a number of inadequacies and bottlenecks that hinder effectiveness of islands' developmental efforts. Managing insularity constraints and tracing visionary place- and people-centred future trails of Mediterranean islands is currently dealt by planners and policy makers, seeking to sketch and implement policies that are able to support more sustainable and resilient future end states and enable competitive advantages of islands in the demanding and rapidly evolving external decision environment.

The insularity condition and related drawbacks that frame the future of insular regions have recently gained noteworthy attention by the EU [3, 4]. Equity concerns lie behind this EU policy turn, aiming to ensure regional cohesion objectives and provide equal opportunities to the more than 20 million inhabitants (4,6% of the total EU population), residing in island areas and being spread over approximately 2400 islands in 13 Member States [5]. Given the distinct geographical features of EU island regions and their diverse institutional setups, the challenges the European islands are currently confronted with can vary significantly, due to e.g. size, location, economic profile, value systems, vulnerability to climate change (CC), etc. Some key concerns when studying island territories are as follows [5–7]:

- Geographical diversity: Islands in the Mediterranean face diversified challenges, compared to those in the Northern Atlantic or the Baltic Sea. Climatic conditions, sociocultural regimes and natural/cultural resources can vary significantly, impacting thus local economies and lifestyles, while conditioning future trails.
- Environmental vulnerabilities: Many European islands are vulnerable to environmental pressures, emanating from the impacts of CC or other natural phenomena. As such can be mentioned the rising sea level, extreme weather events, biodiversity loss, etc. These can shape the type and pace of their future development and need to be properly handled through effective adaptation strategies.
- Unique economic opportunities: The geographical attributes of islands, including their ecosystems and climatic peculiarities, give rise to unique economic opportunities, linked to both the land and the sea. Main sectors of their economic profile are agriculture, fishing and particularly tourism, namely critical sectors in terms of sustainable development and resilience objectives.
- Infrastructure and connectivity: Connectivity, both within the islands' territory and between the islands and the mainland, can be a critical factor for islands' flourishing. Some islands are confronted with challenges as to the transport and energy connectivity, and access to digital infrastructure; while others may have well-established connections.
- Institutional frameworks: The governance and administrative structures of islands can vary due to historical, cultural, political, etc. factors. Some islands may have a high degree of autonomy, while others are depended on administrative bodies of larger islands, being the main nodes of relevant island complexes [8], further enhancing insularity implications (double insularity).

- Cultural and social factors: Each island is marked by its unique identity, formed by the natural and cultural assets, historical trajectory, social dynamics, etc. [1]. Future pathways should be structured in harmony with this identity and definitely engage communities in visionary planning processes and related policy decisions.
- Tourism repercussions: Many islands are heavily depended on specific economic sectors, such as agriculture, fisheries and especially tourism. The latter is quite vital for most Mediterranean insular economies, with noticeable contribution to GDP, employment, and foreign exchange earnings. However, the prevalence of the Tourism-Led Growth (TLG) model [9] can render islands' economies more vulnerable to external shocks, global tourism market fluctuations, changes in tourism demand pattern, etc. In addition, managing the impacts of tourism on the environment, infrastructure, and local communities lies currently at the heart of the policy agenda and calls for specific strategies, tailored to each single island's context.
- Energy independence/resilience: Many islands are currently heavily relied on imported energy sources. Developing sustainable energy solutions and increasing autonomy or resilience to energy-related disruptions are of key importance for island regions both in developmental and spatial terms [10].

Given the aforementioned challenges, a one-size-fits-all approach does not seem a relevant choice for studying insular territories. As Barca et al. [11], but also McCann [12] claim, place-based approaches are of key importance for effectively addressing regional peculiarities in policy formulation. Towards this end, a detailed collection and management of spatial and other – quantitative and qualitative – data is necessary, as part of a planning endeavour. These data form the ground for better understanding distinctiveness of each single study region, while are perceived as valuable input for conducting a scenario planning exercise, i.e. structuring and evaluating alternative future trails that fit well into or take advantage of developments of the wider policy decision environment. That said, the focus of this work is on demonstrating the value of data management and especially scenario planning tools in the case of Milos Island, Greece. The structure of the paper has as follows: in Sect. 2, contemporary policies, establishing the decision environment within which development in insular territories takes place, are discussed; Sect. 3 demarcates the methodological approach of this work; Sect. 4 demonstrates the results obtained by implementing this approach in Milos Island, Greece; while finally in Sects. 5 and 6 discussion and conclusions are respectively drawn.

2 Grasping the Broader Decision Environment

As part of every policy formulation exercise at the local level (Milos Island in this respect), exploration of policy directions that demarcate the broader decision environment within which such an exercise is conducted, needs to be carried out. The key pillars of this exploration in the present work are demonstrated in Fig. 1 and are shortly discussed in the following.

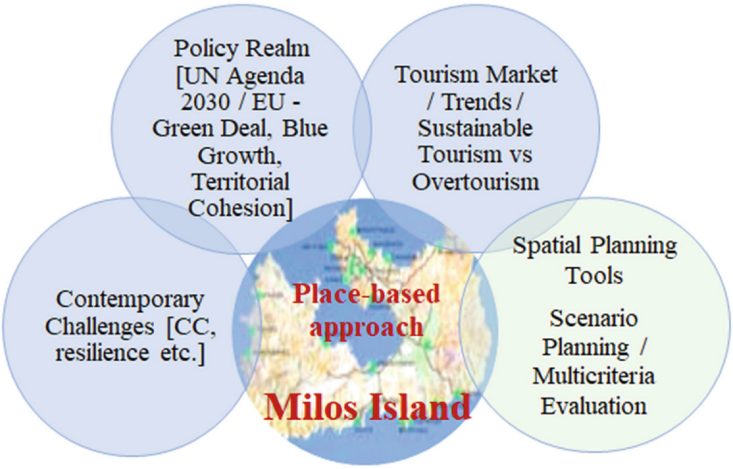

Fig. 1. Key pillars of the external decision environment. Source: Own elaboration.

Wealth of Mediterranean islands has been largely determined by the sea, acting, among others, as the means for economic/trade transactions and development of societal ties among Mediterranean communities; and a valuable resource for economic activity, such as commerce, fishing, maritime transport, tourism, etc. [13]. However, currently the Mediterranean region is perceived as a CC hotspot [13], with CC being recognized as a key driving force of global reach [14]. In fact various estimations demonstrate a general warming and drying trend of Mediterranean as a whole, a fact that is source of multiple socioeconomic stresses affecting health, energy and water consumption, food safety and security, habitat and biodiversity loss, risk of fire and drought, etc. [15]. Within the Mediterranean Region, islands seem to be more affected by CC impacts, lying in one of the most susceptible to CC areas of the world [16].

Overall reduction of GHG emissions and climate neutrality lie at the heart of the United Nations' Agenda 2030 for Sustainable Development, but also the European policy aspirations, as these are expressed by the Green Deal [17]. Speaking of the Agenda 2030, CC confrontation is reflected in SDG 13. Indeed, SDG13 is dedicated to "Climate Action" and highlights the urgent need to undertake steps that can tackle transition to carbon neutrality. This SDG is further specialized into sub-objectives that aim, inter alia, at [18]: boosting resilience and adaptive capacity of states/regions to climate-related hazards and natural disasters; integrating CC measures into national policies, strategies and planning processes; building capacity and raising awareness of population and institutions, etc. In addition, the concept of resilience comes to the forefront, leading a number of countries to undertake mitigation and adaptation actions, targeting the reduction of their national emissions and promoting national and / or regional / local adaptation plans for addressing CC challenges. Despite the critical importance of SDG 13 in confronting CC, this effort is further strengthened by a number of other SDGs as well, such as the SDG 7 ('Affordable and Clean Energy'), SDG 9 ('Industry innovation and infrastructure'), SDG 10 ('Reduced inequalities'), SDG 12 ('Responsible production

and consumption'), etc., all being closely related or relevant to challenges faced today by insular communities.

In order to harmonize its climate policy with the United Nation's Agenda 2030 and the 17 SDGs, the European Union has put forward the Green Deal, i.e. a strategy aiming to promote more green and sustainable pathways by serving the transition of the European territories towards [17]: a just and prosperous society; a resource-efficient and competitive economy, marked by the decoupling of economic growth from resource use; and a continent seeking to become a pioneer in climate neutrality achievements. In its effort to attain climate neutrality, a clear and coherent EU 2050 vision is set up; while Green Deal's strategic objectives are downscaled to the member states' level by enforcing legislation updates and policy reforms as well as by monitoring their implementation [18]. An ambitious EU strategy, targeting adaptation to CC, is also predicted in the Green Deal for enhancing resilience of spatial systems; while emphasis is placed on data and instruments in support of the integration of CC into risk management practices, smart energy infrastructure, and digital transformation, all three being grasped as critical 'vehicles' for reaching the Green Deal visionary end state [17]. In complementing the Green Growth perspective of the European territories, the EU has set up its vision for the marine environment. Realizing the (economic) value of the five seas surrounding the European territory, it has put in place the Integrated Maritime Policy (IMP) [19], emphasizing the need to promote the sustainable growth of maritime sectors and coastal regions. In support of the IMP, the Blue Growth Strategy [20] is articulated, aiming to attain sustainable growth of maritime sectors as a whole, with these sectors perceived as a new source of economic prosperity of the European regions, particularly of coastal and insular ones.

Further to the above statements, a thorough reflection is needed on how to best tailor policies to the peculiar economic profiles and geographical features of insular regions for better addressing the multiple developmental challenges, as well as the diversified social and employment circumstances such regions imply. In such a context, a place-based approach is highlighted in the new Territorial Agenda 2030 [21], perceived as the key to transposing priorities for a 'Just Europe' into practice. Thus place-based approaches have guided the reform of the EU territorial cohesion policy; and have introduced a new developmental strategy for better accounting place-specific contexts, assets and capacities [11, 12].

Speaking of developments in the global tourism market, sustainable tourism is nowadays largely advocated by both the demand and the supply side. As to the demand side, well-informed and environmentally-aware consumers rate environmentally-committed tourist destinations high in their preferences [1]. The supply side, in turn, has set up systems and procedures in its management processes that aim at fulfilling consumers' sustainability expectations. Thus environmental concerns and rational use of resources, both natural/cultural and human, are placed at the epicentre of the tourism production processes [22]. Same holds for decision makers at the local level, e.g. local government, Destination Management Organizations (DMOs), etc., in order for long term developmental perspectives, on behalf of both local population and visitors, to be supported. Concurrently, regionalization of policy making processes of the last decades and the rising power of local decision-making bodies has increased capabilities for more inclusive

approaches in planning and implementing sustainable local tourist development trails. The aforementioned orchestrated efforts reflect reactions to the realization that sustainable tourism is capable of boosting the sector's contribution to economic growth, job and income creation; while simultaneously addressing the major environmental challenges of the times [23]. In fact, sustainable tourism development is of critical importance for insular territories as fragile and geographically-confined land compartments. This holds even truer when considering that islands are perceived among places under intense and steadily increasing risk to overtourism, a currently alarming phenomenon in the policy discourse. In fact, the TLG model in island regions renders, in a longer run, sustainability objectives at stake by overcoming carrying capacity limits. Thus overcrowded islands destinations are confronted with various risks such as [24]: deterioration of their natural/cultural assets; high pressure on local community due to the loss of identity and sense of place; overconsumption of scarce resources; traffic congestion and air quality worsening; excessive waste volumes; etc. These, in turn, lead also to the degradation of tourist satisfaction, experience and loyalty to the destination; and, in a longer term, to destination's stagnation or decline by jeopardizing the very nature of its attractiveness, i.e. the natural and cultural beauty [24].

Taking into consideration the aforementioned key pillars as well as the main strategic guidelines at the national level, guiding spatial decisions with regard to tourism, Renewable Energy Sources (RES), aquaculture and industry as additional key drivers that frame the decision environment, a scenario planning exercise is conducted in the following that aims to sketch a sustainable future of Milos Island, Greece. Such a future seeks to achieve a well-structured balance among economic perspectives, environmental protection and social well-being. At the heart of this exercise lies a holistic and integrated, place-based approach for islands' development, ensuring sustainability objectives and seeking to attain a balance – in spatial and developmental terms – of sectoral objectives on the ground of the available natural and cultural assets [25, 26], while keeping track with directions of the broader decision environment.

3 The Methodological Approach

The proposed methodological approach consists of two main streams (Fig. 2). More specifically, in Stream 1 the external decision environment is investigated, aiming to identify those key drivers that can affect future developments of island regions. Out of this search, two key uncertainty axes are sought that can form the backbone of the *scenario planning approach.* In Stream 2, a *spatial data analysis* is conducted, aiming to grasp the very nature of the study region by: highlighting spatial dimensions of the natural, cultural, socioeconomic, infrastructural, etc. attributes; and identifying strengths and weaknesses as well as the region's dynamics. Combination of outcomes of Stream 1 and 2 guides the scenario planning endeavour in order for decision support as to the future sustainable pathways of the region at hand to be enabled and potential policy paths for their implementation to be sketched.

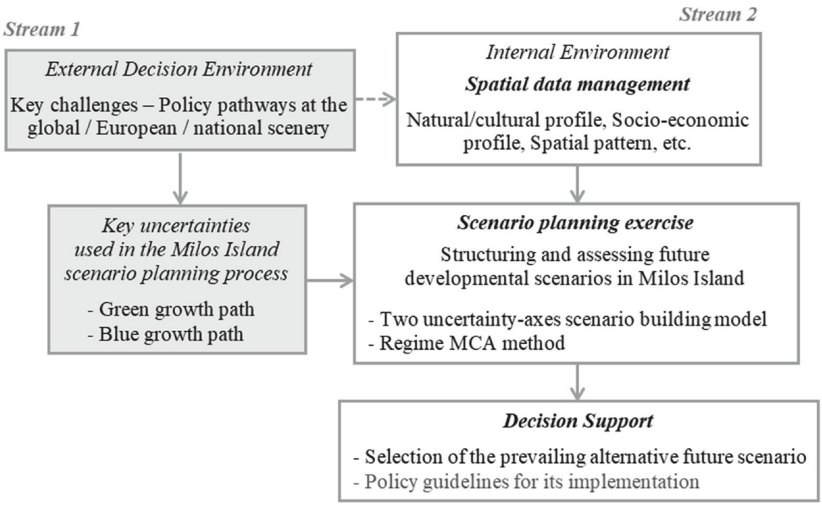

Fig. 2. Steps of the methodological approach. Source: Own elaboration.

3.1 The Scenario Planning Approach

Studying the future is an effort to find ways to explore the "unknown [27]. Thanks to professional futurists' work, a range of techniques and methods are currently available for thinking and discussing the future; and are used at both the micro (business) and the macro (regions) level. Among them falls scenario planning [27, 28] as a foresight technique for developing cohesive, plausible and flexible long-term strategic plans in support of policy-makers in their effort to anticipate/understand change, prepare responses to evolving conditions and establish more robust strategies. At the heart of the scenario planning process lie questions as to what is going to happen in the future and how this can affect the region under study. Out of this thinking, key uncertainties can be identified and can be further explored; especially those that present a high uncertainty as to their future state, while are also highly impacting the studied system. These can be used as building blocks in the scenario development process.

In setting up scenarios for the sustainable future of Milos Island, the *two uncertainties axes* scenario planning model is applied. The rationale of this model is displayed in Fig. 3. At the heart of this model lie two critical uncertainties (Key uncertainty A and B) (Fig. 3a) that are grasped as both highly uncertain and piercingly impacting the future of island regions (Fig. 3b). As key uncertainties for the future development of Milos Island are perceived two strategic EU/national policy directions namely the *Green and Blue Growth* that are compatible to the islands' context; while aligning with the aforementioned key pillars of the external decision environment (see Fig. 2).

In fact, pursuing "Green Growth" can potentially foster economic development, while ensuring that natural assets will continue to provide environmental services upon which community's well-being relies. In addition, promotion of "Blue Growth" rests upon the sustainable utilization of ocean and coastal resources – i.e. resources of critical importance for insular contexts through the centuries – in order for socioeconomic

prosperity, improved livelihoods and environmental sustainability of coastal and marine space to be attained. Downscaling the Green and Blue Growth EU directions on the studied island can in fact sketch a new spatial and developmental model which, among others, enables an internally-balanced pattern of activities in the various settlements of the island – inland and coastal ones – thus removing inequalities and promoting socio-economic and spatial cohesion.

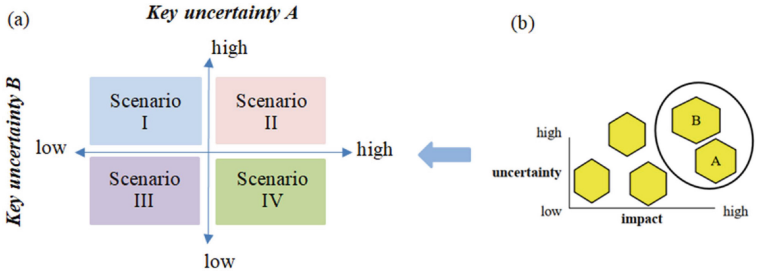

Fig. 3. The rationale of the two uncertainty-axes scenario model. Source: adapted from [27]

3.2 Assessment of Structured Scenarios – The REGIME Method

The structured scenarios for Milos Island are assessed by use of the REGIME discrete multicriteria method [29]. This method is used for evaluating both projects and policies; and has the advantage of utilizing quantitative, qualitative and/or mixed data with regard to the effects and criteria priorities considered in the evaluation problem. The main input for applying the REGIME method comprises the [30]:

- *evaluation (impact) matrix*, composed of elements e_{ij} that measure the performance of each alternative i, i = 1,2,…,I (4 discrete alternatives in the case of Milos Island) as to every evaluation criterion j, j = 1,2,…,J (17 evaluation criteria, falling into the environmental, economic and social sustainability pillars in the Milos example);
- *set of political weights* that provide information on the relative importance of criteria to be considered in the evaluation context.

The REGIME method is founded on a pairwise comparison of all alternatives. Produced outcome of the method is the probability of alternative i to rank higher than the rest of the alternatives; and is calculated by the following formula [31]:

$$P_i = [1/I - 1] \sum_{i \neq i'} P_{ii'} \quad (1)$$

where P_i is the average probability that alternative i ranks higher than any other alternative. Ranking order of P_i's is then defining the prioritization of respective alternative options (scenarios). It is worth highlighting that the comparison of every set of alternatives is not influenced by the presence and effects of other alternatives, while the potential ranking order of a certain alternative is conditioned by all remaining ones (for more information see [18, 29, 30]). Application of the REGIME method is accomplished by use of the DEFINITE (DEcisions on a FINITE set of alternatives) software.

4 Implementation of the Proposed Methodology and Results

4.1 The Study Region

Milos is a Greek island, holding a surface of 150.6 km2 and a coastline of 125 km long. It is located in the southwestern part of Cyclades complex, Aegean Sea (Fig. 4a). It disposes quite distinguishable and fragile natural ecosystems, coupled with environmentally-sensitive coastal parts (Fig. 4b). The island is distinguished for its volcanic origin, resulting in impressive landscapes, beaches, rock formations and other geological configurations (e.g. caves); while it is well-known for its mining activity, served by a dispersed pattern of mining sites all around the island (Fig. 4c).



Fig. 4. The study region: (a) Location of Milos Island, (b) Natura 2000 areas, c) Mining sites. Source: (a) [32], (b) [33], and (c) Own elaboration.

Milos Island counts for 5,193 inhabitants (2021 provisional Census data), with the population displaying escalating trends during the last three decades (Fig. 5). Traditional economic sectors are mining, tourism and fishing. More specifically, the primary sector is based on agriculture, livestock farming and fishing; and displays signs of decay, shifting its share in the local economy from of 7.71% in 1991 to 3.69% in 2011. Secondary sector demonstrates also a declining trajectory (from 34.78% in 1991 to 29.76% in 2011), with mining activity being the prevalent one.

In fact the local economy is gradual shifting towards a tertiarized one – from 57.52% in 1991 to 66.55% in 2011 – dominated by the tourism sector. Milos, as most island regions, attempts to capitalize on its natural and cultural capital; and use it in order to increase its tourism attractiveness. The tourism sector, in this respect, is gradually strengthened in the local economy, as also demonstrated by bed-night stays in the time slot 2015–2022 (Fig. 6); while same holds for hotel/guesthouse and Airbnb beds. Inspection of results of Fig. 6 manifests a steadily escalating trend in overnight stays in the island in the time span 2015–2022; while quite evident is the impact of COVID-19 in 2020.

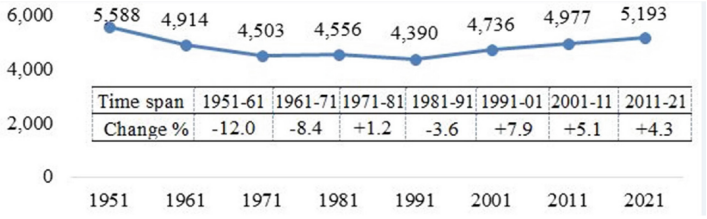

Fig. 5. Evolution of population in Milos Island - Time span 1951–2021. Source: Hellenic Statistical Authority [34].

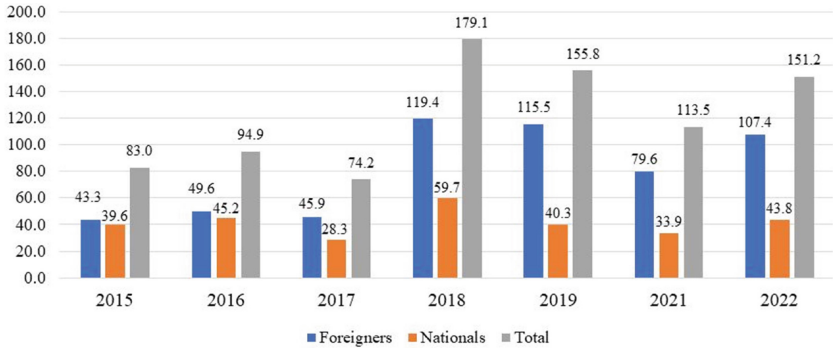

Fig. 6. Evolution of overnight stays in Milos Island 2015–2022 (in thousands). Source: [35].

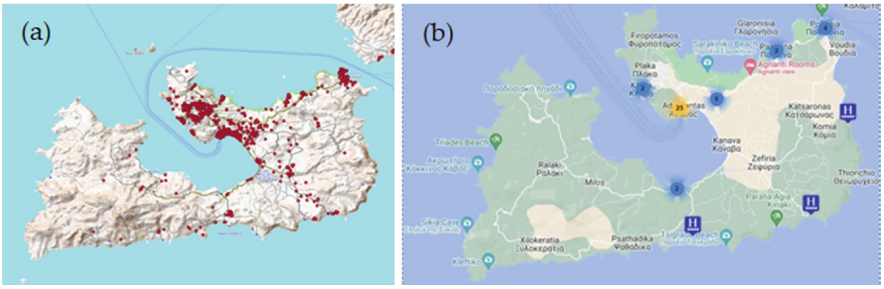

Fig. 7. Current spatial pattern of tourism accommodation in Milos Island. a) Airbnb accommodation, b) Hotel accommodation. Source: a) [36], b) [37]

In addition, tourist accommodation demonstrates a rather concentrated pattern (Fig. 7a and 7b), displaying signs of surpassing carrying capacity of specific island's locations with obvious repercussions in respective settlements. In seeking to avoid the unpleasant consequences of tourism overload and the monocultural pattern of the local economic profile due to the prevalence of the tourism sector, scenarios for a holistic and integrated island's future development are built in the following, having as a backbone the Green and Blue Growth pathways; and aiming to promote a multisectoral and

spatially-balanced pattern to the benefit of environmental protection, social integrity and cohesion, economic prosperity and overall experience of tourists.

4.2 Structuring Scenarios for Sustainable Future Pathways of Milos Island

The two uncertainties axes scenario planning model (see Sect. 3.1) is applied in Milos Island resulting in four distinct scenarios, seeking to achieve more sustainable development pathways, in alignment with directions of the external decision environment and particularly the EU vision. Such a perspective is sought using as a backbone the Green and Blue Growth directions (see also Sect. 2), perceived as the key uncertainties in the scenario building process for island contexts (Fig. 8). The distinct features of each single scenario of Fig. 8 are displayed in Table 1.

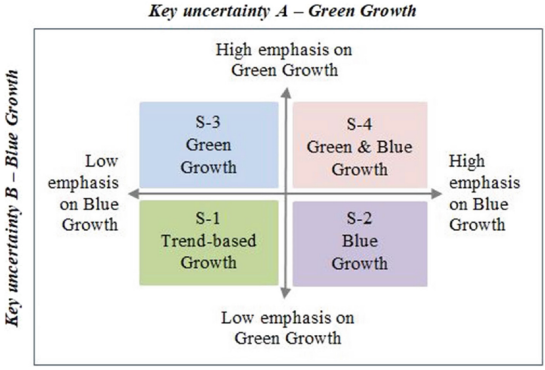

Fig. 8. The rationale of the two-uncertainty axes scenario planning model as featured in the scenario building process of Milos Island, Source: Own elaboration.

4.3 Evaluation of Scenarios by Use of the Regime MCA

The starting point for the scenario assessment is the delineation of the evaluation criteria. Those used in this respect (type, measurement scale and direction) are demonstrated in Table 2. Next follows the construction of the impact matrix (Table 3), describing the performance of each scenario against the set of evaluation criteria. Such a performance is qualitatively assessed by use of the authors' experience as well as evidence-based results in Greek islands [38, 39] that have already implemented relative interventions, as those predicted in each single Milos scenario image. Qualitative values of the impact matrix (Table 3), representing performance of scenarios as to the criteria set, are properly handled by the DEFINITE software. The criteria weights need also to be determined. In this work, three different weights' prioritization schemes of evaluation criteria are used. In the first scheme, all criteria are considered as of equal weight (equal importance of all three pillars, i.e. environment, economy and society); then the rest two criteria prioritization schemes give prominence to environmental and economic criteria respectively.

Table 1. Features of structured scenarios for the sustainable future of Milos Island

Scenario 1 – Trend-based scenario	**Scenario 2 –Blue Growth**
- Limited growth of the primary sector – Steady downward trend - Enhancement of the traditional activities of the secondary sector - Maintaining of mass tourism - Improvement of ferry connections - Low Renewable Energy (RE) penetration	- Promotion of fishing activity - Further development of the secondary sector, based on mining activity - Promotion of mass and alternative tourism model -geological, conference tourism, maritime tourism - Upgrading of maritime transport infrastructure - Upgrading of ports' infrastructure - Limited penetration of RE
Scenario 3 –Green Growth	**Scenario 4 –Green & Blue Growth**
- Prevalence of RE in the energy profile of Milos Island - Sustainable mobility - Green building stock - Innovative crops' development for energy production – Primary sector development - Stagnation of the secondary sector, low manufacturing growth - Mass tourism model, combined with mild nature-based forms of tourism (eco- and agro-tourism)	- Penetration of RE - Smart and sustainable mobility in land and at sea - Energy saving in the building stock - Upgrading of island's infrastructure - Balanced sectoral development / Integration of economic sectors – Establishment of value chains - Organic production in agriculture/animal husbandry - Promotion of fishing activity (aquaculture) - Strengthening of manufacturing activity - Stimulation of export activity of qualitative products - Upgrading of ferry connections / Ports' upgrading - Balance of mass and alternative tourism (eco- and agro-tourism; geological, Spa and conference tourism; maritime tourism)

Ranking of alternatives in the three distinct criteria weighting schemes are demonstrated in Fig. 9. More specifically, in all three REGIME rankings, Scenario 4 (Fig. 10) displays the highest performance. This scenario covers, in a great extent, the goal set for a holistic and integrated development of Milos Island; and fulfills sustainability objectives by making proper use of available resources, both in land and at sea. In fact, the combination of both Green and Blue Growth strategies promotes RE exploitation with considerable environmental repercussions. The scenario invests in the spatially-balanced development and integration of all three productive sectors, taking advantage of available natural and cultural resources and using them in a sustainable way. It also attempts to diminish land use potential conflicts. The island gains autonomy in a number of sectors, while avoiding a tourism developmental pattern that overcomes carrying

Table 2. Evaluation criteria for Milos scenarios' assessment, Source: Own elaboration

Sustainability Pillar/Criterion description			Measurement scale	Direction
Economy	C1	Development of entrepreneurship - New jobs creation	---/+++	Benefit
	C2	Promotion of secondary sector activity	---/+++	Benefit
	C3	Strengthening of primary sector activity	---/+++	Benefit
	C4	Degree of integration of productive sectors	---/+++	Benefit
	C5	Development of new infrastructure	---/+++	Benefit
	C6	Spatial distribution of tourism – Containment of mass tourism	---/+++	Benefit
	C7	Preventing seasonality of tourism activity	---/+++	Benefit
	C8	Attracting high class tourists	Binary	Benefit
Environment	C9	Protection - designation of natural / cultural environment	---/+++	Benefit
	C10	Protection and sustainable use of marine resources	---/+++	Benefit
	C11	Development of alternative types of tourism	---/+++	Benefit
	C12	Shift to Renewable Energy Sources	Binary	Benefit
	C13	High quality products - Organic farming	Binary	Benefit
	C14	Environmentally-friendly tourism infrastructure/transport	---/+++	Benefit
Society	C15	Social cohesion	---/+++	Benefit
	C16	Upgrading of living standards	---/+++	Benefit
	C17	Fostering the development of human resources	---/+++	Benefit

capacity, raises seasonality drawbacks, and places unbearable stress in local resources and community. Attractiveness of Milos Island to visitors is reinforced by the spectrum of tourism forms available; while, in addition, it enables equal opportunities for access to jobs and services, thus strengthening socioeconomic cohesion.

Table 3. Impact matrix as input to the Regime MCA method

Evaluation Criteria	Scenarios	S1	S2	S3	S4
Economy	C1	-	++	++	+++
	C2	--	++	+	+++
	C3	-	+	++	+++
	C4	---	-	++	+++
	C5	-	+	++	+++
	C6	---	++	++	+++
	C7	-	++	++	+++
	C8	no	yes	no	yes
Environment	C9	---	-	++	+++
	C10	--	+++	--	+++
	C11	-	++	+	+++
	C12	no	no	yes	yes
	C13	no	no	yes	yes
	C14	---	---	+++	+++
Society	C15	-	+	++	+++
	C16	--	+	+	++
	C17	--	++	++	++

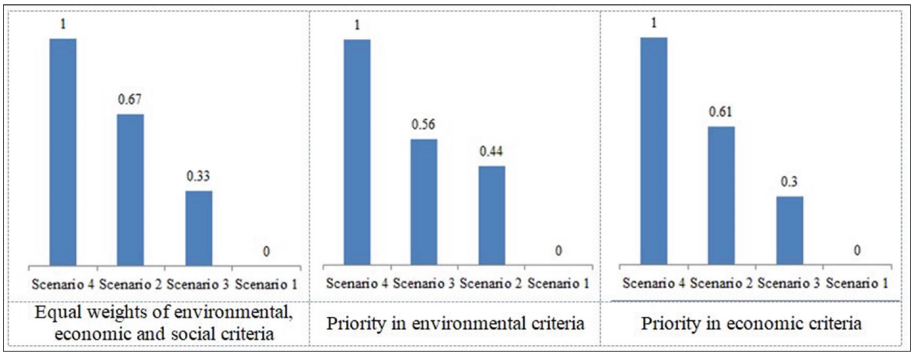

Fig. 9. Regime MCA results of the three distinct scenario assessments. Source: Own elaboration.

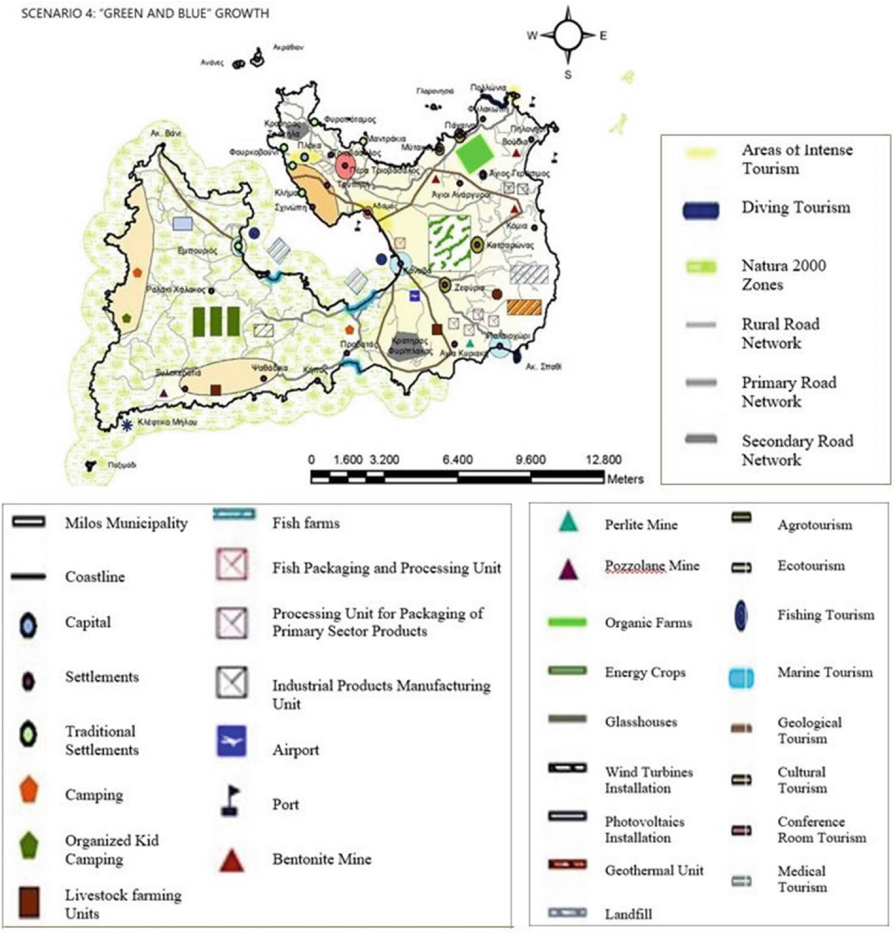

Fig. 10. Spatial development of the prevailing Scenario 4, Source: Own elaboration.

5 Discussion

European in general and Mediterranean Islands in particular, being in most cases lagging-behind territories, are currently confronted with great challenges and dilemmas [25]. Most of them, however, are perceived as a two-sided coin, by carrying certain risks but also presenting new opportunities ahead for awareness raising and action undertaking by local stakeholders; and assessment and valuation of services offered by the natural ecosystems to local communities. For reaping the benefits of these opportunities, more dedicated efforts need to be undertaken, capitalizing on the remarkable potential offered by the current technological advances and stepping forward towards more smart, sustainable and resilient future pathways that address the needs of both island communities and their visitors [26].

In order for such future pathways to be attained, a robust policy path needs to be featured. This should be designed on the basis of a place-based approach [11, 12], taking into consideration the very many peculiarities of such territories; the stakes that need to be served at the local/regional level; and the land use conflicts arising from highly competing actors/activities in both the land and the sea. Moreover, potential contribution of the evolving, of global or European reach, policy directions needs to be taken into account, stressing the potential pathways these can serve and assessing their performance with respect to sustainability and resilience achievements in these remarkable territories [25].

Along these lines, the focus of the present study is on structuring and implementing a methodological framework that sets the ground for a foresight exercise [40] towards a desired end state. This is accomplished by exploring the way EU Green [10, 17] and Blue Growth [20] directions can match to a specific island territory, namely Milos Island. The spatial data collection and management have proven crucial for realizing the distinctiveness of the specific island; and have provided input for unfolding, in spatial terms, the specifics of the Green and Blue potential interventions that have formed the narrative of the selected alternative scenario (Scenario 4 in Fig. 10). In addition, scenario planning has proven quite helpful towards the exploration of diversifying Green, Blue or combination of both future images in the specific spatial context, in alignment with the past and present economic, social, cultural and environmental profile of the study region. When seeking to achieve 'Qualitative islands' and 'Islands of equal opportunities' [6] on the basis of land and marine resource protection and sustainable exploitation, the specific exercise seems to be capable of producing a long term, well-documented, transparent and robust strategic policy direction for further negotiating with local communities and serve the 'big' challenge, being its implementation.

6 Conclusions

Current policy directions as well as technological advances and their applications in insular environments delineate new chances for paving a sustainable and resilient future pathway in such fragmented territorial entities. To the detriment of this pathway, apart from the insularity drawbacks, lie risks mainly linked to CC impacts, coastal urban sprawl and related infrastructure, but also a developmental pattern that goes beyond carrying capacity limits, largely associated with (over)tourism. On the contrary, to the benefit of such a pathway lies the spectacular natural and cultural resources of island territories as well as the, historically-embedded, tight connections with the sea and maritime activities, which lie at the heart of or have, even, formed the local culture and identity; and can structure challenging narratives about how the future might develop. That said, the Green and Blue Growth policy directions, coupled with the remarkable opportunities offered by technological advances, can form the ground for a more visionary developmental perspective, actually a new paradigm that is tightly interwoven with the past and the present of these fragmented land compartments as well as with newly emerging chances for successful implementation of these directions. Dedicated, spatially-designated, and future-oriented proactive efforts towards this end can support the flourishing of island communities, containment of population decline as well as expansion of employment

opportunities and social integrity; while ensuring the steady provision of environmental services.

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Assessing the Tourism Footprint in Dodecanese Complex, Greece – An Islands' Typology Approach

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Abstract. Tourism activity is by principle tightly intertwined with the distinct territorial context of each single destination. That said, the UNWTO anticipated surge in tourism flows, projected to reach 1.8 billion at a global scale by 2030, raises severe concerns as to the preservation of relevant territorial resources in popular but also emerging destinations, particularly those located in vulnerable and geographically-confined island regions. However, despite the nearly five decades of research and policy efforts in multi-level decision-making environments, highlighting the intricate relationship between tourist development and its territorial context, a certain deficit still exists with regards to the deployment of quantitative methods for fully assessing the territorial implications of tourism and informing sustainable tourism planning endeavours. Within such a context, this research advocates for the integration of territorial assessments of tourism into relevant planning exercises and policy decisions for attaining sustainability objectives in destinations, with a specific focus on insular regions. As such, the Dodecanese islands' complex in the South Aegean Region, Greece is considered, namely a region reputable for its diverse natural/cultural and tourism wealth as well as the discrete geopolitical importance in the eastern border of Greece. By use of spatial analysis tools and a set of indicators quantifying the spatial impacts of tourism, the study identifies clusters of islands according to a certain typology; thus initiating a vital discussion and providing evidence-based results useful for incorporating the territorial dimension in effective tourism planning in the Dodecanese islands' complex.

Keywords: Sustainable tourism and regional development · Tourism footprint · Spatial analysis · Dodecanese · Islands' typology

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1 Introduction

According to the UNWTO [1], tourism is defined as "*a social, cultural and economic phenomenon which entails the movement of people to countries or places outside their usual environment for personal or business/professional purposes*". This definition demonstrates the inseparable nature of tourism activity and the territorial context in which it takes place, rendering tourism a place-based activity [2]. In fact, tourism destinations are places mostly characterized by their "uniqueness", a quality that is largely grounded in the harmonious coexistence of natural and cultural wealth [3]. Such uniqueness demarcates the tourism landscape, attracts relative investments and shapes – in conjunction with other factors, e.g., tourism-related infrastructure, services – tourists' preferences in favor of a destination. The aforementioned statements ascertain that every tourism activity *is defined*, *occurs* and *refers* to a place; while it also *consumes and occupies* space [4], thus potentially creating positive but also negative repercussions; while can eventually exert severe pressure on local natural/cultural ecosystems.

The rapidly escalating tourism flows at the global level, trending to reach 1.8 billion in 2030 – i.e., 54% increase since 2015 – are predicted to even further intensify territorial consumption in order for the needs of tourists to be met [5, 6]; thus circumscribing the way tourism development is expected to project in space. Taking into consideration the statement of Pearce [7], claiming that the most common types of tourism development, so far observed, stand out for their spontaneous, pervasive and penetrating nature [8], this pattern, met in the Mediterranean region in general and Greece in particular, remains a major source of territorial pressure and related impacts in tourism-prominent areas [9–11]. These render *spatial planning* and related policies essential control mechanisms, especially in highly-rated tourism destinations, such as the insular ones.

In fact, *insular destinations*, i.e., top tourism destinations in the Mediterranean Region (Greece included), lie at the heart of this discussion as, according to Fernandes and Pinho [12], the "*islandness*" state affects the spatial and developmental pattern in insular territories both in a positive and negative manner, depending on the spatial distribution of terrestrial resources and the way these are managed in alignment with sustainability objectives. The islands' constrained but also vulnerable geographical space is, in most cases, accommodating: *high-valued natural and cultural capital* in need of protection and preservation [10, 13–15]; *sharper land use conflicts* for housing, agricultural, leisure etc. activities [16, 17]; and intense *tourism development*, being the outcome of glocal (global/local) real estate interest and the emerging tourism-oriented entrepreneurship [18, 19]. That said, spatial planning in insular territories is fraught with difficulties and challenges in the effort to manage the ever-increasing demand for "space" in such confined and fragile ecosystems; and the way such territories are evolving due to tourism. Concurrently, it is meant to compromise interests – economic, social, environmental, cultural, political, etc. – while safeguarding day-to-day needs of local communities.

Today, however, research focus on the tourism footprint in islands is mostly highlighting the social and environmental dimensions, e.g. water pollution, biodiversity loss and the COVID-19 aftermath [20]. In fact, only few studies have stressed the need to embed in relevant works the territorial context and the local attributes of the tourism sector by adopting a holistic approach, underlining the importance of such factors in

islands' future developmental patterns. At the same time, further research [4, 21, 22] and policy directions (e.g., EU cohesion policy 2021–2027) [23] endorse the integration of spatial dimensions into national/regional planning, tourism included; and call for the use of methods and tools that are capable of better grasping and representing the spatial footprint of tourism.

Towards this end, *tourism indicators* have currently gained a prominent position in assessing tourism footprint [24–26]. Such indicators apply to all types of destinations, including islands [11, 27]; and are widely used in policy and decision-making endeavours, targeting sustainability objectives [28]. The most commonly used ones relate to both tourism demand and supply, indicating the sector's growth patterns and dynamics [26, 28, 29]. In terms of the spatial impacts of tourism, indicator usage is extended through spatial analysis tools [30], where spatially-referenced data are used to highlight '*the possible importance of data spatial arrangement in the analysis or in the interpretation of results*' [31:137]. Contemporary research in tourism studies indicates that spatial analysis tools are used to demonstrate the pathways of tourists' movement in a destination or the tourism-related mobility means [32] as well as the motives to visit particular places and destinations [33]; and support tourism growth, attractiveness of a destination and tourism product development [34, 35]. In addition, special interest is placed in spotting environmental impacts in places where high valued natural resources and extended tourism development are noticed, e.g. coastal areas or islands [36–38].

Within such a context, a gap in *addressing tourism implications in spatial terms* is observed. That said, the focus of this research work is on highlighting the spatial repercussions of tourism – *tourism footprint* – as a necessary input in relevant planning endeavours that aim to achieve tourism sustainability objectives in insular regions. The study field is Dodecanese islands' complex in South Aegean Region, Greece, i.e., a highly-rated destination, marked by the uniqueness of cultural/natural wealth and a distinct geopolitical importance in the eastern border of Greece. By use of spatial analysis, this work illustrates the tourism footprint in each island of the study region; and, based on that, concludes with *an island typology*. In doing so, the following research questions (RQ) are set:

- RQ1: What are the *spatial implications* of tourism activity in the Dodecanese islands' complex and how such implications can be effectively measured?
- RQ2: What is the *typology of the islands* of the Dodecanese in terms of their current tourism activity and its respective spatial implications?
- RQ3: What is the role of such information in feeding policy decisions seeking to attain sustainable tourism development in insular regions?

In order to address these questions, this paper is structured as follows: in Sect. 2 data and methodology are presented; Sect. 3 sketches the study region; Sect. 4 elaborates on research results and the emerging islands' typology; while finally in Sect. 5 results are discussed and conclusions are drawn.

2 Data and Methodology

By focusing on the Greek Archipelago and particularly the Dodecanese islands' complex, South Aegean, this research aims to illuminate the spatial implications of tourism for feeding policy reaction towards sustainable tourism development. This exploration is a three-stage process (Fig. 1). It starts with the selection of the indicators' set (Stage 1) that can properly capture the effects of tourism at each single island's level. Then statistical elaboration of this indicators' set is conducted in Stage 2; and finally, interpretation of results (Stage 3) guides the structuring of an islands' typology in Dodecanese complex, based on the island-specific tourism footprint.

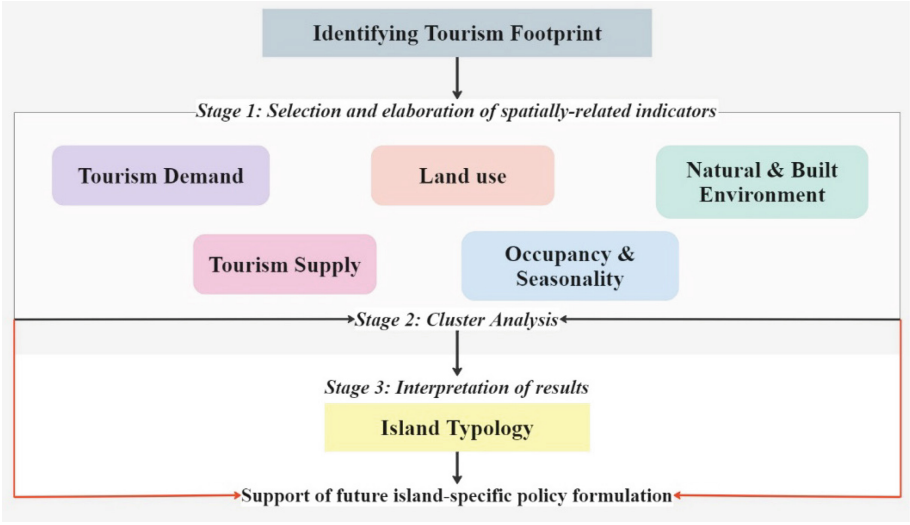

Fig. 1. Stages of the methodological approach, Source: Own elaboration

In more detail, each step of the methodological approach is described below (Fig. 1).

At *Stage 1*, a set of 14 indicators is selected and is classified into two broad categories, i.e., *sectoral* – tourism development both demand and supply side; and *spatial* – displaying the tourism footprint on land use, natural and built environment, etc. Selection of indicators is grounded in international evidence [24, 39, 40], further enriched by additional ones for more accurately representing local islands' peculiarities. The detailed list of indicators is displayed in Table 1, portraying the way these are calculated and the purpose they are serving. As spatial reference, the *municipalities* of the Dodecanese islands' complex are used (15 in total), as the lowest level for which relative data as to the tourism demand and supply side is available.

Going into specifics, the indicators' selection proceeds by taking into account the following *assumptions*:

- Indicators displaying *the impacts of tourism* incorporate: current accommodation supply, including both commercial and non-commercial types; annual tourism arrivals

in hotels and Airbnb; annual arrivals by air and sea – including internal ones – indicating tourism dynamics; and accommodation occupancy rates. In addition, intense *seasonality* observed in the studied islands calls for embedding this aspect in the way specific indicators are weighted, taking for granted a tourist season lasting from May to October, i.e., a total of 183 days [43].

- Indicators on *land use and environmental fragility* focus on the loss of agricultural land, expansion of the built environment and share of Natura 2000 protected areas. Their selection is based on the need to explore: imprints of the built environment on the fragile and contested island areas; agricultural land loss as the common victim of the rapid tourism construction fever of the last decade in island destinations [44]; high valued natural and cultural environment. These indicators derive from various data sources as well as from spatial analysis, combining different sets of geospatial data.

At *Stage 2*, Cluster Analysis is conducted for sorting Dodecanese islands into different groups, based on the combination of indicators selected in Stage 1. This is performed by use of the Hierarchical Clustering method. Ward's Linkage Method – or minimum variance linkage – was used, minimizing the increase in variance when two clusters were merged. Squared Euclidean distance was chosen as a measure of the distance between two clusters. At each step of the clustering process, the sum of squared distances within clusters was calculated; and the aggregated clusters were those resulting in a minimum increase in the overall sum of squares [45]. The method first includes a Z-score normalization of the initial variables.

At *Stage 3*, a qualitative interpretation of the produced island typologies is conducted, based on the shared behavior and attributes of tourism footprint. In fact, at this stage it is necessary to further explain the qualitative characteristics that have led to the structuring of the generated typology; present the key components of each cluster; link outcomes produced to the current tourism model of each island; and explore their positioning in future policy formulation endeavors in the Dodecanese Island complex.

The aforementioned statistical and spatial analysis processes are fueled with various *data sources* to reflect both tourism developments and their spatial repercussions. 2019 is used as the main year of reference for data collection of tourism flows, a year perceived as the most representative one before the pandemic outburst. In fact, data, sketching the contemporary tourism development patterns, are collected from the:

- Statistical Census of the Greek National Statistic Service (ELSTAT), corresponding to years 1991 and 2021.
- Yearly Report of the Aegean Sustainable Tourism Observatory (2019 data), providing tourism data on island municipality basis [41].
- Inside Airbnb Platform, providing beds' capacity/occupancy rate with reference to 2022.
- INSETE Intelligence, South Aegean Region's Annual Report on competitiveness and structural adjustment of the tourism sector (2021).
- Research Institute for Tourism, providing annual hotel arrival data for 2019.

Table 1. Formulating a new tourism impact-based island typology applied in the Dodecanese Island complex, Greece - List of indicators used, Source: Own elaboration based on [25, 39–42].

Indicator	Indicator description
T1 % population change	[(Total population 2021 – Total population 1991)/Total population 2021] * 100 T1 presents the percentage of population change during the last 30 years, highlighting population dynamics on the island level
T2 Tourism Accommodation Intensity	[Total tourist accommodation (beds)/resident] Tourist accommodation reflects the actual beds' capacity of each island, including the number of commercial beds in hotels and camping spots, as defined by the Greek National Statistic Service. Beds' capacity divided by the number of permanent residents represents the potential pressure (intensity) per resident due to the current tourism supply
T3 Tourism Accommodation Density	[Total tourist accommodation (beds)/island's surface] T3 represents the actual beds' capacity of each island, including all registered commercial accommodation types (hotel beds, camping spots, etc.) divided by the island's surface (area in km^2). It is used to sketch the tourism saturation level of each island
T4 Tourism Intensity (a)	[Total hotel arrivals/resident] There are several ways to measure tourism intensity. In this work, T4 displays the ratio of hotel arrivals to the local population on a yearly basis. Data about tourist arrivals are only available in terms of hotel registrations at the island level; while tourist arrivals in other commercial and noncommercial settings are missing
T5 Tourism Intensity (b)	[Total ship and airplane arrivals/resident] This indicator demonstrates the ratio of total arrivals by different transportation means (including maritime and air transport) to the local population on a yearly basis. T4 data limitations are held for T5 as well
T6 Tourism Density	[Total ship and airplane arrivals/island's surface] It calculates the ratio of total arrivals by different transportation means (including maritime and air transport) to each island's surface

(*continued*)

Table 1. (*continued*)

Indicator	Indicator description
T7 % Seasonal Population Density Change	[{[(hotel arrivals * hotel occupancy + Airbnb arrivals * Airbnb occupancy)/183 + local population]/island area}- population density] * 100 T7 estimates the % change in population density during the tourist season and takes into account the intense seasonality phenomenon observed in the Dodecanese Island complex between May - October [43]. Summer season is assumed to expand to 183 days in total
T8 Hotel Occupancy Rate	[Total number of rooms occupied divided by the total number of rooms available in each destination] Occupancy rate is the percentage of occupied rooms in a hotel accommodation at a given time. It is one of the most important indicators of tourism success. Annual data is used for 2022
T9 Airbnb Accommodation Intensity	[Total Airbnb accommodation (beds)/resident] T9 represents the total actual bed capacity in Airbnb of each island divided by the number of permanent residents; and highlights the potential pressure per resident due to Airbnb tourism supply
T10 Airbnb Accommodation Density	[Total Airbnb accommodation (beds)/island's surface in km^2] The actual number of Airbnb bed capacity in each island divided by the island's surface, displaying saturation levels of Airbnb at the island level
T11 Environmental vulnerability	[% area of each island falling into the Natura 2000 zones] It displays areas of highly-rated natural and cultural value
T12 Built-up areas	[% of each island covered by impervious (or built-up) surfaces in 2018] The classified change product (IMCC layer) has been used, and Classes 1 (new cover: from unsealed to sealed), 10 (unchanged sealed), 11 (increased sealing) and 12 (decreased sealing) were combined to identify sealed areas in 2018

(*continued*)

Table 1. (*continued*)

Indicator	Indicator description
T13 Built-up expansion	[% rate of growth of impervious (or built-up) areas in 2006–2018] Class 1 (new cover) was used to identify recent impervious land expansion areas, presenting a pivotal reference for geographically-constrained island regions
T14 Agricultural Impact	[% of total initial agricultural area (as identified by CLC 1990 zones) that has been impacted by urban development] It displays agricultural grid sectors presenting a dispersion of urban land >5%; and manifests vulnerability of agricultural land due to tourism

In addition, data used for calculating *spatial variables* emanate from the elaboration of:

- The Imperviousness dataset. This dataset is part of the Copernicus High-Resolution Layers. It is provided on a pan-European scale [46] and captures the spatial distribution of artificially-sealed areas. Sealed pixels are classified, based on the soil sealing level (imperviousness degree). Non-sealed areas are characterized by a value of IMD = 0%, while built-up areas are characterized by IMD values in the range of 1–100%. The IMP dataset captures accurately dispersed urban development and construction in agricultural areas, including various types of impervious surfaces that also contribute to the land take [47]. Impervious surfaces include a large set of structures, like housing areas and isolated buildings, industrial/commercial areas, roads, railways inside built-up areas, greenhouses, construction sites with discernibly evolving built-up structures, sealed surfaces associated with sport and recreation/tourist areas, etc. [48].
- The Corine Land Cover dataset [49]. This is the pan-European CORINE Land Cover inventory for 44 thematic classes with the reference years 1990, 2000, 2006, 2012, 2018. The dataset has a Minimum Mapping Unit (MMU) of 25 hectares (ha) for areal phenomena and a Minimum Mapping Width (MMW) of 100 m for linear phenomena. The dataset was used to identify existing agricultural areas in the early period of 1990, so as to specify the impact of new urban development on these scarce islands' productive soil resources.
- The Natura 2000 network [50]. The Natura 2000 (N2K) product offers a comprehensive overview of Natura 2000 sites, protected under the European Union's Habitats' Directive. N2K is currently updated every six years. These data were used to specify the environmental fragility of the case study islands.

In terms of digital tools used, statistical analysis was conducted through the SPSS software, while geospatial data were processed using the open source QGIS software.

Realization of the aforementioned steps can shed light on the current impacts of tourism, observed in the Dodecanese Islands' complex, i.e., an islands' complex in the Greek archipelago already characterized by mass tourism waves. The emerging typology presents the way these islands can be grouped on the basis of their similar tourism dynamics, providing critical input as to the spatial implications of tourism in each cluster for further exploitation in tourism planning endeavors.

3 The Dodecanese Islands' Complex

The aforementioned methodology is applied to the Dodecanese islands' complex, Greece, a cluster of 15 inhabited islands and 93 smaller islets at the southeastern part of the South Aegean Region (Table 2). It is a significantly diverse complex in terms of islands' size and population dynamics [51, 52]; accompanied by a substantial role in noteworthy historical events, both national and international, e.g. the Italian occupation during WWII and the late annexation to the Greek State in 1948 [53]. As a result, a vibrant cultural wealth, comprising numerous archaeological sites, medieval castles, architectural treasures and churches is left behind which, in combination with the scenic natural environment, strengthens tourism attractiveness of these islands. Tourism represents a salient sector, counting more than 3.8 million recorded hotel arrivals in Dodecanese islands in 2019 [41], i.e., 69% of total arrivals recorded in South Aegean Region as a whole (Table 2). This is also witnessed through the share of Dodecanese complex in hotel beds, owning the highest percentage in the Southern Aegean Region in 2019 (74%) [43]. Noticeable is also Airbnb bed availability, appearing in addition in small islands, e.g. Symi, Karpathos and Astypalaia. However, each island's tourism profile is significantly diversified, acknowledging islands characterized as famous mass tourism destinations, e.g., Kos and Rhodes; and islands demonstrating a rather alternative, authentic tourism profile, e.g. Astypalaia, Chalki, Symi and Kasos. Also, important to notice is that in 6 out of the 15 Dodecanese islands the whole land area is identified as Natura 2000 zone, proving the particularly vulnerable – and of top conservation priority – ecosystems, owned by these insular territories.

Table 2. The islands of the Dodecanese Complex in numbers, Source: [41, 43, 52, 54].

Dodecanese Municipalities	Population (2021)	Island's size (km^2)	Population Density (2021)	Hotel arrivals (2019)	Total commercial beds' capacity (2019)	Airbnb beds' capacity (2023)
Agathonisi	185	13.50	15.04	–	145	2
Astypalaia	1,399	96.85	14.34	3,729	3,872	504
Kalymnos	16,179	110.88	136.49	27,906	15,341	1,190
Leipsoi	790	15.98	49.68	2,450	1,730	115
Leros	7,917	52.95	137.06	21,328	8,996	477
Patmos	3,047	34.05	79.55	24,495	5,469	891
Karpathos	6,226	301.18	20.44	89,157	20,563	1,103
Kasos	1,084	65.98	18.25	719	2,774	28
Kos	33,388	290.28	128.87	1,295,163	80,445	2,173
Nisyros	1,008	41.40	25.42	2,752	4,953	173
Megisti	492	9.13	63.69	2,568	1,233	92
Rhodes	115,490	1,398.08	89.07	2,398,116	183,950	13,134
Symi	2,590	58.10	41.61	10,473	4,692	576
Tilos	780	62.83	12.04	5,917	3,479	108
Chalki	478	28.13	17.49	2,488	1,916	141
Total	**191,053**	**2,579**	**74.08**	**3,887,261**	**339,558**	**20,707**

Data collected and elaborated witnesses a significantly uneven distribution of tourism in the 15 insular municipalities of the Dodecanese complex (Fig. 2), advocating Sharpley's statement [55] as to the uniqueness and strongly place-based pattern of islands' tourism. In the following, an attempt to classify Dodecanese islands according to their tourism growth patterns and related implications is conducted in support of a more place-based and locally-adjusted policy formulation towards more sustainable tourism pathways.

4 Dodecanese Islands' Typology According to Tourism Footprint – Results

In this section, results obtained by the proposed methodology are presented, highlighting the different island typologies, grounded in each island's tourism footprint.

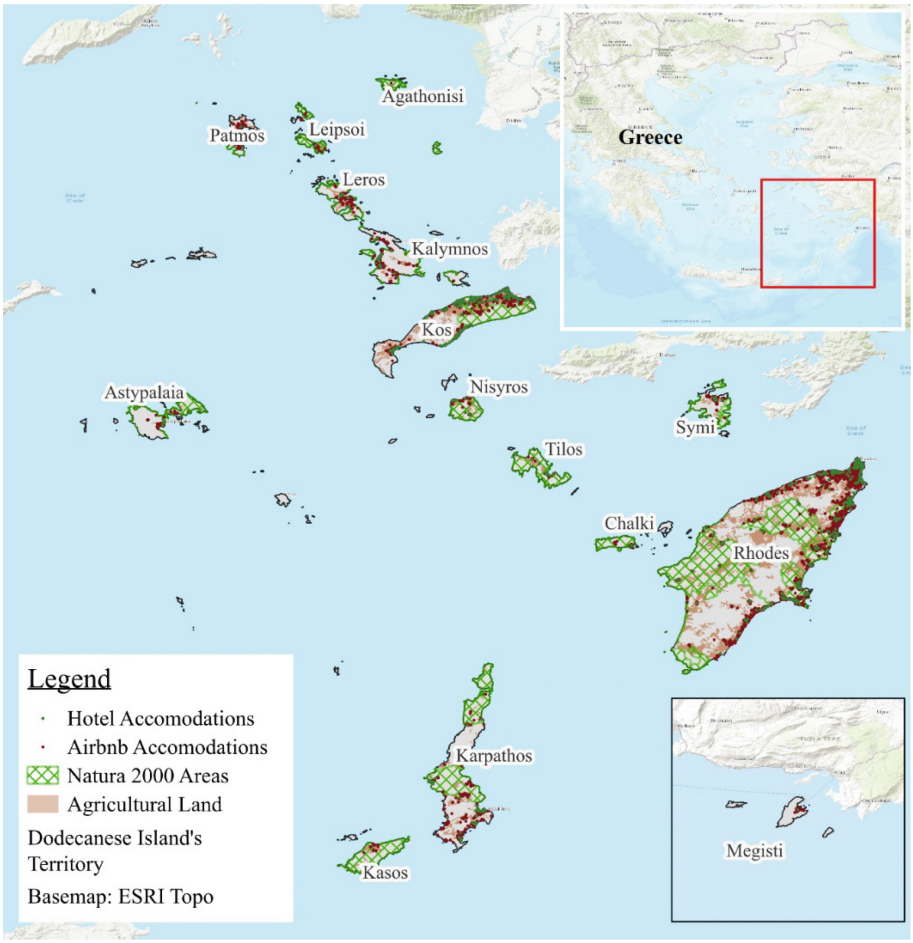

Fig. 2. The spatial pattern of tourism in Dodecanese Complex, Source: Own elaboration

In *Stage 1*, calculation of the 14 indicators provided a comprehensive image of the current tourism footprint in each single island of the Dodecanese complex. Indicator values confirm that Dodecanese Islands, overall, *are significantly affected by mass tourism*; while considerable variations are observed in their tourism profiles. Tourism Accommodation Intensity (T2) ranges from 0.72 in Agathonisi to 4.73 in Nisyros; while Tourism Accommodation Density (T3) shows even more diverse results, with values ranging between 10.8 (Agathonisi) and 279.5 (Kos). The Tourism Intensity Index as to the hotel

arrivals (T4) scores higher in three islands, namely Karpathos (13.58), Rhodes (19.17) and Kos (34.92); while when total arrivals are considered, Kos, Patmos and Symi are the islands with the highest scores of 75.9, 60.4, and 44.2 arrivals per citizen (T5). Kos, Rhodes and Karpathos display also the most significant increase in seasonal population density (T7), ranging between 35.9% and 56.9%; followed by Tilos, Chalki and Patmos (increase between 20–25%). Thus, in these islands seasonal population considerably exceeds the permanent local one.

Hotel Occupancy Rate (T8) is higher in Rhodes, Kos and Karpathos (>50%). It is interesting to notice that T8 is, in most islands, relatively very low (<40%); this fact confirming the high seasonality of the Dodecanese islands' tourism profile, with almost all arrivals reported during the summer period (May to October). Airbnb development is recently affecting Greek islands. However, according to indicators T9 and T10, only Astypalaia, Nisyros, Tilos, Kasos and Rhodes Islands are already hosting a relatively large number of Airbnb beds, compared to their population or size.

Regarding the spatial implications of tourism, built-up areas in Karpathos, Leros, Nisyros and Kalymnos occupy relatively high percentages of the islands' space (T12 is between 3–4.27%). In these islands, the impact of urban development on agricultural areas (T14) is also important, ranging from 9.4% in Leros to 24.8% in Karpathos. In Astypalaia and Agathonisi, large percentages of agricultural land are also already lost. Built-up expansion rate (T13) is over 8% in Kos, Symi, Leros, Karpathos and Megisti; this fact confirming that tourist development has an ongoing and accelerating spatial footprint, already affecting small, not necessarily mass and well-known tourism destinations.

In *Stage 2*, the 14 indicators are used as input to the Hierarchical Cluster Analysis. Clusters are visually represented in the dendrogram of Fig. 3. Based on the results, five (5) clusters were selected as an optimal choice, as less clusters would result in a more aggregated picture, and important information regarding the particularities of the case study islands would be lost. Final cluster memberships are mapped in Fig. 4, while the mean values of the initial indicators per cluster are displayed in Table 3.

Following a qualitative interpretation of the emerging island typologies (Stage 3), each cluster is analyzed as follows:

- *Cluster 1: Islands with limited tourist influence* (Kasos, Leipsoi and Agathonisi): islands falling in this cluster present a considerably low tourism profile, coupled with population stagnation. Both tourism density and intensity scores are very low. Environmental vulnerability is low and impact of tourist development on agricultural land is relatively high due to the considerable scarcity of such land resources. Construction activity is practically absent.
- *Cluster 2: Islands with significant Airbnb presence and high environmental vulnerability* (Astypalaia, Karpathos, Tilos, Chalki and Nisyros): islands marked by important Airbnb development and relatively high tourism intensity. However, arrivals and stays are still low in respect to their geographical area/size. Environmental vulnerability is high, while the impact of tourism on agricultural land is rather low.
- *Cluster 3: Rapidly increasing locally-driven tourism growth with limited seasonality* (Kalymnos and Leros): islands with low tourism intensity, yet relatively high tourism densities and tourism accommodation densities. The local population is growing and

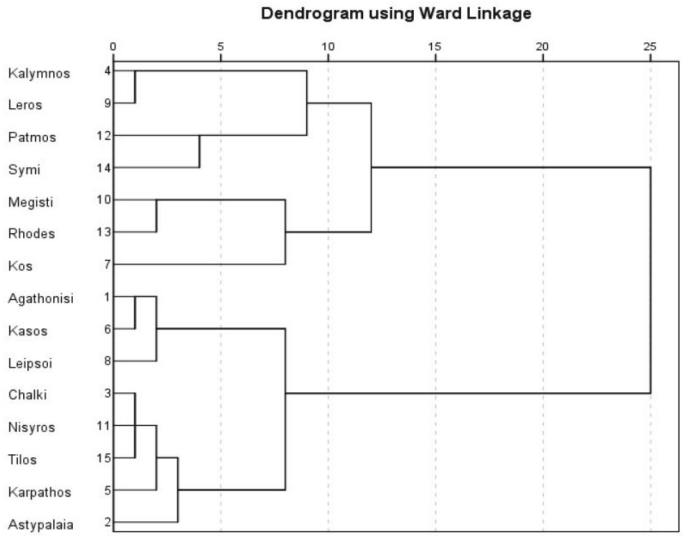

Fig. 3. Dendrogram identifying the Hierarchical Clustering steps of cluster analysis, Source: Own elaboration.

built-up areas occupy large shares of available agricultural land. These cannot be categorized as mass-tourism islands and are mostly based on a locally-driven growth.

- *Cluster 4: Islands with high tourism performance and impact* (Kos, Rhodes, Megisti): islands displaying important tourism and population dynamics, coupled with high rates of built-up expansion. The tourism dynamics are mostly attributed to the official tourism sector (hotel accommodation), leading to a high concentration of beds and arrivals and a rising seasonal population density. Airbnb development is up to now relatively low in comparison to the hotel sector. Especially for Megisti – i.e., a particularly small island –, its grouping in Cluster 4 is mostly attributed to high population growth and high tourism density in respect to its size.
- *Group 5: Dynamic tourism destinations growing at a steady pace* (Patmos and Symi): islands presenting a special typology with stable population and built-up areas, but important Airbnb development and very high tourism density, based on total arrivals. Environmental vulnerability is low and the impact on agricultural land is relatively high. Overall, they seem to rise to dynamic tourist destinations, sharing some similarities with islands of Clusters 2 and 3.

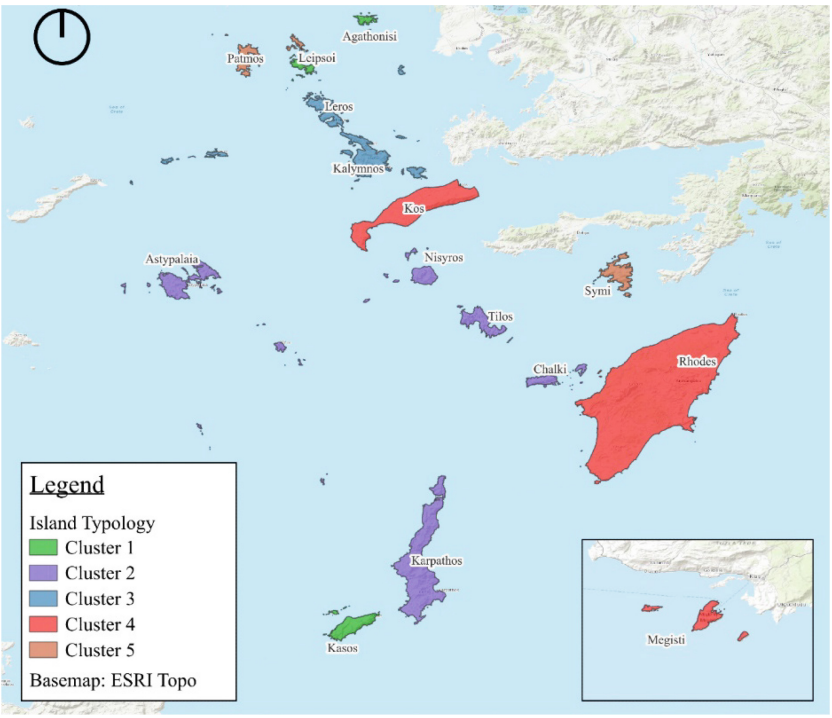

Fig. 4. Dodecanese islands' typology, based on the current tourism footprint and its spatial implications, Source: Own elaboration.

Island typology is a very helpful tool for better grasping the tourism dynamics, assessing their implications on land and local population, defining carrying capacity limits and identifying shared growth patterns and risks at each single island level. Based on the cluster analysis applied in this work, different islands' typologies were identified in the Dodecanese complex, ranging from islands with limited tourism presence (e.g. Kasos and Leipsoi) to very dynamic, of global outreach, mass tourism destinations (e.g. Rhodes and Kos); coupled with several cases in-between, better conceived as being in a transitional stage towards more dynamic tourism growth. Up-to-date tourism implications on the Dodecanese islands demonstrated that tourism growth is not only a matter of size and population density. On the contrary, very small and small islands are already approaching alarming levels of touristification, threatening local natural and cultural wealth and local communities' well-being. Concurrently, increasing vulnerability of those islands to global challenges, e.g., climate change is noticeable.

Table 3. Mean value per explanatory variable/per cluster of islands, Source: Own elaboration.

Cluster	T1	T2	T3	T4	T5	T6	T7
	Population change	Tourism Accomod. Intensity	Tourism Accomod. Density	Tourism Intensity (a)	Tourism Intensity (b)	Tourism Density	Seasonal population density change
1	−2.20	1.73	53.75	1.23	17.57	537.76	5.50
2	3.65	3.87	70.24	6.42	22.34	396.19	22.67
3	6.89	0.99	136.11	2.12	10.86	1,485.33	7.47
4	36.45	1.92	181.64	19.50	31.48	3,192.87	38.89
5	0.00	1.73	103.76	5.74	67.69	3,963.06	19.62
	T8	T9	T10	T11	T12	T13	T14
	Hotel Occupation Rate	Airbnb Accomod. Intensity	Airbnb Accomod. Density	Environ. vulnera-bility	Built-up area	Built-up expan-sion	Agricultural Impact
1	11.63	0.09	3.00	100.00	1.06	2.49	11.00
2	31.48	0.34	5.88	75.57	0.60	5.60	4.07
3	35.45	0.08	12.10	5.21	3.62	7.11	23.33
4	51.67	0.15	12.69	54.31	3.05	19.79	4.64
5	32.30	0.32	23.27	24.35	2.20	4.94	10.06

5 Discussion and Conclusions

Identification of island typologies is critical for providing a better insight into tourism growth patterns and dynamics in such territories [56]; and thus guiding more informed and place-based tourism policy decisions. Such typologies have so far been established by taking into account the tourist demand and supply pattern and have already been used in articulating tourism policy.

Speaking of the Greek context, the revision of the "Special Framework of Spatial Planning and Sustainable Development for Tourism" is currently in progress, representing a key policy instrument in respect of the spatial development of tourism at the national level for achieving tourism sustainability objectives. This Framework aims at providing strategic, nationwide guidelines for tourism development as well as regulatory measures, taking into account the spatial variations of the sector as well as its environmental and socio-economic impacts. The newly proposed revision, expected to be soon announced and institutionalized, classifies the national territory (islands included) into a number of distinct categories, thereby stipulating different sets of measures/strategies for each single one of them. More specifically, typological divisions suggest five (5) tourist development classes. These are grounded in demand and supply figures [57], and are: Saturated Areas, Developed Areas, Developing Areas, Aid Areas, and Areas under Selective Special Support. Additionally, islands receive a separate distinction, based on

their population size, demonstrating thus a nuanced approach in order for the diverse attributes of these specific areas to be properly addressed. Such typologies, fall short of fully capturing the actual developmental and spatial footprint of tourism activity; thereby, more solid scientific methods are needed in order for the typologies produced to be robust.

The present study highlighted this necessity and developed a methodological approach that adopts an integrated view of tourist development, attempting to establish linkages between tourism demand and supply on the one side and the socio-economic, environmental and spatial contexts these refer, on the other. This approach is applied to the Dodecanese Islands' Complex, where quantification of the tourism footprint and its spatial repercussions by dedicated indicators and application of hierarchical cluster analysis, lead to more transparent and robust islands' grouping. Results produced confirm: i) the importance of the spatial dimension for apprehending the footprint of the tourism sector in already developed and developing destinations; ii) the value of simultaneous consideration and interpretation of different tourism-specific and spatial indicators in order for the sector's footprint in terms of intensity, density, type and island's vulnerability to be defined, assessed and properly inform policy reaction; iii) the particular weaknesses of insular territories that call for further attention and strategic planning choices in the tourism sector; and iv) the peculiarities of small islands which, due to geographical limitations and small population size, are more vulnerable to tourism (over)load. Indeed, island groupings – grounded in the developmental and spatial implications of tourism – provide a solid ground for planners and decision-makers in support of tourism transition pathways to sustainability, by offering critical information of insular areas with regard to their current state, the saturation level in spatial terms, the (cultivable) land loss, the spatial distribution of tourist accommodation as well as the local population dynamics against tourism waves.

In conclusion, accommodating intense tourism development in the land-constrained, vulnerable and fragile insular territories is a quite distinct and demanding planning exercise; and a real challenge for planners and policy makers around the globe, given the tremendous natural and cultural attractiveness of these land parcels and the massively escalating tourism trends. Delving into the current tourism footprint in social, economic, environmental, cultural and spatial terms in conjunction with the Tourism Carrying Capacity [58] of each distinct type of island seem to be the starting point and a well-established ground for planning a future trajectory of these peculiar spatial entities that is sustainable and resilient, fair for their population but also appealing to visitors, while well-rooted to their historical trajectory through the centuries.

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Planning Strategies and Practices for Accessibility in Peripheral Sparsely Populated Areas (SPA). A Spatial Knowledge Interpretation Approach

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Abstract. The authors provide a comprehensive and interconnected approach aimed at strategizing the planning of a sustainable alternative and smart mobility in peripheral sparsely populated areas (SPA) with latent tourism potential. The objective is to represent and optimise the potential for knowledge-driven development of existing resources, distinctive features of contexts, and cooperative networks to support decision makers in defining coordinated interventions at different scales, thereby facilitating the emergence, enhancement, and managed of knowledge. This study demonstrates various strategies for enhancing the accessibility to information and services, for both inhabitants and visitors. A permanent and replicable program comprising a series of integrated, cross-cutting activities at different scales is defined. These activities involve multiple figures who contribute to the daily operations of the area. The proposal suggests the development of an interpretive tool for a SPA with weak connectivity, such as the Sulcis-Iglesiente region in Sardinia, Italy. A spatial organisatiSSon through a network system of accessible nodes is planned. The aim is to promote interconnections and interdependencies among the network nodes, which are linked to the places of greatest strategic potential in terms of services and attractiveness. The focus of this model is particularly on User Generated Content (UGC). The authors conclude that this model aims to improve accessibility to basic services and the use of environmental and cultural resources through alternative and smart sustainable mobility solutions integrated with local services according to the five "S.M.A.R.T." parameters: Specificity, Measurability, Achievability, Resilience, and Time-bound nature.

Keywords: Sparsely populated areas (SPA) · peripheral regions · regional development · network system of accessible nodes · User Generated Content (UGC)

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1 Introduction

Peripheral sparsely populated areas (SPA), affected by structural limitations in terms of accessibility, depopulation and rarefaction of services, struggle to implement comprehensive development strategies and projects in line with the new criteria introduced by the EU Commission and the perspectives of the 2021–2027 Programming. The causes seem to be related to the lack of capacity for cooperation among local / regional stakeholders [1–3], as well as the weak endowment and capacity of relevant institutions [4, 5]. OECD has highlighted the need to undertake effective governance agreements and tailor them with business needs [6]. Therefore, the importance of strengthening multi-level governance with a focus on the alignment and coordination of programmes and strategies [7] is acknowledged in the SPA. This serves to establish a cohesive framework of policies that facilitate both local cooperative efforts and cross-cutting projects and proposals, involving the multiple figures that take part in the daily functioning of the region. Indeed, the small size of many towns and hamlets does not allow them to automatically become the nodes of a network to have supra-local comparability. A different spatial model is needed for sparsely populated suburban areas than for urban areas, highlighting the economic basis for their development [8].

Starting from the assumption that plans, programmes, and projects involving the management of resources are crucial for promoting the growth and the enhancement of minor towns as well as the natural and cultural heritage, the results of the TSulki research project – Tourism and Sustainability in Sulcis are here illustrated [1]. The Sulcis-Iglesiente region in southwestern Sardinia, Italy, where a natural environment of considerable public interest coexists alongside abandoned areas severely degraded by mining and industrial activity, is the context of the research project. This decline is evidenced by demographic indicators, with a disappearing population, high average age, and employment below the regional average, concentrated mainly in the service and tourism sectors.

To effectively organise information in sparsely populated areas with inadequate connection, such as the Sulcis-Iglesiente region, it is beneficial to develop an interpretive device that promotes the collaborative development of a territorial organisation model. This model should be built on a network structure of easily accessible nodes. Hence, it fosters interconnections and interdependencies between the nodes of the network linked to the places of greatest strategic potential in terms of services and attractiveness with reference to User Generated Content (UGC) [9]. For the purposes of this study, such a device allows to organise, make accessible, connect, and manage information on tangible and intangible resources (such as historical-cultural, geo-environmental, tourist, etc.) and services. It also allows for the adaptation of accessibility and fruition paths at different connection levels, including economic aspects. By using the existing networks and knowledge-based development potential of rural regions, it is possible to maximise the their knowledge-based representation in an accurate and focused manner. Simultaneously, it is possible to delineate methods to enhance the accessibility of information

[1] Tsulky ("Tourism and Sustainability in Sulcis-Iglesiente area") research project final report – 3rd unit. Project funded by Autonomous Region of Sardinia – fundamental or basic research projects for the implementation of interventions under the research for the "Sulcis Plan", CIPE Resolution n. 31 20.02.2015, and resolution n. 52/36 28.10.2015, "Sulcis Strategic project" – public-private research project.

and services for both inhabitants and visitors. This approach can be implemented in a permanent and replicable way, ensuring lasting and scalable benefits over time [10].

In order to achieve this, the first operational objective is oriented towards the systematisation of expert, local and web knowledge, which brings together basic spatialised information relating to tangible and intangible networks, in order to organise the territory's offer and the rational channelling of the information generated towards the private sector; the second operational objective is geared towards a development strategy through the implementation of a sustainable mobility planning at a *functional* area scale, which efficiently organises physical connections and information, identifying and connecting the areas of greatest strategic potential in terms of the attractiveness of the natural, historical-cultural, residential and productive environment and the potential operators available (Fig. 1).

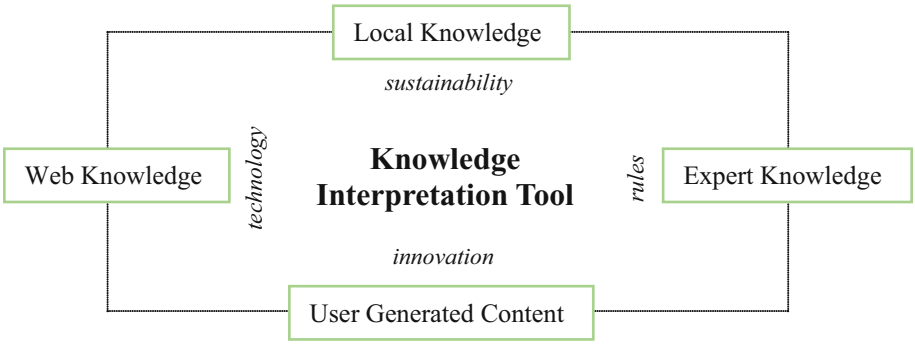

Fig. 1. The basic elements of the strategy

2 The Methodological Path

The activities of TSulki research project – Tourism and Sustainability in Sulcis (see Acknowledgements), along with the Work Packages, are categorised into the following stages: 1. Context analysis; 2. Definition and implementation of a spatial organisation model based on accessibility, enjoyment and use of tangible and intangible heritage; 3. Classification and organisation of knowledge; 4. Model testing. In order to achieve the objectives of the project, a reference framework is used to analysing the planning, programming, and financing instruments. This enables the authors to understand the coherence among them by comparing goals and actions (Fig. 2). This framework can also support decision makers to define guidelines with the aim to identify and promote integrated interventions and to agree reciprocal commitments and obligations for their implementation in the form of agreements.

The highlighted aspects include the environmental relevance of the region, the lack of a unified strategy and coordination among different planning levels, and the necessity of adopting an integrated approach to address environmental, tourism, and mobility concerns (Figs. 3, 4).

Regarding funding tools, with reference to businesses, two territorial development tools are considered: the Sulcis Plan [2] and the S3 strategy [3] both promoted by the Autonomous Region of Sardinia.

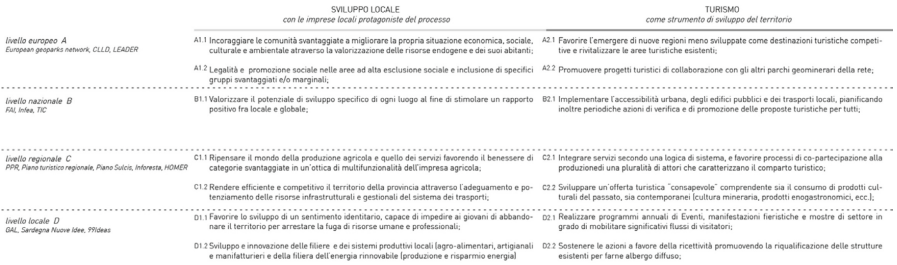

Fig. 2. The reference framework (*part*): programs, strategies, goals for local development, tourism, education, research and innovation in the Sulcis – Iglesiente region

It should be noted that the Smart Specialisation Strategy (S3) represents the European Union's place-based regional innovation strategy, which has been recognised as a key means for strengthening regional growth from local vocations [11]. At the regional level, the ICT sector is the one that registered almost half of the co-funded projects and the main achievements in the "Tourism, Culture and Environment" sector are represented by the ability to digitise and organise market processes in a digital key, and by the definition of tools to support strategies for listening, communication and customer and market loyalty. Some of the proposed solutions were addressed to enhance, access, and use the cultural and environmental heritage of the region [12]. In the Sulcis-Iglesiente region, the scarcity of enterprises benefiting from funding and integrated development projects or with an innovation index confirm the lack of capacity for cooperation among local stakeholders. Finally, the authors tested the model for land knowledge management in a specific spatial area identified within the Sulcis-Iglesiente network, selected from the analyses of processes, relationships and practices of land use and operation, with a special focus on the archaeo-mineral, religious, blue, green etc. landscapes.

[2] The Sulcis Extraordinary Plan is a tool for guiding, planning, and coordinating interventions for the development of Sulcis – Iglesiente region, aimed at safeguarding the productive fabric, technological research and development activities, infrastructural interventions, environmental remediation, training and financial commitments.

[3] With the start of the new programming cycle (2021–2027), the Region of Sardinia is updating the S3 considering the results of the previous period (2014–2020) under which the following thematic areas of smart specialisation were identified: ICT; Agribusiness; Tourism, culture, and environment; Smart networks for efficient energy management; Aerospace; Biomedicine.

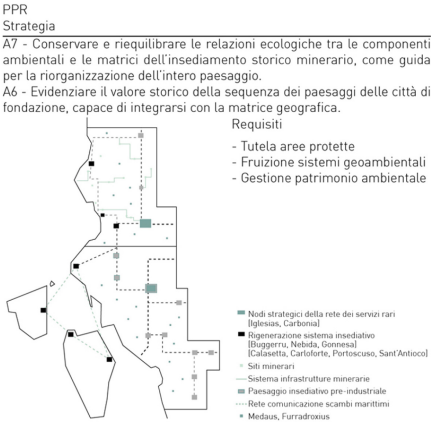

Fig. 3. Regional Landscape Plan; Protection and Special Management Tools

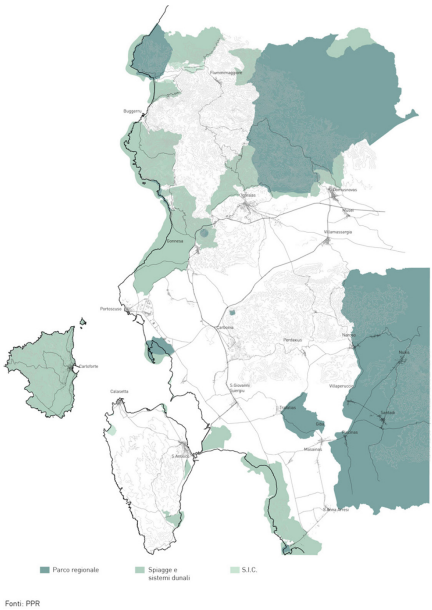

Fig. 4. Regional Landscape Plan; Protection and Special Management Tools

2.1 Context Analysis

The context analysis is aimed at recognizing the evolutionary dynamics that have passed through the Sulcis – Iglesiente region, producing the current spatial configuration [4] (Fig. 5). The analysis of settlement patterns in terms of appearance, and uses, endowment and distribution of resources and services (Fig. 6), has been of crucial importance in defining "organisational / functional perimeters" with which to describe the present and possible functioning of the spatial network and the interactions between nodes (Fig. 7).

The combination of data from various sources has produced a large, coherent and updatable information base. The Open Data base of Sardegna Geoportale [5] was compared and integrated with cartography and content drawn from official documents and other informal but certified information sources. For example, the framework of physical connections is derived by integrating the existing trail base map taken from OpenStreetMap (OSM) with the trail network from the Regional Hiking Trail Network Plan and IGM tables.

[4] Two types of settlements are identified with respect to mining processes: a) settlements built for the mining needs, which have been transformed or/and evolved (e.g. former agricultural settlements) and b) abandoned settlements. The research delves into only the first type to first recognise and support those settlements that auto poetically reinterpret the evolutionary dynamics following the closure of the mines (1960s and 1970s), in line with a sustainable development model based on human resources.

[5] https://www.sardegnageoportale.it/

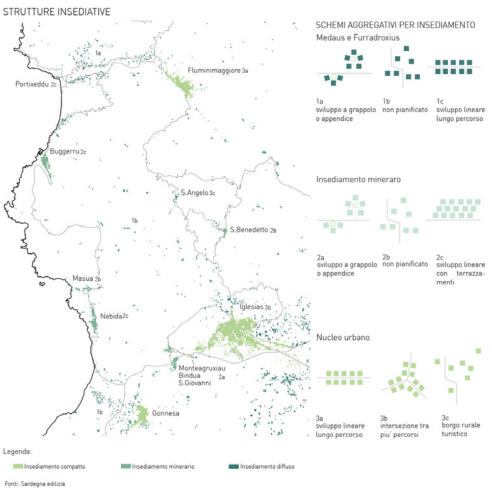

Fig. 5. Settlement patterns and service center systems

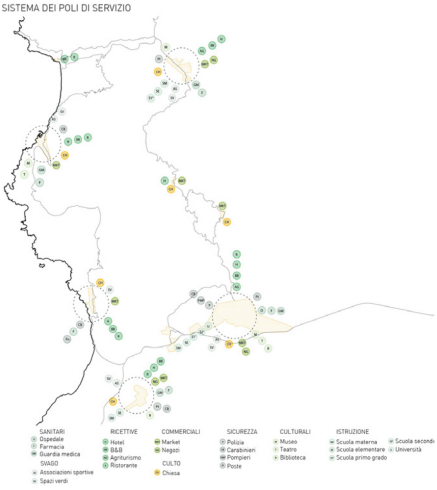

Fig. 6. Settlement patterns and service center systems

Other analyses include: a. the existing and potential spatial networks taken from the unstructured information base of the "S. Barbara Mining Trail Foundation", which includes 21 municipalities of the region; b. Web data and User Generated Contents (UGC) taken from specialised platforms and sites with the help of GIS tools, OpenStreetMap [6] and other applications to understand the level of tourist attractiveness of the area (Fig. 8).

It is notable that data collection was done through OSM and social networks including Twitter, and Facebook (Instagram showed difficulties in accessing information). Some other applications include Epicollect, Mapillary [7], Fieldpaper [8], Mapwarper, *etc.* All these tools assume georeferenced mapping of data to support the design and the implementation of the proposed model and its attributes. Additional specific aspects were explored, such as for example, the presence of accommodation facilities (Airbnb [9]), and the representation of the most photographed locations (Flickr [10]). This first phase has revealed the poor recognition of obvious patterns related to mining activities, which have characterised the region since ancient times: most of them are not visible or do not return immediate information of the processes that generated them. The present state of the sites shows frequent abandonment and lack of any kind of spatial organisation, as well as sporadic cases of collaborative forms.

6 OSM allows the identification of some detailed data such as drinking fountains, stairways, cliffs, paths, fences, etc.

7 http://mapillary.com

8 GPS technologies do not always perform well due to antenna reception problems. Fieldpaper is an alternative tool for data collection when there is no connection.

9 https://umap.openstreetmap.fr/it/map/airbnb-tsulki_314332#11/39.3293/8.5187.

10 https://umap.openstreetmap.fr/it/map/airbnb-tsulki_314332#16/39.4093/8.4215.

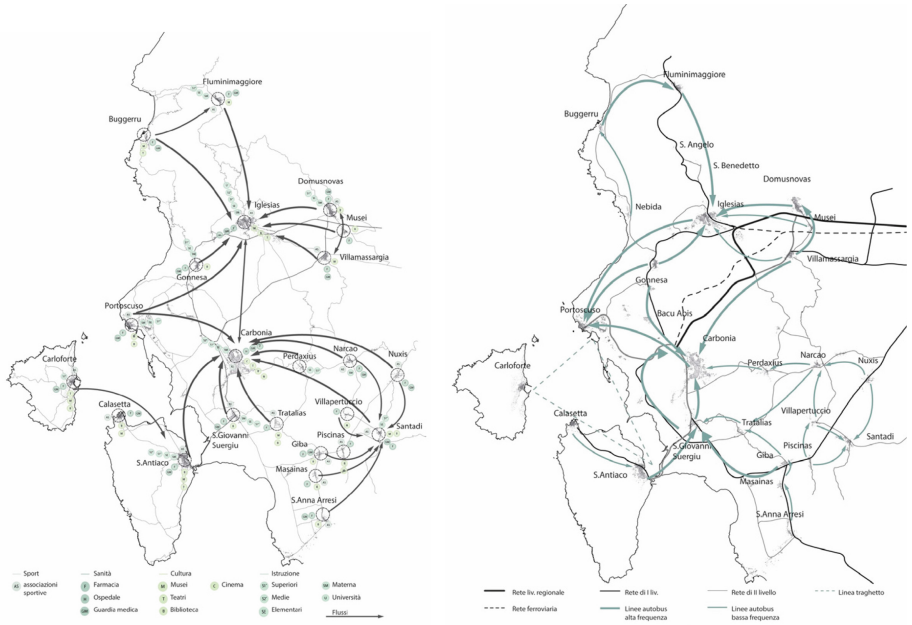

Fig. 7. The existing system of connections: the system of services and the system of mobility

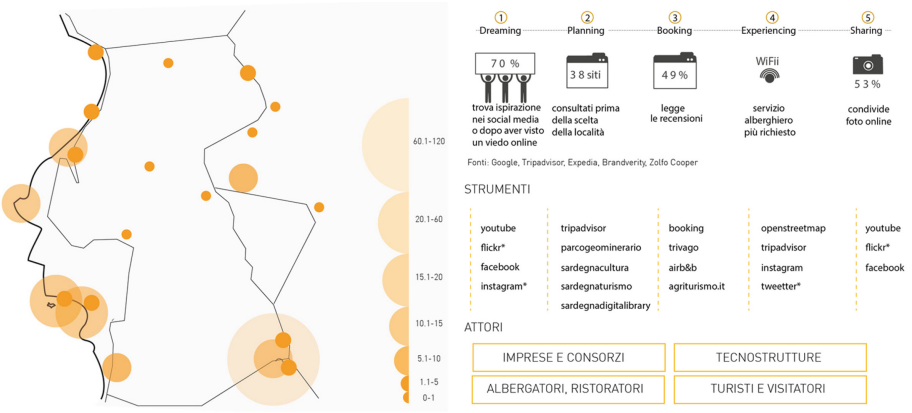

Fig. 8. Multi – media knowledge (UGC) in thousands and steps of web use during the trip.

2.2 Definition and Implementation of a Spatial Organisation Model

The second phase focuses on the interpretive device of spatial knowledge to co-plan accessibility routes at different levels of knowledge and scales. This model of spatial organisation is based on:

a. a networked system of accessibility nodes with relationships of mutual influence and conditioning. Each node refers to an inhabited location, as surveyed by ISTAT [11], and is characterised by a number of attributes. The following have been identified: *nodes with contextual attributes*, which have played a generative role in the definition and evolution of the mining landscape; *nodes with general attributes*, specified with respect to three typologies: *spatial, functional, and sociocultural accessibility*.
b. The relationships between nodes and guidelines for the recognition, organisation and future management of nodes in terms of spaces and offered services.
c. Identification of key stakeholders (residents, authorities, administrators, managers, businesses, cooperative networks, visitors, *etc.*) to assess the importance of individual nodes in relation to the subjects.

SPATIAL ACCESSIBILITY NODES: Attributes | Indicators
Physical infrastructure | infrastructural artifacts
Connectivity of the public transportation system | connections provided by public transportation
Modes of travel | Type and total number of displacement possibilities of the transportation system
Internal connectivity | Alternative connections by possible mode of transport

FUNCTIONAL ACCESSIBILITY NODES: Attributes | Indicators
Access to basic services | basic services present, e.g., drinking water, electricity, sewage, garbage, telephone network, internet network
Infrastructure/services | Cultural (e.g., library, museums, etc.), Education (schools of all levels), Transportation (e.g., car rental, bicycles, nautical vehicles and products, etc.), Health and Social Care (hospitals, doctor's offices, pharmacies, etc.), Sports, Public Administration (city hall, offices, personal services, etc.), Post Offices and Banks, Churches, Tourism (accommodation, info points, etc.), Commerce (food, clothing, handicrafts, etc.); Security garrisons at urban and regional scale
Character of the service | Stable or temporary
Correlation with other services | multiple services (e.g., a bar kiosk that operates as a ticket office, information point, and food store)
Catchment area of influence | Dependence of inhabited locations on service or vice versa.
Internet visibility | Official website of the node

SOCIOCULTURAL ACCESSIBILITY NODES: Attributes | Indicators
Inhabitants and employment | Number of inhabitants and employment rate
Official "local community networks" | Number of formal and informal associations and categorization by themes of the activities they carry out.
Artistic and cultural events | Events that express and celebrate artistic or/and cultural values
Identity components | Identity places recognised by the local community

2.3 Classification and Organisation of Knowledge

The result of this phase is the survey and selection of already available basic data and sources from which to draw information for each descriptive attribute of the nodes. The

[11] The National Institute of Statistics.

survey sources are of three types: the first group is represented by various regional registers, archives and specialised publications of relevance; the second group is represented by official databases and computer archives of different institutional and non-institutional nature and relevance, and accessible such as, e.g., Sardinia Geoportal, websites of municipalities and the Integrated Water Service; the third group includes a campaign of direct surveys, in the field or through interviews. Next, the different attributes were measured. Note that given the variety of attributes considered, quantitative and qualitative measures were chosen, ranging from coding and use of the binary system (e.g. for the attribute "Connectivity of the public transport system" the value "0" indicates the absence of the service and the value "1" indicates the existence of at least one connection with subsequent specification of the total number of existing connections) to qualitative assessment. An instruction set ensures that the data are collected in a self-contained and replicable manner.

2.4 Model Testing. The Case Application

A microstructure of the peripheral SPA is identified [13], between the urban centres of Iglesias and Fluminimaggiore. It was chosen for its landscape-settlement peculiarities and includes the mining village of Buggerru (about 1029 inh.), the rural settlement of Grugua (nr), the rural village of S. Angelo (about 19 inh.) and the mining village of S. Benedetto (about 220 inh.).

In particular, the focus is on a route, central in the connections between the coast and the main road system, obtained by connecting four hiking routes, which refer to the mining and rural agro-pastoral dimension, with the aim of strengthening the relationship between the coast and the inner areas, connecting strategic nodes, and crossing different types of landscapes (Fig. 9).

The following are assumed as design requirements:

Access to information.
strengthening of coast-to-coast relations.
establishment of service spaces, intermodal exchange at strategic nodes of the route.
integration of territorial and cultural services.

Three types of interventions support the strategy:

1. multimedia technologies: strengthening of telematics networks for adequate access to services and knowledge; representation and sharing of data and information through crowdsourcing and UGC technologies; *etc.*
2. spatial-programmatic interventions: green road / smart road; trail resurfacing, path construction, safety enhancement; integrated platform for mobility management through demand management; parking areas and modal exchange; monitoring systems with integrated sensor technology for data and information management regarding environmental conditions and safety; *etc.*

Itinerant services: organisation and management of stable and temporary services.

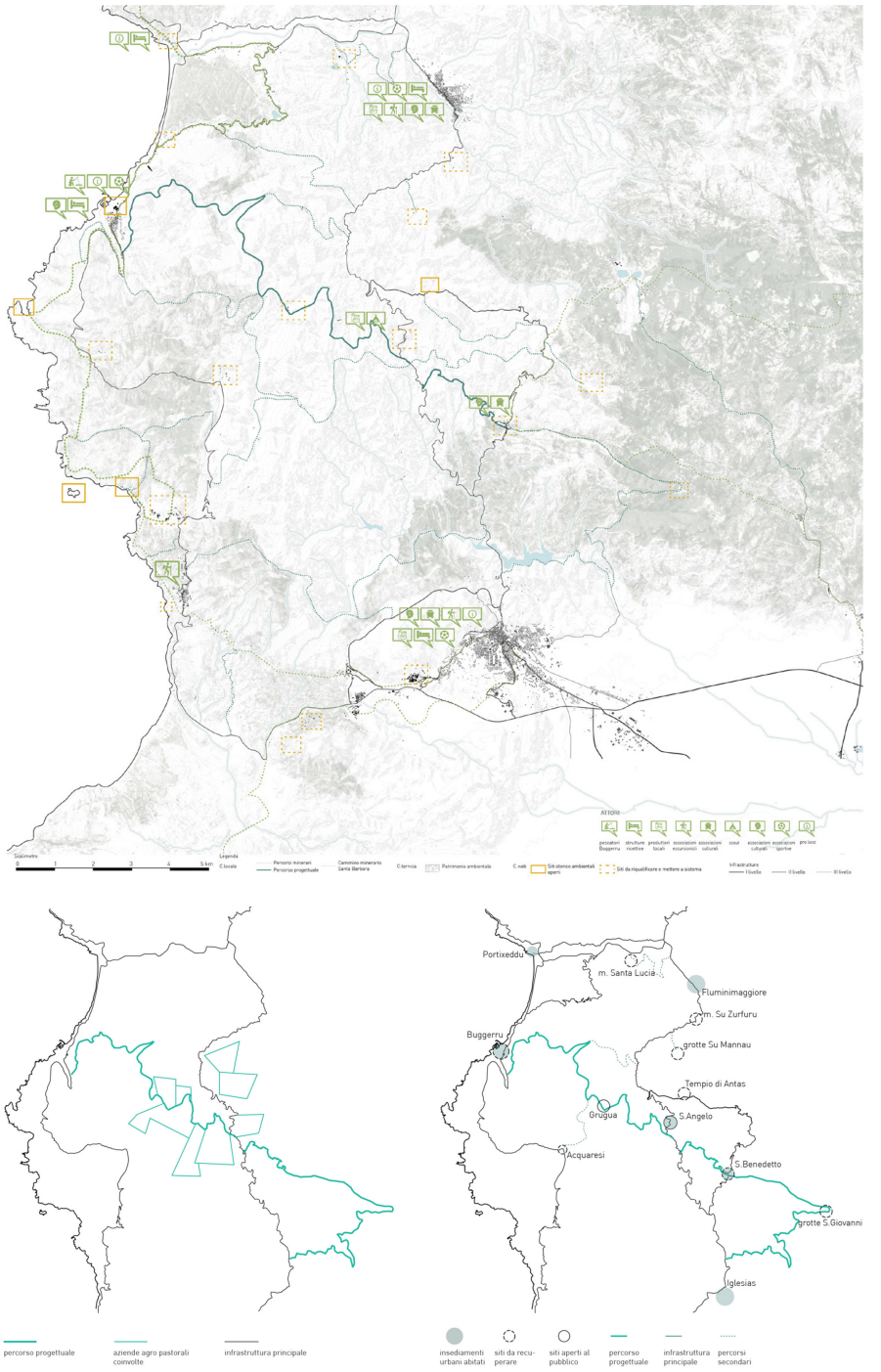

Fig. 9. Masterplan. Connections between production system and historical-settlement elements

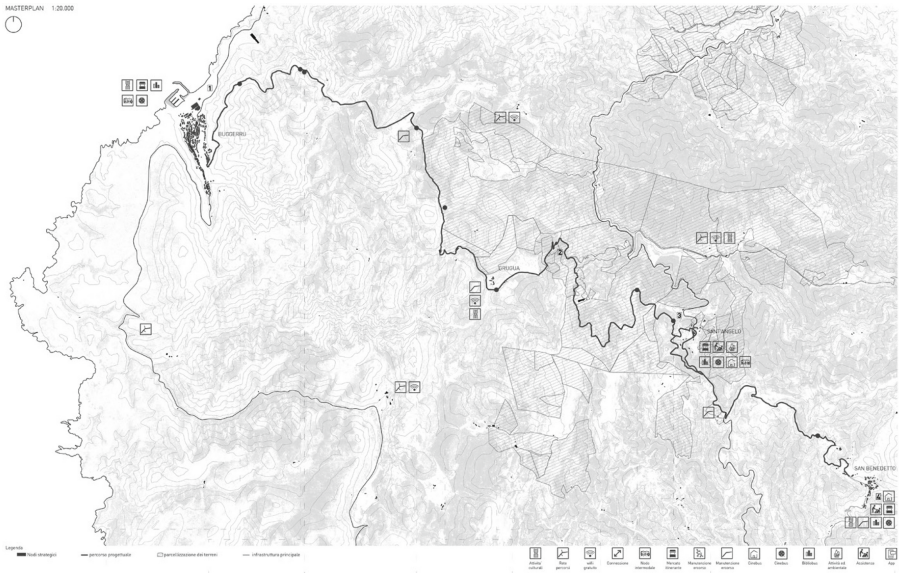

Fig. 10. The networked system of strategic nodes for knowledge accessibility (1:20.000)

In other words, the networked system of accessibility nodes with relationships of mutual influence and conditioning is supported by crowdsourcing and UGC technologies, an integrated platform for mobility management through demand management, and itinerant services (Figs. 10 and 11).

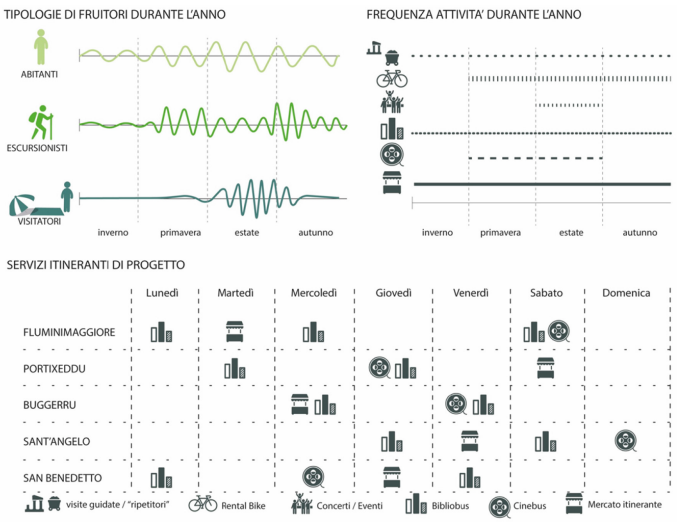

Fig. 11. Types of itinerant services

In this way, the proposed organisational model intends to enhance the interconnections and interdependencies among the elements of the system to ensure that inhabitants and visitors can use the essential services at the identified nodes, promote the organisation and management of the nodes, and strengthen the networks of local actors, while at the same time move and enjoy the environmental and cultural resources through sustainable and intelligent alternative mobility systems.

3 Conclusions

The use of effective data analysis, communication and sharing tools assists learning and mutual exchange of knowledge and experience, as well as the more informed use of local services, including optimization of economic aspects, fostering growth of SPA. Not the least, the ability to locate information on open editable online maps based on local knowledge and user experiences, offers targeted possibilities for planning sustainable, flexible and responsive transportation infrastructure and services. For example, it is possible to organise in participatory and cost-effective ways the strategic nodes of the territorial network according to different access possibilities, through forms, functions and rhythms that allow everyone, for each place, a complete, free and effective knowledge and enjoyment of the surrounding landscapes. Such an approach characterises many transport system reorganisation models in peripheral sparsely populated and weak demand areas that have been experimented in recent years at the European level. Consider, for example, the projects of the 13 regions participating in the EU-funded "Move on Green" program [14].

In this sense, the prospects of each place will depend on its ability to offer different opportunities and forms of comparative advantage based on accessibility to resources, knowledge and, in general, environmental quality.

To summarise, the paper pursues three practical things:

1. To know and access tangible networks such as services, and intangible ones such as environmental or landscape, through the development of a knowledge approach based on a system of strategic nodes for accessibility that combines quantitative and qualitative, freely editable information.
2. To connect the local productions and businesses through integrated projects to strengthen local economic systems. The focus is on organised networks and territorial cooperation in the context, as a fundamental element on which the principle of subsidiarity at the local level is based, which assumes a crucial role in SPA governance.
3. To represent and maximise the knowledge-based development potential of rural territories and their existing networks, and, on the other hand, to outline possible ways to enhance accessibility to information and services, both for residents and visitors, according to a permanent and replicable program.

This paper faces several limitations, which deserve further work. First, regarding funding tools, the survey of this study has investigated S3 strategy for the region of Sardinia, and the authors have not been able to fully assess the implications for specific peripheral SPA like the Sulcis – Iglesiente region. Second, the difficulties in identifying and verifying all the enterprises in the area due to the lack of up-to-date reference data.

The analysis of this study has identified the capacity for cooperation among local / regional stakeholders and the importance of strengthening multi-level governance with a focus on the alignment and coordination of programmes and strategies, we have been neither able to consider the crucial role of strategic stakeholders like the Geo-mining Park. Third, this research has considered one peripheral SPA only and this requires testing temporary services and its transferability.

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Relevance of Structural Conditions in the Sustainable Management and Reuse of Historical Military Buildings: An Interdisciplinary Approach

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Abstract. Nowadays, the management of existing historical military buildings has acquired paramount importance since, assessing the complexity and the significance of its inheritance, military strategies and standards have been changed, and structures have to be updated to meet current safety, energy, and functional needs. In Sardinia (Italy), an island characterized by a high number of historical military buildings and highly affected by the negative aspects of insularity, such as high costs for the supply of materials and energy, the development of sustainable strategies for the management of these buildings, not rarely underutilized or even abandoned, can represent an opportunity to meet current military standards and needs containing public expenses and reducing the environmental impact and additional use of land. The paper proposes an interdisciplinary approach specifically designed for the sustainable management and reuse of this historical military heritage. The proposed methodology emphasizes the aspect of structural safety, combining it with aspects related to conservation and restoration. Starting from the study of indirect sources and the acquisition of geometric/material/structural data using direct analysis and surveys, the protocol identifies a set of descriptors that defines the current condition of the building from both safety and conservation views. At the end of the process of knowledge, the index of priority of intervention is defined considering the overall state of conservation, use, and structural efficiency, to highlight the degree of urgency of the conservation or transformation/reuse processes and allow the sustainable planning of interventions on military real estate assets. The application to a case study is presented and discussed. The interdisciplinary approach has been developed within the research project IMASS-CHAIN (Infrastructure Management Support System CHAIN).

Keywords: military heritage · integrated knowledge · sustainable transition

1 Introduction

The Italian Ministry of Defence's built heritage is a complex and diversified inheritance with high levels of specialism, strict safety regulations, distributed and centralised management as well as a considerable historical value. Its management becomes increasingly

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difficult as its historical and artistic significance increases, if we consider the current requirement to minimise energy use, pollutant emissions, and land usage.

Nowadays, about 70% of Italy's building stock is approaching the end of its lifecycle in terms of age, exposing it to greater risks of vulnerability, decay, and energy inefficiency. At the same time, current European policies are pushing towards the effective zeroing of land consumption and the sustainability of any building and urban transformation affecting the built heritage (National Green Economy Council 2017). In this context, the recovery and reuse of the existing building stock assume a fundamental role and are rightfully among the actions to promote sustainable development, bringing benefits that affect environmental, economic, and socio-cultural aspects. Globally, several number of cases of conversion show the importance and potentialities of restoring historical military buildings, such as the former English Tanglin Barracks in the Dempsey Hill (Singapore), after several military reuses transformed into a dining, wining and green lifestyle enclave, or the Sardinian Arbuticci Fort, placed in La Maddalena, converted into a museum and actually known as the Giuseppe Garibaldi Memorial.

This process of transition is particularly relevant in the case of large state-owned building complexes, which in Italy are largely part of the above-mentioned Ministry of Defence assets (Fiorino 2021). About 65% of Italian military property is located in Sardinia, an island characterized by a high number of historical military buildings and highly affected by the negative aspects of insularity, such as high costs for the supply of materials and energy, which would benefit greatly from effective strategies for the sustainable management of this building heritage.

Dealing with these criticalities, a research project entitled IMASS-CHAIN (Infrastructure Management Support System CHAIN)[1] has been started, to define an effective protocol for the sustainable management of historical military building heritage.

Within the framework of the IMASS-CHAIN project, the present paper presents a research focused on implementing an interdisciplinary approach designed for the sustainable management of this historical military heritage.

Specifically, the proposed methodology aims to identify a set of descriptors that defines the current condition of the building from both safety and conservation points of view. These descriptors derive from a process of knowledge of the asset, conducted through the study of indirect sources and the acquisition of geometric/material/structural data using direct analysis and surveys. The combination of the identified descriptors leads to defining the priority index of intervention to be carried out on the buildings, taking into particular account the aspect of structural safety, which is appropriately combined with the aspects of conservation and restoration. The priority index of intervention is intended as a tool to highlight the urgency of the conservation or transformation/reuse process and allow the sustainable planning of interventions on military real estate assets. The methodology application to a case study is presented and discussed.

[1] The project has been developed and co-financed by the Italian Ministry of Defence, with resources from the National Military Research Plan 2020. See the acknowledgements for more info.

The paper is structured as follows: Sect. 2 illustrates the main characteristics of Sardinian military building heritage; Sect. 3 gives an overview of the IMASS-CHAIN research project; Sect. 4 highlights the importance of structural aspects in the process of knowledge of the building and gives an account of the chosen descriptors; Sect. 5 defines the index of priority of intervention; Sect. 6 reports on the application of the methodology to a case study; Sect. 7 summarizes the findings.

2 The Sardinian Historical Military Heritage: Management and Typologies

The Italian built inheritance, even more the Sardinian one, includes a complex and widespread historical military heritage composed of a high number of complexes – each one consisting of a variable number of buildings - heterogeneous in typology, uses and state of conservation. These military compounds distributed both in urban and peripherical contexts according to their function and the Armed Force (A.F.) of provenance, are defined by an extraordinary historical value, and a distributed and centrally organised governing structure.

Due to these considerations, managing these assets is extremely difficult. This is particularly true when they require maintenance and restoration interventions as well as new performance upgrades for responding to new military functions and demands, rationalisation strategies, financial constraints and minimisation of environmental impact. In Sardinia, due to the high number of buildings belonging to military state property, the issue is especially crucial, and it can be seen as a representation of the dynamics and processes occurring not just in the Italian region but also in the larger Mediterranean and European context.

Considering the management of this defence heritage, this is generally controlled by a complex network of institutions, authorities, and departments, both inside and outside the Ministry of Defence. These entities are involved in the infrastructure governance cycle and the legal framework of the main technical-administrative procedures at the various scales of intervention, including monitoring, maintenance, restoration, upgrading, and regeneration. Each of the A.F. has a separate Engineer Corp (*Genio*) specialised in building management, that is hierarchically organised[2] and operates according to precise Directives for infrastructure activities that are regularly updated and typically establish the knowledge, operations, and interactions between various offices. Also, the Engineer Corps register and manage their building stock in an information system platform (Management of the State Property of the Defence Administration) called Ge.Pa.D.D. and entrusted by the AID General Directorate. This platform contains all the information of the complexes designated by a special ID code (Compendium Code) which is organised according to the scale of investigation (building, floor, rooms, and elements) and themes (localisation, history, geometry, structural, technical-performance end hydraulic efficiencies, estimative assessment).

[2] Infrastructure management involves three hierarchical levels, summarised in the directive GEN G-001 as follows: Responsible Apex Commands, Technical bodies of Armed Force, Engineer executive bodies.

Looking at the architectural aspects of this valuable heritage, from the study of the national literature[3], it has been possible to define the historical models developed over time by the Military Engineers (typologies and profiles), with particular attention to the local variants and the diversities between the A.F. Also, the study has considered the uses associated with these typologies (functional taxonomies) and the requirements for today's military logistics. Thus, each functional macro-area has been linked to the type of asset according to the defined taxonomy. This information is fundamental for proceeding with the sustainable planning of interventions on buildings.

In general, complexes are characterised by a variable number of buildings, typologically different and in some cases specifically referred to as the A.F. For instance, the typology of isolated buildings, common in all the A.F., can have two different subtypologies: linear buildings with orthogonal wings or inclined wing, the last ones specifically designed by the Air Force. The Command and the Guard Corps are the uses associated with this building typologies. Other typologies, such as terraced buildings (offset-bodies or comb-shaped), courtyard buildings, and aggregation of volumes with different shapes (U, H, T, L, Z) are instead associated with logistic or residential uses. Moreover, the reuse of former convents is specifically linked to the Nineteenth-century process of reorganisation of the Army inside urban contexts with the installation of multifunctional barracks or hospital structures. Other specific typologies instead relate to A.F. peculiarities such as hangars for the Air Force and lighthouses for the Navy.

3 IMASS-CHAIN: Purposes and Integrated Research Protocol

The IMASS-CHAIN (Infrastructure Management Support System CHAIN)[4] research project aims at implementing an innovative certified and protected protocol for monitoring and intelligent governance of the historical military building heritage, starting from the existing heterogeneous information on the built heritage owned by the Italian Ministry of Defence, and to achieve functional and logistical models of the different infrastructural categories, applicable in a scalar manner from Sardinia throughout the national territory. In pursuing this goal, the project goes beyond the single A.F. (Armed Force) and considers the inter-force Defence infrastructural stock – the Army, the Air Force, the Navy and Carabinieri.

Within the project, a set of specific objectives have been identified for contributing to the general objective of the research and, although in their individuality, these have been significant for the understanding, interpretation, and management of the military heritage. According to the main project, the study of the buildings has been carried out

[3] The analysis is based on the cases study investigated and from some publications specifically concerning the national Armed Forces (Donesana 1875; Rocchi 1908, Rocchi 2010; Melis 1939; Geniodife 1991; Cassi 1996; FStorelliFTurri2014; Fiorino & Vargiu 2023) and Armed Force directives such as the *Direttiva S.M.E. Ispettorato dell'Arma del Genio, Pub. n. 6252 D.T. n.1 - Direttive per la Progettazione di accasermamenti, Roma, 26.11.1980.*

[4] The project has been developed and co-financed by the Italian Ministry of Defence, with resources from the National Military Research Plan 2020. See the acknowledgements for more info.

through the reconstruction of their historical transformations and the taxonomic classification of military functions and spaces. Then, to understand their state of conservation as well as to be able to make comparisons on the consistency of the heritage and the effectiveness of interventions (maintenance, upgrading, etc.), a series of descriptors and indicators for monitoring, evaluating and comparing the technical, functional and performance characteristics of the properties have been defined and codified. All this information is managed thanks to the implementation of an information management protocol, that transforms the information repository into integrated knowledge. The information collected during the process of knowledge has been dematerialised, and an innovative digital heritage file called DEF (Digital Enhanced Folder) has been implemented. The DEF aims to associate HBIM (Heritage Building Information Modelling), adopted as a knowledge synthesis and project control tool, with the possibilities offered by digital certification processes typical of the blockchain and the potentialities from intelligent predictive models.

The project proposes to identify and develop the management process needed for the adaptation, modernisation, and efficiency improvement of the building stock, taking into consideration the historical and architectural values embodied in the historical buildings, and the sustainability and cost-effectiveness of the interventions. Based on the study of the typological characteristics, uses and facilities required for these buildings, descriptors and indicators are useful for assessing the current state of conservation and, consequently, for monitoring the degree of efficiency and suitability of the constructions after the interventions. In addition, the comparison of these descriptors and indicators with the current regulatory framework can help to assess the nature and intensity of the corrections to be made using appropriate programming, planning and intervention strategies.

Overall, the IMASS-CHAIN project protocol can be structured into three phases (Fig. 1), and has been developed with the interaction and synergic research of five departments of the University of Cagliari (Sardinia-Italy): the Departments of Civil and Environmental Engineering and Architecture (DICAAR); Mathematics and Computer Science (DMI) for the IT aspects; Literature, Languages and Cultural Heritage for the aspects related to archives and history; Chemical and Geological Science (DCGS) for investigations on historical natural and artificial materials; Economics and Business Sciences (DSEA), for economic assessments and financial strategies. Other partners involved are the companies Leonardo S.p.A. and Flosslab S.r.l., important components of the research group to cover the field of data management and blockchain technologies and applications.

A selection of case studies, acknowledged as iconic symbols for each A.F., has been chosen for testing and evaluating the IMASS-Chain protocol[5] (Fig. 2).

[5] Pursuant to art. 333, c. 8 of the Code of Military Order.

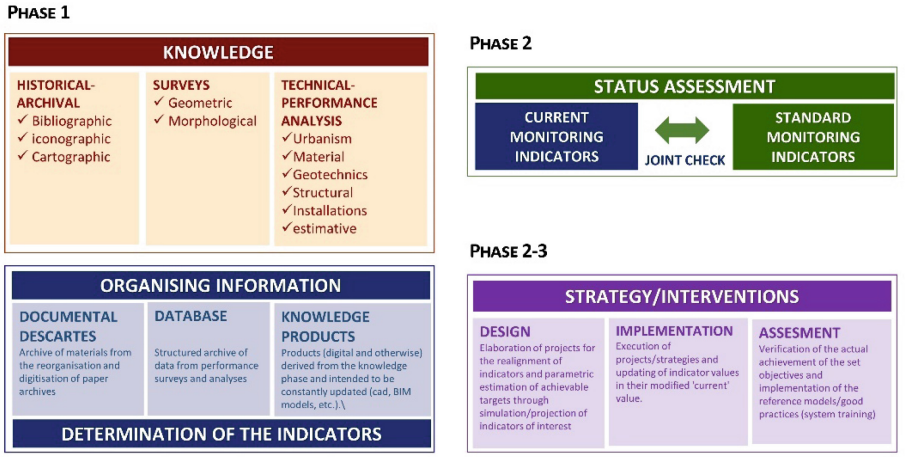

Fig. 1. Methodological scheme of the IMASS-CHAIN project

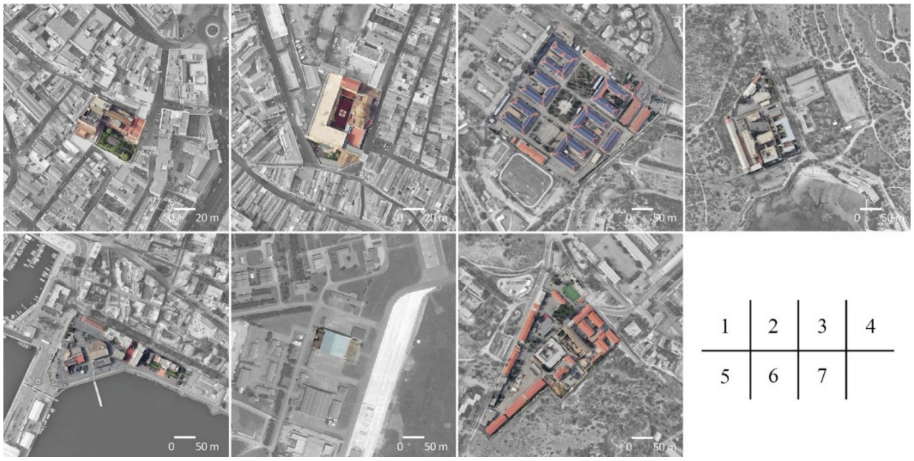

Fig. 2. Identification of the pilot sites: 1) De la Vallée Palace, Sardinia Army Headquarters, Cagliari; 2) De Murtas Barrack, Headquarters of the Military District of Legal Medicine in Cagliari former Military Hospital (typology of former convent, XVII-XX cent.); 3) Riva Villasanta Barracks, Cagliari, 14° Infrastructure Department (typology of functional pavilion barrack, XX Cent.); 4) Carlo Ederle Barracks, Cagliari, Military Documentary Centre (typology of the military complex, XX Cent.); 5) Naval Base, Ex Maricommi, Maritime Military Commissariat Headquarters, Cagliari (typology of naval base, post 1860); 6) Decimomannu Air Base, Hangar PG61 (typology of 555 model, post 1954); 7) Livio Duce Barracks, Headquarters XI Battalion Carabinieri Sardinia, Cagliari (typology of former penal colony, XIX Cent.).

4 The Process of Knowledge Acquisition

In restoration and reuse projects of architectural heritage of historical interest, recognizing the signs of history is equivalent to considering the different levels of protection and transformability of the individual construction elements as well as the relative constraints associated with them which must be recognized by reuse processes compatible with historical memory.

The topic is decidedly relevant if considered in the context of the reuse interventions of historic state-owned structures, mostly characterized by large dimensions, by a high number of construction stratigraphies which are also highly heterogeneous, by different and often contrasting uses during their history, as well as high levels of material compromise, caused by improper use or prolonged periods of abandonment.

A fundamental step for the management of built heritage is the definition of its current condition, in terms of the general state of conservation and detail of its components and all the aspects involved. Therefore, any building management project should start from the process of knowledge of the building itself.

To this end, within the framework of the IMASS-CHAIN project, an interdisciplinary approach has been proposed and implemented, combining the following steps of knowledge.

- Historical-archival analysis, carried out through the materials (historical and contemporary surveys, cadastral cartographies, historical iconographies, inventories, minutes and acts of delivery, technical project documents) conserved in the military archives of the same barracks;
- Chrono-typological and transformation analyses, conducted codifying the information with the *Raumbuch*, a methodology in which every element is uniquely codified and analysed not only under the historical point of view but also in its morphology and state of conservation;
- Morphological and dimensional analysis, also applying geomatics methods and tools such as total station and photogrammetry for the restitution of plans, façades, and sections;
- Analysis and characterisation of building elements (foundations, structures, masonry, facades, floors, vertical connections, roofs, plasters, mortars, decorative elements, fixed industrial apparatus, etc.) and their state of conservation, starting from all the previous analyses and applying proper protocols and tools of diagnostics;
- Structural characterisation of the building and each building element, with reference to the protocol explained in the following Subsect. 4.1;
- Technical performance analyses considering energetic, illumination, comfort, and hydraulics aspects.

4.1 Structural Issues in the Process of Knowledge

The choice of possible intervention strategies for the historic military building must necessarily take into account the structural aspects such as the static scheme, the constituent materials, the residual load-bearing capacity, and the state of conservation. It is, in fact, essential to carry out the compatibility check between the current structural conditions of the building and the performance demand in the possible reuse scenario, in

terms of structural configuration and loading conditions. It is important to avoid relevant alterations in the overall structural behaviour of the building which could affect the original distribution of loads and require significant structural interventions with possible heavy impact on the identity, costs, and on fulfilment of current technical regulations requirements. The most in-depth knowledge possible of the current structural conditions is therefore mandatory.

The process of knowledge acquisition focused on the definition of the relevant structural issues (Fig. 3), as suggested by the Italian regulations NTC (Technical Standards for Construction 2018), consists of the following three main steps:

1. Research, collection and critical review of existing data and information, such as original designs and so on, to reconstruct the building process, the changes the building has undergone over time, and the events that have affected the building over time;
2. Geometric and structural survey, to clearly define the geometry of each element and the overall building, the load-bearing frame, and the type and extent of any damage if present;
3. Determining the properties of materials, such as strength, stiffness, and density.

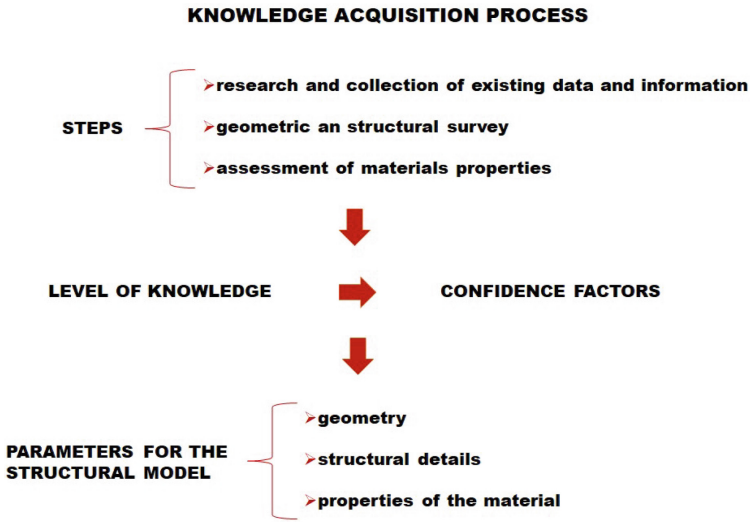

Fig. 3. The knowledge acquisition process

The structural models adopted consider the knowledge, with a level of depth that depends on the available documentation and the quality and extent of the investigations carried out, of the following characteristics of the construction: the geometry and construction details; the mechanical properties of materials and soils; the permanent loads.

Key factors in the structural compatibility check are linked to the maximum extent of overloads, or imposed loads, permitted by current technical standards, such as the Italian NTC (Technical Standards for Construction 2018). These loads include both the specific

loads linked to the intended use of the rooms and buildings and the seismic action, to which existing buildings, especially historic ones, can be vulnerable. The indications for the evaluation of the loads on buildings depending on their type and intended use are provided by the technical standards. A detailed discussion on this topic and the proposal of a methodology to support the decision-making process in which the impact of the structural intervention on the reuse scenario of the asset is made explicit can be found in (Concu, Fiorino, Pilia 2023).

Within the IMASS-CHAIN project, the survey, the analysis of the state of structural conservation, the identification of the performance requirement as well as the definition of proper descriptors have been carried out on three levels with an increasing degree of detail: compendium, building and structural element. According to the knowledge acquisition process above described, a set of descriptors of the current structural condition of the building has been identified.

Concerning the choice of building descriptors, the choice fell on descriptors relating to structurally significant documentary information, data necessary for the calculation of the seismic action and descriptors that would give an accurate description of the structural types present on each building. Regarding the identification of structural types, to be able to classify them, reference was made to UNI8290, a classification system that was chosen unanimously with the other groups participating in the project, e.g. plant engineers and architects. For each structural type, the materials, and vertical and horizontal construction types were identified. For the calculation of seismic actions, it is also very important to assess the regularity in plan and height, the distribution of infills and the presence of structural joints. Finally, descriptors were identified for the building to give an idea of the level of knowledge of the building about the percentage of knowledge of its geometric-structural characteristics, material characteristics and construction details. A further set of descriptors has been chosen to identify the type and level of structural damage of the building and each building element.

Subsequently, based on the analysis and systematisation of the data, the factors (descriptors) capable of representing, punctually and effectively, the state of the art of the building and its variation consequent to the realisation of interventions (maintenance, corrective, upgrading, etc.) were identified.

The objective was to systematise all the descriptors and to select from among them, those particularly useful for monitoring the transformations over time and, consequently, first to represent and then to simulate the impact on the building heritage of the interventions, both in terms of technical and performance effectiveness and cost.

5 Index of Priority of Intervention

According to the specific objectives of the IMASS-CHAIN project and the descriptors defined for the structural aspects, it has been possible to define an important indicator to support the decision-making choices concerning the military built heritage: the index of priority of intervention, which can be related to both the building and the individual element. In fact, following the results of the study of the regulatory framework and analysis conducted on the buildings, it is possible to express the degree of urgency for the activation of the transformation process.

This index of priority is defined by assigning a scale of numeric values of two descriptors: the damage index, strictly linked to structural aspects, and the degree of transformability, linked to conservation/restoration aspects.

The damage index is defined globally and locally. The global damage index expresses an indication of the level of damage/vulnerability at the level of the building depending on the severity of the damage.

In the presence of structural damage, rather than non-structural damage or external hazards which occur rarely, there will be higher levels of the damage index. Structural damage is generally more critical to resolve than non-structural damage. The global damage index is defined as follows:

- Index 1 | low damage index. There is no significant damage to the structural and non-structural elements, nor specific external hazards;
- Index 2 | medium-low damage index. There is no significant damage to the structural and non-structural elements, nor specific external hazards. The possible presence of other minor risk factors is considered;
- Index 3 | medium-high damage index. There is damage in non-structural elements, or specific external hazards and minor risk factors;
- Index 4 | high damage index. There is significant damage in the structural elements or the non-structural elements in association with external hazards and minor risk factors.

The local damage index indicates the percentage of damage spreading at the level of the structural element and the relative severity. The greater the extent of the damage, the higher the damage index will be, i.e. more interventions will be necessary to resolve it.

The local damage index is defined as follows:

- Index 1 | low damage index. The damage affects less than 10% of the element;
- Index 2 | medium-low damage index. The damage affects between 10% and 30% of the element;
- Index 3 | medium-high damage index. The damage affects between 30% and 50% of the element;
- Index 4 | high damage index. The damage affects more than 50% of the element.

The degree of transformability is associated with the historical interest of the building, strictly related to the cultural value of its constructive elements: historic-artistic interest, historic-constructive interest, historical-textual interest, historical-textual-functional, or to the non-value, typological-material incongruence, or inadequacy to standards.

These degrees of transformability can be summarised in:

- Grade 0 | Not transformable, historic, and artistic interest. All the buildings marked with an interest cannot be altered and/or removed in any way. The only allowed intervention is conservation and maintenance;
- Grade 1 | Building with a compromised historic-artistic interest. This happens when the elements of this building are consistent with the artefact but no longer efficient in terms of technical performance. In this case, a moderate improvement intervention is permitted.

– Grade 2 | Not listed building but compatible within the complex. This grade is associated with buildings highly characterised by elements without a specific historical and artistic interest, but which are nevertheless compatible with the historical context in terms of both material and performance. In this case, an extraordinary maintenance is allowed.
– Grade 3 | Not listed building incompatible within the complex. The building is incongruous from the material, functional and performance points of view, as it is a modern/contemporary addition. It can constitute an anthropic degradation and for this reason, can be removed or replaced.

The damage index and the degree of transformability are then combined through a matrix that provides the priority index of the intervention (Fig. 4).

Damage index / *Degree of transformability*	*Grade 0* | **Not transformable building, historic and artistic interest** > conservation (4)	*Grade 1* | **Building of compromised historical and artistic interest** > conservation and partial reintegration (6)	*Grade 2* | **Uninteresting but compatible building** > extraordinary maintenance (8)	*Grade 3* | **Building to be removed** > new integration (10)
Index 1 > global | low demage > local | less than 10% (0)	4	6	8	10
Index 2 > global | medium-low damage > local |between 10% and 30% (4)	8	10	12	14
Index 3 > global | medium-high damage > local |between 30% and 50% (8)	12	14	16	18
Index 4 > global | high damage > local |more than 50% (10)	14	16	18	20

Index of priority*
High priority: 20-14 | Medium priority: 12-10 | Low priority: 8-4

Fig. 4. Matrix of the index of priorities of intervention

According to the matrix, the index of priority of intervention defines three levels of priorities: high priority for buildings with a score between 20–14; medium priority for scores between 12–10; low priority for scores between 8–4. The index of priority can be an effective tool for understanding and assessing the real urgencies and priorities of intervention within the wide historical military-built heritage, and for supporting a more coherent and strategic programme of interventions that should be evaluated and confirmed after an economic assessment of costs.

6 Case Study

The interdisciplinary protocol leading to the definition of the index of priority of intervention has been applied on one of the pilot sites described in Fig. 2: the Riva Villasanta Barracks, headquarters of the 14° Infrastructure Department, placed in Cagliari, in the area between the San Bartolomeo hill and the Poetto Avenue, typologically composed by six functional pavilions (1-3D and 1-3S), and two other blocks, the Command (C) and the dining (B) buildings (Fig. 5).

Each structure of this complex, built in the XX century and independent as functions, has been analysed and studied through the interdisciplinary approach described in Sect. 4.

In particular, after its in-depth investigation and the definition of the set of descriptors, the functional barrack 3S has been used for testing the index of priority of intervention, according to the damage index and the grade of transformability.

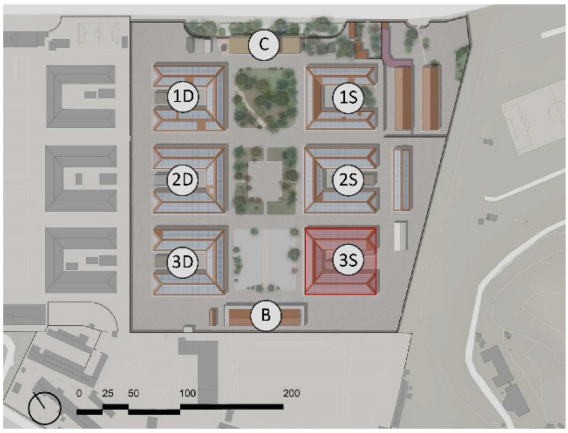

Fig. 5. Riva Villasanta Barracks, headquarters of the14° Infrastructure Department. Localisation of the functional pavillon 3S

The building is one of the six U-shaped modular bodies that are part of the complex and is intended for office and service use. The building develops on a partially mezzanine level above ground, planimetrically inscribed in a rectangle of approximate dimensions 64.00 × 58.00 m, with blocks approximately 14.00 m wide. The internal courtyard houses a technical compartment for technical systems. The building is therefore characterized by regularity in height, with regular openings and very dense windows. From a planimetric point of view, the plan is not compact and has a recess which makes the system irregular under the NTC2018. The internal distribution of the rooms is made up of quadrangular rooms with an average size of between 5.00 m and 6.00 m on each side. The load-bearing structure is made up of longitudinal walls, both the perimeter and internal partition walls, and the transverse walls that define the quadrangular rooms arranged at regular intervals. The elevation structures are made - as in the other structures of the compendium - from load-bearing partitions in limestone ashlars. Initially, the double-pitched gable roof was created using wooden trusses, but, following an intervention to position photovoltaic

panels on it, it was rebuilt in brick and concrete with a system of reinforced concrete beams. The foundations are direct and continuous, with increased thickness compared to the wall above. The state of conservation of the structure is generally good; no significant manifestations of damage and instability were detected.

On the one hand, considering the damage index, the building has value 1, low damage index, both at global and local levels, since there is no significant damage to the structural and non-structural elements, nor specific external hazards, and the damage affects less than 10% of the element.

Also concerning the degree of transformability the building has value 1, since the building, built around the 1930 and 1940, has a historical interest but it is partially compromised by some constructive elements that are not totally compatible and sustainable from the technical-performance point of view.

The combination of the damage index and the degree of transformability by using the matrix described in Fig. 4 gives an index of priority of intervention of 6, which is a low-priority index.

The application of the procedure and the definition of the index of priority of intervention for all the buildings in the compendium will allow the management and planning of the interventions in terms of urgency and priority.

7 Conclusions

This paper presents an interdisciplinary methodology for the definition of the index of priority of intervention on buildings belonging to military state property.

As part of the broader IMASS-CHAIN research project, aimed at defining an effective protocol for the sustainable management of historical military building heritage, a methodological protocol is proposed here, following the process of knowledge suggested by current legislation, for the determination of the state of conservation of buildings belonging to military state property. This protocol highlights the particular relevance of the aspects linked to the structural performance of the construction.

The index of priority of intervention has been defined by the combination of two factors: the damage index, closely linked to the structural aspects, and the degree of transformability, dependent on the conservation and restoration aspects. This index can be acknowledged as an indicator of the general state of conservation of the building, but above all, it is intended as a useful tool for planning the interventions to be carried out on the large number of properties belonging to the vast military built heritage.

The proposed methodology can easily be extended to other sectors of the Public Administration, that, like the Ministry of Defence, need to make conscious decisions on the efficient use and valorisation of their building stock.

Credits The introduction and conclusion are written by all the authors; par. 2 is edited by E. Pilia, par. 3 is edited by D.R. Fiorino; par. 4 is edited by G. Concu, E. Reccia, and D. Meloni; par. 5 and 6 are edited by G. Concu and E. Pilia.

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Author Index

A
Amato, Federico 49
Andrulli, Giovanna 285
Anelli, Debora 21, 36
Assumma, Vanessa 78

B
Basbas, Socrates 159
Bianchi, Sara 247
Boi, Biagio 144
Bouhouras, Efstathios 159

C
Campisi, Tiziana 159
Cerra, Erika 285
Concu, Giovanna 421
Congiu, Tanja 407
Corrado, Simone 285
Costagliola, Gennaro 113

D
D'Ugo, Davide 66
De Luca, Claudia 78
De Paola, Pierfrancesco 49, 66
De Rosa, Mattia 113
Del Giudice, Francesco Paolo 49
Di Liddo, Felicia 21, 94

E
Esposito, Christian 144

F
Falasca, Federico 268
Fanfani, Marco 353
Fico, Raffaello 302
Fiorino, Donatella Rita 421
Fonnesu, Viola 407
Fuccella, Vittorio 113

G
Garau, Chiara 407
Gatto, Rachele Vanessa 285, 293
Giunta, Marinella 233

I
Iacono, Mauro 126

K
Koutsi, Dionisia 388

L
Lagarias, Apostolos 388
Leka, Akrivi 369
Leonardi, Giovanni 233
Locurcio, Marco 21

M
Manganelli, Benedetto 49, 66
Marucci, Alessandro 268, 302
Marulli, Matteo 353
Mastroianni, Michele 126
Meloni, Daniel 421
Miltiadou, Marios 159
Morano, Pierluigi 21, 36, 94
Moschella, Marialuisa 173
Musolino, Giuseppe 173, 188

N
Nesi, Paolo 353

P
Palmieri, Francesco 126
Panuccio, Paola 202
Perrone, Francesca 285, 293
Pilia, Elisa 421
Plaisant, Alessandro 407

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R
Reccia, Emanuele 421
Richiedei, Anna 247
Rindone, Corrado 217
Rojíková, Darina 317
Russo, Antonio 159, 217
Russo, Francesco 173, 188

S
Sabatelli, Emma 36
Saporito, Antonio 113, 126
Scorza, Francesco 285
Seo, Jung Taek 144
Sgro, Domenico 188
Sica, Francesco 66
Spanogianni, Eleni 335
Stara, Federico 94
Stratigea, Anastasia 369, 388
Sýkorová, Katarína 317

T
Tabari, Parinaz 113
Tajani, Francesco 21, 36, 49, 66, 94
Tesoriere, Giovanni 159
Theodora, Yiota 335, 369
Tira, Maurizio 247
Trovato, Maria Rosa 3

U
Ulisse, Carmen 268, 302

V
Vaňová, Anna 317
Vavrúšová, Mária 317
Ventura, Vittoria 3
Vitálišová, Katarína 317