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Computational Science and Its Applications – ICCSA 2024 Workshops

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

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Geomatics for Resource Monitoring and Management (GRMM 2024)

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

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Regenerating Brownfields Enhancing Urban Resilience Appeal (INFERENCE 2024)

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

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

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

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Multidimensional Evolutionary Evaluations for Transformative Approaches (MEETA 2024)

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

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

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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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Scientific Computing Infrastructure (SCI 2024)

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

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

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Paola Amoruso	LUM, Italy

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

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Marco Petrelli	Roma Tre University, Italy

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Massimiliano Bencardino	University of Salerno, Italy

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

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Smart Tourism (SmartTourism 2024)

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

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

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Francesca Perrone	Sapienza University of Rome, Italy
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Specifics of Smart Cities Development in Europe (SPEED 2024)

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Venue

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

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

Debora Anelli[1], Pierluigi Morano[1], Francesco Tajani[2], and Emma Sabatelli[2(✉)]

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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).

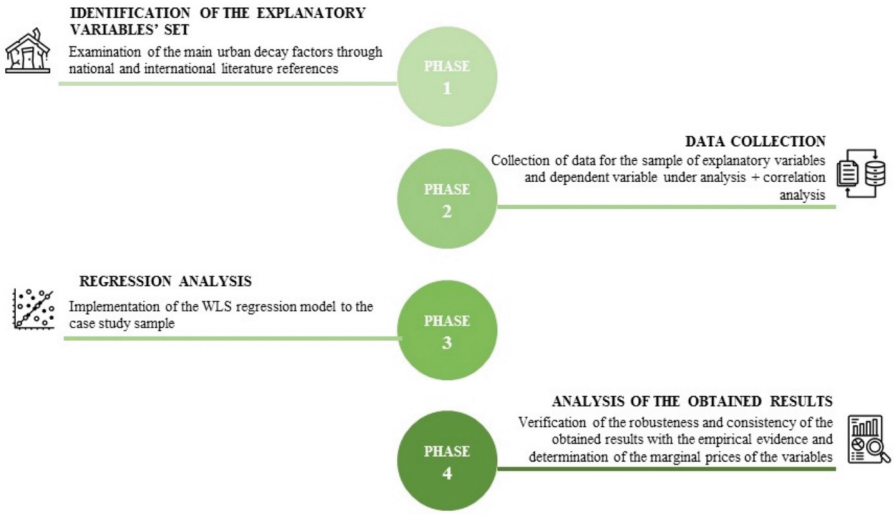

Fig. 1. The phases of the proposed evaluation methodology

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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