Land Use Policy 128 (2023) 106595

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Spatial decision support systems for effective *ex-ante* risk evaluation: An innovative model for improving the real estate redevelopment processes

Debora Anelli [a,*], Francesco Tajani [b]

[a] Department of Civil, Environmental, Land, Building Engineering and Chemistry, Polytechnic University of Bari, Via Orabona 4, 70125 Bari, Italy
[b] Department of Architecture and Design, Sapienza University of Rome, Italy

A R T I C L E I N F O

Keywords:
Risk assessment
Synthetic risk index
Multi-criteria analysis
Spatial decision support system
Risk map
Real estate risk
Urban redevelopment

A B S T R A C T

The real estate redevelopment process is an important route for achieving the sustainable development goals established worldwide, but at the same time it represents a complex and not very transparent decision-making issue for the public and private subjects involved. In particular, for the private entrepreneurs it is generally considered more risky than new construction, therefore it requires a careful evaluation for avoiding losses. Most of the existent risk assessment tools provide for the analysis at the aggregated scales or require knowledge of many financial data of the project which are often not yet known in an *ex-ante* evaluation condition. Aim of the work is to define a structured framework for creating a Spatial Real Estate Risk Index (I_{SRR}) through a spatial decision support system based on an innovative model that allows public and private subjects to carry out an effective *ex-ante* risk assessment at the sub-municipal territorial scale for public-private partnerships (PPP) risks. The proposed model adopts the flexibility of the Analytic Hierarchy Process multicriteria technique for managing qualitative and quantitative real estate data, the capability of indicators system to reduce the complexity of the real estate risk issues and the sleight of the Geographic Information System to clearly show the spatial distribution of the real estate risk. The I_{SRR} is a territorial synthetic index that represents the “base risk”, i.e. the risk level that is expressed by the different features that characterize the demand and supply of the several urban areas within the city at the time of the evaluation. In order to test the usefulness of the proposed model, the application to the city of Rome (Italy) is described. The obtained results highlight the immediate ability to recognize the riskiest urban areas located on the northern and eastern boundaries of the city. The innovative contribution of the work is mainly represented by the analysis of the real estate risk carried out at the sub-municipal scale by using both quantitative and qualitative real estate data, therefore the proposed structured framework for creating the I_{SRR} allows to immediately recognize the riskiest and least risky sub-municipal areas through an adequate risk map.

1. Introduction

The evolving uncertainty that characterizes the actual historical period have increased the difficulty of draw up efficient evaluation of the risk level related to real estate redevelopment processes. Growing importance is widely shared and recognized for urban regeneration projects in the “17 Sustainable Development Goal” (SDGs) set in the 2015 by the Agenda 2030 (Morano et al., 2020) and with the more recent “New Green Deal” and “National Plans of Recovery and Resilience” after the Covid-19 pandemic (Tajani et al., 2018). Although the planning process has often been used to prevent or limit the uncontrolled expansion of suburban areas, further stress is needed if risk factors are to be overcome in urban real estate redevelopment locations. Traditionally, these territories are perceived by the Private Entrepreneurs (PE) as areas of high risk, complexity and long lead times (Adair et al., 2000). Nevertheless, the rising necessity of provisioning several facilities for communities, such as residential, commercial, public services and infrastructure, led to the trend of mixed-use spaces that have a multitude of risks that can affect their feasibility. In terms of investment, mixed-use development represents a good way for the PE to allocate the market risk more effectively, by differentiating the several land uses. On the other hand, this exposes his capital to further risk factors and costs that need more skills for managing the relevant complexity of the project (Tsimperis, 2015; Serrano-Jiménez et al., 2019).

* Corresponding author.
E-mail addresses: debora.anelli@poliba.it (D. Anelli), francesco.tajani@uniroma1.it (F. Tajani).

https://doi.org/10.1016/j.landusepol.2023.106595
Received 17 May 2022; Received in revised form 10 January 2023; Accepted 16 February 2023
Available online 24 February 2023
0264-8377/

In general, an increased recognition of the value of a structured framework for effective risk management in order to avoid losses, accidents and disasters has led to numerous definitions of risk corresponding to approaches to its reduction, depending on the context and the implementation sector. A considerable effort has made worldwide in the last decades by the "Integrated Risk Management Solution" during the international agreement of Basel II (Basel II, 2016) for the bank sector, the Committee of Sponsoring Organizations of the Treadway Commission (COSO, 2004) "Enterprise Risk Management framework" in the corporate risk area and the general guidelines provided by the International Standardization Organization (ISO) 31000 of (2018) "Risk management – Guidelines", that can be used by any organization regardless of its size, activity or sector. In Italy, the main reference for public urban projects developed with public-private partnerships (PPP) contracts is the "Guidelines n.9" of the National Anti-Corruption Authority (ANAC) Guidelines n.9 of the National Anti-Corruption Authority (ANAC). It contains in the first part the analysis on the allocation of the different types of risk between the contracting authority and the PE, while in the second part the rules for the construction of the risk matrix and the information flow for its monitoring are outlined. The risk matrix identifies and analyzes the risks connected to the intervention to be carried out and is used, in the planning phase, to verify the convenience of using the PPP compared to a traditional contract and, in the execution phase, for risk monitoring. One of its major limit is constituted by the superficial assessment of the likelihood of the occurrence of each type of risk through qualitative values (e.g. high, low etc.) and the increased costs and/or delays associated with the risk. The analysis of all these documents outlines that there are differences in the terminology and the practical approaches in applying the frameworks as a result of different environments, contexts, needs and objectives. However, the overall principles overlap regarding the entire risk assessment procedure which includes: i) identification, ii) evaluation followed by iii) management/allocation (Chen and Khumpaisal, 2009).

Before the assessment and management phases, it is primary to define and identify the risks that can occur. The real estate redevelopment interventions could be affected by two categories of risk: *systematic* and *unsystematic* (Gyourko and Nelling, 1996; Bulan et al., 2009; Sdino et al., 2018; Gang et al., 2020). The systematic type of risk is generated by external macroeconomic factors and affects all the different type of investments: this component is extremely connected with the fluctuations of the general financial market. Unsystematic (or specific) risk refers to the critical factors that characterizes a precise investment decision (Khumpaisal et al., 2010). The first one is generally more uncontrollable for the real estate redevelopment process, because it cannot be removed introducing elements of diversification (Peng and Zhang, 2021). The second ones, instead, are the principal types of risk assessed and considered in the real estate redevelopment/development procedures because they mainly affect the feasibility of the projects and numerous typologies can be identified: by imagining to divide the process of a generic real estate redevelopment intervention into its main phases, each of them can be affected by one or more types of specific risk, as shown in Fig. 1.

As the probability that a target rate of return will not be achieved, in the real estate development field the risk depends on the complexity of the initiative to be realized and it is often treated by considering uncertainty on the cash flows generated from the sale, rent or management of the realized buildings (Adair and Hutchison, 2005). However, the analysis of the cash flows of the project leads to have many information and quality data, first of all the length of the investment period, the interest rate, the sales plan of the project and the construction costs. These data can be clearly known once the project is in its feasibility stage, but they are unknown previously and especially if the subjects involved need to have a general overview of the local real estate market dynamics. Moreover, the evaluation of the financial parameters can lead to a partial result that excludes several other significant factors. In fact, the pressure provided by the public and private sectors for transforming

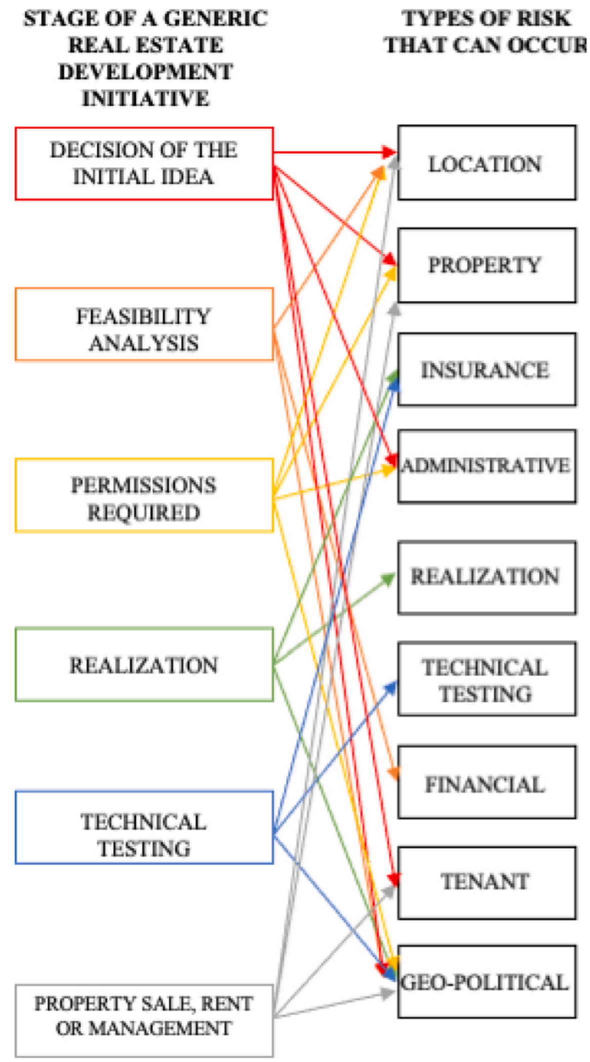

Fig. 1. Types of specific risk that can occur during the stages of a generic real estate development initiative.

and decommission old and degraded urban assets explains the amount of property in an inner-city area and its spatial distribution, which in turn involves real estate value models across local land and property markets (Coakley, 1994). The real estate redevelopment and investment activities exploit the specific qualities of sites and locations to create development opportunities and generate value in terms of earnings. As Loftman and Nevin argue, locations provide the greatest investment potentials and financial returns. In order to decide on the best opportunity among the sites and the properties available, and to understand their development and investment potential, it is necessary to have some essential information on the local market conditions, such as the demand and supply dynamicity and the attractivity level with, most of all, their spatial distribution of the context to analyze (Healey, 1994). These aspects relate to the analysis of the so-called "base risk" that represents the risk level expressed by the real estate market features of the area. A useful type of tools is represented by the improvement of the classical decision support system (DSS) with the spatial components of the analysis, thus creating a spatial decision support system (SDSS). The latter combines the ability to store, search and retrieve data based on Geographic Information System (GIS) with multicriteria models or specific algorithms able to optimize decisions which must be taken on the basis of the distributions, differences and spatial characteristics of the aspects under consideration. However, it is important to highlight that even if SDSS are powerful tools enable to analyze complex data that is impossible for humans to carry out due to limited cognitive abilities, these tools remain a source of support. The final decision will have to be made by the final users (public and private decision makers involved). In fact, according to the Data-Information-Knowledge-Wisdom (DIKW) pyramid structure (Rowley, 2007) the final users are responsible for receiving the information produced by the data elaboration through the SDSS, and based on it and their knowledge, make a final decision (wisdom) (Kazak and van Hoof, 2018).

It can happen that the SDSS structure is often inadequate to take into account the several multi-dimensional data related to the complex framework of the risk assessment (Sun and Zhu, 2009), therefore the semi-quantitative multi-criteria decision methods (MCDM) based on both quantitative and qualitative indicators that represent the risk factors that affect the spatial distribution of the specific risk related to urban redevelopment projects, characterizes an increasingly relevant reference (Pereira et al., 2020; Hill and Steurer, 2020).

Therefore, the gap noticed in both academician and professional knowledge fields of adequate models for these purposes, makes necessary, in this climate of uncertainty, to define new tool aimed at an *ex-ante* risk evaluation model able to support the investment decisions of the PE - and also the Public Administration (PA) - involved in the planning of urban redevelopment interventions based on the consideration, first of all, of the conditions present at the time of the evaluation in the local real estate market. It is relevant to outline that a risk assessment methodology based on the existent spatial and territorial conditions of the local real estate market (demand and supply), could be a real useful support for the practitioners and both the public and private investors involved into PPP urban regeneration initiatives within the city.

2. Aim

The aim of the work is the definition of an *ex-ante* risk assessment model that can support the PA and the PE involved into urban planning issues for PPP redevelopment projects. In particular, the research aims to provide for a structured framework of an assessment methodology that can allows to construct a Spatial Real Estate Risk Index (I_{SRR}) used for assessing the "base risk" level and, subsequently, in order to verify its usefulness and robustness, it is proposed an application to the city of Rome (Italy). Due to the retrieved gap in the literature regarding the scarcity of risk assessment at the sub-municipal territorial scale, the case study of the city of Rome (Italy) adopts as reference territorial scale the sub-municipal subdivision of the city. It is relevant to outline that the proposed methodology for the construction of the I_{SRR} is applicable in any territorial context (national and international), for any different type of urban redevelopment intervention's complexity, land-uses and for territorial scales (urban-regional etc.) and demand and supply conditions different from the ones considered in the study. In fact, the I_{SRR} does not depend on the spatial and temporal conditions that distinguish each case study, and its correct use is exclusively related to the quality and quantity of the available data that constitute the set of indicators and their relative importance. The proposed I_{SRR} is able to represent the "base risk" that takes into account the local market conditions of the sub-municipal territorial scale and by considering a generic mixed-use redevelopment project. From a methodological point of view the structured framework is based on an innovative model that integrates multi-criteria technique, indicators system and Geographic Information System (GIS) adopted in the field of the risk assessment for creating a semi-quantitative *ex-ante* risk assessment model that, due to its overall features, constitutes a spatial decision support system. In fact, it uses the multidimension management capability and the flexibility of the Analytic Hierarchy Process (AHP) for structuring a set of *n* quantitative and qualitative risk indicators - articulated into 4 hierarchical levels - and for aggregating into the final risk index proposed. After that, a georeferencing of all the index's values obtained is carried out through an opensource GIS thus obtaining the risk map that shows the entire spatial distribution of the specific risk level within the city. The proposed model is based on the real estate market conditions known and retrieved at the moment of the evaluation through a set of 24 indicators selected for adequately represents the three types of specific risk analyzable: i) market, ii) context and iii) insolvency.

The paper is structured as follows: Section 3 provides an analysis on the features of the most relevant methodologies retrieved in the literature for identifying, assessing and managing the risks that can occur in the urban redevelopment projects; Section 4 describes each step of the proposed methodology with reference to the case study of Rome and holds the results discussions; Section 5 deals with the results discussion and Section 6 contains the conclusions of the work with the future insights.

3. Risk identification, assessment and management tools for PPP redevelopment projects

The approaches that address the risk of PPP urban redevelopment projects have been extensively explored in the literature of feasibility analysis of urban planning issues (Ansah and Sorooshian, 2017; Qazi et al., 2020). Several frameworks and techniques have been proposed to identify, assess and manage or efficiently allocate the types of risk that can occur, generating an extremely varied and heterogeneous international and national scientific panorama.

3.1. Risk identification

During this stage a primary role is played by the national regulatory framework provided by the Governments as a guide for the public and private subjects involved in the urban redevelopment procedures. In fact, as also stated by the study of Rubin (2010), the absence of clear State's definition of PPP, the inability to correctly structure agreements and the poor legal background, are relevant barriers to the success of PPP initiative. Government risks are mostly related to its intervention (Ke et al., 2010), government default (Gao, 2017), project authorization and permissions, public credit, inadequate supervision structure (Xu et al., 2010), immature law and changes in tax regulation (Lang et al., 2017). Related to the government risk there is the economic category where the fluctuation of the interest rate, the foreign exchange, inflation and financial stability of the national context can determine significant changes in the expected returns of the PE, his capacity to guarantee the costs established in the PPP agreement and the loan fees (Chan et al., 2011). To these first two kind of systematic risk categories, another one is relevant: the risks generated by unforeseen weather/geotechnical conditions, like earthquakes, hurricanes, floods, fires etc. In territorial context often affected by environmental critical issues, these factors can hinder the entire completion of the project and heavy financial losses (Xiang et al., 2017).

The specific project-related risk category is much wider than the previous one and there are different classifications of risk groups in the literature. In fact, it refers to the features of the entire PPP initiative and, therefore, the types of risk that can occur depend from a range of factors that pertain to the: i) simultaneous pursuit of public and private benefits; ii) long period of the project; iii) various stakeholders and their complex relationships; iv) strong involvement of public sector organizations; v) many risk-return profiles and skills of PE; vi) local real estate market conditions. Due to their instable complexity, the measures used to determine the factors change according to the context, stakeholder's utility, availability, quality, adequacy and robustness of the data necessary for the analyzes. Therefore, a long list of practiced measures for each factor can be detected, and this makes difficult to identify a unique one (Yu and Kwon, 2011). Some Authors have focused their attention on the systematical review of the specific risk factors in the PPP redevelopment projects by individuating some major groups: Wu et al. (2018) identify 37 risk factors of the PPP projects from the literature review, divided into legal and sociopolitical, construction and operation, macroeconomic, and government risks categories; present 42 critical factors that affected the success of PPP projects in Malaysia which were assigned to two categories or the government and the private sector; Jin and Zhang (2011) group into four categories, including economic, institutional, social and industrial, and other the risk factors in the PPP projects. Similarly, also Li et al. (2005) identify five groups of critical success factors for PPP projects in the UK: effective procurement; project implementability; government guarantee; favorable economic conditions; and available financial market. Chan et al. (2010) explore five relevant critical success factors for PPP projects in China: macroeconomic environment; shared responsibility between public and private sectors; transparent and efficient procurement process; stable political and social environment; and judicious government control. Krane et al. (2012) classify risks according to project objectives: operational, short-term strategic, and long-term strategic.

From the methodological point of view, the most utilized techniques for identify the risk factors according to Kee et al, are the document review, similar cases comparison and SWOT analysis. By analyzing the results of the studies, it is possible to note that an uneavy classification is mainly associated to a common parameter: the contextualization. This means that each category, group, factor and measure is strictly dependent from the territorial and legislative context where the PPP intervention takes place.

In Italy, the main reference for the types of risk that can occur is the Guidelines n.9 of the ANAC. In this document alongside the general construction, demand and availability risks, there are a number of other risks that may arise both in the phase prior to the award and/or signing of the contract, and in the subsequent one, that is, during the entire life-cycle of the PPP contract. Among these, are reported, by way of non-exhaustive example, the commissioning, administrative, expropriation, environmental and / or archaeological, legislative-political-regulatory, of financing, financial, insolvency risks.

3.2. Risk assessment

After classifying the types of risk, it is very important to select and prioritize them in order to have an efficient risk management plan. Risk assessment approaches can be qualitative, quantitative and semi-quantitative, depending on the quality of required available data and the moment of the evaluation during the life-cycle of the project. In addition to the classic Discount Cash Flow Analysis, many quantitative risks ranking and assessment techniques are used in construction industry, such as Fault Tree, Event Tree, Monte Carlo and Sensitivity Analyzes, the Scenario Planning, the Failure Mode and Risk Premium (Rezakhani, 2012). Platon and Constantinescu (2014), apply the quantitative Monte Carlo simulation – a very frequently used method for these purposes - in the risk assessment of environmental projects consists of studying the probability that projects will achieve a satisfactory performance for Internal Rate of Return (IRR) or Net Present Value (NPV). Kokkaew and Tongthong (2021) provide for a computational framework for the determination of duration and revenue sharing rates in PPP concession renewal with a Monte Carlo simulation and a Risk Premium approach. Xing and Guan (2017) use the Fault Tree Analysis to determine the risk factors and their importance order for a PPP project during its preparation stage.

Although these approaches are theoretically well established and have improved rapidly, providing for numerous methods, they are limited in practicality because they need incorporating many factors and their weights, tedious calculations, high mathematical knowledge and great quality data. Such data are hard to obtain in construction industry therefore, according to Dikmen et al. (2007), the difficulties have led experts to base their decisions on personal experience and subjective judgments, in fact qualitative tools are more common among practitioners. Above all, the qualitative risk matrix is extensively used in the construction industry (Qazi and Dikmen, 2019; Qazi et al., 2021). It is a two-dimensional mapping of probability and impact ratings associated with individual risks, where the product of these ratings yields the overall exposure of individual risks (Aven, 2017). One of the main limitations of this technique is the use of average values for capturing the exposure of individual risks and also the aggregation is problematical, with a level of detail that may led to lower underestimate (Duijm, 2015). The significance of risk tail is not considered therefore the prioritization procedure may lead to making sub-optimal decisions regarding the selection of suitable risk mitigation strategies (Tong et al., 2018).

The semi-quantitative risk assessment is a growing typology of approaches and due to the multidimensionality of the risks several applications in the context of the MCDM can be noticed. Above all, the AHP is one of the most used MCDM (Manganelli et al., 2014), first introduced by Mustafa and Al-Bahar (1991) for assessing the risk of a construction project in Bangladesh. Li and Zou (2011) propose a fuzzy-AHP-based risk assessment for PPP projects for identifying some major critical success factors. Dey (2002) combines the AHP with the Decision Tree Analysis as a quantitative approach for determining the probability of occurrence of various risk factors. Millet and Wedley (2002), instead, demonstrate the AHP flexibility for modelling risk and uncertainty in a variety of ways and contexts. The strength of this approach is that it organizes both qualitative and quantitative factors in a systematic way and provides a hierarchical structure yet relatively simple solution to the decision-making problems regarding the complexity of the risk assessment in the PPP projects (Al-Harbi, 2001). Sun et al. (2008) define a risk evaluation method for residential real estate projects based on the integration of fuzzy set theory within the AHP technique.

The results of the risk assessment can, at times, be very complex and not easily understood by the interested subjects if they do not have the appropriate skills. In this, some visualization tools such as graphs and maps can make a significant contribution. In particular, when localization, understood as the effects of the spatial components of a certain area or site on the formation of risk, plays a pivotal role within the analysis, the risk maps are particularly useful both for the visualization of the results and for the for understanding of them. Widely used in the natural risk sector, where the space component is the cornerstone, they find little application in the real estate risk sector, except for analyzes focused on identifying the most suitable sites for specific real estate development projects. According to the authors' knowledge, the only reference in this regard is represented by the work of (Çam, 2018) who creates a Turkey's financial risk map with GIS by using the parameters that determine Turkey's financial risk. In fact, the concept of risk map is often associated to a non-GIS based matrix of frequency and impact of the factors that allows to identify 4 different level of risk (e.g. low, moderate, high and critical) like proposed by Dey (2010) and Sharma (2013) within a conceptual risk management framework using AHP.

A recent trend sees the growing applications of the composite indicators methodologies (Anelli et al., 2022) for assessing the real estate risk at the Country level and then ranking them according to their relative riskiness. A significant reference is represented by Lieser and Peter Groh (2011) that determines the attractiveness of 66 Countries for institutional real estate investments through a Global Real Estate Investment Attractiveness Index (Global REIA Index). Chen and Hobbs (2003) develop a Global Real Estate Risk (GRER) index for 44 Countries based on the cyclical, structural and national features of the real estate market conditions. Lee (2005) assesses the attractiveness of 51 Countries by developing a Real Estate Potential Index (REP index) based on four groups of indicators related to expected growth, geo-political risk, transparency and market specific risk. For the single project level Boateng et al. (2015) model an Analytic Network Process quantitative approach to prioritize the potential risks across the megaprojects performance with a Risk Priority Index. In fact, one of the most practical feedback and operational support of the composite indicators system in the filed of the risk assessment is represented by the possibility of creating a clear ranking list after the evaluation process carried out on the set of considered indicators.

3.3. Risk management/allocation

Public and private subjects involved into PPP real estate redevelopment process must place particular attention to ensure a fair risk allocation between them. A general principle, also followed by the Italian regulatory framework (Guidelines no.9 of ANAC), is that each risk should be allocated to the subject best able to manage it with low cost. In other words, an optimal risk allocation is to seek a solution minimizing both the total management costs of the public and private sectors, but this can be difficult and often badly realized. Osipova and Eriksson (2011) identify three factors as a basis for determining risk allocation in construction projects: the contract form, the payments form and the risk management in partnership projects. Ng and Loosemore (2007) claim that a risk should be given to someone who: i) has been made fully aware of the risks he is taking; ii) has the greatest capacity to manage the risk effectively and efficiently; iii) has the capability and resources to cope with the risk eventuating; iv) has the adequate risk appetite; v) has been given an appropriate risk premium. To help ensure that this happens, a number of standard risk allocation matrices have been produced to guide appropriate risk allocation in PPP projects, the most known is the one provided by Grimsey and Lewis (2007).

In summary, several researchers have attempted to identify and evaluate risks of PPP projects using different perspectives and methods. Many variable types of risk and related approaches have been observed in the literature, according to i) the features of the application's context; ii) the complexity and dimension of the project; iii) the numbers of stakeholders involved iv) the risk appetite and capacity/skills to manage it by the subjects involved; v) the quality of data required and the aim or utility of the risk assessment results; vi) the phase of the project for which the evaluation is conducted. It is possible to observe that, due to the intrinsic characteristic variables of the concept of risk, there is no consolidated framework for identifying each of the numerous and different types of risk that can arise in real estate redevelopment processes that can be adequate for all the risk assessment procedures. This is the main reason according to which every national/international regulatory framework could guide the risk assessment process, but inevitably the factors to be considered must be specifically identified according to the purpose(s) of the assessment, the time of the evaluation (*ex ante* or *post*) and the quality and coherence of the disposable data. After all, this is the reason for the extensive literature on the matter but also for the scarcity of schemes that are capable of integrating the spatial component of the sub-municipal territorial scale of the real estate market into the analysis of the specific risk assessment with a structured framework able to consider the importance of each risk factor into a MCDM synthetic index approach. The need for the practitioners to utilize such kind of effective decision support systems is considered as an important research gap that the proposed work intends to fill.

4. Description of the methodology and its application for the case study

The structured framework defined for the proposed assessment methodology able to create the I_{SRR} is described in each of the 10 phases with reference to the application to the case study of the city of Rome (Italy). Rome is the capital of the Lazio region as well as the capital of Italy and from the analysis of the real estate market in absolute terms it remains the Italian city with the largest volume of property sales, close to 30 thousand units, a third of the trading volume of the large Italian cities, and a growing volume of non-residential property sales. It is characterized by a mix of real estate assets, including architectural and historical ones, that brings the city into one of the most dynamic real estate markets both nationally and internationally. Even if the city has a dynamic real estate market, private investors often consider it riskier to invest in urban regeneration projects than other cities such as Milan. The main reason is due to the historical substratum and the vastness of the cultural real estate heritage which represents one of the main real estate risk factors of the city, because it is able by itself not only to slow down the process of realization of the urban intervention but, in some cases, even to stop it, with consequent losses of revenues and capital. Therefore, it is very useful for public and private subjects to obtain a real estate risk map of the various sub-municipal areas of the city of Rome which clearly and immediately identifies the "base risk" level at which, initially, each real estate development will have to deal with by adding the other risks deriving from the subsequent construction and management phases. As valid general assumptions two reference categories of properties are examined: the first, relating to the residential sector, including housing, garages and parking spaces; the second one relating to the non-residential sector including all the remaining intended uses like offices, laboratories, industrial sheds.

In order to obtain a georeferenced risk map that allows to visualize the spatial distribution of three types of specific risk levels (market, context and insolvency) that identify the "base risk" at the time of the evaluation, the structured framework on which the model is based is represented in Fig. 2.

4.1. Phase 1: goal definition

The first step to be carried out regards the definition of the specific goals that the development of the I_{SRR} intends to pursue. It needs to be specifically calibrated for taking into account both the goal and the utility of the risk index for the final users considered. In the case study, the goal of the risk index is to provide a support for the regulation of the urban parameters of a generic PPP urban redevelopment project with mixed-uses that will be realized on a land plot area partially to be regenerated and partially to be built entirely. In particular, the risk index should allow for better regulation of the parameters from which depends on the convenience of the subjects involved, or the PA that will delivers the infrastructure and services works, and a generic PE for the realization of the mixed-uses established buildings. The final utility of the generic PE regards its use for an *ex-ante* evaluation of the so-called "base risk" level to which specific factors of the subsequent urban intervention development must then be added to it (e.g. risk of construction, management, etc.). On the other hand, the function for the PA concerns the possibility to clearly and immediately identify the riskiest areas within the city of Rome, for then deciding how to draw up a regeneration project.

In the case study, the main final user of the index is principally the generic PE. For this reason, it needs to know the general conditions of the real estate markets sectors of the intended uses established. For doing this, it is essential to conduct a deep analysis on the main adept modalities in the professional practice and in the referenced literature regarding the types of risk to be taken into account, whether systematic or specific, and the factors that make it possible to determine it. After having examined the study reported in the Section 3 of the present research and due to the characteristics of the case study, the type of risk considered is the specific one. Therefore, in order to achieve the defined goal related to the risk index, the following types of specific risk are considered:

- *Market* risk, understood as the risk deriving from demand and supply conditions of the local real estate market at the time of the valuation (end of 2020) within the urban areas considered;
- *Context* risk, concerning the main extrinsic characteristics of the urban area enclosed in the territorial unit of investigation which help to define the desirability of the area for the local real estate market;
- *Insolvency* risk, with reference to solidity and solvency capacity of the future users, stated as the inhabitants of the survey unit;

The I_{SRR} is calculated as the weighted sum of these three types of specific risk (Eq.1):

$$I_{SRR} = p_m \bullet MarketRisk + p_c \bullet ContextRisk + p_i \bullet InsolvencyRisk \quad (1)$$

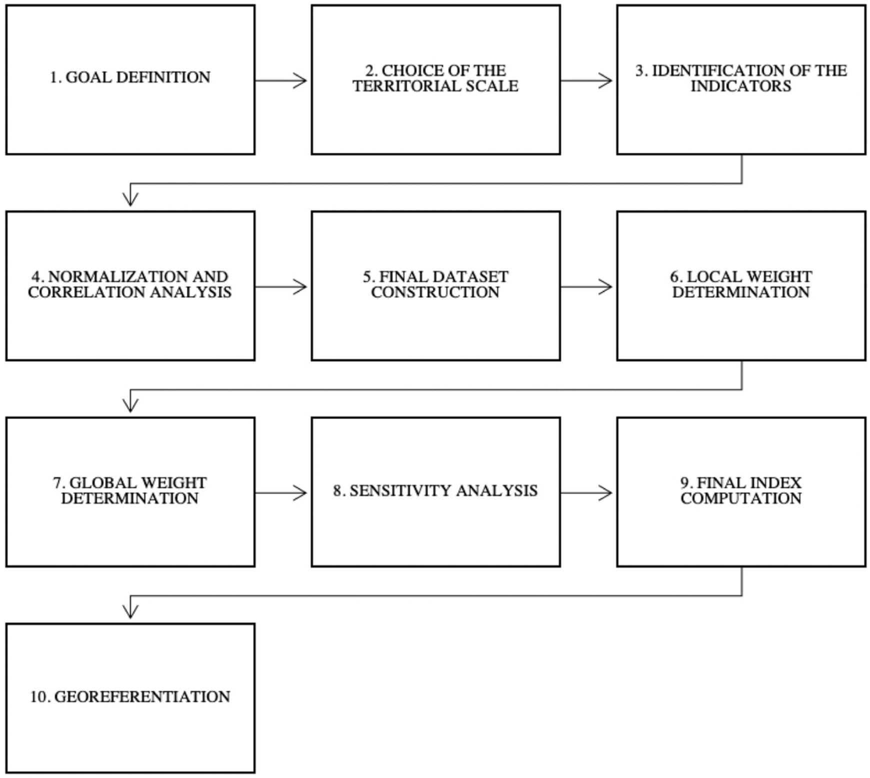

Fig. 2. Structured framework of the proposed methodology.

With p_m, p_c and p_i the local weights of respectively the market, context and insolvency risk.

4.2. Phase 2: choice of the territorial scale

The territorial scale for which the index is calculated must pertains to the effective utility of the final users. It could range from the national to

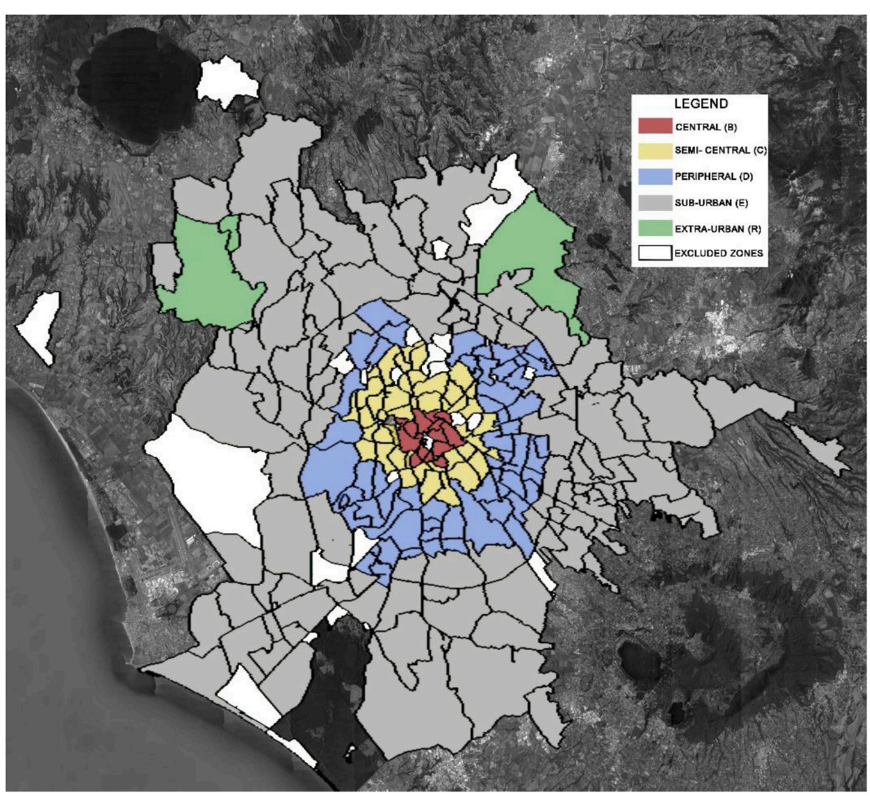

Fig. 3. Perimeters and classification of the 234 OMI zones of Rome updated to the second half of 2020.

the sub-municipal one, passing through the regional, provincial and municipal. According to the goal defined on Phase 1, the most suitable territorial scale is chosen to be the sub-municipal one, or the same of the generic urban regeneration project considered, in order to allow the generic PE to take the most efficient decisions for its convenience. In fact, the other scales are inadequate to achieve the defined goals of the risk index.

For the city of Rome, the sub-municipal scale refers to the 234 perimeters of the municipal area carried out by the Real Estate Market Observatory (OMI) of the Revenue Agency for the year 2020 (last update). The OMI zones are identified according to characteristics of homogeneity from an urban planning point of view and the dynamics of the local real estate market, and they are classified into 5 categories: i) B, the central, ii) C, the semi-central, iii) D, the peripheral, iv) E, the suburban and v) R, the extra-urban. The Fig. 3 shows the distribution of the 234 OMI zones within the city of Rome at the reference date of 31 December 2020, by highlighting the 21 extra-urban (R) excluded by the analysis (white color) because are characterized by the absence of data on real estate values, this condition does not allow to conduct the study on these areas.

These perimeters are chosen for the case study due to their relevance in both professional and academic practice. In fact, they are often used as main reference for acquiring data on real estate quotations, sales volumes and the characteristics of the cadastral stock present in the municipality. The six-months real estate quotations consist of a minimum/maximum range, per unit of commercial surface in €/m^2, of the market and rental values, by type of property and state of conservation. Therefore, 213 of the 234 OMI zones of the city of Rome are considered as the territorial unit of investigation used for the purposes of this research.

4.3. Phase 3: identification of the indicators

In this phase it is essential the analysis of the local real estate dynamics for understanding what are the most suitable indicators able to represent each of the three types of specific risk considered. It consists into a contextualization phase, where the indicators retrieved by the reference literature and professional practice are matched with the features of the urban tissue and the typology of available data on the properties within the areas considered. For the city of Rome, this operation has been conducted by analyzing the main documents and reports on the real estate market dynamics, features and maintenance conditions of the existent stock (e.g. *Nomisma, Scenari Immobiliari, Tecnoborsa*) as well as from the comparison with real estate agents operating in the real estate market of Rome and with local professionals.

The analysis of the real estate dynamics present in the local market of the *i-th* OMI zone is carried out through the identification of an initial set of indicators capable of representing the dynamism, volatility, trend of values, times of sale and lease and the absorption rate of the stock offered. The initial set of indicators comprises a total of 24 items reported in Table 1, of which 14 refer to the market risk, 5 to context risk and 5 to the insolvency risk.

4.4. Market Risk indicators determination

- *Indicators 1,2,5,6,9,10:* The trend in real estate sales and rent values for both residential and non-residential sector (e.g. 1–2, 9–10) and also the Number of Normalized Transactions (NTN) and the Real Estate Market Intensity (IMI) indicators (respectively 5 and 6) are determined by considering the angular coefficient of the trend in real estate values, calculated through the construction of the regression line of the index numbers of residential and non-residential destinations surveyed by the Revenue Agency between the first semester of 2015 (base 100) and the second one of 2020. In this way it is possible to obtain the desired information by a-dimensionalize the values to facilitate comparison among the trends of each OMI zone. If

Table 1
Features of the initial set of the 24 indicators system.

Type of specific risk	Indicator	Type	Measure	Data source
MARKET	Trend in real estate sales values in the residential sector Trend in real estate sales values in the non-residential sector Volatility of the sales values in the residential sector Volatility of the sales values in the non-residential sector NTN trend IMI trend Average sales times in the residential sector Average sales times in the non-residential sector Trend in real estate rental values in the residential sector Trend in real estate rental values in the non-residential sector Volatility of the rental values in the residential sector Volatility of the rental values in the non-residential sector Average leasing times in the residential sector Average leasing times in the non-residential sector	All quantitative	Angular coefficient Angular coefficient Standard deviation Standard deviation Angular coefficient Angular coefficient Mean number of months Mean number of months Angular coefficient Angular coefficient Standard deviation Standard deviation Mean number of months Mean number of months	For all the indicators the real estate quotations provided by the Revenue Agency for the 2020 semesters are considered.
CONTEXT	Urban life quality Attractivity Building maintenance Urban decay Archeological sites	Qualitative Quantitative Quantitative Quantitative Qualitative	Average determined score Number of people detected Average cost of ordinary maintenance	Agency for the control and quality of public services of Rome U-Geo Urbistat

(*continued on next page*)

Table 1 (*continued*)

Type of specific risk	Indicator	Type	Measure	Data source
			per capita Percentage of empty dwellings Percentage of territorial surface occupied by archeological sites	database (1 January 2020) U-Geo Urbistat database (1 January 2020) U-Geo Urbistat database (1 January 2020) Quality Charter
INSOLVENCY	Purchasing capacity Owned properties Rented properties Employment stability Potential demand	All quantitative	Disposable income per capita Percentage of families living in owned properties Percentage of families living in rented properties Unemployment male rate Population density	All U-Geo Urbistat database (1 January 2020)

the angular coefficient is positive, it means that also the trend is positive, instead if it is negative, it means that the trend is too.

- *Indicators 3,4,11,12:* The volatility of the real estate values is determined by calculating the standard deviation of each historical series of index numbers of real estate values for sale and lease included in the same period of years used for the construction of the trend of the previous indicators (1,2,5,6,9,10) with a base of 100 equal to the first semester of 2015. It is thus obtained the average volatility of expected returns in both the residential and non-residential sectors.
- *Indicators 7,8,13,14:* The time span between the moment in which a property is placed on the market (for sale or for lease) until its exit, which is assumed to correspond to the signing of a lease or a preliminary sale agreement, is one of the possible measures of the average timing of the market. Based on the date of the sale and rental announcements of the units belonging to the residential and non-residential sector between 2015 and 2020 detected by the *Immobiliare.it* website, the most important real estate announcements site of Italy, retrieved by the private database of the Geomarketing software named "*Urbistat*" (https://www.urbistat.com/ita/), the average number of months for sales and leasing of each OMI zone are calculated.

4.5. Context risk indicators determination

- *Indicator 1:* The quality of the urban environment circumscribed within the *i-th* OMI zone represents a highly relevant factor within the demand formation mechanisms for the specific area. The presence of public services, transport infrastructures, places of culture and recreation, parks and well-kept and accessible green areas, are the main elements that guide the choices of buyers and, consequently, allow to identify the most attractive areas of the real estate market. The survey on public services and the quality of life conducted with reference to the year 2019 by the " Agency for the control and quality of public services of Rome (ASPL)", provides a complete overview of the perception that users, occasional or habitual, have of 18 local public activities and of the quality of life in the OMI zone where they live. Therefore, each score resulting from the analysis is useful for determining the quality of life in each OMI area considered.
- *Indicator 2:* The level of attractiveness of the area represents a fundamental factor in the analysis of demand formation mechanisms. In general terms, the municipality of Rome registers 3.7 million of individuals transiting for reasons of work, leisure, tourism, even from outside. The greater the number of individuals passing through the area, the greater the attractiveness of the area and therefore the lower the risk that the final products of the urban regeneration intervention considered may remain unused and / or underused or unsold. The number of individuals passing through the *i-th* OMI area is determined as the sum of the resident, non-resident, tourist population and workers who transit from 8.00 A.M to 9.00 P.M.
- *Indicator 3:* The state of conservation of the properties in the *i-th* OMI area is detected through the analysis of the average per capita expenditure for house maintenance works. The higher the expense, the greater the probability of old buildings or buildings constructed with poor quality materials such as low-cost housing or of historical-architectural value with a scarce or difficult (and onerous) state of maintenance in the urban area. The data was drawn from the per capita consumption database of *Urbistat Geomarketing* software.
- *Indicator 4:* The level of degradation of public and private buildings in the urban area helps to define the quality of the same in the context in which they are located. The presence of disused and old buildings reduces the attractiveness of the area and highlights the greater need for interventions that improve the general structure of the present buildings. The risk will therefore be greater in urban areas characterized by a widespread presence (or concentrated in some districts) of buildings in poor state of repair or abandoned, both due to the possibility of incurring higher costs of rehabilitation or maintenance of the same, both due to the high capacity of these areas to attract phenomena of crime or social marginalization which can significantly reduce the ability to use the building products of the urban transformation in progress. The percentage of houses that are empty or occupied by non-residents provides a measure of whether or not there are properties in a state of neglect or decay. This indicator is determined on the basis of the data available in this regard on the *Urbistat* Geomarketing software.
- *Indicator 5:* The main risk of delays in issuing the necessary permits, restrictions and modifications of the urban intervention methods or the imposition of interruptions on the municipal territory of Rome, is due to the numerous archaeological elements present on the entire territory of the city. The system of urban constraints of the city of Rome, complex by nature and consistency of the territory and of the real estate assets present, is polarized on the archaeological-monumental pre-existing structures and on the consistencies associated with it. In the "Charter for Quality" (elaborated G1) of Rome all the archaeological and monumental elements visible in the fabric of the contemporary city, both constrained and unconstrained, have been mapped. The percentage of the territorial surface of the *i-th* OMI area affected by all the elements pertaining to the categories of archaeological-monumental pre-existing structures and the archaeological and natural subsoil deposit, defines the level of associated risk. Specifically, a reference threshold value is identified, equal to the average territorial surface occupied by these elements, beyond which the OMI area has a maximum score (5) for a higher probability than the municipal average of administrative-operational problems due to pre-existing elements. If the percentage of territorial surface occupied by archaeological elements is equal to the municipal average with a variation of about 10%, the OMI area will have a

score of 3. In the event that the percentage of surface occupied by archaeological elements is significantly lower than that municipal, the score is 1. The scores are determined according to the consultation with a panel of real estate developer's expert and based on their experience with development process of the past on these type of sites.

4.6. Insolvency risk indicators determination

- *Indicator 1:* The per capita income is among the most relevant variables for the purpose of detecting socio-economic inequalities in the various urban areas of the city. This variable provides a measure of the economic potential of the resident population. As this indicator increases, the probability for the PE to enter a real estate market whose demand is unable to economically absorb the real estate units envisaged by the urban intervention will decrease. It will also be possible to modulate the sale and rental prices offered on the basis of the average per capita income which, therefore, where it will be lower, will not allow large profit margins. The data on these indicators are collected through the access at the database of *Urbistat.*
- *Indicators 2 and 3:* The title of use of the houses present in the urban area is an indirect measure of housing stability. A family can move towards one right of enjoyment or the other by taking into consideration numerous elements, which involve not only the actual possibility of buying a house (having its own funds available, or by taking out a mortgage depending on the advantageous rates or not) and the social context in which it is located, but also - and above all - the work needs and the transience of the employment contract. Families who own the house in which they live, even if acquired in part with the activation of a mortgage, are assumed to have at least one member with a stable employment contract that guarantees the minimum maintenance of the other members. Families who, on the other hand, have a lease contract may be more subject to precarious employment contracts or reduced economic stability than families who have a right of ownership. All things being equal, the first group expresses a greater potential for economic stability than the second group, therefore the associated risk will be higher in the presence of a high percentage of rented households in the area.
- *Indicator 4:* The employment status of the demand retrieved by *Urbistat* defines the probability of the occurrence of states of arrears and / or non-compliance with the fees established between the parties for the units built. A high level of this indicator represents a significant risk for the PE.
- *Indicator 5:* The population density represents the consistency of the potential demand existent in the real estate market of the OMI area under examination. The higher the population density, the lower the risk that the functions established with the urban regeneration intervention remain scarcely or not used at all. Through the socio-demographic dataset available on *Urbistat*, it was possible to detect the persistent population density in each OMI area.

4.7. Phase 4: normalization and correlation analysis

The set of indicators collected presents a difference in terms of data measurement methods: there are both scoring scales (e.g. 1–3–5), ratios (e.g. inhab/km^2) and intervals (e.g. 5.13, 8.45, 3.2). Normalization is necessary to eliminate these differences in the measurement units of the indicators and therefore to be able to compare and aggregate them in the final summary risk index. The choice of the most appropriate normalization method therefore depends on the need to reward/penalize certain issues of the problem, on the importance of the maximum and minimum levels of the values collected in the phenomenon under investigation and on the possibility of wanting to compare them in different time intervals. In fact, depending on the normalization technique used, the final value of the I_{SRR} can vary significantly (Vafaei et al., 2016, 2018; Shao et al., 2020). The choice of normalizing the indicators with the min-max technique was identified as the most appropriate to achieve and meet the specific needs required. In particular, it allows to normalize the indicators within a range of values between 0 (minimum) and 1 (maximum) and takes into account the extremes, thus avoiding underestimating the total risk and providing a more effective assessment index for the objectives of the analyses.

After the normalization, the AHP requires the lack of correlation between the elements pertaining to a hierarchical level, in order to be used. For this reason, the correlation levels are checked by analyzing the Pearson coefficient among the 24 normalized indicators (Podvezko and Sivilevičius, 2013). The results of the correlation analysis shown in Figure A of the Supplementary Files highlight the presence of the seven couples of highly correlated indicators of which, six couples pertain to the risk market factors and only one pertains to context and insolvency risk factors:

- Volatility of the sales values in the residential sector (3) and the trend in real estate sales values in the residential sector (1)
- Trend of the IMI (6) and the trend of the NTN (5)
- Trend in real estate rental values in the non-residential sector (10) and the trend in real estate sales values in the non-residential sector (2)
- Volatility of the rental values in the residential sector (11) and the trend in real estate rental values in the residential sector (9)
- Volatility of the sales values in the non-residential sector (4) and the volatility of the rental values in the non-residential sector (12)
- Volatility of the rental values in the non-residential (12) and the trend in real estate rental values in the non-residential sector (10)
- Purchasing capacity (1) and building maintenance (3)

To avoid redundancy of the information provided by the indicators and to limit the average correlation between them, it was decided to eliminate the following ones:

- Trend in real estate sales values in the residential sector (1)
- Volatility of the sales values in the non-residential sector (4)
- Trend of NTN (5)
- Trend in real estate rental values in the residential sector (9)
- Volatility of the rental values in the non-residential sector (12)
- Purchase capacity (1)

Therefore, the final set of elementary indicators for the construction of the proposed risk index, after having carried out the correlation analysis, is composed of 17 indicators, of which 8 for market risk, 5 for context risk and 4 for insolvency one. The final indicators considered present the following direct and indirect proportional relationships with respect to the I_{SRR}: (Table 2).

4.8. Phase 5: final dataset construction

Once the indicators that will constitute the proposed risk index have been identified, the identification of the ranges of variation of the values of the indicators on the totality of the OMI zones, in order to effectively grasp the spatial distribution of the same, is carried out. This operation is accomplished first by observing the set of data collected and subsequently by analyzing the percentiles of each indicator, thus identifying a variable number from 3 to 6 percentiles, depending on the variability of each indicator. If the indicator is determined through a scale of scores, as in the case of the presence of archaeological elements (Indicator 5 of Context risk), the number of classes of variation of the values is exactly equal to the number of different scores that the indicator presents. In this way, starting from the normalized indicators, a further hierarchical level below the latter is added, attributes to the variation classes of the values identified for each indicator - called *intensity range* -, in such a way as to obtain the final structure of AHP represented in Fig. 4.

Table 2
Proportional relationships between the indicators and the risk index.

Type of specific risk	Indicator	Risk index
	1. Trend in real estate sales values in the residential sector	-
	2. Trend in real estate sales values in the non-residential sector	-
	3. Volatility of the sales values in the residential sector	+
	4. Volatility of the sales values in the non-residential sector	+
	5. NTN trend	-
	6. IMI trend	-
	7. Average sales times in the residential sector	+
MARKET	8. Average sales times in the non-residential sector	+
	9. Trend in real estate rental values in the residential sector	-
	10. Trend in real estate rental values in the non-residential sector	-
	11. Volatility of the rental values in the residential sector	+
	12. Volatility of the rental values in the non-residential sector	+
	13. Average leasing times in the residential sector	+
	14. Average leasing times in the non-residential sector	+
	1. Urban life quality	-
	2. Attractivity	-
CONTEXT	3. Building maintenance	+
	4. Urban decay	+
	5. Archeological sites	+
	1. Purchasing capacity	-
	2. Owned properties	-
INSOLVENCY	3. Rented properties	+
	4. Employment stability	-
	5. Potential demand	-

4.9. Phase 6: local weights determination

In order to take into account the contribution of each factor considered in the formation of the real estate risk, summarized within the final value of the index, it is necessary to determine the importance - in terms of local weight - of all the factors that constitute the structure of the AHP, starting from the individual intensity ranges, then continuing with each indicator and finally the three types of specific risk considered. To do this, 20 pairwise comparison matrices are constructed, of which 17 to determine the local weight of the intensity ranges and 3 for that of the indicators, respectively a matrix of order 9 for market risk, one of order 5 for context risk and finally one of order 4 for insolvency risk. In the proposed case study, the local weight of the three types of specific risk is assumed to be equal to 1, given the difficulty of objectifying the importance of one type of risk compared to another by comparison in pairs, moreover in the absence of indications more specific on the type of intervention, its location, the subjects involved and the socio-economic, environmental and legal profile.

Consultation with a panel of experts composed of subjects operating in the real estate development, construction of the private sector and urban planning section of the PA (e.g. 5 of the major local private entrepreneurs, 3 investment fund managers with portfolios containing located properties in the city of Rome, 5 real estate agents of the main real estate agencies of the city for a long time present in the area, 2 administrative technicians competent in the urban planning functions of the city of Rome), allows to formulate preference judgments for each comparison matrix, transformed into values through the adoption of the Saaty scale (Table A of Supplementary file).

It is important to note that if the indicator has a direct proportionality with respect to the real estate risk index, the classes with the highest value of the intensity ranges will have a greater weight than those with the lowest value. For the elementary indicators that have an inverse proportionality with the risk index, i.e. the increase in their values reduces the real estate risk, the lower value ranges will have greater weight than the higher value ranges. Please refer to Figure B in the Supplementary Files for a summary of all the local weights determined for each indicator and intensity range of the risk index.

The consistency of the judgments expressed by the panel of experts is constantly checked through the calculation of the Consistency Index (CI), a control parameter that considers the maximum eigenvalue of the matrix λ_{max} and the order n of the same, as Eq. (2) follows:

$$CI = [(\lambda_{max} - n)/(n-1)]/\text{Random Index} \tag{2}$$

The Random index is a predefined table value depending on the order n of the comparison matrix, shown in Figure C of the Supplementary files. In order for the judgments expressed by the panel of experts to be used for the determination of the weights, the CI of each comparison matrix is less than 0.1, as reported in Figure D of the Supplementary Files.

4.10. Phase 7: global weight computation

The final aggregation of the local weights within the global weight, or the final risk index I_{SRR}, takes place by adopting the definition of risk taken as a reference in Eq. (1). Specifically, taking into account each determined local weight, the following Eq. (3) is applied to calculate the index:

$$I_{SRR} = p_m\left(\sum_{n=1}^{n} v_{n,m} \bullet w_{n,m}\right) + p_c\left(\sum_{n=1}^{n} v_{n,c} \bullet w_{n,c}\right) + p_i\left(\sum_{n=1}^{n} v_{n,i} \bullet w_{n,i}\right) \tag{3}$$

With:

- p_m, p_c and p_i the local weights of the three risk types, respectively market, context and insolvency;
- $v_{n,m}$, $v_{n,c}$ and $v_{n,i}$ the local weights determined through the pairwise comparisons matrices for the *n-th* indicators related to each type of risk (m= market, c= context, i = insolvency);
- $w_{n,m}$, $w_{n,c}$ and $w_{n,i}$ is the weight of the defined *m-th* intensity range associated to the *n-th* indicator related to each type of risk.

The obtained index value, normalized through the min-max technique to obtain results included in the range 0 (minimum) and 1 (maximum) easily comparable, refers to the *i-th* OMI zone considered in the municipal area of Rome. The higher the index value for the *i-th* OMI zone, the greater the real estate risk associated with it on the basis of the considered indicators. This operation must be carried out for each of the

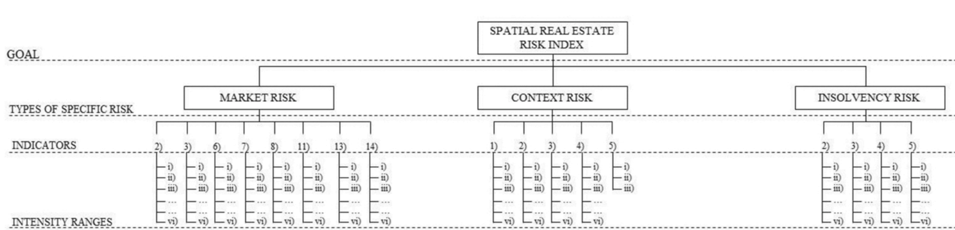

Fig. 4. Final structure of the AHP for determining the proposed Spatial Real Estate Risk Index.

examined 213 OMI zones.

4.11. Phase 8: sensitivity analysis

All the index values obtained are subjected to sensitivity analysis by comparing the ranking of the areas obtained by varying the weights of the market, context and insolvency risk indicators according to the following 3 scenarios:

i. Market risk is more important than context and insolvency risk;
ii. Context risk is more important than the market and insolvency risk;
iii. Tenancy risk is more important than the market and context risk.

In particular, the ranking variations that occur in the three scenarios between the highest and lowest values of the index, i.e., the top and bottom 10% of all the values sorted in descending order, are analized. The comparison of the three scenarios takes place with respect to the ranking obtained in the base scenario, i.e. the one deriving from Phase 7 of the proposed model applied to all the OMI zones considered. The purpose is to verify the effects induced by varying the weights of the indicators on the stability of the final index results. The results of the sensitivity analysis are following reported in Figs. 5 and 6.

The obtained results lend to some important observations. First of all, in Fig. 5 it can be possible to see the position of the R40 area (extra-urban in light green) that remains unchanged, which is the one with the highest risk in all 4 scenarios examined, followed by E65 (sub-urban in light gray) which always occupies the 2nd place except where the importance attributed to context risk is greater than to the other two types, while remaining among the top 5 OMI zones most at risk. In the scenario in which the context risk has the greatest weight (importance), in fact, the central areas (in orange) B2 and B14 (2nd and 4th place) rise in position, which in the ranking with equal importance of the three types they rank 10th and 12th, to which are added others such as B13, B12, B25, B15 (10th, 13th, 14th and 16th place respectively). It is clear how the indicators chosen to represent the context risk (quality of life, pre-existing archaeological sites, number of abandoned buildings, state of conservation of buildings and level of attractiveness) are characteristic of central urban areas, especially with reference to the extension of the territorial surface affected by pre-existing archaeological sites that can induce slowdowns and difficulties in obtaining permits, as well as excavation and construction operations, in the generic urban regeneration intervention considered in the work. As a unit belonging to the semi-central band, zone C31 (in light yellow) rises, in any case placed in the first 20% of the base scenario, therefore with significant levels of risk. If market risk prevails, in the OMI zones of the top 10% of the highest values of the index there are few variations compared to the base scenario, with the exception of the absence of central zones B2 and B14, and zones D68 (in light blue) and C45, respectively in 7th and 21st place, all within 20% of the OMI zones at greatest risk in the base scenario. The scenario in which insolvency risk prevails is compounded in very similar to that of main reference except for the absence of the peripheral area D37, and of the sub-urban areas E64, E9, E87, E105, E143 that move up, but still present in the first 20% of the comparison ranking. In general, the prevalence of sub-urban areas is observed in all 4 scenarios.

The comparison between the results obtained for the lowest values of the index (last 10% of the OMI zones) shown in Fig. 6 reveals an overall consistency between all the scenarios, without significant variations: the semi-central zone C29, the one with the lowest risk in absolute (213th place), it is in fact always within the last 3 positions. In the case of market risk with greater importance, the lowest positions are mainly covered by the semi-central zones (C9, C24 and C7), while in the other two scenarios the presence of zones is observed sub-urban (E98 and E179) or peripheral (D7, D34 and D27). The reasons can be traced back to the almost non-existence of pre-existing archaeological sites in the E98 and E179 zones, in the first case, and to a low unemployment rate in the D7, D34 and D27 zones, in the second case. The variability of the OMI zones observed in the remaining positions does not affect the robustness of the results as all the zones that appear in the last 10% of the values are strictly included within and not beyond the last 20% of the ranking.

BASE SCENARIO			SCENARIO 1			SCENARIO 2			SCENARIO 3		
INDEX VAL.	RANKING	OMI ZONE	INDEX VAL.	RANKING	OMI ZONE	INDEX VAL.	RANKING	OMI ZONE	INDEX VAL.	RANKING	OMI ZONE
1,00	1°	R40	1,00	1°	R40	1.00	1°	R40	1,00	1°	R40
0.89	2°	E65	0.86	2°	E65	0.92	2°	B2	0.92	2°	E65
0.80	3°	E61	0.82	3°	E160	0.89	3°	E61	0.79	3°	E64
0.77	4°	E79	0.81	4°	E61	0.89	4°	B14	0.79	4°	E140
0.76	5°	E160	0.72	5°	E79	0.89	5°	E65	0.78	5°	E171
0.75	6°	E171	0.72	6°	E89	0.87	6°	E166	0.77	6°	B2
0.74	7°	E89	0.71	7°	D68	0.86	7°	E79	0.77	7°	E9
0.73	8°	E166	0.70	8°	E181	0.81	8°	E171	0.76	8°	E166
0.72	9°	E140	0.68	9°	E171	0.81	9°	C31	0.76	9°	E160
0.71	10°	B2	0.68	10°	R7	0.79	10°	B13	0.75	10°	E123
0.70	11°	E64	0.67	11°	E24	0.79	11°	E89	0.75	11°	E170
0.70	12°	B14	0.66	12°	E140	0.78	12°	E168	0.75	12°	E87
0.70	13°	R7	0.63	13°	E84	0.77	13°	B12	0.74	13°	E105
0.69	14°	E170	0.61	14°	E71	0.77	14°	B25	0.74	14°	E168
0.68	15°	E168	0.61	15°	E19	0.76	15°	D37	0.74	15°	B14
0.68	16°	E123	0.61	16°	D37	0.75	16°	B15	0.74	16°	E79
0.66	17°	E71	0.61	17°	E170	0.75	17°	E170	0.74	17°	E71
0.64	18°	E22	0.60	18°	E114	0.74	18°	R7	0.73	18°	E89
0.64	19°	D37	0.60	19°	E64	0.73	19°	E140	0.71	19°	E61
0.64	20°	E114	0.60	20°	E166	0.73	20°	E64	0.70	20°	E143
0.63	21°	E25	0.60	21°	C45	0.73	21°	E123	0.69	21°	R7

Fig. 5. Ranking comparison among the first 10% of the highest index values obtained by the sensitivity analysis.

BASE SCENARIO			SCENARIO 1			SCENARIO 2			SCENARIO 3		
INDEX VAL.	RANKING	OMI ZONE	INDEX VAL.	RANKING	OMI ZONE	INDEX VAL.	RANKING	OMI ZONE	INDEX VAL.	RANKING	OMI ZONE
0.17	191°	E185	0.19	191°	C38	0.20	191°	E3	0.13	191°	C2
0.16	192°	D53	0.17	192°	D27	0.20	192°	D9	0.12	192°	D36
0.16	193°	C10	0.16	193°	C46	0.20	193°	C11	0.11	193°	E185
0.15	194°	D5	0.16	194°	C51	0.20	194°	D78	0.11	194°	D47
0.15	195°	C11	0.16	195°	E179	0.19	195°	C14	0.11	195°	D78
0.15	196°	E98	0.14	196°	D53	0.19	196°	D5	0.10	196°	D16
0.14	197°	D16	0.14	197°	D34	0.19	197°	C10	0.10	197°	C22
0.14	198°	C18	0.14	198°	D14	0.19	198°	E185	0.09	198°	C17
0.14	199°	D19	0.13	199°	D16	0.18	199°	D36	0.09	199°	D53
0.12	200°	D46	0.13	200°	D5	0.18	200°	C7	0.09	200°	C46
0.12	201°	E179	0.13	201°	C18	0.17	201°	E21	0.09	201°	D1
0.12	202°	C40	0.12	202°	C11	0.17	202°	D19	0.08	202°	C40
0.11	203°	C51	0.12	203°	D7	0.16	203°	C18	0.08	203°	D46
0.11	204°	D9	0.12	204°	C10	0.14	204°	C51	0.06	204°	C9
0.10	205°	C24	0.12	205°	D9	0.13	205°	D1	0.06	205°	C7
0.10	206°	C9	0.10	206°	C21	0.11	206°	C21	0.05	206°	C51
0.09	207°	C7	0.09	207°	C40	0.10	207°	D46	0.04	207°	C24
0.09	208°	D1	0.08	208°	D19	0.10	208°	D7	0.03	208°	D9
0.07	209°	D27	0.08	209°	D1	0.09	209°	E98	0.02	209°	C21
0.07	210°	D7	0.07	210°	C7	0.06	210°	E179	0.00	210°	D27
0.07	211°	C21	0.07	211°	C24	0.04	211°	D27	0.00	211°	C29
0.05	212°	D34	0.07	212°	C9	0.01	212°	C29	0.00	212°	D34
0.00	213°	C29	0.00	213°	C29	0.00	213°	D34	0.00	213°	D7

Fig. 6. Ranking comparison among the last 10% of the lower index values obtained by the sensitivity analysis.

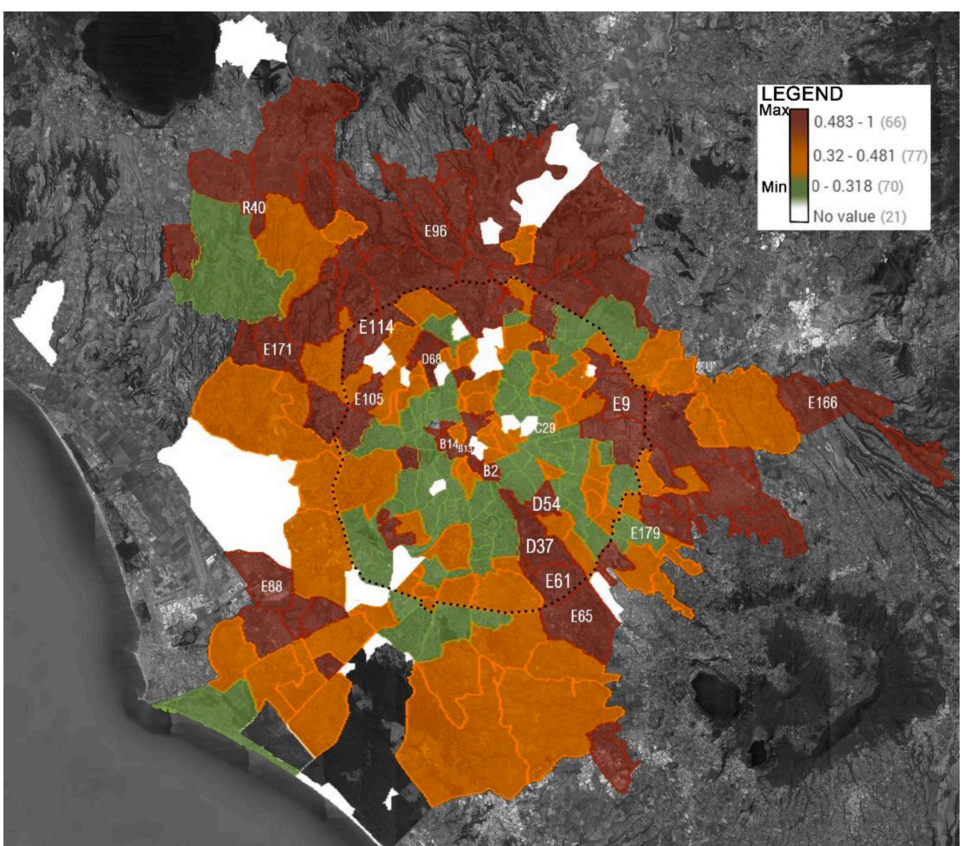

Fig. 7. Georeferenced map of the Spatial Real Estate Risk Index for the city of Rome.

4.12. Phase 9: final index computation

From the examination of the sensitivity analysis, the results obtained for the value of the synthetic real estate risk index are consistent with the specificities of each OMI zone and robust in terms of the determined weights. The OMI zones that appear to have the highest and lowest values of the I_{SRR} are consistently positioned in all the scenarios considered and the minimum observed ranking variations do not lead to significant changes in the entire general ranking. The condition resulting from the *base scenario* is therefore effective in representing the specific characteristics of the market, context and insolvency of the municipal area of the city of Rome, and for these reasons it is used in this analysis. Otherwise, in this phase of the model a recalibration of the local weights of the indicators has to be carried out, so that the index is more stable.

4.13. Phase 10: georeferentiation

Once the index values have been obtained for all the OMI zones considered in the analysis, it is possible to georeference the results to allow an immediate visualization of the distribution of the values within the territory of the city of Rome. Based on the perimeters of the OMI zones in *.kmz* format available in the GEOPOI (Geocoding Point of Interest) section, i.e. the cartographic framework of the Revenue Agency that allows to consult the quotes by municipality and by OMI area through geolocalized navigation (https: // www1.agenziaentrate.gov.it/servizi/geopoi_omi/index.php), imported into the Google opensource application "MyMaps", it was possible to attribute to each OMI zone its risk index value on a georeferenced map, as well as shown in Fig. 7.

5. Results discussions

Observing the distribution of the risk index values a heterogeneity is noted, with value peaks more distributed outside the Great Ring Road (GRA) (black color), especially north of the city. At the municipal level, 70 areas belonging to a low-risk band, 77 with medium risk and 66 with high levels of investment risk are identified. However, it is not possible to identify an area of the city in which all the riskiest areas are concentrated, as many of them are also found in urban contexts which on average appear to be low risky. Except for the areas excluded from the analysis (white color), in the city center there are OMI areas whose risk values are very variable, from 0.8 of the E61 area to 0.01 of the C29, located behind the “Verano” site. The OMI zones with the highest risk (deep red color), the D68, E114, E105 are to the North-West with an index between 0.6 (D68) and 0.64 (E114) and E9 with 0.59. The R40, is the one with the highest risk in absolute (1.00) and has an average sales time of the non-residential of about 21 months, an unemployment rate of 13.7%, 9 points higher than the city’s average and a population density of 31.9 inhabitants/km^2, extremely low compared to the average of 6142.23 inhabitants/km^2, in addition to having a considerably reduced level of attractiveness. The D54, the D37 and the E61, with respectively 0.6,0.64 and 0.8, and the B14 that with the B13 the B2 have a risk equal to 0.79, 0.59 and 0.70. These areas belonging to the central band (B), are characterized by a high volatility of real estate values in the residential sector, average times of sale and leasing of the residential asset, a quality of life rating below the municipal average (5.45), a high extension of the surface affected by archaeological-monumental pre-existing structures and a state of conservation of the buildings below average. These factors bring the B zones into the urban center to identify itself in the range with the highest risk values. As regards the OMI areas of the peripheral band (D), these are particularly affected by a very negative trend in real estate sales values in the non-residential sector, high volatility, high average sales times in the residential and non-residential sector and an unemployment rate above the average. The areas belonging to the sub-urban band (E) are characterized especially by market risk indicators which express a weak overall stability.

Outside the GRA, the highest concentration of real estate risk occurs in the northern areas. All the OMI zones between 1 of the R40 and 0.62 of the E96 in this territorial context are characterized by particularly negative levels of insolvency and market risk indicators. East of the GRA, the greatest criticality is found in the E166, with a risk index of 0.72, which has about 30% of the buildings empty or abandoned, a volatility of residential sales values equals to 0.12, 4 points higher than to the average of Rome, and a very low population density, equal to 296 inhabitants/km^2. South of the GRA, the E65 is the only one to have a level of risk to be aware of, with an index equal to 0.89, due to the high volatility of residential and non-residential sales and lease values, the high unemployment rate and the low population density. West of the GRA, only the E171 is in the higher risk ranges, with the value of 0.75, due to the number of abandoned buildings, the high volatility and the average sales and leasing times above the municipal average of 4 points. Some attention is focused on the E88, on the South-West where the illegal building, the high average times of sale of the non-residential and lease of the non-residential make the zone riskiest than the neighboring ones.

As regards the best conditions, in terms of real estate risk, the OMI E179 zone, south-east of the peripheral areas, has the risk equal to 0.21. The market characteristics have an average stability and values, while the quality of life rating is among the highest (5.46), the area affected by archaeological-monumental pre-existing structures is minimal (1), the number of abandoned buildings and the state of conservation of the same is much lower than the average, respectively € 109 per capita and 8.3%.

Inside the urban ring of the GRA, on the other hand, there is the urban area with the absolute lowest risk, the C29, has a positive trend in the IMI index, a stability of the residential sale and rental values well above the average with 0.05, a quality of life rating of 5.32, a high level of attractiveness (19,630 gravitating individuals per day), average sales and rental times below the municipal average, as well as the trend in real estate values, a low unemployment rate (7.5%) and an almost absence of surfaces affected by pre-existing archaeological sites.

Among the total examined set of risk factors, it is possible to observe that the volatility of the sale values and the rental values in the residential sector (no. 3 and 11 of market risk) with the archeological sites (no. 5 of the context risk) and the employment stability (no. 4 of the insolvency risk) represent the most affecting indicators. In fact, the OMI zones that appear to have the highest I_{SRR} values are also those that have disadvantageous circumstances for these indicators. The obtained results of the risk index appear to be consistent with the empirical evidence for the real estate market conditions of the city of Rome at the time of the evaluation and, at the same time, also for the public and private subjects operating in the risk assessment of the real estate redevelopment processes within the city. At this point, it will be up to them to make efficient decisions, based on their knowledge of the issues addressed and the DIKW pyramid of the SDSS, for sustainable urban planning.

6. Conclusions

Urban redevelopment processes have long represented the driver of the socio-economic and environmental recovery of urban contexts, but the significant uncertainty that characterizes the current historical period makes considerably difficult to carry out real estate risk assessments that are useful to public and private decision makers involved in the settlement of urban redevelopment interventions (Morano and Tajani, 2013). The existent methodologies, in fact, are based on quantitative approaches that need laborious operations and specific skills are often required to understand and visualize their results, or the qualitative ones are not sufficiently adequate for taking into account the multidimensionality and complexity of the risk assessment (Morano et al., 2021; Locurcio et al., 2022). Moreover, a gap in the reference literature can be noted: the absence of SDSS able to provide an efficient *ex-ante* risk assessment at the sub-municipal scale for analyzing, ranking and study the spatial distribution of the real estate risk levels among the urban areas of a city.

The work is part of the outlined framework, and it is aimed at providing an innovative semi-quantitative risk assessment model that can support the PA and the PE involved into *ex-ante* evaluations regarding urban planning issues for redevelopment projects. The proposed model, based on a structure framework of 10 sequential and ordered phases, has allowed to determine a Spatial Real Estate Risk Index that represents the level of the specific risk of a generic PPP urban regeneration project with mixed-uses on a land plot area partially to be regenerated and partially to be built entirely. The research has proposed an innovative integration in the field of the risk assessment between the AHP multi-criteria technique, an indicators system with 17 parameters and a GIS tool for creating a synthetic index at the sub-municipal territorial scale. Through the application of the proposed assessment methodology to the city of Rome (Italy) its robustness and consistency have been verified. In fact, the index values calculated for each of the 213 OMI zones considered and georeferenced in the risk map were consistent both to the retrieved indicators values and their importance in the risk assessment. Moreover, the risk index values were coherent also with the empirical evidence of the real estate market conditions of the city of Rome at the time of the evaluation.

Overall, by analyzing the results there were about 80 areas that express a criticality of the three types of specific risks examined - market, context and insolvency - that requires careful evaluation. The north peripheral areas of the GRA could involve the intervention of a PE who, in agreement with the PA, can intervene with urban transformation solutions mainly focused on increasing the level of attractiveness of these areas, by establishing of most necessary or missing intended uses, in such a way as to indirectly operate also on the unemployment rate of these areas by providing new jobs on site, thus also reducing the average sales and leasing times. The areas at greatest risk in the urban center, on the other hand, require urban redevelopment interventions that can mitigate the risk associated with the probability of detecting archaeological pre-existing elements that compromise the entire intervention. In particular, the PE and PA can choose for the recovery and enhancement of the existing, rather than the construction of new buildings, both to improve the state of conservation and the quality of life in the most exposed areas, and to reduce the time required for obtaining permissions and reducing the probability that the intervention will stop for the detection of archaeological elements. It is worth noting that, according to the features of the SDSS structure, the obtained risk map, serves as a support for the PA and the PE involved in the PPP redevelopment projects to increase their knowledge on the demand and supply conditions existent at the time of the evaluation on the sub-municipal divisions based on the information produced by the data elaboration and, subsequently, identify the most critical areas and the already existent "base risk" level, to be analyzed with their personal knowledge. The results are not to be considered as ultimately only acceptable decision but can they be questioned and modified by the PA and PE involved during the negotiation phases before the realization of the urban redevelopment project to be assessed, therefore any optimal scenario or solution has been provided.

The proposed spatial decision support system has been revealed several advantages: its structured approach of decomposing the real estate risk into hierarchical levels; its support on expert advices rather than on data extracted from third parties; the transparency and simplicity of the approach; the ability to integrate qualitative and quantitative data and check inconsistencies; the possibility to consider the importance of each risk factors (indicators) and their spatial distribution (intensity ranges) in the final assessment; the flexibility of its structure in order to be applied at different territorial scales and for several purposes. Even if the dependency on the judgment of the experts can be seen as a limit of the proposed model since it can be sensitive to changes in the local weights, in this research the AHP has proved to be a transparent, well-structured, and "fit-for-purpose" real estate risk assessment approach. In conclusion, the strengths of the developed model can be summarized as follows:

- it allows for effective considerations of the market, context and insolvency risks main influencing factors;
- the hierarchy provides the final users a tool for obtaining an overview of the problem and monitoring the conditions by applying the proposed model in the following years, in order to have a trend;
- it represents an *ex-ante* evaluation based on the data and information known at the time of the assessment and at the existent local real estate market conditions;
- both quantitative and qualitative indicators can be analized into a semi-quantitative approach, by reducing the laborious difficulties of the most applied methodologies;
- the general procedure is very flexible as it can work for different purposes of ranking, comparing or analyzing the real estate risk issues;
- it results in a final priority rank, immediately visible on the risk map;
- its simple and clear process avoid misinterpretations;
- the consistency of the judgements can be controlled (inconsistency index and ratio);
- it takes into account the spatial component of the real estate risk;
- it provides a synthetic risk index for the sub-municipal territorial scale for supporting in an effective way the real estate redevelopment processes.

The practical implications concern: the ranking the urban areas according to the risk levels; the identification of the most critical and profitable urban areas; the possibility for the PA to carefully decide the most suitable PE typology to involve, according to the risk-return profile, for carrying out effective redevelopment processes; the definition of the urban parameters on which depends the financial conveniences of the subjects during the negotiation phases; the possibility to give to the PE a primary idea of the "base risk" to be faced, on which the further ones related to the advanced stages of the projects have to be added and considered.

Future insights of the work will concern the improvement of the indicators system by including other risk factors according to new territorial scales, such as the municipal ones, for ranking the cities within a Country. It could be useful to test its robustness by comparing the results obtainable with other multi-criteria techniques or aggregation formula like the geometric mean and use the obtained values to carry out a real *ex-ante* risk assessment by considering a redevelopment project to be realized.

Authors contribution

The work must be attributed in equal parts to the Authors.

Note

The research has been developed within the project "Post-Covid future cities. Methods and Tools to Design and Assess, Healthy, Sustainable and Resilient Suburbs", Sapienza University of Rome.

Data Availability

Data will be made available on request.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.landusepol.2023.106595.

References

Adair, A., & Hutchison, N. (2005). The reporting of risk in real estate appraisal property risk scoring. *Journal of Property Investment & Finance*.

Adair, A., Berry, J., McGreal, S., Deddis, B., Hirst, S., 2000. The financing of urban regeneration. Land Use Policy 17 (2), 147–156.

Al-Harbi, K.M.A.S., 2001. Application of the AHP in project management. Int. J. Proj. Manag. 19 (1), 19–27.

Anelli, D., Tajani, F., Ranieri, R., 2022. Urban resilience against natural disasters: mapping the risk with an innovative indicators-based assessment approach. J. Clean. Prod. 371, 133496.

Ansah, R.H., Sorooshian, S., 2017. Effect of lean tools to control external environment risks of construction projects. Sustain. Cities Soc. 32, 348–356.

Aven, T., 2017. Improving risk characterisations in practical situations by highlighting knowledge aspects, with applications to risk matrices. Reliab. Eng. Syst. Saf. 167, 42–48.

Basel II, 2016. Integrated Risk Management Solution. available at:https://silo.tips/download/basel-ii-integrated-risk-management-solution.

Boateng, P., Chen, Z., Ogunlana, S.O., 2015. An analytical network process model for risks prioritisation in megaprojects. Int. J. Proj. Manag. 33 (8), 1795–1811.

Bulan, L., Mayer, C., Somerville, C.T., 2009. Irreversible investment, real options, and competition: evidence from real estate development. J. Urban Econ. 65 (3), 237–251.

Çam, A., 2018. Geographic Information Systems based financial risk map of Turkey. Acta Info 2 (2), 52–58.

Chan, A.P., Lam, P.T., Chan, D.W., Cheung, E., Ke, Y., 2010. Critical success factors for PPPs in infrastructure developments: Chinese perspective. J. Constr. Eng. Manag. 136 (5), 484–494.

Chan, A.P., Yeung, J.F., Yu, C.C., Wang, S.Q., Ke, Y., 2011. Empirical study of risk assessment and allocation of public-private partnership projects in China. J. Manag. Eng. 27 (3), 136–148.

Chen, J., Hobbs, P., 2003. Global real estate risk index. J. Portf. Manag. 29 (5), 66–75.

Chen, Z., & Khumpaisal, S. (2009). An analytic network process for risks assessment in commercial real estate development. *Journal of Property Investment & Finance*.

Coakley, J., 1994. The integration of property and financial markets. Environ. Plan. A 26 (5), 697–713.

COSO (2004) Enterprise Risk Management.

Dey, P.K., 2002. Project risk management: a combined analytic hierarchy process and decision tree approach. Cost. Eng. 44 (3), 13–27.

Dey, P.K., 2010. Managing project risk using combined analytic hierarchy process and risk map. Appl. Soft Comput. 10 (4), 990–1000.

Dikmen, I., Birgonul, M.T., Han, S., 2007. Using fuzzy risk assessment to rate cost overrun risk in international construction projects. Int. J. Proj. Manag. 25 (5), 494–505.

Duijm, N.J., 2015. Recommendations on the use and design of risk matrices. Saf. Sci. 76, 21–31.

Gang, J., Peng, L., Thibodeau, T.G., 2020. Risk and returns of income producing properties: core versus noncore. Real. Estate Econ. 48 (2), 476–503.

Grimsey, D., Lewis, M., 2007. Public private partnerships: The worldwide revolution in infrastructure provision and project finance. Edward Elgar Publishing.

Guidelines n.9 of the National Anti-Corruption Authority (ANAC).

Gyourko, J., Nelling, E., 1996. Systematic risk and diversification in the equity REIT market. Real. Estate Econ. 24 (4), 493–515.

Healey, P., 1994. Urban policy and property development: the institutional relations of real-estate development in an old industrial region. Environ. Plan. A 26 (2), 177–198.

Hill, R.J., Steurer, M., 2020. Commercial Property Price Indices and Indicators: review and Discussion of Issues Raised in the CPPI Statistical Report of Eurostat (2017). Rev. Income Wealth 66 (3), 736–751.

International Standardization Organization (ISO) 31000 of 2018 "Risk management – Guidelines"

Jin, X.H., Zhang, G., 2011. Modelling optimal risk allocation in PPP projects using artificial neural networks. International journal of project management 29 (5), 591–603.

Kazak, J.K., van Hoof, J., 2018. Decision support systems for a sustainable management of the indoor and built environment. Indoor Built Environ. 27 (10), 1303–1306.

Ke, Y., Wang, S., Chan, A.P., Lam, P.T., 2010. Preferred risk allocation in China's public–private partnership (PPP) projects. Int. J. Proj. Manag. 28 (5), 482–492.

Khumpaisal, S., Ross, A., Abdulai, R., 2010. An examination of Thai practitioners' perceptions of risk assessment techniques in real estate development projects. J. Retail Leis. Prop. 9 (2), 151–174.

Kokkaew, N., Tongthong, T., 2021. Computational framework for the determination of duration and revenue sharing rates in PPP concession renewal: a monte carlo and risk premium approach. Eng. J. 25 (7), 59–71.

Krane, H.P., Olsson, N.O., Rolstadås, A., 2012. How project manager–project owner interaction can work within and influence project risk management. Proj. Manag. J. 43 (2), 54–67.

Lang, Q., Xu, D., Li, L., 2017. Study on risk sharing mechanism of Sponge city PPP project. Manag. Adm. 11, 141–144.

Lee, S.L. (2005). Gauging the investment potential of international real estate markets.

Li, B., Akintoye, A., Edwards, P.J., Hardcastle, C., 2005. Critical success factors for PPP/PFI projects in the UK construction industry. Constr. Manag. Econ. 23 (5), 459–471.

Li, J., Zou, P.X., 2011. Fuzzy AHP-based risk assessment methodology for PPP projects. J. Constr. Eng. Manag. 137 (12), 1205–1209.

Lieser, K., Peter Groh, A., 2011. The attractiveness of 66 countries for institutional real estate investments. J. Real. Estate Portf. Manag. 17 (3), 191–211.

Locurcio, M., Tajani, F., Anelli, D., Ranieri, R., 2022. A multi-criteria composite indicator to support sustainable investment choices in the built environment. Valori E Valutazioni (30)..

Manganelli, B., Morano, P., Tajani, F., 2014. Risk assessment in estimating the capitalization rate. WSEAS Transactions on Business and Economics 11 (1), 197–206.

Millet, I., Wedley, W.C., 2002. Modelling risk and uncertainty with the analytic hierarchy process. J.Multi Criteria Decis. Anal. 11 (2), 97–107.

Morano, P., Tajani, F., 2013. The transfer of development rights for the regeneration of brownfield sites. In: *Applied mechanics and materials*, (Vol. 409,. Trans Tech Publications Ltd., pp. 971–978

Morano, P., Tajani, F., & Anelli, D. (2020). A decision support model for investment through the social impact bonds. The case of the city of Bari (Italy). *Valori e Valutazioni*, (24).

Morano, P., Tajani, F., & Anelli, D. (2021). Urban planning variants: A model for the division of the activated "plusvalue" between public and private subjects. *Valori e Valutazioni*, (28).

Mustafa, M.A., Al-Bahar, J.F., 1991. Project risk assessment using the analytic hierarchy process. IEEE Trans. Eng. Manag. 38 (1), 46–52.

Ng, A., Loosemore, M., 2007. Risk allocation in the private provision of public infrastructure. Int. J. Proj. Manag. 25 (1), 66–76.

Osipova, E., Eriksson, P.E., 2011. How procurement options influence risk management in construction projects. Constr. Manag. Econ. 29 (11), 1149–1158.

Peng, L., Zhang, L., 2021. House prices and systematic risk: evidence from microdata. Real. Estate Econ. 49 (4), 1069–1092.

Pereira, L., Ferreira, S., Santos, J., 2020. The main causes of risk in residential real estate projects. J. Gen. Manag. 45 (3), 152–162.

Platon, V., Constantinescu, A., 2014. Monte Carlo Method in risk analysis for investment projects. Procedia Econ. Financ. 15, 393–400.

Podvezko, V., Sivilevičius, H., 2013. The use of AHP and rank correlation methods for determining the significance of the interaction between the elements of a transport system having a strong influence on traffic safety. Transport 28 (4), 389–403.

Qazi, A., Dikmen, I., 2019. From risk matrices to risk networks in construction projects. IEEE Trans. Eng. Manag. 68 (5), 1449–1460.

Qazi, A., Dikmen, I., Birgonul, M.T., 2020. Mapping uncertainty for risk and opportunity assessment in projects. Eng. Manag. J. 32 (2), 86–97.

Qazi, A., Shamayleh, A., El-Sayegh, S., Formaneck, S., 2021. Prioritizing risks in sustainable construction projects using a risk matrix-based Monte Carlo Simulation approach. Sustain. Cities Soc. 65, 102576.

Rezakhani, P., 2012. Fuzzy MCDM model for risk factor selection in construction projects. Eng. J. 16 (5), 79–94.

Rowley, J., 2007. The wisdom hierarchy: representations of the DIKW hierarchy. J. Inf. Sci. 33 (2), 163–180.

Rubin, P. (2010). Factors affecting public private partnerships in urban renewal and development projects (Doctoral dissertation, University of Pretoria).

Sdino, L., Rosasco, P., Magoni, S., 2018. Real estate risk analysis: the case of Caserma Garibaldi in Milan. Int. J. Financ. Stud. 6 (1), 7.

Serrano-Jiménez, A., Lima, M.L., Molina-Huelva, M., Barrios-Padura, Á., 2019. Promoting urban regeneration and aging in place: APRAM–an interdisciplinary method to support decision-making in building renovation. Sustain. Cities Soc. 47, 101505.

Shao, M., Han, Z., Sun, J., Xiao, C., Zhang, S., Zhao, Y., 2020. A review of multi-criteria decision making applications for renewable energy site selection. Renew. Energy 157, 377–403.

Sharma, S.K., 2013. Risk management in construction projects using combined analytic hierarchy process and risk map framework. IUP J. Oper. Manag. 12 (4), 23–53.

Sun, L., Zhu, H., 2009. GIS-Based spatial decision support system for real estate appraisal (November). 2009 Fourth International Conference on Computer Sciences and Convergence Information Technology. IEEE,, pp. 1339–1344 (November).

Sun, Y., Huang, R., Chen, D., Li, H., 2008. Fuzzy set-based risk evaluation model for real estate projects. Tsinghua Sci. Technol. 13 (S1), 158–164.

Tajani,, F., Morano, P., Ntalianis, K., 2018. Automated valuation models for real estate portfolios: a method for the value updates of the property assets. Journal of Property Investment & Finance.

Tong, R., Cheng, M., Zhang, L., Liu, M., Yang, X., Li, X., Yin, W., 2018. The construction dust-induced occupational health risk using Monte-Carlo simulation. J. Clean. Prod. 184, 598–608.

Tsimperis, M. (2015). Identification of investment opportunities in urban regeneration projects (Master's thesis).

Vafaei, N., Ribeiro, R.A., & Camarinha-Matos, L.M. (2016, April). Normalization techniques for multi-criteria decision making: analytical hierarchy process case study. In doctoral conference on computing, electrical and industrial systems (pp. 261–269). Springer, Cham.

Vafaei, N., Ribeiro, R.A., & Camarinha-Matos, L.M. (2018, May). Selection of normalization technique for weighted average multi-criteria decision making. In Doctoral Conference on Computing, Electrical and Industrial Systems (pp. 43–52). Springer, Cham.

Wu, Y., Xu, C., Li, L., Wang, Y., Chen, K., Xu, R., 2018. A risk assessment framework of PPP waste-to-energy incineration projects in China under 2-dimension linguistic environment. J. Clean. Prod. 183, 602–617.

Xiang, P., Wang, Y., Deng, Q., 2017. Inclusive nature-based solutions for urban regeneration in a natural disaster vulnerability context: a case study of Chongqing, China. Sustainability 9 (7), 1205.

Xing, Y., Guan, Q., 2017. Risk management of PPP project in the preparation stage based on Fault Tree Analysis. In (March). In: IOP Conference Series: Earth and Environmental Science, Vol. 59. IOP Publishing, 012050 (March).
Xu, Y., Yeung, J.F., Chan, A.P., Chan, D.W., Wang, S.Q., Ke, Y., 2010. Developing a risk assessment model for PPP projects in China—a fuzzy synthetic evaluation approach. Autom. Constr. 19 (7), 929–943.
Yu, J.H., Kwon, H.R., 2011. Critical success factors for urban regeneration projects in Korea. Int. J. Proj. Manag. 29 (7), 889–899.